# The Microscopical Characters of Artificial Inorganic Solid Substances: Optical Properties of Artificial Minerals 

Alexander Newton Winchell
Horace Winchell

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## The Microscopical Characters of

Artificial Inorganic Solid Substances:
Optical Properties of Artificial Minerals

# The Microscopical Characters of 

# Artificial Inorganic Solid Substances: Optical Properties of Artificial Minerals 

by<br>Alexander Newton Winchell<br>Late Professor of Mineralogy and Petrology<br>University of Wisconsin, Madison, Wisconsin<br>and<br>Horace Winchell<br>Associate Professor of Mineralogy and Crystallography<br>Yale University, New Haven Connecticut

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## Preface and Introduction

The first edition of this book was prepared and published in 1927, and the second was published in 1931 as an adjunct to the senior author's "Elements of Optical Mineralogy, Part II, Descriptions of Minerals." The objective here is to emphasize compounds that a chemist might consider relatively "pure"-at least, pure as compared with naturally occurring compounds known as minerals. Such substances have constant compositions and therefore constant physical (including optical) properties. The polarizing microscope is a powerful tool for elucidating these properties quantitatively, and in conjunction with suitable tables, for identifying the substances. The problem of identification in the case of most artificial chemical preparations is likely to be less difficult than it is in the case of minerals because of the widely variable composition, and consequently variable optical properties, of the minerals. A compensating factor, however, is the larger number of artificial compounds. Most minerals can be made artificially, and must therefore be included here; but it is not necessary to treat the effects of chemical variations so thoroughly, and thus there is room to include the many inorganic artificial compounds that do not occur as minerals.

A description of microscopic methods is omitted from this book for two reasons. First, inclusion would make the size of the book unwieldy; and second, there are many good books on crystal optics and the polarizing microscope already. Among these may be listed A. N. Winchell's "Elements of Optical Mineralogy, Part I, Principles and Methods" (John Wiley and Sons, New York); also a useful pair of pocket-sized books, A. F. Hallimond's "Manual of the Polarizing Microscope," and its companion volume, C. E. Marshall's "Introduction to Crystal Optics" (Cooke, Troughton, and Simms, York, England); also N. H. Hartshorne and A. Stuart's "Crystals and the Polarizing Microscope" (Arnold and Co., London); and for a special viewpoint, H. Insley and Van D. Fréchette's "Microscopy of Ceramics and Cements" (Academic Press Inc., New York). A full listing of all of the excellent texts on this subject would be too long for inclusion here.

Descriptions of substances in this book are given in approximately the following order: Chemical formula and name, if any. Crystal symmetry and the dimensions of the unit cell, or the axial ratios if the dimensions are unknown. Brief data on crystal habit, cleavage, twinning, and such. Hardness (H., according to Mohs' scale) and specific gravity (G.), and fusibility (F., according to von Kobell's scale) or melting point in degrees Celsius. Optical properties, including optic orientation; extinction angles to prominent elongation, cleavages, or crystal faces (for which the orientation of the section must always be specified); principal refractive indices
( $n_{\mathrm{X}}, n_{\mathrm{Y}}, n_{\mathrm{Z}} ; n_{\mathrm{O}}, n_{\mathrm{E}} ; n$; rarely $n_{1}, n_{2}$ for non-principal indices such that $n_{\mathrm{X}} \leqq n_{1} \leqq n_{\mathrm{Y}} \leqq n_{2} \leqq n_{\mathrm{Z}}$ ) for light of wavelength corresponding to the Fraunhofer line D of sodium, and if possible for other wavelengths; optic sign, optic axial angle (2V), dispersion, color, pleochroism, and absorption.

The method of synthesis is mentioned briefly if at all, and often refers to the method of preparing crystals suitable for measurement rather than to a method for causing the compound to form. Near the end of each description, the symbol PD stands for "X-ray powder diffraction data" and is followed by the d-spacings of the three strongest lines of the X-ray powder pattern, and then by the serial number of the index card containing the full powder diffraction pattern, as published by the American Society for Testing Materials (1916 Race Street, Philadelphia 3, Pennsylvania), under the auspices of the Joint Committee on Chemical Analysis by Powder Diffraction Methods, in the X-ray Powder Data File. In cases where two or more cards are listed in the Index to the X-ray Powder Data File (1960), a star is added to the serial number of the card. The kind permission of Professor J. V. Smith, Editor of the X-ray Powder Data File, to use these card-index references is gratefully acknowledged. His cooperation makes this book considerably more useful to all, and at the same time makes it possible for me to call attention to the existence of X-ray diffraction data that are conveniently available for certain compounds.
A. N. Winchell did considerable preliminary collecting of data for this book while he was Resident Consultant at the Research Laboratories of American Cyanamid Company, Stamford, Connecticut. The stimulating associations and excellent facilities there furthered the project immeasurably. Further collecting and most of the writing were done after he moved to New Haven, Connecticut, and became associated with Yale University as Honorary Fellow in Geology. During this time, and after his death in 1958, the present writer became increasingly responsible for the work, including some collecting, more writing, final checking of data and references, and insertion of X-ray powder data.

It is a pleasure to acknowledge the assistance of Mary E. Mrose, U. S. Geological Survey, Washington, D. C., who performed a herculean task consisting of checking all references and many data throughout the book. The cooperation of the Yale University Library in locating unusual or rare volumes was most important in this research. Editorial and typing assistance by Mrs. Florence S. Winchell, and the assistance of Mrs. Jean H . Winchell in preparing certain tables, are most gratefully acknowledged.

Horace Winchell

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## From the Preface to the First Edition

While preparing the second edition of Part II of the writer's "Optical Mineralogy," it seemed undesirable to attempt to discriminate between natural and artificial minerals since the distinctions between them are so vague and unstable. Therefore the manuscript was prepared so as to include all minerals, both natural and artificial, if their optic properties were sufficiently well known to permit their identification microscopically. More concretely stated, all inorganic substances were included whose indices of refraction had been measured. When the manuscript was completed it was found to be too long for one volume and therefore the part dealing with artificial minerals was eliminated for separate treatment as given in this book. The following account may accordingly be considered as a supplement to Part $\mathrm{II}^{1}$ of the author's "Optical Mineralogy."

Undoubtedly some artificial substances, whose optic constants are known, have been omitted from this compilation, but the writer has spent many months searching all available literature for data (unfortunately almost never indexed), and trusts that he has achieved a reasonable measure of success.

It is obvious that a work of this kind is largely a compilation of all available data, and in its preparation the writer has made free use of the standard publications on the subject, including especially:
P. Groth: Chemische Krystallographie, Vols. I-II, 1906-1908.

Zeitschrift für Kristallographie, Vols. I-LX, 1877-1924.
H. Dufet: Recueil de Données Numériques, Vols. II and III, 1900.
H. R. Landolt and R. Bornstein: Physikalisch-chemische Tabellen, 1923.
L. J. Spencer, Tables Annuelles Internationelles de Constantes, etc., Vols. I-V for 1910-1922, published 1912-1926.
E. S. Larsen: Microscopic Determination of the Nonopaque Minerals, 1921.

No attempt is made in this work to give the source of all the data which are included. So far as they are derived from the standard reference works already cited it is considered unnecessary to cite these repeatedly. On the other hand, the author has aimed to give references to the source of all data from unusual sources or from current literature.

Alexander N. Winchell

Madison, Wisconsin
October, 1927

[^1]
## I. Elements, Carbides, Nitrides

A. Metallic Elements ..... 3
B. Semi-metals and Non-metals ..... 3
C. Carbides and Nitrides ..... 5

## A. METALLIC ELEMENTS

Fe (Iron) is isometric. Space group Im $3 m . a=2.861 \AA$. U.C. 2. Distinct cubic cleavage. Malleable. H. 4. G. 7.87 . Fuses at $1535^{\circ}$ C. Color steel-gray to iron-black. Luster metallic. $n=2.36$ (Drude); 1.73 (Kundt). Reflection percentages ${ }^{1}$ : red 58, orange 59, green 64 . Easily forms mix-crystals with nickel up to about $30 \%$. PD 2.03, 1.17, 1.43; 6-0696.
$\mathbf{C u}$ (Copper) is isometric. Space group ${ }^{2}$ Fm3m. $a=3.607 k X$. U.C. 4. No cleavage. Malleable. H. 2.5-3. G. 8.95. Fuses at $1083^{\circ}$ C. Color copperred. Luster metallic. Reflection percentages ${ }^{1}$ : red 89, orange 83, green 61. PD 2.09, 1.81, 1.28; 4-0836.

Ag (Silver) is isometric. Space group $F m 3 m . a=4.07 \AA$. U.C. 4. No cleavage. Malleable. H. 2.5-3. G. 19.3. Fuses at $961^{\circ}$ C. Color silver-white. Luster metallic. Reflection percentages ${ }^{1}$ : red 93, orange 94, green 95.5. Forms a continuous series of mix-crystals with gold. PD 2.36, 2.04, 1.23; 4-0783.

Au (Gold) is isometric. Space group $F m 3 m . a=4.078 \AA$. U.C. 4. No cleavage. Malleable. H. 2.5-3. G. 19.3. Fuses at $1062^{\circ}$ C. Luster metallic. Color gold-yellow. Reflection percentages ${ }^{1}$ : red 85.6 , orange 82.5 , green 47 . Opaque except in thinnest films, which transmit some greenish light. Forms continuous series of mix-crystals with silver and with copper. PD 2.36, 2.04, 1.23; 4-0784.

## B. SEMI-METALS AND NON-METALS

Se (Selenium) has at least three crystal phases. The $\alpha$-phase is monoclinic with $a: b: c=1.635: 1: 1.610, \beta=104^{\circ} 2^{\prime}$. Crystals basal plates or nearly equant with $\{001\}$ and $\{111\}$ prominent. G. 4.47. Color orange red. A simpler cell for this has ${ }^{2 a} a=8.99, b=8.97, c=11.52, \beta=91^{\circ} 34^{\prime}$. The $\beta$-phase is monoclinic with ${ }^{2 a} a=12.74, b=8.04, c=9.25 k X, \beta=93^{\circ} 4^{\prime}$.

[^2]Crystals short prisms or plates. Color dark red. A third phase is trigonal with $a / c=1.134$. Crystals hexagonal prismatic with $^{3} a=4.36397 \AA$., $c=4.95945^{\circ} \AA$ at $20^{\circ} \mathrm{C}$. Crystals may show rhombohedral end faces. Good $\{01 \overline{1} 2\}$ cleavage. H. 2. G. 4.79. Fuses at $220^{\circ}$ C. Color gray. Streak red. Luster bright metallic. Transparent only in very thin flakes. Uniaxial positive with ${ }^{3 \mathrm{a}} n_{\mathrm{O}}=3.00 \mathrm{Na}, n_{\mathrm{E}}=4.04, n_{\mathrm{E}}-n_{\mathrm{O}}=1.04$. Liquid selenium has $n=2.9$. Selenium is recovered from flue deposits in the manufacture of $\mathrm{H}_{2} \mathrm{SO}_{4}$. Isotropic mixtures of fused selenium and sulfur are useful immersion media for refractive index measurements. Data follow : ${ }^{4}$

| $\% \mathrm{Se}$ | 100 | 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | 0 |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $\% \mathrm{~S}$ | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| $n(\mathrm{Li})$ | 2.716 | 2.53 | 2.40 | 2.30 | 2.22 | 2.16 | 2.11 | 2.08 | 2.03 | 2.00 | 1.978 |
| $n(\mathrm{Na})$ | 2.92 | 2.67 | 2.49 | 2.37 | 2.27 | 2.20 | 2.15 | 2.10 | 2.06 | 2.025 | 1.998 |
| $n(\mathrm{Tl})$ |  |  |  | 2.43 | 2.32 | 2.25 | 2.19 | 2.13 | 2.09 | 2.05 | 2.018 |

PD 3.01, 3.78, 2.07; 6-0362.
S (Sulfur) has six crystal phases. The low temperature $\alpha$-phase is orthorhombic dipyramidal with $a: b: c=0.813: 1: 1.903$. Crystals pyramidal or varied with poor $\{001\},\{110\}$, and $\{111\}$ cleavages. H. 2.5. G. 2.07. Melts at $112.8^{\circ} \mathrm{C}$. after inversion at $98^{\circ}$. Insoluble in acids; soluble in $\mathrm{CS}_{2}$. The optic plane is $\{010\} ; \mathrm{Z}=c .(+) 2 \mathrm{~V}=68^{\circ} 58^{\prime} \mathrm{Na}, 68^{\circ} 46^{\prime} \mathrm{Tl}$. $n_{\mathrm{X}}=1.9398 \mathrm{Li}, 1.9579 \mathrm{Na}, 1.9764 \mathrm{Tl}, n_{\mathrm{Y}}=2.0171 \mathrm{Li}, 2.0377 \mathrm{Na}, 2.0586$ $\mathrm{Tl}, n_{\mathrm{Z}}=2.2158 \mathrm{Li}, 2.2452 \mathrm{Na}, 2.2754 \mathrm{Tl}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.2875 \mathrm{Na}$. Color yellow. The natural substance is found around some volcanoes and also in some salt and gypsum deposits. $\beta$-Sulfur is monoclinic with $a: b: c=$ 0.996:1:0.9998, $\beta=95^{\circ} 46^{\prime}$. Crystals tabular or elongated; pseudo-isometric. Distinct $\{001\}$ and $\{110\}$ cleavages. H. 1.5. G. 1.958. Melts at $119^{\circ} \mathrm{C} . \mathrm{Y}=b, \mathrm{X} \wedge c=52^{\circ}\left(44^{\circ}\right.$ on $\left.\{110\}\right)$. $(-) 2 \mathrm{~V}=58^{\circ}$. Mean index, $n=2.058 . n_{\mathrm{Z}}-n_{\mathrm{X}}=$ weak. Color honey-yellow. Easily crystallized from fusion. $\gamma$-Sulfur is also monoclinic ${ }^{5}$ with $a: b: c=1.061: 1: 0.709, \beta=91^{\circ} 47^{\prime}$. Crystals thin, tabular. H. soft. G. $<2.075$. $\mathrm{Y}=b, \mathrm{X} \wedge c=1.25^{\circ} c a$. ( -2 V $=$ ?. Refringence and birefringence strong. Colorless to pale yellow. Called rosickyite. Three other phases are known; one is probably monoclinic, one is hexagonal (and uniaxial negative) and one (black sulfur) is perhaps hexagonal. PD 3.85, 3.21, 3.44; 8-247 [presumably for $\alpha-\mathrm{S}$ ].

I (Iodine) is orthorhombic. G. 4.93. M.P. $113.5^{\circ} \mathrm{C}$. Color violet black; opaque except in very thin flakes. Metallic luster. Mean index, $n=3.34$. Volatilizes readily at ordinary temperature, forming a violet vapor. PD 3.10, 3.71, 3.64; 5-0558.
${ }^{3}$ Straumanis: Zeit. Krist. CII, p. 432 (1940) [Struc. Rpts. VIII, p. 109].
${ }^{3 a}$ Skinner: Phys. Rev. IX, p. 148 (1917).
${ }^{4}$ Merwin and Larsen: Am. Jour. Sci. CLXXXIV, p. 42 (1912).
${ }^{5}$ Sekanina: Zeit. Krist. LXXX, p. 174 (1931).
$\mathbf{P}$ (Phosphorus) is polymorphous. One phase is isometric in dodecahedral crystals. G. 1.84. F. $44^{\circ} \mathrm{C}$. Isotropic with $n=2.093 \mathrm{C} ; 2.117 \mathrm{D}$, 2.158 F. Colorless or yellow. Prepared by reduction of phosphate with carbon. Another phase ${ }^{6}$ is ditetragonal dipyramidal. Uniaxial positive with $n_{\mathrm{O}}=2.72, n_{\mathrm{E}}=3.15, n_{\mathrm{E}}-n_{\mathrm{O}}=0.43$. A third phase is hexagonal (trigonal). Uniaxial positive with $n_{\mathrm{O}}=2.72, n_{\mathrm{E}}=3.20, n_{\mathrm{E}}-n_{\mathrm{O}}=0.48$. A fourth phase is triclinic. $(-) 2 \mathrm{~V}=24^{\circ} 26^{\prime}, n_{\mathrm{X}}=3.11, n_{\mathrm{Y}}=3.20, n_{\mathrm{Z}}=$ $3.21, n_{\mathrm{z}}-n_{\mathrm{X}}=0.10$. Phases 2,3 , and 4 are red phosphorus and may be grown from vapor. Amorphous phosphorus has $n=2.7$ to 3.0. PD 2.64, 2.58, 5.26; 9-20* [which phase?].

C (Carbon) has at least two crystal phases. One is opaque and black and about as soft as a solid can be; the other may be as transparent as the clearest glass and is the hardest substance known.

C (Graphite) is hexagonal with $a=2.47, c=6.79 \AA$. U.C. 4. Crystals usually thin basal lamellæ. Perfect basal cleavage. H. 1-2. G. 2.09-2.23. Infusible. Luster metallic or dull. Color and streak black. Translucent and blue or green only in very thin flakes. Uniaxial negative ${ }^{7}$ with $n_{0}$ between 1.98 and 2.03 Li . In reflected light strongly pleochroic and birefringent. Reflection percentages for O ; red 23 , orange 23.5 , green 22.5 ; for E : red 5.5 , orange 5 , green 5 . Graphite can be made from coal; also found in some iron melts. PD 3.37, 1.68, 2.04; 8-415.
C (Diamond) is isometric with $a=3.560 \AA$. U.C. 8. Crystals usually equant - cubes, octahedrons, dodecahedrons, etc. Perfect $\{111\}$ cleavage. H. 10. G. 3.51. Infusible. Insoluble. Isotropic in thin plates, but often weakly anisotropic in thick plates, probably due to strain. Very strong refringence and dispersion with $n=2.4135 \mathrm{Li}, 2.4195 \mathrm{Na}, 2.4278 \mathrm{Tl}$. Colorless, white, yellow, orange, red, green, blue, brown, black. Made at pressures of about $1,500,000 \mathrm{lbs} / \mathrm{sq}$. in. and at temperatures of about $1,000^{\circ} \mathrm{C} \cdot{ }^{8}$ many other attempts to make it have failed or, in a few cases, achieved doubtful results. ${ }^{8 \mathrm{a}}$ PD 2.06, 1.26, 1.08; 6-0675.

## C. CARBIDES AND NITRIDES

$\mathrm{CaC}_{2}$ is orthorhombic ${ }^{9}$ (?) and pseudocubic with complex multiple twinning on the dodecahedral face; perfect $\{001\},\{010\}$ and $\{100\}$

[^3]cleavages and $\{110\}$ parting. Combines with water freely to form acetylene and calcium hydroxide. Apparently uniaxial to biaxial, with ( + ) $2 \mathrm{~V}=$ $0^{\circ}-30^{\circ}$ and $\mathrm{r}<\mathrm{v}$; the optic plane is parallel with the twinning lines; extinction parallel with cleavages. Index $n>1.75, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.050$. Color purplish red, yellow, greenish; slightly pleochroic in thicker sections; nearly colorless in very thin flakes. The yellow carbide probably contains other material in crystal solution; it has extinction at about $10^{\circ}$ to $24^{\circ}$ to the cleavages and is probably triclinic. PD 2.74, 2.08, 1.94; 4-0712.
$\mathbf{A l}_{4} \mathbf{C}_{3}$ is hexagonal ${ }^{10}$ in six-sided plates with perfect $\{0001\}$ cleavage. Uniaxial positive with $n_{\mathrm{O}}=2.7(700 m \mu), n_{\mathrm{E}}=2.75 \pm, n_{\mathrm{E}}-n_{\mathrm{O}}=0.05 \pm$. Color yellow. PD 2.87, 2.80, 1.66; 1-0953.

SiC has many crystal phases, one being isometric, others hexagonal or rhombohedral. $\boldsymbol{\alpha} \mathbf{- S i C}$ is hexagonal or rhombohedral; crystals are thin basal plates with rare twinning on $\{10 \overline{1} 1\}$ and poor basal cleavage. H. 9.5. G. 3.2. Infusible, but dissociates at about $3400^{\circ} \mathrm{C}$. Insoluble even in HF. Uniaxial positive with extremely high refringence, strong birefringence and very strong dispersion, as follows ${ }^{11}$ :

|  |  |  |  |  |
| ---: | :--- | :---: | :---: | :---: |
|  |  |  |  | Disper- <br> sion |
| $\lambda$ | $=671(\mathrm{Li})$ | $589(\mathrm{Na})$ | $546(\mathrm{Hg})$ | $486(\mathrm{~F})$ |$(486-671)$

Colorless when perfectly pure, but usually colored green, blue, red, black by small amounts of iron, aluminum, carbon, etc., present as impurities. Pleochroic with $\mathrm{E}>\mathrm{O}$; also, in some cases, $\mathrm{O}>\mathrm{E}$. Surface films of silica, often present, produce iridescent colors. Luster brilliant, adamantine.

All hexagonal and rhombohedral polytypes described below have essentially the same optical properties. PD 2.51, 2.63, 1.54; 4-0756*.
$\beta-\mathbf{S i C}$ is isometric with $a=4.349 \AA$ and G. 3.216. U.C. 4. Isotropic (but may have anisotropic lamellæ) with $n=2.63$ (Li). PD 2.51, 1.54, 1.31; 1-1119.

Polytypes. The crystal structure of SiC may be described as consisting of $\{0001\}$ layers; in a vertical section along $\{11 \overline{2} 0\}$, if a C (or Si) atom is at the origin-point (1) in one layer, the corresponding atom in the next layer will be at a point either (2), one-third unit to the right, or (3), one-third unit to the left; in the third layer the next atom may be to the right again

[^4](3) or it may be to the left (1), but in no case may one ever be directly over the one in the preceding layer. In a sequence like (1)-(2)-(1)-(2), the pattern forms a zigzag. If the structure has two to the right, then two to the left, it can be described as 22 . If it has three to the right, then three to the left, it is designated 33 . But in some cases there may be three to the right, then two to the left; this is repeated three times in the unit cell and it is described as 323232 ; or it may be abbreviated to 32 . These variations of the crystal structure are called "polytypes." This notation is explicit and clear, but it is cumbersome for polytypes with many layers. A simple, but less descriptive system is to write the number of layers in the unit cell followed by the letter C (cubic), R (rhombohedral) or H (hexagonal) to designate the symmetry.

Many polytypes are known; a few examples follow:

| Isometric | Hexagonal | Rhombohedral |
| :--- | :--- | :--- |
| $\beta-\mathrm{SiC}(3 \mathrm{C}$ or $3,-$ | 4 H or 22 | 15 R or 323232 |
| no zigzag $)$ | 6 H or 33 | 21 R or 343434 |
|  | 19 H or 22232323 | 33 R |
|  |  | 51 R |
|  |  | 87 R |
|  |  | 141 R |
|  |  | etc. |

With increasing numbers of layers the length of the vertical axis increases in proportion. For example:

$$
\begin{aligned}
& \text { For } 19 \mathrm{H}^{12}: a=3.073, c=47.75 \mathrm{kX}=19 \times 2.512 \\
& \text { For } 21 \mathrm{R}^{12}: a=3.073, c=52.78 \mathrm{kX}=21 \times 2.513 \\
& \text { For } 51 \mathrm{R}^{13}: a=3.073, c=128.17 \mathrm{kX}=51 \times 2.511 \\
& \text { For } 87 \mathrm{R}^{14}: a=3.073, c=218.66 \mathrm{kX}=87 \times 2.511
\end{aligned}
$$

SiC was found by Moissan in the Canyon Diablo meteorite and is known as moissanite. It is an important product of the electric furnace. It is readily recognized by its extreme hardness, extreme refringence and dispersion.
$\mathbf{A g N}_{3}$ is orthorhombic dipyramidal ${ }^{15}$ with $a: b: c=1.056: 1: 1.068$. Crystals acicular along $c$ with $\{110\},\{100\},\{010\}$, and $\{001\}$. Good $\{001\}$ and another cleavage. G. 4.50 ( 5.02 from X-ray study). The needles have parallel extinction and negative elongation. (-) $2 \mathrm{~V}=?, n_{\mathrm{X}}=1.80 \pm$. $n_{\mathrm{Y}}$ and $n_{\mathrm{Z}}>2.05, n_{\mathrm{Z}}-n_{\mathrm{X}}>0.25$. PD 2.41, 4.08, 2.04; 3-0906.

[^5]AlN is hexagonal with $a=3.10$ and $c=4.965 \AA$. H. 5. G. 3.25. Crystals long prismatic. Uniaxial positive ${ }^{16}$ with $n_{\mathrm{O}}=2.13, n_{\mathrm{E}}=2.20, n_{\mathrm{E}}-n_{\mathrm{O}}=$ 0.07 . Color pale blue or green. Slowly soluble in molten borax. Made at a temperature of about $2100^{\circ}$ C. PD 2.70, 2.37, 2.49; 8-262.
$\mathbf{B a}\left(\mathrm{N}_{3}\right)_{2} \cdot \mathbf{H}_{2} \mathrm{O}$ is triclinic; the mean refractive index is 1.7.
$\mathbf{C a}\left(\mathbf{N}_{3}\right)_{2} \cdot \mathbf{2} \mathbf{N}_{2} \mathbf{H}_{4}$ is orthorhombic. ${ }^{17}$ Crystals $\{001\}$ plates with $\{100\}$, $\{110\},\{101\},\{011\}$. The optic plane is $\{100\} ; \mathrm{Z}=c .(+) 2 \mathrm{~V}=80^{\circ} \pm$, $\mathrm{r}>\mathrm{v}$ distinct. $n_{\mathrm{X}}=1.583, n_{\mathrm{Y}}=1.610, n_{\mathrm{Z}}=1.70, n_{\mathrm{Z}}-n_{\mathrm{x}}=0.117$, all $\pm 0.003$.
$\mathbf{C a C N}_{2}$ is rhombohedral ${ }^{18}$ with perfect rhombohedral cleavage at $74^{\circ}$ and poor basal parting. Uniaxial positive with $n_{\mathrm{O}}=1.60, n_{\mathrm{E}}>1.95, n_{\mathrm{E}}-n_{\mathrm{O}}>$ 0.35. Colorless. Often present in commercial "carbide." PD 2.93, 4.92, 2.42; 3-0656.
$\mathbf{P N O}_{2} \mathbf{H}_{2}$ is tetragonal ${ }^{19}$ with $a=7.57, c=7.60 k X$. Crystals show $\{100\}$ and $\{101\}$. G. 1.775. Uniaxial negative with $n_{\mathrm{O}}=1.522, n_{\mathrm{E}}=1.479$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.043$.
$\mathbf{P N O}_{4} \mathbf{H}_{6}$ is tetragonal ${ }^{19}$. Crystals show $\{100\}$ and $\{101\}$. Uniaxial negative with $n_{\mathrm{O}}=1.515, n_{\mathrm{E}}=1.477, n_{\mathrm{O}}-n_{\mathrm{E}}=0.038$ (Senarmont). Again: $n_{\mathrm{O}}=1.5246, n_{\mathrm{E}}=1.4792, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0454$ (Topsoe and Christiansen).

[^6]
## II. Sulfides, Selenides, Tellurides and Sulfosalts

Few sulfides transmit any light in the visible part of the spectrum, but rather many are transparent to infrared light.

1. Formula Type $A_{2} X$ ..... 9
2. Formula Type AX ..... 9
3. Formula Type $\mathrm{A}_{2} \mathrm{X}_{3}$ ..... 12
4. Formula Type $\mathrm{AX}_{2}$ ..... 12
5. Formula Type $\mathbf{A}_{m} \mathbf{B}_{n} \mathbf{X}_{p}$ with $(m+n): p \approx 3: 2$; also $4: 3$ ..... 12
6. Formula Type $\mathbf{A}_{m} \mathbf{B}_{n} \mathbf{X}_{p}$ with $(m+n): p \approx 1: 1$; also $<1: 1$ ..... 13

## 1. Formula Type $\mathrm{A}_{2} \mathrm{X}$

$\mathbf{N a}_{2} \mathbf{S} \cdot \mathbf{9 H}_{2} \mathrm{O}$ is tetragonal with $a / c=0.982$. Crystals prismatic. G. 1.45. Uniaxial positive ${ }^{1}$ with $n_{\mathrm{O}}=1.534, n_{\mathrm{E}}=1.550, n_{\mathrm{E}}-n_{\mathrm{O}}=0.016$. Colorless. PD 2.80, 2.98, 3.21; 3-0745.
$\mathbf{N H}_{4} \mathbf{S H}$ is ditetragonal ${ }^{2}$ dipyramidal with $a=6.01, c=4.01 k X$. U.C. 2 . G. 1.18. Uniaxial negative with $n_{\mathrm{O}}>1.74, n_{\mathrm{E}}<1.74, n_{\mathrm{O}}-n_{\mathrm{E}}=$ moderate.

## 2. Formula Type AX

$\mathbf{M g S}$ is isometric ${ }^{3}$ with NaCl space lattice. Perfect cubic cleavage. G. 2.84. Isotropic with $n=2.254 \mathrm{C}, 2.271 \mathrm{Na}, 2.285 \mathrm{Tl}$. Colorless. Made in an electric oven. PD 2.60, 1.84, 1.50; 8-478.

CaS (Oldhamite) is isometric ${ }^{3}$ with $a=5.686$. U.C. 4. Perfect cubic cleavage. H. 4. G. 2.71. Isotropic with $n=2.120 \mathrm{C}, 2.137 \mathrm{Na}, 2.161 \mathrm{Tl}$. Colorless. PD 2.85, 2.01, 1.64; 8-464.

SrS is isometric ${ }^{3}$ with perfect cubic cleavage. G. 3.913. Isotropic with $n=2.087 \mathrm{C}, 2.107 \mathrm{Na}, 2.122$ ( $540 \mathrm{~m} \mu$ ). Colorless. PD 3.01, 2.13, 3.48; 8-489.

BaS is isometric ${ }^{3}$ with perfect cubic cleavage. G. 4.377. Isotropic with $n=2.140 \mathrm{C}, 2.155 \mathrm{Na}, 2.183 \mathrm{Tl}$. Colorless. PD 3.19, 2.26, 3.69; 8-454.

ZnS has two phases ${ }^{4}$ : the $\alpha$-phase is hexagonal and the $\beta$-phase is isometric. PD 2.93, 3.31, 1.91; 10-434.
$\boldsymbol{\alpha}-\mathrm{ZnS}$ (Wurtzite) is hexagonal with $a=3.811 . c=6.234 k X$. U.C. 2 . Crystals hemimorphic with good prismatic cleavage. H. 3.5-4. G. 4.087. Soluble in HCl . Uniaxial positive with $n_{\mathrm{O}}=2.330 \mathrm{Li}, 2.365 \mathrm{Na}, n_{\mathrm{E}}=$ $2.350 \mathrm{Li}, 2.378 \mathrm{Na}, n_{\mathrm{E}}-n_{\mathrm{O}}=0.022 \mathrm{Na} . \mathrm{PD} 3.31,3.13,2.93 ; 5-0492$.
${ }^{1}$ West: pers. comm. 2 Nov. 1936.
${ }^{2}$ West: Zeit. Krist. LXXXVIII, p. 97, (1934).
${ }^{3}$ Spangenberg: Naturwiss. XV, p. 266 (1927); Haase: Zeit. Krist. LXV, p. 509 (1927); LXVI, p. 236 (1928).
${ }^{4}$ Allen, Crenshaw and Merwin: Am. J. Sci. XXXLV, p. 341 (1912).

Wurtzite, like SiC, has several different polytypes ${ }^{5}$ so that the length of the vertical axis varies. The commonest type is 2 H , with $c=6.234 k X$. Other types are 4 H , with $c=12.44 k X$; 6 H with $c=18.69 k X$; and 15 R with $c=46.79 \mathrm{kX}$. The optical properties of the types are the same. All types may contain up to 8 per cent Fe (and less Cd). Pure ZnS is colorless; ordinary wurtzite is colored yellow to brown by iron. With maximum iron $n_{\mathrm{O}}=2.46 c a$. and $n_{\mathrm{E}}=2.48 c a$.; weakly pleochroic with $\mathrm{O}>\mathrm{E}$. It is stable above $1020^{\circ} \mathrm{C}$. (or, with maximum $\mathrm{Fe}, 880^{\circ} \mathrm{C}$.)
$\boldsymbol{\beta}$-Zns (Sphalerite) is the stable low temperature phase. It is isometric with perfect dodecahedral cleavage. H. 3.5-4. G. 4.09. Isotropic with $n=2.34 \mathrm{Li}, 2.368 \mathrm{Na}, 2.398 \mathrm{Tl}$. It may be slightly anisotropic, probably due to strain, since anisotropic areas are easily produced by pressure. Often contains Fe; maximum 8 per cent causes brown to black color and $n=2.395 \mathrm{Li}, 2.47 \mathrm{Na}$. Colorless (to yellow?) when pure. PD 3.12, 1.91, 1.63; 5-0566.

CdS has two phases ${ }^{52}$ : the $\alpha$-phase is hexagonal and the $\beta$-phase is isometric. PD 3.16, 3.58, 3.36; 6-0314.
$\boldsymbol{\alpha}$-CdS (Greenockite) is hexagonal with $a={ }^{5 b} 4.14, c=6.72 k X$. Crystals hemimorphic, short prismatic with distinct prismatic cleavage. H. 3.-3.5. G. 4.82. M.P. $780^{\circ}$ C. Soluble in HCl . Uniaxial positive for red to blue-green; negative for blue-green to blue; isotropic for $\lambda=523$. $n_{\mathrm{O}}=2.431 \mathrm{Li}, 2.506 \mathrm{Na}, n_{\mathrm{E}}=2.456 \mathrm{Li}, 2.529 \mathrm{Na}, n_{\mathrm{E}}-n_{\mathrm{O}}=0.023 \mathrm{Na}$. For $n_{\mathrm{O}}, n_{\mathrm{F}}-n_{\mathrm{C}}=0.23 c a$. For $\lambda=516$. $n_{\mathrm{O}}>2.6$ and $n_{\mathrm{O}}-n_{\mathrm{E}}=0.016$. Color yellow with weak pleochroism. Made from solution.
$\boldsymbol{\beta}$-CdS (Hawleyite) is isometric ${ }^{5 a}$ with $a=5.818 \AA$. A fine-grained coating in vugs. G. 4.87 calc. Index not measured but must be near 2.52 since G. of $\beta$-CdS is a little above G. of $\alpha$-CdS. Color bright yellow. Made from solution under reducing conditions from acidic sulfate solutions. PD 3.36, 2.06, 1.75; 10-454.

HgS has three phases, ${ }^{4}$ the stable $\alpha$-phase and two metastable ( $\beta$ - and $\gamma$-) phases.
$\boldsymbol{\alpha}$-HgS (Cinnabar) is hexagonal with $a=4.160, c=9.540 \AA$. U.C. 3 . Crystals prismatic or tabular with perfect prismatic cleavage. H. 2-2.5. G. 8.09. Volatile. Uniaxial positive with $n_{\mathrm{O}}=2.81 \mathrm{Li}, n_{\mathrm{E}}=3.14, n_{\mathrm{E}}-n_{\mathrm{O}}$ $=0.33$. Color bright red or scarlet. PD 3.36, 2.86, 1.98; 6-0256.
$\beta$-Hgs (Metacinnabar) is isometric with $a=5.854 \AA$. U.C. 4. Black and opaque. G. 7.60. Formed only from acid solutions, and alters to cinnabar rather easily. PD 3.38, 2.07, 1.76; 6-0261.

Another metastable phase is hexagonal and prismatic with G. 7.2.

[^7]Uniaxial positive with $n_{\mathrm{O}}=2.58 \mathrm{Li}, n_{\mathrm{E}}=2.82, n_{\mathrm{E}}-n_{\mathrm{O}}=0.24$. Color bright red.

CuS (Covellite) is hexagonal with $a=3.802, c=16.43 \AA$. U.C. 6 . Massive or in basal plates. Perfect basal cleavage. H. 1.5-2. G. 4.67. Opaque except in very thin plates. Uniaxial positive ${ }^{6}$ with $n_{0}=1.33(\lambda=610)$, $1.45 \mathrm{Na}, 1.97(\lambda=505), n_{\mathrm{E}}=$ ?. Pleochroic with $\mathrm{O}>\mathrm{E}$; color blue. PD $2.81,1.90,3.05 ; 6-0464$. Reflection percentages: red 10 , orange 15 , green 18.5.

PbS (Galena) is isometric with $a=5.95 \AA$. U.C. 4. Perfect cubic cleavage. H. $=2.5$. G. 7.5. M.P. $1115^{\circ} \mathrm{C}$. Opaque. Metallic luster. $n=3.912 \mathrm{D}$. Again: ${ }^{7} n=4.71$. Reflection percentages: red 35, orange 37.5, green 33.5. PD 2.97, 3.43, 2.10; 5-0592.

MnS (Alabandite) is isometric with $a=5.214 \AA$ A. U. 4 . Crystals cubic, or octahedral. Perfect cubic cleavage. H. 3.5-4. G. 4.0 ca. (calc. 4.07). Color iron-black. Streak green. Very thin splinters give ${ }^{8} n=2.70 \mathrm{Li}$. Reflection percentages: green 24, orange 21, red 20. PD 2.61, 1.85, 1.51; 6-0518.

AsS (Realgar) is monoclinic ${ }^{9}$ with $a=9.27, b=13.50, c=6.56 \AA$. $\beta=106^{\circ} 32^{\prime}$. U.C. 16. Crystals short prisms with distinct $\{010\}$ cleavage. H. 1.5-2. G. 3.56. M.P. $310^{\circ}$ C. Volatile. $\mathrm{X} \wedge c=11^{\circ}$, $\mathrm{Y}=b$. Strong inclined dispersion with $\mathrm{r}>\mathrm{v}$. (-) $2 \mathrm{~V}=49^{\circ} 34^{\prime}$ (648), $46^{\circ} 42^{\prime}$ (589). For $\mathrm{m} \mu=590: n_{\mathrm{X}}=2.538, n_{\mathrm{Y}}=2.684, n_{\mathrm{Z}}=2.704, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.166$. Color and streak aurora-red to orange yellow; pleochroic with X nearly colorless to orange red, Y and Z pale golden yellow to vermilion red. PD 5.40, 3.19, 2.94; 9-441.

NiS is monoclinic ${ }^{10}$ with $a: b: c=0.888: 1: 0.848, \beta=90^{\circ} 23^{\prime}$. Crystals pseudo-cubic with lamellar twinning on $\{\overline{1} 01\}$. G. 2.2. $\mathrm{Y}=b, \mathrm{Z} \wedge c=$ large. $(+) 2 \mathrm{~V}=$ large, $n_{\mathrm{X}}=1.908, n_{\mathrm{Y}}=2.046, n_{\mathrm{Z}}=3.22$ calc. $n_{\mathrm{Z}}-n_{\mathrm{X}}=$ extreme. Color orange red; yellow in powder. PD 2.77, 1.85, 2.50; 3-0760*.
$\mathbf{M g S e}$ is isometric ${ }^{3}$ with G. 4.268 and $n>2.42 \mathrm{Na}$ ( 2.48 calc.).
CaSe is isometric ${ }^{3}$ with G. 3.806 and $n=2.245 \mathrm{C}, 2.274 \mathrm{Na}, 2.292$ ( $555 \mathrm{~m} \mu$ ).

SrSe is isometric ${ }^{3}$ with G. 4.544 and $n=2.190 \mathrm{C}, 2.220 \mathrm{Na}, 2.252$ ( $540 \mathrm{~m} \mu$ ). PD 3.11, 2.20, 1.80; 10-182.

BaSe is isometric ${ }^{3}$ with G. 4.937 and $n=2.230(675 \mathrm{~m} \mu), 2.268 \mathrm{Na}$, $2.289(560 \mathrm{~m} \mu)$.

[^8]ZnSe is isometric ${ }^{3}$ with G. 5.42 and $n=2.89$. PD 3.27, 2.00, 1.71; 5-0522.

CaTe is isometric ${ }^{3}$ with G. 4.873 and $n>2.51$ (2.605 calc.).
SrTe is isometric ${ }^{3}$ with G. 5.218 and $n=2.367 \mathrm{C}, 2.408 \mathrm{Na}, 2.460 \mathrm{Tl}$.
BaTe is isometric ${ }^{3}$ with G. 7.593 and $n=2.379 \mathrm{C}, 2.440 \mathrm{Na}, 2.520 \mathrm{Tl}$. PD 3.50, 2.48, 2.02; 2-0393.
$\mathrm{Sb}_{2} \mathbf{S}_{2} \mathbf{O}$ (Kermesite) is monoclinic with $a=10.97, b=8.19, c=$ $10.36 k X, \beta=101^{\circ} 45^{\prime}$. U.C. 8. Crystals lath shaped on $\{001\}$, long $11 b$. H. $1-1.5$. G. 4.68. M.P. $516^{\circ}$ C. Color cherry-red. $Z=b$. $(-) 2 \mathrm{~V}=$ ?, $n_{\mathrm{X}}>2.72$. Birefringence strong. ${ }^{8}$

## 3. Formula Type $A_{2} X_{3}$

$\mathrm{As}_{2} \mathbf{S}_{3}$ (Orpiment) is monoclinic ${ }^{9}$ with $a=11.47, b=9.57, c=4.24 k X$, $\beta=90^{\circ} 27^{\prime}$. U.C. 4. Crystals small with perfect $\{010\}$ cleavage. Laminæ flexible but not elastic. H. 2. G. 3.48. M.P. $328^{\circ}$ C. Volatile. $X=b$, $\mathrm{Y} \wedge c=1-3^{\circ}$ in acute angle $\beta .(-) 2 \mathrm{~V}=76^{\circ}, \mathrm{r}>\mathrm{v}$ strong. $n_{\mathrm{X}}=2.4 c a$. $\mathrm{Li}, n_{\mathrm{Y}}=2.81, n_{\mathrm{Z}}=3.02, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.62 c a$. Color yellow with Y yellow, Z greenish yellow. PD 4.82, 2.70, 4.00; 1-0273.
$\mathbf{S b}_{2} \mathbf{S}_{3}$ (Stibnite) is orthorhombic ${ }^{9}$ with $a=11.20, b=11.28, \quad c=$ $3.83 \AA$. U.C. 4. Crystals long prismatic with perfect $\{010\}$ cleavage. H. 2. G. 4.59-4.63. M.P. $546-551^{\circ} \mathrm{C}$. Soluble in $\mathrm{HCl} . \mathrm{Y}=a ; \mathrm{Z}=c$. $(-) 2 \mathrm{~V}=$ $25^{\circ} 45^{\prime} . \quad n_{\mathrm{X}}=3.194, \quad n_{\mathrm{Y}}=4.046, \quad n_{\mathrm{Z}}=4.303, n_{\mathrm{Z}}-n_{\mathrm{X}}=1.109$. Very strong dispersion. Color and streak steel-gray, subject to black tarnish. Luster metallic. Nearly opaque to translucent to red and infrared rays. PD 2.76, 3.05, 3.56; 6-0474.

## 4. Formula Type $\mathrm{AX}_{2}$

$\mathbf{M n S}_{2}$ (Hauerite) is isometric with ${ }^{10 a} a=6.101 \AA$ A. U.C. 4. H. 4. G. 3.463. Perfect cubic cleavage. $n=2.69 \mathrm{Li},{ }^{8} 2.58$ (910). ${ }^{10 a}$ Color brown to black; deep red in thin section. PD 3.07, 1.18, 1.84; 10-476.
$\mathbf{F e S}_{2}$ (Pyrite) is isometric with $a=5.405$ Å. U.C. 4. H. 6-6.5. G. 5.02 M.P. $642^{\circ}$ C. Opaque. Metallic luster. $n^{7}=6.22$. Reflection percentages: red 52.5 , orange 53.5 , green 54 . PD 1.63, 2.71, 2.42; 6-0710.

## 5. Formula Type $A_{m} B_{n} X_{p}$ with ( $m+n$ ):p $\approx 3: 2$; also $4: 3$

$(\mathbf{A g}, \mathbf{C u})_{16} \mathbf{S b}_{2} \mathbf{S}_{11}$ (Polybasite) is monoclinic with $a=12.99, b=7.50$, $c=11.95 k X, \beta=90^{\circ}$. U.C. 2. Crystals pseudo-hexagonal basal plates. Perfect $\{001\}$ cleavage. H. 2-3. G. 6.1. Color iron-black; nearly opaque. ${ }^{11}$ $\mathrm{X}=c, \mathrm{Y}=a .(-) 2 \mathrm{~V}=22^{\circ}, n>2.72$. Birefringence very strong. Reflec-
${ }^{10 \mathrm{a}}$ Gordon: Am. Min. XXXVI, p. 918, (1951).
${ }^{11}$ Larsen and Berman: U. S. Geol. Surv. Bull. 848, p. 213 (1934).
tion percentages: red 25.5, orange 25.5, green 29.5. PD 3.00, 3.19, 2.88; 8-123.
$\mathbf{A g}_{3} \mathbf{S b S}_{3}$ (Pyrargyrite) is hexagonal with $a=11.04, c=8.72$. U.C.6. Prismatic, scalenohedral, massive. Distinct $\{10 \overline{1} 1\}$ cleavage. H. 2.5. G. 5.85. M.P. $486^{\circ}$ C. Uniaxial negative with $n_{\mathrm{O}}=3.084, n_{\mathrm{E}}=2.881$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.203$. Color deep red. Reflection percentages: red 24.5, orange 27, green 32.5. PD 2.81, 2.57, 3.22; 2-0835.
$\mathbf{A g}_{3} \mathbf{A s S}_{3}$ (Proustite) is hexagonal ${ }^{9}$ with $a=10.74, c=864 \AA$. Space group R3c. U.C. 6. Distinct rhombohedral cleavage. H. 2-2.5. G. 5.51. M.P. $490^{\circ}$ C. Uniaxial negative with $n_{\mathrm{O}}=2.9789 \mathrm{Li}, 3.0877 \mathrm{Na}, n_{\mathrm{E}}=$ $2.7113 \mathrm{Li}, 2.7924 \mathrm{Na}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.2676 \mathrm{Li}, 0.2953 \mathrm{Na}$. Color scarlet: deep red by transmitted light and pleochroic with $\mathrm{O}=$ blood red and $\mathrm{E}=$ cochineal red. Reflection percentages: red 20.5 , orange 21.5 , green 28 . It may contain some Sb in place of As. PD 2.76, 3.28, 3.18; 9-110.
$(\mathbf{C u}, \mathbf{F e})_{12} \mathbf{S b}_{4} \mathbf{S}_{13}$ (Tetrahedrite) is isometric with $a=10.33 k X$. U.C. 2. Crystals tetrahedral. H. 3. G. 4.97. Color gray to black. Opaque except in very fine splinters which are red. ${ }^{11 a} n=3.128$. Reflection percentages: red 20.5, orange 24, green 27. Forms a series with tennantite. PD 2.96, 1.81. 1.54; 3-0639* (obsolete?).
$(\mathbf{C u}, \mathbf{F e})_{12} \mathbf{A s}_{4} \mathbf{S}_{13}$ (Tennantite) is isometric with $a=10.19 k X$. U.C. 2. Crystals tetrahedral. H. 4.5. G. 4.62. Color gray to black; opaque except in very thin splinters which are red. ${ }^{1 \mathrm{a}} n=2.914 \mathrm{Li}$. Reflection percentages: red 21.5 , orange 24 , green 27 . PD 2.95, 1.81, 1.54; 2-0715 (obsolete?).

## 6. Formula Type $A_{m} B_{n} X_{p}$ with (m+n):p $\approx 1: 1$; also <1:1

$\mathbf{A g S b S}_{2}$ (Miargyrite) is monoclinic with $a=13.17, b=4.39, c=$ $12.83 k X, \beta=98^{\circ} 37.5^{\prime}$. U.C. 8. Poor $\{010\}$ cleavage. H. 2.5. G. 5.25. Color iron-black to gray. Thin splinters translucent and red. ${ }^{8}(-) 2 \mathrm{~V}=$ medium. $n_{\mathrm{Y}}>2.72 \mathrm{Li}$. Birefringence very strong. PD 2.89, 3.45, 2.75; 4-0675.
$\mathbf{A g A s S}_{2}$ has two (or three?) crystal phases. The low-temperature phase (trechmannite) is rhombohedral with $c / a=0.653$. Crystals short prismatic with good $\{10 \overline{1} 1\}$ and distinct $\{0001\}$ cleavages. H. 1.5-2. Uniaxial negative with $n_{0}=2.60$; birefringence extreme. Color and streak scarlet. O pale reddish, E nearly colorless. It inverts on moderate heating to a biaxial phase (perhaps smithite) which has (-)2V $=26^{\circ} \pm, \mathrm{r}>\mathrm{v}$ strong, $n_{\mathrm{X}}=2.48 \mathrm{Li}, n_{\mathrm{Y}}=2.58, n_{\mathrm{Z}}=2.60, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.12$.

AgAsS $_{2}$ (Smithite) is monoclinic with $a=17.20, b=7.76, c=$ $15.16 \mathrm{k} X, \beta=101^{\circ} 12^{\prime}$. U.C. 24 . Crystals equant with perfect $\{100\}$ cleavage. H. 1.5-2. G. 4.88. Color red. ${ }^{12} \mathrm{Y}=b, \mathrm{Z} \wedge c=6.5^{\circ} .(-) 2 \mathrm{~V}=65^{\circ} \pm$,

[^9]$n=3.27$ Na. Birefringence very strong. Again: ${ }^{8} n_{\mathrm{X}^{\prime}}=3.18, n_{\mathrm{Z}^{\prime}}=3.27$, $n_{\mathrm{Z}^{\prime}}-n_{\mathrm{X}^{\prime}}=0.18$ [sic].

TlAsS $_{2}$ (Lorandite) is monoclinic with $a=12.25, b=11.32, c=6.10$, $\beta=104^{\circ} 12^{\prime}$. Excellent $\{100\}$ and good $\{\overline{2} 01\}$ and $\{001\}$ cleavages. H. 2-2.5. G. 5.53. Color red. X nearly $\perp 100 ; \mathrm{Z}=b$. ( - ) $2 \mathrm{~V}=$ large, $n_{\mathrm{X}}>2.72 .{ }^{8}$ Birefringence extreme. Pleochroic with Y purple-red, Z orangered. PD 3.58, 2.86, 2.96; 2-0367.
$\mathbf{P b}_{2} \mathbf{A s}_{2} \mathbf{S}_{5}$ (Dufrenoysite) is monoclinic with $a: b: c=0.651: 1: 0.613$, $\beta=90^{\circ} 33.5^{\prime}$. Perfect $\{010\}$ cleavage. H. 3. G. 5.53. Color lead-gray. Dark red-brown ${ }^{8}$ in splinters. $n>2.72 \mathrm{Li}$. Very strong birefringence. PD 3.74, 3.00, 2.70; 10-453.
$(\mathbf{P b}, \mathbf{T l})_{2}(\mathbf{C u}, \mathbf{A g}) \mathbf{A s}_{5} \mathbf{S}_{10}$ ? (Hutchinsonite) is orthorhombic with $a: b: c$ $=0.612: 1: 0.462$. Crystals prismatic or acicular. Good $\{010\}$ cleavage. H. 1.5-2. G. 4.6. Color vermilion to deep cherry-red. $\mathrm{X}=a, \mathrm{Y}=b$. $(-) 2 \mathrm{~V}=37^{\circ} 34^{\prime} \mathrm{Na},{ }^{12} \mathrm{r}<\mathrm{v}$ extreme. $n_{\mathrm{X}}=3.078 \mathrm{Na}, n_{\mathrm{Y}}=3.176, n_{\mathrm{Z}}=$ $3.188, n_{\mathrm{z}}-n_{\mathrm{X}}=0.118$. PD 2.74, 3.78, 3.05; 8-124.
$\mathbf{H g S b}_{4} \mathrm{~S}_{7}$ (Livingstonite) is monoclinic with $a=15.14, b=3.98, c=$ $21.60 \AA, \beta=104^{\circ}$. U.C. 4. Acicular. Perfect $\{001\}$ and poor $\{010\}$ and $\{100\}$ cleavages. H. 2. G. 5.0. Color gray; streak red. Thin splinters translucent red. ${ }^{8} \mathrm{Z}=b$. ( - ? $) 2 \mathrm{~V}=? n \gg 2.72 \mathrm{Li}, n_{\mathrm{Y}}=3$. $c a$. Birefringence extreme. Pleochroic with $\mathrm{X}>\mathrm{Z}$. PD 3.00, 3.74, 3.48; 4-0654.
$\mathbf{N a}_{2} \mathbf{S n S}_{3} \cdot \mathbf{3 H}_{2} \mathrm{O}$ is tetragonal; ${ }^{13}$ crystals dipyramids. Uniaxial positive with $n_{0}>1.8, \mathrm{~N}_{\mathrm{E}}-\mathrm{N}_{\mathrm{O}}=$ extreme.
$\mathrm{Na}_{4} \mathrm{SnS}_{4} \cdot 18 \mathrm{H}_{2} \mathrm{O}$ is monoclinic ${ }^{13}$ in prisms with positive elongation and $(+) 2 \mathrm{~V}=68^{\circ} 12^{\prime}, n_{\mathrm{X}}=1.643, n_{\mathrm{Y}}=1.6485, n_{\mathrm{Z}}=1.663, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.020$.
$\mathrm{Na}_{2} \mathrm{SnS}_{3} \cdot \mathbf{8 H}_{2} \mathrm{O}$ is probably monoclinic ${ }^{13}$ in prisms with (-)2V $=66^{\circ} \pm$, $n_{\mathrm{X}}=1.605, n_{\mathrm{Y}}=1.647$ calc., $n_{\mathrm{Z}}=1.746, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.141$.
 elongation. (-) $2 \mathrm{~V}=$ small, $n=1.79$ (average), $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.024$.
$\mathbf{N a}_{4} \mathrm{Sn}_{5} \mathrm{O}_{2} \mathrm{~S}_{10} \cdot \mathbf{1 8} \mathrm{H}_{2} \mathrm{O}$ is probably triclinic. ${ }^{13}$ Crystals acicular. (-)2V $=$ $60^{\circ}$, with strong dispersion. $n=1.80$ (average), $n_{\mathrm{z}}-n_{\mathrm{X}}=0.0016$.
$\mathrm{Na}_{4} \mathrm{Sn}_{5} \mathrm{O}_{2} \mathrm{~S}_{10} \cdot \mathbf{2 0 H}_{2} \mathrm{O}$ is orthorhombic. ${ }^{13}$ Crystals acicular with negative elongation. (-) $2 \mathrm{~V}=$ small. $n=1.79$ (average), $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.019$.
$\mathrm{Na}_{3} \mathrm{AsS}_{4} \cdot \mathbf{8 H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=0.668: 1: 0.528, \beta=103^{\circ} 22^{\prime}$. Crystals short, prismatic. $\mathrm{X} \wedge c=81^{\circ} 11^{\prime}, \mathrm{Y}=b$. (-) $2 \mathrm{~V}=87^{\circ} 44^{\prime} . n_{\mathrm{Y}}=$ $1.6802, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ weak. Very weakly pleochroic.
${ }^{13}$ Jelley: Jour. Chem. Soc. 1934, p. 1076.

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## 1. Anhydrous Halides, etc., of Monovalent Bases. Formula Type AX

NaCl (Halite or common salt) is isometric with $a=5.64$ and a facecentered arrangement of each kind of its atoms as shown in Fig. 3-1. Crystals cubic with perfect cubic cleavage. H. 2.5. G. 2.17. M.P. $750^{\circ} \mathrm{ca}$. Soluble in water. Isotropic with $n=1.5407 \mathrm{C}, 1.5443 \mathrm{D}, 1.5534 \mathrm{~F}$. Colorless unless stained. PD 2.82, 1.99, 1.63; 5-0628.
$\mathbf{K C l}$ (Sylvite) is isometric with $a=6.29$ and the NaCl space lattice. Crystals cubic with perfect cubic cleavage. H. 2. G. 1.997. F. easy ( $776^{\circ}$ ) with violet flame. Soluble in water. Isotropic with $n=1.4872 \mathrm{C}, 1.4904 \mathrm{D}$, 1.4984 F. Colorless or stained.

[^10]KH is isometric with the NaCl space lattice. Crystals acicular. G. 1.431.47. Isotropic with ${ }^{20} n=1.453$. PD 3.30, 2.86, 2.02; 3-0454.
$\mathbf{N a C N}$ is isometric with the NaCl space lattice. Crystals cubic. M.P. $564^{\circ} \mathrm{C}$. Isotropic with $n=1.452$. Colorless. PD 2.95, 2.09, 1.78; 4-0665.

KCN is isometric. G. 1.52. M.P. $635^{\circ}$ C. Crystals often cubes or octahedrons. Isotropic with ${ }^{19} n=1.410 \pm 0.003$. Colorless. Very poisonous. PD 3.26, 2.31, 3.77; 4-0547.
$\mathbf{N a K}(\mathbf{C N})_{2}$ is isometric. Colorless. Isotropic with ${ }^{9} n=1.465 \pm$.
$\mathbf{A g C N}$ crystallizes in prisms ${ }^{9}$ which are probably uniaxial. G. 3.95. Optic sign positive. $n_{\mathrm{O}}=1.685 \pm, n_{\mathrm{E}}=1.94, n_{\mathrm{E}}-n_{\mathrm{O}}=0.255 \pm$. White. PD 3.00, 3.70, 2.33; 1-0859.
$\mathbf{K A g}(\mathbf{C N})_{2}$ (?) is trigonal with $c / a=2.07$. No good cleavage. Uniaxial positive ${ }^{21}$ with $n_{\mathrm{O}}=1.625, n_{\mathrm{E}}=1.63, n_{\mathrm{E}}-n_{\mathrm{O}}=0.005$.
$\mathbf{K}_{3} \mathbf{C u}(\mathbf{C N})_{4}$ is trigonal in rhombohedral forms. Uniaxial negative with $n=1.5185 \mathrm{Li}, 1.5215 \mathrm{Na}, 1.5285$ blue, $n_{\mathrm{o}}-n_{\mathrm{E}}=$ very weak.

NaCNO is hexagonal ${ }^{9}$ with rhombohedral cleavage. Uniaxial positive with $n_{\mathrm{O}}=1.389, n_{\mathrm{E}}=1.627, n_{\mathrm{E}}-n_{\mathrm{O}}=0.238$. Colorless.

KCNO is tetragonal ${ }^{18}$ with $c / a=0.577$. Crystals basal tablets with $\{111\}$. G. 2.056. No cleavage seen. Uniaxial negative with $n_{0}=1.552$, $n_{\mathrm{E}}=1.377, n_{\mathrm{O}}-n_{\mathrm{E}}=0.173$. Colorless.

NaCNS forms ${ }^{19}$ clear prismatic crystals, probably orthorhombic, with X parallel elongation. $(-) 2 \mathrm{~V}=82^{\circ} \pm 3^{\circ}$ calc., $n_{\mathrm{X}}=1.545 \pm 0.005, n_{\mathrm{Y}}=$ $1.625 \pm 0.005, n_{\mathrm{Z}}=1.695 \pm 0.005, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.150 \pm 0.01$. Colorless. PD 3.20, 3.49, 2.96; 1-0741.

KCNS forms ${ }^{19}$ long prismatic crystals, probably monoclinic with $\mathrm{Z} \wedge c=16^{\circ} \pm .(-) 2 \mathrm{~V}=68^{\circ} \pm 3^{\circ}$ calc., $n_{\mathrm{X}}=1.532 \pm 0.003, n_{\mathrm{Y}}=1.660$ $\pm 0.005, n_{\mathrm{Z}}=1.730 \pm 0.005, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.198 \pm 0.01$. Colorless. PD 2.97, 2.78, 2.79; 9-388.
$\mathbf{N H}_{4} \mathbf{C N S}$ is monoclinic ${ }^{22}$ with $a: b: c=2.035: 1: 2.367, \beta=117^{\circ} 2^{\prime}$. Crystals $\{100\}$ plates or prisms with perfect $\{100\}$ and $\{10 \overline{1}\}$ cleavages. $\mathrm{Y}=b,{ }^{19} \mathrm{Z} \wedge c=22^{\circ}$. (-) $2 \mathrm{~V}=23^{\circ} \pm 3^{\circ}$ calc., $\mathrm{r}<\mathrm{v}$ strong, and also inclined dispersion. $n_{\mathrm{X}}=1.546 \pm 0.003, n_{\mathrm{Y}}=1.685 \pm 0.003, n_{\mathrm{Z}}=1.692$ $\pm 0.003, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.146 \pm 0.006$. Again: $:^{22} \mathrm{X} \wedge \perp\{10 \overline{1}\}=18^{\circ}$. PD 3.66, 3.11, 2.99; 1-0511.
$\mathbf{L i N H}_{2}$ is isometric. Crystals often cubes modified by a tetrahedron. ${ }^{18}$ G. 1.178. M.P. $373-5^{\circ} \mathrm{C}$. Isotropic with $n=1.610$. Colorless or stained. PD 2.91, 1.78, 2.52; 6-0418.
$\mathbf{N a N H}_{2}$ is biaxial with good cleavage. M.P. $210^{\circ} \mathrm{C} .(+) 2 \mathrm{~V}=$ moderate,

[^11]r > v. $n_{\mathrm{X}}=1.500, n_{\mathrm{Y}}=1.527, n_{\mathrm{Z}}=1.562, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.062$. Colorless or stained. PD 5.20, 1.96, 3.18; 3-0123.

## 2. Hydrated Halides, etc., of Monovalent Bases. Formula Type $\mathrm{AX} \cdot \mathrm{nH}_{2} \mathrm{O}$

$\mathbf{K F} \cdot \mathbf{2} \mathbf{H}_{2} \mathrm{O}$ is pseudo-hexagonal and probably monoclinic. Optic orientation unknown. ${ }^{9}(+) 2 \mathrm{~V}=$ very large. $n_{\mathrm{X}}=1.345 \pm, n_{\mathrm{Y}}=1.352, n_{\mathrm{Z}}=$ $1.363 \pm, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.018 \pm$. Colorless. PD 3.01, 2.58, 4.42; 1-0854.
$\mathrm{NaBr} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ is monoclinic ${ }^{23}$ with $a=6.59 k X, b=10.20, c=6.51$, $\beta=112^{\circ} 05^{\prime}$, U.C. 4. Crystals short six-sided prisms or thick basal plates. G. 2.166 (calc. 2.28 ). $\mathrm{Y}=b .(-) 2 \mathrm{~V}=$ very large with weak inclined dispersion. $n_{\mathrm{X}}=1.5128, n_{\mathrm{Y}}=1.5192, n_{\mathrm{Z}}=1.5252$ D. $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0124$. Colorless.

LiI $\cdot \mathbf{3} \mathbf{H}_{2} \mathbf{O}$ is hexagona ${ }^{24}$ with $c / a=0.731$. Crystals short prisms. Plastic with no cleavage. G. 3.48. Loses water and melts at $73^{\circ} \mathrm{C}$. Uniaxial negative with $n_{\mathrm{O}}=1.655, n_{\mathrm{E}}=1.625, n_{\mathrm{O}}-n_{\mathrm{E}}=0.030$. Colorless or yellowish. PD 4.20, 2.79, 3.73; 1-0411.

## 3. Anhydrous Halides, etc., of Divalent Bases. Formula Type $\mathbf{A X}_{2}$

$\mathbf{M g F}_{2}$ (Sellaite) is tetragonal with $a=4.660, c=3.078 k X$. U.C. 2. Crystals prismatic with perfect $\{010\}$ and $\{110\}$ cleavages. H. 5. G. 3.15. Uniaxial positive with ${ }^{25} n_{\mathrm{O}}=1.378, n_{\mathrm{E}}=1.390, n_{\mathrm{E}}-n_{\mathrm{O}}=0.012$. Colorless to white. PD 3.27, 2.23, 1.71; 6-0290.
$\mathbf{C a F}_{2}$ (Fluorite) is isometric with a space lattice as shown in Fig. 3-4. Crystals often cubic, as in Fig. 3-5, or octahedral, with perfect \{111\} cleavage and common twinning on $\{111\}$ (see Fig. 3-6). H. 4. G. 3.18. Fuses at $1360^{\circ} \mathrm{C}$. with red flame color. Soluble in $\mathrm{H}_{2} \mathrm{SO}_{4}$ with evolution of HF. Isotropic with ${ }^{26} n=1.4325 \mathrm{C}, 1.43385 \mathrm{D}, 1.4370 \mathrm{~F}$. Colorless or stained green, purple, etc. Often shows weak birefringence probably due to strain. It may contain Y or Ce to about $\mathrm{Y}, \mathrm{Ce}: \mathrm{Ca}=1: 2$; with about ${ }^{27}$ 17 per cent (Y, Ce) $\mathrm{F}_{3}$ : G. $3.40, n=1.448$. PD 1.93, 3.15, 1.65; 4-0864.
$\mathbf{Z n F}_{2}$ is tetragonal or hexagonal. G. 4.84. M.P. $872^{\circ}$ C. Uniaxial positive ${ }^{28}$ with $n_{\mathrm{O}}=1.510, n_{\mathrm{E}}=1.526, n_{\mathrm{E}}-n_{\mathrm{O}}=0.016 . \mathrm{PD} 3.33,2.61,1.75 ; 7-214$.
$\mathbf{S r F}_{2}$ is isometric with the $\mathrm{CaF}_{2}$ space lattice. G. 4.24 . M.P. $1190^{\circ} \mathrm{C}$.

[^12]

Fig. 3-4. Space lattice of $\mathrm{CaF}_{2}$.


Fig. 3-5. A crystal habit of $\mathrm{CaF}_{2}$.
Isotropic with ${ }^{30} n=1.438$ D. Again: ${ }^{29} n=1.442 \pm 0.001 \mathrm{D}$. Miscible in all proportions ${ }^{31}$ with $\mathrm{CaF}_{2}$. PD 3.35, 2.05, 1.75; 6-0262.
$\mathbf{C d F}_{2}$ is isometric ${ }^{32}$ with the $\mathrm{CaF}_{2}$ space lattice. G. 6.64 . M.P. $1100^{\circ} \mathrm{C}$. Isotropic with $n=1.56$. Miscible in all proportions with $\mathrm{CaF}_{2}$ with rectilinear variation of the refractive index. PD 3.11, 1.90, 1.62; 5-0567.
${ }^{29}$ Wulff and Heigl: Zeit. Krist. LXXVII, p. 98 (1931).
${ }^{30}$ Thilo: Zeit. Krist. LXV, p. 720 (1927); Wulf: Zeit. Elektrochem. XXXIV, p. 611 (1928).
${ }^{31}$ Rumpf: Zeit. phys. Chem. B, VII, p. 148 (1930).
${ }^{32}$ Goldschmidt: Skr. Norsk. Vid. Akad. I, p. 84 (1926).
$\mathbf{B a F}_{2}$ is isometric ${ }^{29}$ with G. 4.89. M.P. $1280^{\circ}$ C. Isotropic with $n=1.475$. Again: ${ }^{5} n=1.4741$ D. PD 3.58, 2.19, 1.87, 4-0452.
$\mathbf{C a B e F}_{4}$ is tetragonal ${ }^{33}$ with $a=6.90, c=6.07 \AA$. Uniaxial with $n=$ 1.355 .
$\mathbf{M g Z n F}_{4}$ is uniaxial positive with $^{28} n_{\mathrm{O}}=1.40 \mathrm{ca}$., $n_{\mathrm{E}}=1.41 \mathrm{ca}$., $n_{\mathrm{E}}-$ $n_{\mathrm{O}}=0.01 \mathrm{ca}$. M.P. $1185^{\circ} \mathrm{C}$.


Fig. 3-6. Penetration spinel twin in $\mathrm{CaF}_{2}$.
$\mathbf{C a Z n F}_{4}$ is uniaxial negative with $^{28} n_{\mathrm{O}}=1.465, n_{\mathrm{E}}=1.455, n_{\mathrm{O}}-n_{\mathrm{E}}=$ 0.010 . M.P. $796^{\circ} \mathrm{C}$.
$\mathrm{SrZnF}_{4}$ is uniaxial negative with $^{28}$ mean index $=1.455, n_{\mathrm{O}}-n_{\mathrm{E}}<$ 0.009. M.P. $729^{\circ} \mathrm{C}$.
$\mathbf{B a Z n F}_{4}$ is uniaxial negative with $^{28}$ mean index $=1.544, n_{\mathrm{O}}-n_{\mathrm{E}}=$ $0.004 \pm$ M.P. $790^{\circ} \mathrm{C}$.
$\mathrm{MnZnF}_{4}$ is uniaxial positive with $^{28} n_{\mathrm{O}}=1.487, n_{\mathrm{E}}=1.517, n_{\mathrm{E}}-n_{\mathrm{O}}=$ 0.030. M.P. $897^{\circ} \mathrm{C}$.

ZnClF is biaxial with $^{28}(+) 2 \mathrm{~V}=70^{\circ} c a$., mean index $=1.70, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}<0.009$. M.P. $689^{\circ} \mathrm{C}$.

SrCIF is tetragonal ${ }^{34}$ with good basal cleavage and G. 4.62 . M.P. $962^{\circ} \mathrm{C}$. Uniaxial negative with $n_{\mathrm{O}}=1.651, n_{\mathrm{E}}=1.627, n_{\mathrm{O}}-n_{\mathrm{E}}=0.024$.

BaCIF is tetragonal with ${ }^{34}$ good basal cleavage and G. 5.93. M.P. $1008^{\circ}$ C. Uniaxial negative with $n_{\mathrm{O}}=1.640, n_{\mathrm{E}}=1.633, n_{\mathrm{O}}-n_{\mathrm{E}}=0.007 \mathrm{PD}$ 3.77, 3.09, 2.35; 3-0304.

[^13]PbCIF (Matlockite) is tetragonal with $a=4.09, c=7.21 k X$. Crystals basal tablets with perfect $\{001\}$ cleavage. H. 2.5-3. G. 7.12. M.P. $601^{\circ} \mathrm{C}$. Uniaxial negative with ${ }^{35} n_{\mathrm{O}}=2.145 \mathrm{Na}, 2.191$ (486), $n_{\mathrm{E}}=2.006 \mathrm{Na}$, $2.039 \mathrm{Tl}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.139 \mathrm{Na}$. Sometimes biaxial probably due to strain. Colorless or yellow, amber or green. Colorless in section.
$\mathbf{M g C l} \mathbf{2}_{2}$ (Chloromagnesite) is hexagonal with $a=3.58, c=17.59 \mathrm{kX}$. Crystals basal plates. G. 2.325. M.P. $708^{\circ} \mathrm{C}$. Uniaxial negative with ${ }^{12}$ $n_{\mathrm{O}}=1.675, n_{\mathrm{E}}=1.59, n_{\mathrm{O}}-n_{\mathrm{E}}=0.085$. Colorless. PD 2.56, 1.82, 2.96; 3-0854.
$\mathbf{C a C l}_{2}$ (Hydrophilite) is orthorhombic ${ }^{36}$ and pseudo-tetragonal with $a=6.24, b=6.43, c=4.20 k X$. G. 2.2. M.P. $772^{\circ}$ C. Perfect prismatic cleavage and lamellar twinning on $\{110\} .(+) 2 \mathrm{~V}=$ moderate, ${ }^{37} n_{\mathrm{X}}=$ $1.600, n_{\mathrm{Y}}=1.605, n_{\mathrm{Z}}=1.613, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.013$. The substance may react with index liquids containing turpentine, etc., but it does not react with $\alpha$-monobromnaphthalene nor with paraffin oil. PD 4.49, 3.05, 2.33; 1-0338.
$\mathbf{C a C l}_{2}$ forms a brown-yellow powder which is hygroscopic. G. 3.05. M.P. $498^{\circ} \mathrm{C}$. Uniaxial negative. $n_{\mathrm{O}}{ }^{29}=1.542, n_{\mathrm{E}}=1.531, n_{\mathrm{O}}-n_{\mathrm{E}}=0.011$.
$\mathbf{Z n C l}_{2}$ is uniaxial and positive ${ }^{9}$ with $n_{\mathrm{O}}=1.687, n_{\mathrm{E}}=1.713, n_{\mathrm{E}}-n_{\mathrm{O}}=$ 0.026 . Colorless. Also said to be isometric with ${ }^{38}$ G. 2.91 and M.P. $262^{\circ}$ C. PD 3.06, 4.79, 1.86; 1-0822.
$\mathbf{S r C l}_{2}$ is isometric ${ }^{30}$ with G. 3.08 and M.P. $872^{\circ}$ C. Isotropic with $n=$ 1.6499 D. PD 2.47, 4.03, 2.10; 6-0537.
$\mathbf{F e C l}_{2}$ (Lawrencite) is hexagonal in basal plates with $a=3.57, c=$ $17.51 k X$. U.C. 3. Perfect basal cleavage. Uniaxial negative with ${ }^{39} n_{\mathrm{O}}=$ $1.567, n_{\mathrm{O}}-n_{\mathrm{E}}$ is rather weak. Color green to brown or yellow. Made by sublimation. PD 2.54, 5.9, 1.80; 1-1106.
$\mathbf{B a C l}_{2}$ is monoclinic (inverts to isometric at $925^{\circ}$ ); G. 3.856. ( + ) $2 \mathrm{~V}=$ near ${ }^{30} 90^{\circ} . n_{\mathrm{X}}=1.73024, n_{\mathrm{Y}}=1.73611, n_{\mathrm{Z}}=1.74196, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.01172$. PD 2.85, 2.59, 2.46; 2-0794*.
$\mathbf{H g C l}_{2}$ is orthorhombic with $a: b: c=0.725: 1: 1.070$. Crystals equant or thin basal tablets with perfect $\{011\}$ and poor $\{001\}$ cleavages. G. 6.22. M.P. $153^{\circ} \mathrm{C} . \mathrm{X}=c, \mathrm{Y}=a .^{14}(-) 2 \mathrm{~V}=85^{\circ}, n_{\mathrm{X}}=1.725, n_{\mathrm{Y}}=1.859$, $n_{\mathrm{Z}}=1.965, n_{\mathrm{z}}-n_{\mathrm{X}}=0.240 . \mathrm{PD} 4.35,2.99,4.10 ; 4-0331$.
$\mathbf{P b C l}_{2}$ (Cotunnite) is orthorhombic with $a=7.67, b=9.15, c=$ $4.50 k X$. U.C. 4. Perfect basal cleavage. H. 2.5. G. 5.8. Soluble in hot water.

[^14]$\mathrm{Y}=b,{ }^{40} \mathrm{Z}=c .(+) 2 \mathrm{~V}=66^{\circ} 12^{\prime} \mathrm{Na}, n_{\mathrm{X}}=2.179 \mathrm{Li}, 2.199 \mathrm{Na}, n_{\mathrm{Y}}=2.192$ $\mathrm{Li}, 2.217 \mathrm{Na}, n_{\mathrm{Z}}=2.260 \mathrm{Na}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.061 \mathrm{Na}$. Colorless, greenish or yellowish. PD 3.58, 3.89, 2.78; 5-0416.
$\mathbf{P b B r}_{2}$ is orthorhombic ${ }^{41}$ with $a: b: c=0.588: 1: 1.183$. Crystals columnar parallel $a$ with perfect basal cleavage. G. 6.62 . M.P. $373^{\circ} \mathrm{C} . \mathrm{X}=c, \mathrm{Y}=b$. $(+) 2 \mathrm{~V}=$ large, $n_{\mathrm{X}}=2.434, n_{\mathrm{Y}}=2.476, n_{\mathrm{Z}}=2.553, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.119$. Color white. PD 2.92, 3.75, 2.64; 5-0608.
$\mathbf{C a I}_{2}$ is hexagonal with $c / a=0.8599$. Crystals tabular with basal cleavage. G. 5.67. Uniaxial negative with $^{42} n_{\mathrm{O}}=1.743 \mathrm{Na}, n_{\mathrm{E}}=1.652, n_{\mathrm{O}}-$ $n_{\mathrm{E}}=0.091$. Colorless in thin plates; thick ones are weakly pleochroic in bluish or brownish tints. Inverts to a monoclinic phase (with G. 5.305) before melting at $388^{\circ} \mathrm{C}$. PD 3.49, 2.24, 2.00; 4-0481.
$\mathbf{H g I}_{2}$ is dimorphous; one phase is orthorhombic with $a: b: c=0.649: 1: ?$. Crystals prismatic with $\{001\}$. G. 6.22. Forms isomorphous mix-crystals with $\mathrm{HgBr}_{2}$ which have perfect basal cleavage. The acute bisectrix is $b$ and $\mathrm{Y}=c$. Color yellow with weak pleochroism- $\mathrm{X}=\mathrm{Y}<\mathrm{Z}$. The other phase is tetragonal with $c / a=2.008$. Crystals basal tablets or pyramidal; twinning on $\{102\}$. Perfect $\{001\}$ cleavage. G. 6.30. Uniaxial negative with $^{14} n_{\mathrm{O}}=2.600 \mathrm{C}, 2.711$ (600), $2.748 \mathrm{D}, n_{\mathrm{E}}=2.375 \mathrm{C}, 2.438$ (600), $2.455 \mathrm{D}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.293 \mathrm{D}$. Also biaxial with 2 E up to $30^{\circ}$. Color red with X orange-red, Z blood-red. PD 3.57, 4.12, 2.19; 4-0454/5 [which polymorph?].
$\mathbf{H g}(\mathbf{C N})_{2}$ is tetragonal with $c / a=0.459$. Crystals short prismatic with a sphenoid or, rarely, a base. G. 4.00 . Poor $\{100\}$ cleavage. Uniaxial negative with ${ }^{43} n_{\mathrm{O}}=1.645, n_{\mathrm{E}}=1.492, n_{\mathrm{O}}-n_{\mathrm{E}}=0.153$. PD 3.73, 4.85, 2.52; 7-213.

## 4. Hydrafed Halides, etc., of Divalent Bases. Formula Type $\mathrm{AX}_{2} \cdot \mathrm{nH}_{2} \mathrm{O}$

$\mathbf{M g C l}_{\mathbf{2}} \cdot \mathbf{6 H} \mathbf{H} \mathbf{O}$ (Bischofite) is monoclinic with $a: b: c=1.387: 1: 0.854$, $\beta=93^{\circ} 42^{\prime}$. Crystals short prismatic. H. 1-2. G. 1.59. Bitter taste. Decomposes at $116-8^{\circ} \mathrm{C}$. Deliquescent. $\mathrm{X}=b, \mathrm{Y} \wedge c=9.5^{\circ}$. ( + ) $2 \mathrm{~V}=$ $79^{\circ} 24^{\prime}, \mathrm{r}>\mathrm{v}$ weak. ${ }^{44} n_{\mathrm{X}}=1.495, n_{\mathrm{Y}}=1.507, n_{\mathrm{Z}}=1.528, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.033 Na . Colorless or white. PD 4.10, 2.65, 2.88; 1-0431.
$\mathbf{C a C l}_{\mathbf{2}} \cdot \mathbf{4 \mathbf { H } _ { 2 } \mathbf { O }}$ is stable between $14^{\circ}$ and $45^{\circ}$. It has three crystal phases. ${ }^{45}$

[^15]One is triclinic and granular with $(-) 2 \mathrm{~V}=63^{\circ}, n_{\mathrm{X}}=1.532, n_{\mathrm{Y}}=1.560$, $n_{\mathrm{Z}}=1.571, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.039$. A second phase is orthorhombic in needles with Z parallel with elongation and $(-) 2 \mathrm{~V}=5^{\circ} . n_{\mathrm{X}}=1.506, n_{\mathrm{Y}}$ nearly $=$ $n_{\mathrm{Z}}=1.530, n_{\mathrm{z}}-n_{\mathrm{x}}=0.024$. A third phase is orthorhombic(?) in sixsided plates with $(-) 2 \mathrm{~V}=68^{\circ}, n_{\mathrm{X}}=1.447, n_{\mathrm{Y}}=1.477, n_{\mathrm{Z}}=1.491$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.044$. Another report gives ${ }^{23} n_{1}=1.566, n_{2}=1.548$. PD 2.63, 2.22, 4.70; 1-1080.
$\mathbf{C a C l}_{2} \cdot \mathbf{6 H} \mathbf{2} \mathbf{O}$ is trigonal with $c / a=0.505$. Crystals prismatic with perfect basal and prismatic cleavages. G. 1.68. M.P. $30^{\circ}$ C. Uniaxial negative with $n_{\mathrm{O}}=1.417, n_{\mathrm{E}}=1.393$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.024$. Colorless. Again: $:^{23} n_{\mathrm{O}}=$ $1.5504, n_{\mathrm{E}}=1.4949$. PD 2.16, 3.93, 2.78; 1-1220.
$\mathrm{CaMg}_{2} \mathrm{Cl}_{6} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ (Tachyhydrite) is trigonal with ${ }^{46} \quad c / a=1.761$. Perfect $\{10 \overline{1} 1\}$ cleavage. H. 2. G. 1.67. Deliquescent. Uniaxial negative with $n_{\mathrm{O}}=1.520, n_{\mathrm{E}}=1.512 \mathrm{Na}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.008$. Color pale yellow. Made from a solution ${ }^{47}$ of $\mathrm{MgCl}_{2}$ and large excess of $\mathrm{CaCl}_{2}$. PD 2.60, 3.09, 3.80; 1-1092.
$\mathbf{M n C l}_{2} \cdot 2 \mathbf{H}_{2} \mathbf{O}$ is monoclinic ${ }^{48}$ with $a: b: c=1.094: 1: 0.421, \beta=130^{\circ} 48^{\prime}$. Crystals long prisms. Perfect $\{110\}$ and good $\{001\}$ cleavages. H. 1. G. 2.31. Easily deformed. $\mathrm{X}=b, \mathrm{Z} \wedge c=-32^{\circ}$. $(+) 2 \mathrm{~V}=72^{\circ}, n_{\mathrm{X}}=$ $1.584, n_{\mathrm{Y}}=1.611, n_{\mathrm{Z}}=1.666 \mathrm{Na}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.082$. PD 2.80, 5.59, 4.39; 3-0743*.
$\mathbf{F e C l}_{2} \cdot \mathbf{2 H}_{2} \mathrm{O}$ is monoclinic ${ }^{48}$ with $\beta=130^{\circ} 30^{\prime}$. Crystals long prisms. Cruciform twinning on $\{001\}$. Soft. G. 2.387. $\mathrm{X}=b, \mathrm{Z}$ (or Y ?) $\wedge c=$ $-38^{\circ} . n_{\mathrm{Y}}=1.6435$. Colorless or pale green. PD 4.80, 5.60, 3.50; 1-0277*.
$\mathbf{C o C l}_{2} \cdot \mathbf{2 H} \mathbf{2}$ is monoclinic ${ }^{48}$ with $a: b: c=1.111: 1: 0.420, \beta=130^{\circ} 31^{\prime}$. Crystals long prisms; twinning on $\{302\}$. Good $\{110\}$ and distinct $\{001\}$ (?) cleavages. G. 2.477. $\mathrm{X}=b, \mathrm{Z} \wedge c=-33^{\circ}$. ( + ) $2 \mathrm{~V}=78^{\circ}$ calc., $n_{\mathrm{X}}=$ $1.626 \pm 0.002, n_{\mathrm{Y}}=1.662, n_{\mathrm{Z}}=1.721 \mathrm{Na}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.095$. Color dark violet with $X$ inky blue, $Y$ clear carmine red, $Z$ strong carmine red. Formed from $\mathrm{CoCl}_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ by drying in a desiccator at $50^{\circ} \mathrm{C}$. Hydrates easily. PD 2.73, 5.49, 4.27; 3-0786.
$\mathbf{N i C l}_{2} \cdot \mathbf{2 H} \mathbf{H} \mathbf{O}$ is orthorhombic ${ }^{48}$ with $a: b: c=0.784: 1: 0.391$. Crystals long prisms; cruciform twinning. Perfect $\{110\}$ and good $\{001\}$ cleavages. H. 1. G. 2.58. Easily deformed. $\mathrm{X}=b, \mathrm{Y}=a$. (-) $2 \mathrm{~V}=72^{\circ} c a$., $n_{\mathrm{X}}=$ $1.620, n_{\mathrm{Y}}=1.723, n_{\mathrm{Z}}=1.783, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.163$. Pleochroic with X pale yellow to brown, Y and Z canary yellow-green. PD 2.44, 5.40, 4.42; 1-1143.
$\mathrm{SrCl}_{2} \cdot \mathbf{6 H} \mathbf{H} \mathbf{O}$ is hexagonal with $c / a=0.515$. Crystals prismatic with perfect basal cleavage. G. 1.93. Uniaxial negative with $n_{0}=1.5364 \mathrm{Na}$,

[^16]$n_{\mathrm{E}}=1.4866, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0498$. Again: ${ }^{49} n_{\mathrm{O}}=1.5356, n_{\mathrm{E}}=1.4857, n_{\mathrm{O}}-$ $n_{\mathrm{E}}=0.0499$ D. Colorless. PD 6.89, 3.54, 3.98; 6-0073.
$\mathrm{SrBr}_{2} \cdot \mathbf{6} \mathrm{H}_{2} \mathrm{O}$ is hexagonal. Crystals prismatic. ${ }^{18}$ G. 2.358. Uniaxial negative with $n_{\mathrm{O}}=1.557, n_{\mathrm{E}}=1.535, n_{\mathrm{O}}-n_{\mathrm{E}}=0.022$. Colorless. PD 4.12, 3.60, 2.26; 6-0176.
$\mathbf{C u C l}_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ (Eriochalcite) is orthorhombic with $a=7.38, b=8.04$, $c=3.72 \mathrm{kX}$. U.C. 2. Crystal aggregates of fibers often grooved and bent. Perfect $\{110\}$ and good $\{001\}$ cleavages. H. 2.5. G. 2.55. $\mathrm{X}=b, \mathrm{Y}=c .{ }^{9}$ $(+) 2 \mathrm{~V}=80^{\circ} 40^{\prime}, \mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.644, n_{\mathrm{Y}}=1.684, n_{\mathrm{Z}}=1.742, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.098. Again: ${ }^{50}(+) 2 \mathrm{~V}=86^{\circ} 14^{\prime}, n_{\mathrm{X}}=1.644, n_{\mathrm{Y}}=1.683, n_{\mathrm{Z}}=1.731$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.087$. Color bluish green; pleochroic with X pale blue, Y pale tawny green, Z pale yellow-green. PD 5.40, 4.03, 2.63; 1-0217.
$\mathbf{M n C l}_{2} \cdot \mathbf{4 \mathbf { H } _ { 2 } \mathbf { O }}$ ( $\alpha$-phase) is monoclinic with $a: b: c=1.141: 1: 1.641$, $\beta=110^{\circ} 46^{\prime}$. Crystals basal tablets with a pyramid or prismatic with negative ${ }^{19}$ elongation. Twinning common. $(+) 2 \mathrm{~V}=78^{\circ} \pm 3^{\circ}$ calc., $\mathrm{r}<\mathrm{v}$ moderate. $n_{\mathrm{X}}=1.555, n_{\mathrm{Y}}=1.575, n_{\mathrm{Z}}=1.607 \pm 0.003, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.052$. PD 4.37, 4.91, 2.90; 1-0362.
$\mathbf{N i C l}_{2} \cdot \mathbf{6 H} \mathbf{2} \mathbf{O}$ is monoclinic with $a: b: c=1.468: 1: 0.943, \beta=122^{\circ} 30^{\prime}$. Crystals $\{100\}$ tablets with $\{110\}$ and $\{001\}$. Perfect basal cleavage. $\mathrm{X} \wedge c=+8^{\circ} \pm . \mathrm{Y}=b .(+) 2 \mathrm{~V}$ very large, ${ }^{51} n_{\mathrm{X}}=1.535, n_{\mathrm{Y}}=?, n_{\mathrm{Z}}=$ $1.61, n_{\mathrm{z}}-n_{\mathrm{X}}=0.075$. PD 5.50, 4.85, 3.53; 1-0200.
$\mathrm{SrCl}_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ is probably monoclinic with ${ }^{49} \mathrm{G} .2 .37$. ( + ) $2 \mathrm{~V}=$ small, $n_{\mathrm{X}}=1.5942 \pm 0.0002, \quad n_{\mathrm{Y}}=1.5948 \pm 0.0004, \quad n_{\mathrm{Z}}=1.6172 \pm 0.0001$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0230$. PD 3.20, 2.66, 2.10; 3-0500.
$\mathbf{C d C l}_{2} \cdot \mathbf{2 . 5 H _ { 2 }} \mathbf{O}$ is monoclinic with $a: b: c=1.177: 1: 1.112, \beta=95^{\circ} 48^{\prime}$. Crystals varied with distinct $\{001\}$ cleavage. G. 3.327. $\mathrm{Y}=b, \mathrm{Z} \wedge c=$ $+1^{\circ} 40^{\prime}$. $(+) 2 \mathrm{~V}=56^{\circ} 42^{\prime}$ red, $56^{\circ} 27^{\prime} \mathrm{Na}, \mathrm{r}>\mathrm{v}$ weak; $n_{\mathrm{Y}}=1.6428 \mathrm{red}$, $1.6513 \mathrm{Na}, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ ?. Colorless. Another phase is also monoclinic.
$\mathrm{BaCl}_{2} \cdot \mathbf{2 H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=0.618: 1: 0.655, \beta=91^{\circ} 5^{\prime}$. Crystals octagonal tablets parallel to $\{010\}$, twinned on $\{001\}$ or $\{100\}$. No good cleavage. G. 3.09. $\mathrm{Y}=b, \mathrm{Z} \wedge c=8^{\circ}$. ( + ) $2 \mathrm{~V}=84^{\circ} 50^{\prime}$ red, $83^{\circ} 46^{\prime} \mathrm{Na} ; n_{\mathrm{X}}=1.635 \mathrm{Na}, n_{\mathrm{Y}}=1.641 \mathrm{red}, 1.646 \mathrm{Na}, n_{\mathrm{Z}}=1.660 \mathrm{Na}$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.025 \mathrm{Na}$. Again: ${ }^{29} n_{\mathrm{X}}=1.6291, n_{\mathrm{Y}}=1.6419, n_{\mathrm{Z}}=1.6583$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0292$. Colorless. PD 4.48, 2.91, 2.54; 1-0342.
$\mathbf{B a B r}_{2} \cdot \mathbf{2 H}_{2} \mathbf{O}$ is monoclinic with $a: b: c=1.45: 1: 1.16, \beta=113^{\circ} 30^{\prime}$. Crystals short prismatic (see Fig. 3-7) or basal tablets or columnar by elongation of $\{11 \overline{1}\}$. Poor $\{100\},\{10 \overline{1}\}$ or $\{001\}$ cleavages. G. 3.69. Y $=b$,

[^17]$\mathrm{Z} \wedge c=+89^{\circ} 35^{\prime} \mathrm{Na} .(+) 2 \mathrm{~V}=83^{\circ} 30^{\prime} \mathrm{Li}, 83^{\circ} 49^{\prime} \mathrm{Na}, 84^{\circ} 8^{\prime} \mathrm{Tl} . n_{\mathrm{X}}=$ $1.7067 \mathrm{C}, 1.7129 \mathrm{D}, 1.7282 \mathrm{~F}, n_{\mathrm{Y}}=1.7205 \mathrm{C}, 1.7266 \mathrm{D}, 1.7418 \mathrm{~F}, n_{\mathrm{Z}}=$ $1.7382 \mathrm{C}, 1.7441 \mathrm{D}, 1.7588 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0312 \mathrm{D}$. Colorless. Formed from $\mathrm{H}_{2} \mathrm{O}$ solution; crystals easily deformed.


Fig. 3-7. A crystal habit of $\mathrm{BaBr}_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$.
$\mathrm{BaCdCl}_{4} \cdot \mathbf{4 H}_{2} \mathrm{O}$ is triclinic with $a: b: c=0.855: 1: 0.513, \alpha=92^{\circ} 35^{\prime}$, $\beta=106^{\circ} 18^{\prime} \gamma=88^{\circ} 26^{\prime}$. Crystals short prismatic with twinning resembling that of plagioclase. Perfect $\{110\}$ and $\{1 \overline{1} 0\}$ cleavages. G. 2.97. X nearly normal to $\{110\}$; optic plane nearly vertical with extinction at $11^{\circ}$ on (110), $6^{\circ}$ on (010), $2.5^{\circ}$ on (100) and $4.5^{\circ}$ on (110). ( - ) $2 \mathrm{~V}=61^{\circ} 1^{\prime}$, $\mathrm{r}<\mathrm{v} . n_{\mathrm{Y}}=1.638 \mathrm{red}, 1.651 \mathrm{Na}, 1.664$ blue, $n_{\mathrm{Z}}-n_{\mathrm{X}}$ not very strong. Again: ${ }^{52} n_{\mathrm{X}}=1.610, n_{\mathrm{Y}}=1.646, n_{\mathrm{Z}}=1.653$ all $\pm 0.003, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.043$.
$\mathbf{B a C d B r}_{4} \cdot 4 \mathbf{H}_{2} \mathbf{O}$ is isomorphous with $\mathrm{BaCdCl}_{4} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ with the same cleavages and twinning. G. 3.69. Optic orientation differs only $1^{\circ}$ or $2^{\circ}$. $(-) 2 \mathrm{~V}=70^{\circ} 13^{\prime}, \mathrm{r}<\mathrm{v} . n_{\mathrm{Y}}=1.693 \mathrm{red}, 1.702 \mathrm{Na}, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ ?
$\mathbf{C d}_{2} \mathbf{M g C l}_{6} \cdot \mathbf{1 2} \mathbf{H}_{2} \mathbf{O}$ is orthorhombic with $a: b: c=0.913: 1: 0.304$. Crystals prismatic with probable $\{100\}$ and $\{010\}$ cleavages. Deliquescent. $\mathrm{Y}=a$, $\mathrm{Z}=c .(+) 2 \mathrm{~V}=$ very large, $\mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{X}}=1.49 \pm, n_{\mathrm{Y}}=1.5268$ red, $1.5331 \mathrm{Na}, n_{\mathrm{Z}}=1.5728 \mathrm{red}, 1.5769 \mathrm{Na}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.08 \pm$.
$\mathbf{Z n F}_{2} \cdot \mathbf{4 H}_{2} \mathbf{O}$ is biaxial negative ${ }^{28}$ with $2 \mathrm{~V}=50^{\circ}$ ca., $n_{\mathrm{X}}=1.46$ ca., $n_{\mathrm{Y}}=1.468$ calc., $n_{\mathrm{Z}}=1.47 \mathrm{ca} ., n_{\mathrm{Z}}-n_{\mathrm{X}}=0.01 \mathrm{ca}$. Soluble in $\mathrm{NH}_{4} \mathrm{OH}$. Decomposes below $100^{\circ}$ C. PD 4.91, 4.13, 2.99; 1-0253.
$\mathbf{C u}_{2}(\mathbf{O H})_{3} \mathbf{C l}$ (Atacamite) is orthorhombic with $a=6.01, b=9.13$, $c=6.84 k X$. U.C. 4. Crystals often prismatic. Perfect $\{010\}$ and fair $\{101\}$
${ }^{52}$ Quodling and Mellor: Zeit. Krist. CII, p. 146 (1939).
cleavages. $\mathrm{H} .3-3.5$. G. 3.78. $\mathrm{X}=b,{ }^{53} \mathrm{Y}=a .(-) 2 \mathrm{~V}=75^{\circ}, \mathrm{r}<\mathrm{v}$ strong. $n_{\mathrm{X}}=1.831, n_{\mathrm{Y}}=1.861, n_{\mathrm{Z}}=1.880, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.049 \mathrm{Tl}$. Color bright green, streak apple-green. Weakly pleochroic with X pale green, Y yellowish green, Z grass-green. Found in boiler deposits. Made by heating $\mathrm{Cu}_{2} \mathrm{O}$ with $\mathrm{FeCl}_{3}$ solution in a sealed tube. ${ }^{54} \mathrm{PD} 5.40,5.00,2.82 ; 2-0146$.
$\mathrm{Cu}_{2}(\mathbf{O H})_{3} \mathrm{Cl}$ (Paratacamite) is hexagonal with $a=13.65, c=13.95 \mathrm{kX}$. Good rhombohedral cleavage. H. 3. G. 3.74. Uniaxial positive ${ }^{55}$ with $n_{\mathrm{O}}=$ $1.842, n_{\mathrm{E}}=1.848, n_{\mathrm{E}}-n_{\mathrm{O}}=0.006$. Often biaxial (due to strain) with 2 V up to about $50^{\circ}$ and $\mathrm{r}>\mathrm{v}$. Made ${ }^{55}$ by reaction of Cu with salt water. PD 5.74, 2.41, 2.48; 4-0193.
$\mathbf{P b}(\mathbf{O H}) \mathbf{C l}$ (Laurionite) is orthorhombic with ${ }^{56} a=7.1, b=9.7, c=$ $4.05 k X$. U.C. 4. Elongated along $c$. Distinct $\{011\}$ cleavage. H. 2-2.5. G. 6.24. $\mathrm{X}=a, \mathrm{Y}=b .(-) 2 \mathrm{~V}=$ large, ${ }^{53} n_{\mathrm{X}}=2.077, n_{\mathrm{Y}}=2.116, n_{\mathrm{Z}}=$ 2.158, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.081$. Colorless to white. PD 3.30, 4.01, 2.52; 6-0268.
$\mathbf{P b C u}(\mathbf{O H})_{2} \mathbf{C l}_{2}(?)$ (Percylite) is isometric(?). Crystals usually cubic or dodecahedral with cubic cleavage. H. 2.5. G. 2.25. F. 1. Isotropic ${ }^{12}$ with $n=2.05 \pm .01$. Color blue. Also birefringent ${ }^{57}$ in some cases, cause not known. Made by the reaction of $\mathrm{Pb}(\mathrm{OH})_{2}$ on a solution of $\mathrm{CuCl}_{2}$.
$\mathbf{P b}(\mathbf{C u}, \mathbf{A g}) \mathrm{Cl}_{2}(\mathbf{O H})_{2} \cdot \mathbf{H}_{2} \mathbf{O}$ (Boléite) is tetragonal ${ }^{58}$ with $a=15.4, c=$ $62 k X$. Crystals equant and pseudo-isometric. Perfect $\{001\}$, good $\{101\}$ and poor $\{100\}$ cleavages. H. 3-3.5. G. 5.05. Uniaxial negative with ${ }^{12}$ $n_{\mathrm{O}}=2.05, n_{\mathrm{E}}=2.03, n_{\mathrm{O}}-n_{\mathrm{E}}=0.02$. Again ${ }^{59} n=2.081$ and 2.087 in different parts of a zoned crystal. Color deep blue; in section bluish green and not pleochroic. PD 4.40, 3.83, 3.13; 2-0240.
$\mathbf{M g P t}(\mathbf{C N})_{4} \cdot \mathbf{7 H}_{2} \mathbf{O}$ is tetragonal with $c / a=0.61$. Perfect basal cleavage. Uniaxial positive with ${ }^{60} n_{\mathrm{O}}=1.5585 \mathrm{C}, 1.5608 \mathrm{D}, n_{\mathrm{E}}=1.905 \mathrm{C}, 1.91 \mathrm{D}$, $n_{\mathrm{E}}-n_{\mathrm{O}}=0.35 \mathrm{D}$. Color carmine-red with O more, and E less, bluish. Surface color on $\{100\}$ metallic greenish. Strongly pleochroic; phosphorescent.
$\operatorname{MgPt}(\mathrm{CN})_{4} \cdot \mathrm{C}_{3} \mathrm{H}_{8} \mathrm{O}_{3} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=0.965: 1: 0.492$, $\beta=94^{\circ} 4^{\prime}$. Crystals short prismatic (vertically striated) with distinct $\{001\}$ cleavage. The optic plane is normal to $\{010\}$ for Li and parallel to $\{010\}$ for Na and Tl light. $\mathrm{X} \wedge c=24^{\circ}$ for $\mathrm{A}, 30^{\circ}$ for $\mathrm{D}, 36^{\circ}$ for E and $68^{\circ}$ for G

[^18]light. (-) $2 \mathrm{~V}=17^{\circ} 39^{\prime} \mathrm{Na}, 34^{\circ} 18^{\prime} \mathrm{Tl}, 60^{\circ}$ (blue). $n_{\mathrm{Y}}=1.584 \mathrm{Na}, 1.589 \mathrm{Tl}$, $n_{\mathrm{z}}-n_{\mathrm{X}}=$ ?
$\mathbf{C a N i}(\mathbf{C N})_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ is orthorhombic with $^{61} a: b: c=0.911: 1: 0.361$. Crystals show $\{010\},\{100\},\{120\},\{111\}$. Perfect $\{100\}$ cleavage. Soluble in $\mathrm{H}_{2} \mathrm{O}$. G. 1.83. $\mathrm{X}=c, \mathrm{Y}=a$. $(-) 2 \mathrm{E}=70^{\circ} 40^{\prime}(646), 71^{\circ} 20^{\prime}(591), 78^{\circ} 40^{\prime}$ (541). For $\lambda=646: n_{\mathrm{X}}=1.529, n_{\mathrm{Y}}=1.612, n_{\mathrm{Z}}=1.632, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.103$. For $\lambda=578: n_{\mathrm{X}}=1.5405, n_{\mathrm{Y}}=1.617, n_{\mathrm{Z}}=1.638, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0975$. For $\lambda=546: n_{\mathrm{X}}=1.5515, n_{\mathrm{Y}}=1.623, n_{\mathrm{Z}}=1.645, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0935$. Color brown.
$\mathbf{C a P d}(\mathbf{C N})_{4} \cdot 5 \mathbf{H}_{2} \mathbf{O}$ is orthorhombic with ${ }^{61} a: b: c=0.895: 1: 0.350$. Crystals long parallel $c$ with $\{120\},\{100\},\{111\}$. Perfect $\{100\}$ cleavage. G. 2.02. Soluble in $\mathrm{H}_{2} \mathrm{O} . \mathrm{X}=c, \mathrm{Y}=a$. (-)2V $=68^{\circ}$. For $\lambda=646$ : $n_{\mathrm{X}}=1.532, n_{\mathrm{Y}}=1.598, n_{\mathrm{Z}}=1.632$. For $\lambda=591: n_{\mathrm{X}}=1.539, n_{\mathrm{Y}}=$ $1.602, n_{\mathrm{Z}}=1.639, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.100$. For $\lambda=541: n_{\mathrm{X}}=1.549, n_{\mathrm{Y}}=$ $1.605, n_{\mathrm{z}}=1.645$. Colorless.
$\mathbf{C a P t}(\mathbf{C N})_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ is orthorhombic ${ }^{61}$ with $a: b: c=0.899: 1: 0.349$. Crystals prismatic with $\{120\},\{100\}$ and $\{010\}$ and perfect $\{100\}$ cleavage. G. 2.61. $\mathrm{X}=a, \mathrm{Y}=b$. For $588 \mathrm{~m} \mu(+) 2 \mathrm{~V}=48^{\circ} 10^{\prime}, n_{\mathrm{X}}=1.623, n_{\mathrm{Y}}=$ $1.644, n_{\mathrm{Z}}=1.767, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.144$. For $486 \mathrm{~m} \mu:(+) 2 \mathrm{~V}=30^{\circ} 23^{\prime}, n_{\mathrm{X}}=$ $1.636, n_{\mathrm{Y}}=1.658, n_{\mathrm{Z}}=2.030 \pm, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.394 \pm$. Color green, not distinctly pleochroic; fluorescent.
$\mathrm{Ca}_{2} \mathbf{F e}(\mathbf{C N})_{6} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ is triclinic with $a: b: c=1.054: 1: 0.841, \alpha=97^{\circ} 9^{\prime}$, $\beta=89^{\circ} 57^{\prime}, \gamma=107^{\circ} 24^{\prime}$. Perfect $\{001\}$ cleavage. G. 1.68. Optic plane nearly normal to $\{001\}$; an optic axis nearly normal to $\{010\}$. The normal to $\{010\}$ makes an angle of $16^{\circ} 18^{\prime}(\mathrm{Na})$ with Z and $77^{\circ} 10^{\prime}$ with X . A normal to $\{100\}$ makes an angle of $59^{\circ} 31^{\prime}$ with Z and $71^{\circ} 21^{\prime}$ with X . $(+) 2 \mathrm{~V}=85^{\circ} 12^{\prime} \mathrm{Na}, \mathrm{r}>\mathrm{v} . n_{\mathrm{x}}=1.5646 \mathrm{Li}, 1.5700 \mathrm{Na}, 1.5753 \mathrm{Tl}$, $n_{\mathrm{Y}}=1.5764 \mathrm{Li}, 1.5818 \mathrm{Na}, 1.5871 \mathrm{Tl}, n_{\mathrm{Z}}=1.5902 \mathrm{Li}, 1.5961 \mathrm{Na}, 1.6017$ $\mathrm{Tl}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0261 \mathrm{Na}$. Color yellow. PD 5.1, 5.5, 4.70; 1-0237.
$\mathbf{C a}\left[\mathbf{N}(\mathbf{C N})_{2}\right]_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ loses water at $\mathrm{t}^{62} 100^{\circ} \mathrm{C}$. $(+) 2 \mathrm{~V}=50^{\circ}$ calc. $n_{\mathrm{X}}=$ $1.405, n_{\mathrm{Y}}=1.480 . n_{\mathrm{Z}}=1.82, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.415$.
$\mathbf{S r N i}(\mathrm{CN})_{4} \cdot \mathbf{5 H}_{2} \mathrm{O}$ is monoclinic ${ }^{61}$ with $a: b: c=0.676: 1: 0.474, \beta=$ $92^{\circ} 23^{\prime}$. Good basal cleavage. G. 2.03. Soluble in $\mathrm{H}_{2} \mathrm{O}$. Crystals show $\{110\}$, $\{001\},\{111\} . \mathrm{X} \wedge c=14^{\circ}, \mathrm{Y}=b$. (-) $2 \mathrm{E}=50^{\circ}, \mathrm{r}<\mathrm{v}$. For $\lambda=578$ : $n_{\mathrm{X}}=1.492, n_{\mathrm{Y}}=1.612, n_{\mathrm{Z}}=1.6235, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.1315$. For $\lambda=546$ : $n_{\mathrm{X}}=1.499, n_{\mathrm{Y}}=1.6155, n_{\mathrm{Z}}=1.630$. Color brown.
$\operatorname{SrPd}(\mathrm{CN})_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ is monoclinic ${ }^{61}$ with $a: b: c=0.682: 1: 0.468, \beta=$ $97^{\circ} 18^{\prime}$. Crystals show $\{110\},\{001\}$, $\{111\}$. Good $\{001\}$ cleavage. G. 2.17. Soluble in $\mathrm{H}_{2} \mathrm{O}, \mathrm{X} \wedge c=+12.5^{\circ}, \mathrm{Y}=b$. (-) $2 \mathrm{E}=66^{\circ}$. For $\lambda=578$ :

[^19]$n_{\mathrm{X}}=1.495, n_{\mathrm{Y}}=1.6025, n_{\mathrm{Z}}=1.612, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.117$. For $\lambda=546$ : $n_{\mathrm{X}}=1.499, n_{\mathrm{Y}}=1.607, n_{\mathrm{Z}}=1.618$. Colorless.
$\operatorname{SrPt}(\mathbf{C N})_{4} \cdot \mathbf{5 H}_{2} \mathbf{O}$ is monoclinic ${ }^{61}$ with $a: b: c=0.682: 1: 0.463, \beta=95^{\circ} 7^{\prime}$. Crystals $\{010\}$ tablets often twinned on $\{100\}$. G. 2.70. Soluble in $\mathrm{H}_{2} \mathrm{O}$. Perfect $\{001\}$ cleavage. $\mathrm{X} \wedge c=19^{\circ}(594), 21^{\circ}(565), 25^{\circ}(544), 32^{\circ}(505)$, $45^{\circ}$ (474), $59^{\circ}(460)$. (-) $2 \mathrm{E}=106^{\circ} 40^{\prime}$. For $\lambda=578: n_{\mathrm{X}}=1.547, n_{\mathrm{Y}}=$ $1.613, n_{\mathrm{Z}}=1.637, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.090$. For $\lambda=546: n_{\mathrm{X}}=1.557, n_{\mathrm{Y}}=1.619$, $n_{\mathrm{Z}}=1.641$. Positive for $\lambda=436$. Colorless, with blue fluorescence.
$\mathbf{B a N i}(\mathbf{C N})_{4} \cdot 4 \mathbf{H}_{2} \mathrm{O}$ is monoclinic ${ }^{61}$ with $a: b: c=0.872: 1: 0.494, \beta=$ $104^{\circ} 50^{\prime}$. G. 2.383. Soluble in $\mathrm{H}_{2} \mathrm{O} . \mathrm{X} \wedge c=8^{\circ}$ (590), $14^{\circ}$ (488). $\mathrm{Y}=b$. $(-) 2 \mathrm{~V}=4^{\circ} 40^{\prime}$. For $\lambda=646: n_{\mathrm{X}}=1.558, n_{\mathrm{Y}}=1.652, n_{\mathrm{Z}}=1.652$. For $\lambda=591: n_{\mathrm{X}}=1.569, n_{\mathrm{Y}}=1.658, n_{\mathrm{Z}}=1.658, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.089$. For $\lambda=$ 486: $n_{\mathrm{X}}=1.608, n_{\mathrm{Y}}=1.6715, n_{\mathrm{Z}}=1.6715$. Color orange-yellow.
$\mathbf{B a P d}(\mathrm{CN})_{4} \cdot \mathbf{4 \mathbf { H } _ { 2 } \mathrm { O }}$ is monoclinic ${ }^{61}$ with $a: b: c=0.871: 1: 0.483, \beta=$ $104^{\circ} 25^{\prime}$. G. 2.574. Crystals $\{010\}$ plates long parallel $c$ with $\{110\},\{011\}$. $\mathrm{X} \wedge c=6^{\circ}(644), 6.5^{\circ}(590), 10^{\circ}(474), 20^{\circ}(426) . \mathrm{Z}=b .(-) 2 \mathrm{~V}=28^{\circ} 50^{\prime}$. For $\lambda=646: n_{\mathrm{X}}=1.570, n_{\mathrm{Y}}=1.642, n_{\mathrm{Z}}=1.647$. For $\lambda=578: n_{\mathrm{X}}=$ $1.583, n_{\mathrm{Y}}=1.646, n_{\mathrm{Z}}=1.651, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.068$. For $\lambda=436: n_{\mathrm{X}}=1.651$, $n_{\mathrm{Y}}=1.668, n_{\mathrm{Z}}=1.674$.
$\mathrm{BaPt}(\mathbf{C N})_{4} \cdot \mathbf{4 H}_{2} \mathrm{O}$ is monoclinic ${ }^{61}$ with $a: b: c=0.869: 1: 0.479, \beta=$ $103^{\circ} 54^{\prime}$. Crystals prismatic or $\{010\}$ tablets. G. 3.01. $\mathrm{Y}=\mathrm{b}, \mathrm{Z} \wedge c+1^{\circ}$. $(+) 2 \mathrm{~V}=25^{\circ} 21^{\prime}(646), 20^{\circ} 20^{\prime}(541)$. For $\lambda=646: n_{\mathrm{X}}=1.662, n_{\mathrm{Y}}=1.670$, $n_{\mathrm{Z}}=1.833$. For $\lambda=578: n_{\mathrm{X}}=1.666, n_{\mathrm{Y}}=1.6745, n_{\mathrm{Z}}=1.919, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.253$. For $\lambda=546: n_{\mathrm{X}}=1.672, n_{\mathrm{Y}}=1.6806, n_{\mathrm{Z}}=2.001, n_{\mathrm{Z}}-$ $n_{\mathrm{x}}=0.329$. Color clear green. Also may be yellow with Z darkest. Surface color on (110) blue or violet. Emerald green fluorescence on (001).

## 5. Halides, etc., of Trivalent Bases, Hydrated and Anhydrous. Formula Type $\mathrm{AX}_{3} \cdot \mathrm{nH}_{2} \mathrm{O}$

$\mathrm{C}_{2} \mathrm{Cl}_{6}$ is orthorhombic ${ }^{63}$ with $a: b: c=0.568: 1: 0.316$. Crystals $\{100\}$ tablets without cleavage. G. 2.091. $\mathrm{X}=c, \mathrm{Y}=a .(+) 2 \mathrm{~V}=38^{\circ}, \mathrm{r}<\mathrm{v}$. $n_{\mathrm{X}}=1.590 . n_{\mathrm{Y}}=1.598$ calc., $n_{\mathrm{Z}}=1.668, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.078$. Clear and colorless. It inverts to a triclinic phase at $43^{\circ}$, and to an isometric phase (with G. 1.94) at $71^{\circ}$, melting at $185^{\circ} \mathrm{C}$.
$\mathrm{AlF}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ (Fluellite) is orthorhombic with $a=11.40, b=21.14, c=$ $8.52 k X$. Poor $\{010\}$ and $\{111\}$ cleavages. H. 3. G. 2.17. The optic plane ${ }^{64}$ is $\{001\}, \mathrm{X}=a .(+) 2 \mathrm{~V}=$ very large. $n_{\mathrm{X}}=1.473, n_{\mathrm{Y}}=1.490, n_{\mathrm{z}}=1.511$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.038$. Again: ${ }^{64} n_{\mathrm{X}}=1.489, n_{\mathrm{Y}}=1.495, n_{\mathrm{Z}}=1.506, n_{\mathrm{Z}}-$

[^20]$n_{\mathrm{X}}=0.017$. The variation in indices may be due to partial replacement of F by OH. Colorless. PD 6.60, 3.29, 2.66; 2-0121.
$\mathrm{AlCl}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ (Chloraluminite) is rhombohedral with $c / a=0.534$. Deliquescent in air. Uniaxial negative ${ }^{65}$ with $n_{\mathrm{O}}=1.560, n_{\mathrm{E}}=1.507$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.053$. Colorless. Made from $\mathrm{H}_{2} \mathrm{O}$ solution. ${ }^{66} \mathrm{PD} 3.30$, 3.25, 2.31; 8-453.
$\mathrm{AlBr}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is isomorphous ${ }^{18}$ with $\mathrm{AlCl}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$. G. 2.27. Uniaxial negative with $n_{\mathrm{O}}=1.605, n_{\mathrm{E}}=1.555, n_{\mathrm{O}}-n_{\mathrm{E}}=0.050$. PD 3.84, 3.59, 3.38; 1-0480.
$\mathbf{A s I}_{3}$ is rhombohedral with $c / a=2.998$. Crystals usually six-sided basal plates with perfect $\{0001\}$ cleavage. Uniaxial negative with ${ }^{9} n_{\mathrm{O}}=2.59 \pm \mathrm{C}$, $n_{\mathrm{E}}=2.23 \pm, n_{\mathrm{O}}-n_{\mathrm{E}}=0.36 \pm$. Color deep red. PD 3.22, 3.58, 2.08; 7-272.
$\mathbf{S b B r}_{3}$ is orthorhombic ${ }^{67}$ with $a: b: c=0.781: 1: 1.165$. Crystals $\{001\}$ tablets with good $\{010\}$ cleavage. G. 4.15 . Very deliquescent. Index $n$ very high, much above 1.74 . Optically negative. $n_{\mathrm{Z}}-n_{\mathrm{X}}=$ very strong. Colorless with luster and dispersion like that of diamond. PD 5.20, 3.18, 2.98; 1-0235.
$\mathbf{S b I}_{3}$ has three crystal phases; the low temperature trigonal crystals are often in six-sided basal plates. G. 4.85. Uniaxial negative ${ }^{9}$ with $n_{\mathrm{O}}=2.78$ Li, $n_{\mathrm{E}}=2.36 \pm, n_{\mathrm{O}}-n_{\mathrm{E}}=0.42 \pm$. Color deep ruby red. PD 3.30, 2.55, 2.16; 7-273.
$\mathbf{G d C l}_{3} \cdot \mathbf{6 H} \mathbf{2} \mathbf{O}$ is monoclinic ${ }^{68}$ with $a: b: c=1.473: 1: 1.219, \beta=93^{\circ} 40^{\prime}$. Crystals often $\{010\}$ tablets with $\{110\},\{011\}$, etc. Perfect $\{100\}$ cleavage. Hygroscopic. G. 2.424. $\mathrm{Y}=b, \mathrm{Z} \wedge c=-50^{\circ}$. (-) $2 \mathrm{~V}=75^{\circ} \pm$, $n_{\mathrm{X}}=1.565, n_{\mathrm{Y}}=1.570, n_{\mathrm{Z}}=1.575, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.010$. One optic axis nearly normal to the cleavage. Colorless. PD 3.42, 2.41, 3.97; 3-0392.
$\mathbf{S m C l}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is monoclinic ${ }^{69}$ with $a=8.00, b=6.62, c=9.60, \beta=$ $93^{\circ} 40^{\prime}$. Crystals often $\{010\}$ tablets with $\{110\},\{011\}$, etc. Perfect $\{100\}$ cleavage. Hygroscopic. G. 2.414. $\mathrm{Y}=b, \mathrm{Z} \wedge c=-33^{\circ}$. An optic axis nearly normal to the cleavage. $(-) 2 \mathrm{~V}=$ large, $n_{\mathrm{X}}=1.564, n_{\mathrm{Y}}=1.569$, $n_{\mathrm{Z}}=1.573, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.009$. Colorless in thin flakes, but thicker crystals are greenish yellow with $\mathrm{X}>\mathrm{Z}$.

[^21]
## 6. Halides, etc., of Tetravalent Bases. Formula Type AX

GeBr $_{4}$ is isometric ${ }^{70}$ in octahedral crystals. G. 3.13. M.P. $26^{\circ}$. Isotropic with $n=1.6269$.
$\mathrm{SeCl}_{4}$ is isometric. Crystals cubic. G. 3.75-3.85. M.P. $305^{\circ}$ C. Deliquescent. Isotropic with $n=1.807$. Color whitish yellow.
$\mathrm{SnI}_{4}$ is isometric. Crystals often octahedral. G. 4.70. Isotropic ${ }^{9}$ with $n=2.063 \pm \mathrm{Li}, 2.106 \pm \mathrm{Na}, 2.161 \pm \mathrm{Tl}$. Color red. PD 3.54, 2.17, 3.07; 6-0232.
$\mathbf{Z r F}_{4}$ is monoclinic prismatic ${ }^{71}$ with $a: b: c=0.959: 1: 0.774, \beta=94^{\circ} 30^{\prime}$. Crystals show $\{100\},\{110\},\{011\}$, etc. G. 4.54. Indices are 1.57 and 1.60. Again ${ }^{72}(-) 2 \mathrm{~V}=$ ?, $n_{\mathrm{Y}}=1.59$. (Apparently $n_{\mathrm{X}}=1.57$ and $n_{\mathrm{Z}}=$ 1.60.-A. N. W.)
$\mathbf{H f F}_{4}$ is monoclinic ${ }^{72}$ with $a: b: c=0.967: 1: 0.774, \beta=94^{\circ} 26^{\prime}$. Crystals show $\{100\},\{001\},\{110\},\{011\}$, etc. G. 7.13. Indices are 1.54 and 1.58 from a prism with faces $\{011\}$ and $\{001\}$.

## 7. Anhydrous Halides, etc., of Monovalent and Divalent Bases. Formula Type $\boldsymbol{A}_{m} \mathbf{B}_{n} \mathbf{X}_{m+2 n}$

$\mathbf{L i B e F}_{3}$ is orthorhombic (? $)^{73}$ in fibers with cleavage and extinction parallel length. Mean index $n=1.33 c a$. PD 2.21, 2.08, 3.19; 9-344.
$\mathbf{L i}_{2} \mathbf{B e F}_{4}$ is orthorhombic ${ }^{73}$ with $a=10.08, b=12.45, c=4.92 \AA$. Crystals basal plates. M.P. $>375^{\circ} \mathrm{C}$. Optically biaxial with $\mathrm{Y}=c$ and mean index $n=1.34 c a$.
$\mathbf{L i N a B}_{2} \mathbf{F}_{6}$ is monoclinic ${ }^{73}$ with $a=9.71, b=8.89, c=5.22, \beta=105^{\circ}$. Crystals acicular along $c$ with cleavage parallel to $c$. M.P. $280^{\circ} \mathrm{C} . \mathrm{Y}=b$. $(+) 2 \mathrm{~V}=$ ? ; mean index $n=1.33 c a$.
$\mathbf{N a}_{2} \mathbf{B e F}_{4}$ has several crystal phases. ${ }^{73}$ The high temperature $\alpha$-phase fuses at about $600^{\circ} \mathrm{C}$. It is hexagonal with $a=5.27, c=6.96 \AA$. G. 2.60. An $\alpha^{\prime}$-phase is orthorhombic with $a=5.22, b=9.40, c=6.72 \AA$. G. 2.64. On cooling it inverts to the $\beta$-phase at $290^{\circ} \mathrm{C}$. and to the $\gamma$-phase at $190^{\circ} \mathrm{C}$. The $\beta$-phase is monoclinic with $a=5.5, b=6.75, c=9.3 \AA ., \beta=95^{\circ}$. U.C.4. G. $\approx 2.65$. The $\gamma$-phase is orthorhombic with $a=4.89, b=10.90, c=$ $6.56 \AA$. G. 2.48. Another phase (called $\gamma^{2}$ ) is hexagonal with $a=8.98$, $c=4.93 \AA$. M.P. $<600^{\circ} \mathrm{C}$. This may be a hydrate. All the phases have very weak birefringence. PD 2.93, 2.65, 2.44; 3-0660* [which polymorph?].
$\mathbf{N a K}_{3} \mathbf{F e C l}_{6}$ (Rinneite) is hexagonal-scalenohedral with $a=11.86$, $c=13.81 k X$. Crystals basal tablets or short prismatic. Good $\{11 \overline{2} 0\}$

[^22]cleavage. H. 3. G. 2.35. Uniaxial positive ${ }^{74}$ with $n_{\mathrm{O}}=1.5836 \mathrm{Li}, 1.5886 \mathrm{Na}$, $1.5930 \mathrm{Tl}, n_{\mathrm{E}}=1.5842 \mathrm{Li}, 1.5894 \mathrm{Na}, 1.5939 \mathrm{Tl}, n_{\mathrm{E}}-n_{\mathrm{O}}=0.0008 \mathrm{Na}$. Colorless when pure, but often rose, violet, yellow or brown.
$\mathbf{K}_{2} \mathbf{M g F}_{4}$ is tetragonal ${ }^{75}$ with $a=3.977, c=13.16 \AA$. G. 2.71. Uniaxial negative with $n_{\mathrm{O}}=1.379, n_{\mathrm{E}}=1.377, n_{\mathrm{O}}-n_{\mathrm{E}}=0.002$. PD 2.20, 6.61, 1.65; 6-0589.
$\mathrm{KCaCl}_{3}$ (Chlorocalcite) is probably orthorhombic ${ }^{76}$ and is pseudoisometric. Cleavage cube-like, but with one direction better than the other two. H. 2.5-3. May show lamellar twinning parallel with "cubic" faces Optic plane normal to a "cubic" face. (-) $2 \mathrm{~V}=$ ?, $n_{\mathrm{Y}}=1.52$ ca., $n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=$ weak. Color white or stained violet.
$\mathbf{K}_{4} \mathbf{M n C l}_{6}$ (Chlormanganokalite) is hexagonal with $c / a=0.5797$. Crystals rhombohedral. H. 2.5. G. 2.31. Uniaxial positive with mean index $n=1.59, n_{\mathrm{E}}-n_{\mathrm{O}}=$ very weak. Color yellow. PD 2.55, 2.69, 5.90; 3-0856.
$\mathbf{K}_{2} \mathbf{P d C l}_{4}$ is tetragonal with $c / a=0.410$. Crystals prismatic with $\{110\}$ and $\{111\}$. Uniaxial negative with $^{18} n_{\mathrm{O}}=1.715, n_{\mathrm{E}}=1.537, n_{\mathrm{O}}-n_{\mathrm{E}}=$ 0.178. Again: ${ }^{77} n_{\mathrm{O}}=1.710, n_{\mathrm{E}}=1.523, n_{\mathrm{O}}-n_{\mathrm{E}}=0.187$. Color brown; pleochroic with $\mathrm{O}>\mathrm{E}$ strong.
$\mathbf{K}_{4} \mathbf{C d C l}_{6}$ is hexagonal with $c / a=0.607$. Crystals rhombohedral with perfect rhombohedral cleavage. Twinning common. Uniaxial positive with $n_{\mathrm{O}}=1.5841 \mathrm{~B}, 1.5906 \mathrm{D}, 1.5965 \mathrm{E}, 1.6208 \mathrm{H}, n_{\mathrm{E}}=1.5842 \mathrm{~B}, 1.5907 \mathrm{D}$, $1.5966 \mathrm{E}, 1.6210 \mathrm{H} . n_{\mathrm{E}}-n_{\mathrm{O}}=0.0001 \mathrm{D}$.
$\mathbf{K}_{2} \mathbf{P t C l}_{4}$ is tetragonal with $c / a=0.416$. Crystals prismatic. G. 3.3. Uniaxial negative ${ }^{78}$ with $n_{\mathrm{O}}=1.693, n_{\mathrm{E}}=1.548, \quad n_{\mathrm{O}}-n_{\mathrm{E}}=0.145$. Again: ${ }^{18} n_{\mathrm{O}}=1.690, n_{\mathrm{E}}=1.557, n_{\mathrm{O}}-n_{\mathrm{E}}=0.133$. Also: ${ }^{78 \mathrm{a}} n_{\mathrm{O}}=1.683$, $n_{\mathrm{E}}=1.553, n_{\mathrm{O}}-n_{\mathrm{E}}=0.130$. Bolland ${ }^{79}$ found that "potassium platinum chloride" of unknown formula was uniaxial positive with $n_{0}=1.64$, $n_{\mathrm{E}}=1.67, n_{\mathrm{E}}-n_{\mathrm{O}}=0.03$ and had a dark red-brown color with flakes clear violet, O being brighter than E and slightly greenish. PD 6.94, 3.16, 3.55; 9-367.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{F e C l}_{4}$ is isometric ${ }^{80}$ and isotropic with $n=1.6439 \mathrm{D}$.
${ }^{74}$ Boeke: N. Jahrb. Min. II, p. 39 (1909).
${ }^{75}$ Brehler and Winkler: Heidelb. Beit. Min. Pet. p. 6 (1954). Also De Vries and Roy: J. Am. Chem. Soc. LXXV, p. 2479 (1953).
${ }^{76}$ Renner: Centralb. Min. 1912, p. 106; Zambonini: Mineralogia Vesuviana, p. 50 (1910), p. 99 (1935).
${ }^{77}$ Mellor and Quodling: Proc. Roy. Soc. N. So. Wales LXX, p. 205 (1936).
${ }^{78}$ Bokii and Burovaya: Trudy Inst. Krist. p. 47 (1947); [Chem. Abst. XLIV, p. 7704 (1950)].
${ }^{78 \mathrm{a}}$ Mellor and Quodling: Proc. Roy. Soc. N. So. Wales LXIX, p. 167 (1935).
${ }^{79}$ Bolland: Sitz. Akad. Wiss. Wien CXIX, p. 275 (1910).
${ }^{80}$ Landolt-Börnstein: Tabellen, 1924.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{Z n C l}_{4}$ is orthorhombic with $a: b: c=0.722: 1: 0.570$. Crystals $\{010\}$ platelets. G. 1.88. $\mathrm{Y}=c . \mathrm{Z}=a .(+) 2 \mathrm{~V}=53^{\circ} 48^{\prime}, \mathrm{r}>\mathrm{v}$ weak. $n_{\mathrm{Y}}=1.5055 \mathrm{D}$. Colorless. Formed from $\mathrm{H}_{2} \mathrm{O}$ solution with excess of $\mathrm{NH}_{4} \mathrm{Cl}$. Again: ${ }^{42}(+) 2 \mathrm{~V}=33^{\circ}, n_{\mathrm{X}}=1.585, n_{\mathrm{Y}}=1.590, n_{\mathrm{Z}}=1.600$, $n_{\mathrm{z}}-n_{\mathrm{x}}=0.015$ PD 5.20, 2.76, 3.12; 2-0155.
$\left(\mathbf{N H}_{4}\right)_{3} \mathbf{Z n C l}_{5}$ is orthorhombic with $a: b: c=0.782: 1: 0.692$. Crystals columnar or $\{010\}$ tablets or equant. G .1 .81 . $\mathrm{Y}=c, \mathrm{Z}=a$. ( + ) $2 \mathrm{~V}=$ $46^{\circ} 10^{\prime}, \mathrm{r}>\mathrm{v}$ weak. $n_{\mathrm{Y}}=1.538$. Colorless. Made from $\mathrm{H}_{2} \mathrm{O}$ solution. PD 3.15, 5.8, 2.46; 2-0548.
$\left(\mathbf{N H}_{4}\right)_{3}\left(\mathbf{U O}_{2}\right) \mathbf{F}_{5}$ is tetragonal with $c / a=0.9 \pm$. Crystals pyramidal; often with cruciform twinning. G. 4.26. Uniaxial negative(? ${ }^{80 a}$ with $n_{\mathrm{O}}=1.495, n_{\mathrm{E}}=1.49, n_{\mathrm{O}}-n_{\mathrm{E}}=0.005$.
$\mathbf{C s}_{2}\left(\mathbf{U O}_{2}\right) \mathbf{C l}_{4}$ is triclinic ${ }^{80 \mathrm{a}}$ with (010) $\wedge(110)=49^{\circ} 7^{\prime}$ and (010) $\wedge$ $(011)=40^{\circ} 31^{\prime}$; crystals like gypsum, much twinned. $Z^{\prime} \wedge c$ in (010) $=15^{\circ}$. A prism parallel to $c$ gives $n_{1}=1.695, n_{2}=1.625$ and a prism parallel to $a$ gives $n_{3}=1.614, n_{4}=1.691$. Color yellow.
$\mathbf{N H}_{4} \mathbf{Z n F}_{3}$ is uniaxial positive ${ }^{28}$ with $n_{\mathrm{O}}=1.47, n_{\mathrm{E}}=1.481, n_{\mathrm{E}}-n_{\mathrm{O}}=$ 0.011 . Decomposes below $150^{\circ} \mathrm{C}$.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{P d C l} \mathbf{l}_{4}$ forms dark green needles ${ }^{81}$ with bronze iridescence. Uniaxial negative with $n_{\mathrm{O}}=1.736, n_{\mathrm{E}}=1.544, n_{\mathrm{O}}-n_{\mathrm{E}}=0.192$. Again $:^{18} n_{\mathrm{O}}=$ $1.723, n_{\mathrm{E}}=1.553, n_{\mathrm{O}}-n_{\mathrm{E}}=0.170 . \mathrm{PD} 7.21,3.67,4.26 ; 7-201$.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{P t C l}_{4}$ is tetragonal ${ }^{78}$ with $a / c=0.60$. Uniaxial negative with $n_{\mathrm{O}}=$ $1.706, n_{\mathrm{E}}=1.574, n_{\mathrm{O}}-n_{\mathrm{E}}=0.132$.
$\mathbf{R b}_{2} \mathbf{P d C l}_{4}$ is tetragonal. Crystals prismatic. Uniaxial negative ${ }^{18}$ with $n_{\mathrm{O}}=1.715, n_{\mathrm{E}}=1.533, n_{\mathrm{O}}-n_{\mathrm{E}}=0.182$. Color brown with $\mathrm{O}>\mathrm{E}$ strong.
$\mathbf{C s}_{2} \mathbf{C u C l}_{4}$ is orthorhombic with $a: b: c=0.786: 1: 0.614$. Crystals short prisms with $\{110\},\{111\},\{120\},\{010\}$, etc. No distinct cleavage. $\mathrm{Y}=a$, $\mathrm{Z}=c .(+) 2 \mathrm{~V}=83^{\circ} 46^{\prime}$ calc., $n_{\mathrm{X}}=1.625, n_{\mathrm{Y}}=1.648, n_{\mathrm{Z}}=1.678, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.053$, all $\pm 0.002$. Faintly pleochroic with X and Y clear yellow, Z orange.
$\mathbf{C s}_{2} \mathbf{P d C l}_{4}$ is tetragonal. ${ }^{18}$ Crystals prismatic. Uniaxial negative with $n_{\mathrm{O}}=1.720, n_{\mathrm{E}}=1.560, n_{\mathrm{O}}-n_{\mathrm{E}}=0.160$. Color brown with $\mathrm{O}>\mathrm{E}$ strong.
$\mathbf{C s H g C l}_{3}$ is orthorhombic (and isometric?). Rhombic crystals have $a: b: c=0.577: 1: 0.409$; extremely weak birefringence with mean index $n=1.779 \mathrm{Li}, 1.791 \mathrm{Na}$. Isometric (?) crystals are octahedral with no

[^23]good cleavage, but are weakly birefringent with extinction parallel to the diagonals of the cube.
$\mathbf{K}_{2} \mathbf{Z n}(\mathbf{C N})_{4}$ is isometric ${ }^{81 a}$ in octahedrons. G. $1.673 . n=1.406 \mathrm{Li}, 1.413$ $\mathrm{Na}, 1.417 \mathrm{Tl}$. Colorless.
$\mathbf{K}_{2} \mathbf{C d}(\mathbf{C N})_{4}$ is isometric ${ }^{81 a}$ and octahedral. G. $1.824 . n=1.415 \mathrm{Li}, 1.4213$ $\mathrm{Na}, 1.425 \mathrm{Tl}$.
$\mathbf{K}_{2} \mathbf{H g}(\mathbf{C N})_{4}$ is isometric ${ }^{81 a}$ and octahedral. G. 2.438. Isotropic with $n=$ $1.451 \mathrm{Li}, 1.458 \mathrm{Na}, 1.461 \mathrm{Tl}$.
$\mathbf{K}_{2} \mathbf{Z n}(\mathbf{C N})_{4}$ and $\mathbf{K}_{2} \mathbf{C d}(\mathbf{C N})_{4}$ form mix-crystals ${ }^{81 a}$; for 20.76 per cent $\mathrm{K}_{2} \mathrm{Zn}(\mathrm{CN})_{4} \mathrm{G}$. is 1.789 and $n=1.4191 \mathrm{Na}$ at $25^{\circ} \mathrm{C}$.; for 39.41 per cent $\mathrm{K}_{2} \mathrm{Zn}(\mathrm{CN})_{4} \mathrm{G}$. is 1.768 and $n=1.4175 \mathrm{Na}$; for 60.02 per cent $\mathrm{K}_{2} \mathrm{Zn}(\mathrm{CN})_{4}$ G. is 1.744 and $n=1.416$; for 81.13 per cent $\mathrm{K}_{2} \mathrm{Zn}(\mathrm{CN})_{4}$ G. is 1.682 and $n=1.4141$.
$\mathbf{K}_{2} \mathbf{Z n}(\mathbf{C N})_{4}$ and $\mathbf{K}_{2} \mathbf{H g}(\mathbf{C N})_{4}$ form mix-crystals ${ }^{81 a}$ in which for 53.21 per cent $\mathrm{K}_{2} \mathrm{Zn}(\mathrm{CN})_{4} \mathrm{G}$. is 1.962 and $n=1.452 \mathrm{Na}$ at $25^{\circ} \mathrm{C}$.; for 65.42 per cent $\mathrm{K}_{2} \mathrm{Zn}(\mathrm{CN})_{4} \mathrm{G}$. is 1.883 and $n=1.447$; for 76.08 per cent $\mathrm{K}_{2} \mathrm{Zn}(\mathrm{CN})_{4} \mathrm{G}$. is 1.801 and $n=1.443$; for 88.36 per cent $\mathrm{K}_{2} \mathrm{Zn}(\mathrm{CN})_{4} \mathrm{G}$. is 1.738 and $n=1.436$.
$\mathbf{K}_{2} \mathbf{C d}(\mathbf{C N})_{4}$ and $\mathbf{K}_{2} \mathbf{H g}(\mathbf{C N})_{4}$ form mix-crystals ${ }^{81 a}$ in which for 22.00 per cent $\mathrm{K}_{2} \mathrm{Cd}(\mathrm{CN})_{4} \mathrm{G}$. is 2.261 and $n=1.451 \mathrm{Na}$ at $25^{\circ} \mathrm{C}$.; for 39.40 per cent $\mathrm{K}_{2} \mathrm{Cd}(\mathrm{CN})_{4} \mathrm{G}$. is 2.151 and $n=1.441$; for 61.29 per cent $\mathrm{K}_{2} \mathrm{Cd}(\mathrm{CN})_{4} \mathrm{G}$. is 2.005 and $n=1.435$; for 82.10 per cent $\mathrm{K}_{2} \mathrm{Cd}(\mathrm{CN})_{4}$ G. is 1.927 and $n=$ 1.428 .
$\mathbf{K H g}(\mathbf{C N S})_{3}$ is orthorhombic ${ }^{81 \mathrm{~b}}$ in acicular crystals with (011) $\wedge(0 \overline{1} 1)=$ $158^{\circ} \pm . \mathrm{X}=c, \mathrm{Y}=a .(-) 2 \mathrm{~V}=65^{\circ}-70^{\circ}, \mathrm{r}<\mathrm{v}$ strong. $n_{\mathrm{X}}=1.735$, $n_{\mathrm{Y}}=1.82$, " $n_{\mathrm{Z}}=1.84$, est." (but the given $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.150$ and the optic angle and sign indicate that $n_{\mathrm{z}}$ should be close to 1.88 ).
$\mathbf{K}_{2} \mathbf{H g}(\mathbf{C N S})_{4}$ is monoclinic ${ }^{81 a}$; crystals varied in habit with $110 \wedge 1 \overline{1} 0=$ $80^{\circ} \pm, \beta=106^{\circ} \pm . \mathrm{X} \wedge a=22^{\circ}$, Y near $c, \mathrm{Z}=b$. (-) $2 \mathrm{~V}=$ nearly $90^{\circ}$, $\mathrm{r}>\mathrm{v}$ strong. $n_{\mathrm{X}}=1.645, n_{\mathrm{Y}}=1.80$ (est.) $n_{\mathrm{Z}}=1.9+$ (est.), $n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.255 (est.)
$\mathbf{C s}_{3} \mathbf{A g}_{2} \mathbf{B a}(\mathbf{C N S})_{7}$ is tetragonal with $c / a=0.906$. Crystals short prismatic with $\{201\}$. Perfect basal cleavage. G. 3.03. Uniaxial negative with $n_{\mathrm{O}}=1.7761, n_{\mathrm{E}}=1.6788, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0973$.
$\mathbf{C s}_{3} \mathbf{C u}_{2} \mathbf{B a}(\mathbf{C N S})_{7}$ is tetragonal with $c / a=0.918$. Crystals short prismatic with $\{201\}$ and $\{001\}$. Perfect basal cleavage. G. 2.92. Uniaxial negative with $n_{\mathrm{O}}=1.8013 \mathrm{Na}, n_{\mathrm{E}}=1.6882, n_{\mathrm{O}}-n_{\mathrm{E}}=0.1131$.
$\mathbf{C s}_{3} \mathbf{C u}_{2} \mathbf{S r}(\mathbf{C N S})_{7}$ is tetragonal with $c / a=0.916$. Crystals short pris-
${ }^{\text {s1a }}$ Carozzi: Gazz. Chim. Ital., LVI, p. 180 (1926); [Tables Ann. Const. Phys., VII, No. 2, p. 1489, (1930)].
${ }^{81 \mathrm{~b}}$ Mason and Forgeng: Jour. Phys. Chem. XXXV, p. 1123 (1931).
matic with $\{201\}$ and $\{001\}$. Perfect basal cleavage. G. 2.88. Uniaxial negative with $n_{\mathrm{O}}=1.8535, n_{\mathrm{E}}=1.6982, n_{\mathrm{O}}-n_{\mathrm{E}}=0.1553$.

## 8. Hydrated Halides, etc., of Monovalent and Divalent Bases. Formula Type $\boldsymbol{A}_{m} \mathbf{B}_{n} \boldsymbol{X}_{m+2 n} \cdot \mathrm{pH}_{2} \mathbf{O}$

$\mathrm{KMgCl}_{3} \cdot \mathbf{6 H} \mathbf{H} \mathbf{O}$ (Carnallite) is orthorhombic ${ }^{82}$ with $a=9.54, b=16.02$, $c=22.52 k X$. U.C. 12. Crystals six-sided pyramidal. No good cleavage. Lamellar twinning not rare. H. 2.5. G. 1.60. $\mathrm{X}=c, \mathrm{Y}=b$. ( + ) $2 \mathrm{~V}=70^{\circ}$, $\mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.4665, n_{\mathrm{Y}}=1.4753, n_{\mathrm{Z}}=1.4937, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0272 \mathrm{Na}$. Colorless, white, or stained red or rarely yellow or blue. PD 3.30, 2.92, 4.65; 8-75.
$\mathrm{KMgBr}_{3} \cdot \mathbf{6 H}_{2} \mathrm{O}$ is orthorhombic pseudo-tetragonal with no cleavage; twinning on $\{110\}$. H. 2. $\mathrm{Y}=c, \mathrm{Z}=b .(+) 2 \mathrm{~V}=87^{\circ}, n_{\mathrm{Y}}=1.535, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=$ very strong. Colorless. Mix-crystals with $\mathrm{KMgCl}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ (15 to 85 per cent) are tetragonal, uniaxial positive, $n_{\mathrm{O}}=1.52 \pm, n_{\mathrm{O}}-n_{\mathrm{E}}=$ very weak, like leucite, increasing with increase of Cl .
 $7.88 k X$. U.C. 2. Crystals pyramidal or short prismatic. H. 2.5. G. 2.418. Uniaxial negative with ${ }^{84} n_{\mathrm{O}}=1.6485$ (578), 1.6636 (492), $n_{\mathrm{E}}=1.6133$ (578), 1.6235 (492), $n_{\mathrm{O}}-n_{\mathrm{E}}=0.0352$ (578). Again: $n_{\mathrm{O}}=1.6365 \mathrm{Na}$, $n_{\mathrm{E}}=1.6148, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0217$. Color greenish blue; pleochroic with O sky-blue, E grass-green, but colorless or nearly so in section. Also biaxial and probably orthorhombic with twinning on $\{110\}$ in four sectors in which the optic plane is parallel with the diagonal (in $\{001\}$ ) and $2 \mathrm{H}=25^{\circ}$. PD 2.64, 5.4, 2.71; 1-1073.
$\mathrm{K}_{2} \mathrm{HgCl}_{4} \cdot \mathbf{H}_{2} \mathrm{O}$ is orthorhombic with $a: b: c=0.707: 1: 0.766$. Crystals prismatic or $\{110\}$ tablets. $\mathrm{X}=a, \mathrm{Y}=c .(-) 2 \mathrm{~V}=78^{\circ} 25^{\prime}, \mathrm{r}>\mathrm{v}$ strong, $n_{\mathrm{X}}=1.648 \mathrm{Na}, n_{\mathrm{Y}}=1.678, n_{\mathrm{Z}}=1.699, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.051$.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{M n C l} \cdot \mathbf{2 H}_{2} \mathbf{O}$ is pseudo-isometric ${ }^{48}$ and uniaxial negative (or may be biaxial with 2 V reaching $10^{\circ}$ ). Crystals dodecahedral in aspect. Distinct $\{100\}$ and $\{001\}$ cleavages. G. $1.91-1.92 . n_{\mathrm{O}}=1.644 \mathrm{Na}, n_{\mathrm{E}}=1.607$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.037$. Pink in mass. PD 2.78, 2.70, 1.88; 2-0844.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{C o C l}_{4} \cdot \mathbf{2 H}_{2} \mathbf{O}$ has $^{85} n_{\mathrm{X}}=1.640, n_{\mathrm{Y}}=?, n_{\mathrm{Z}}=1.682, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.042 .
$\mathbf{C s}_{2} \mathbf{M n C l}_{4} \cdot \mathbf{2 H} \mathbf{H} \mathbf{O}$ is triclinic (?) in long plates formed of $\{001\}$ and $\{100\}$

[^24]at an angle of $84^{\circ} 33^{\prime}$; good $\{001\}$ cleavage. Extinction ${ }^{86}$ on plates at $45^{\circ}$ to edge. $n^{\prime}{ }_{\mathrm{x}}=1.64, n_{\mathrm{Y}}=?, n^{\prime}{ }_{\mathrm{Z}}=1.65, n_{\mathrm{Z}}-n^{\prime}{ }_{\mathrm{x}}=0.01$.
$\left(\mathbf{N H}_{4}\right)_{2} \mathrm{CuCl}_{4} \cdot 2 \mathbf{H}_{2} \mathrm{O}$ is tetragonal with $c / a=0.742$. Crystals pyramidal or pseudo-dodecahedral with $\{111\}$ and $\{100\}$. G. 2.01. Uniaxial negative ${ }^{50}$ with $n_{\mathrm{O}}=1.671, n_{\mathrm{E}}=1.641, n_{\mathrm{O}}-n_{\mathrm{E}}=0.030$. Blue; pleochroic with O very pale yellow green, E weak pure blue. PD 5.5, 2.68, 2.75; 1-0211. Also may be biaxial with 2 H up to $16^{\circ}$ and twinning on $\{110\}$.
$\left(\mathbf{N H}_{4}\right)_{2}\left(\mathrm{UO}_{2}\right) \mathrm{Cl}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ is triclinic ${ }^{86 a}$ with $a: b: c=0.61: 1: 0.56, \alpha=99^{\circ}$, $\beta=102^{\circ}, \gamma=89^{\circ}$. Crystals $\{011\}$ or $\{010\}$ tablets. $n^{\prime}{ }_{x}=1.566-1.574$, $n_{\mathrm{Y}}^{\prime}=1.633, n_{\mathrm{Z}}^{\prime}=1.637,(-) 2 \mathrm{~V}=$ small, $n_{\mathrm{Z}}^{\prime}-n_{\mathrm{X}}^{\prime}=0.063-0.071$. Color yellow with X colorless, Y deep yellow.
$\mathbf{L i}_{2} \mathrm{~K}_{2} \mathbf{F e}(\mathbf{C N})_{6} \cdot \mathbf{3 H _ { 2 }} \mathbf{O}$ is monoclinic with $a: b: c=0.962: 1: 0.747, \beta=$ $96^{\circ} 8^{\prime}$. Crystals $\{100\}$ tablets, long parallel to $c$. Twinning on $\{100\}$. $\mathrm{X} \wedge c=-44^{\circ}, \mathrm{Y}=b .(+) 2 \mathrm{~V}=66^{\circ} 31^{\prime} \mathrm{Li}, 65^{\circ} 56^{\prime} \mathrm{Na}, 65^{\circ} 22^{\prime} \mathrm{Tl} . n_{\mathrm{X}}=$ $1.5883 \mathrm{Na}, n_{\mathrm{Y}}=1.6007, n_{\mathrm{Z}}=1.6316, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0433$.
$\operatorname{LiKPt}(\mathbf{C N})_{4} \cdot 3 \mathbf{H}_{2} \mathbf{O}$ is orthorhombic with $a: b: c=0.715: 1: 0.444$. Crystals prismatic with no good cleavage. $\mathrm{Y}=a, \mathrm{Z}=c .(+) 2 \mathrm{~V}=19^{\circ}, \mathrm{r}>\mathrm{v}$ distinct. For $656 \mathrm{~m} \mu: n_{\mathrm{X}}=1.6183, n_{\mathrm{Y}}=1.6217, n_{\mathrm{Z}}=2.0405, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.4217$. For $588 \mathrm{~m} \mu: n_{\mathrm{X}}=1.6237, n_{\mathrm{Y}}=1.6278, n_{\mathrm{Z}}=2.2916, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.6679$. Color red; pleochroic with X and Y orange yellow, Z red.
$\operatorname{LiRbPt}(\mathbf{C N})_{4} \cdot 3 \mathbf{H}_{2} \mathrm{O}$ is orthorhombic with $a: b: c=0.715: 1: 0.448$. Crystals prismatic. $\mathrm{Y}=a, \mathrm{Z}=c$. $(+) 2 \mathrm{~V}=12^{\circ} 40^{\prime}, \mathrm{r}>\mathrm{v}$ distinct. For $656 \mathrm{~m} \mu: n_{\mathrm{X}}=1.6153, n_{\mathrm{Y}}=1.6176, n_{\mathrm{Z}}=1.827, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.2117$. For $588 \mathrm{~m} \mu: n_{\mathrm{X}}=1.6204, n_{\mathrm{Y}}=1.6233, n_{\mathrm{Z}}=1.9310, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.3106$. Color yellow; fluorescence green; pleochroic with X and Y light yellow, Z gold yellow.
$\mathbf{N a K P t}(\mathbf{C N})_{4} \cdot 3 \mathbf{H}_{2} \mathrm{O}$ is monoclinic with $^{87} a: b: c=0.852: 1: 0.472, \beta=$ $95^{\circ} 8^{\prime}$. Crystals prismatic. The optic plane is nearly normal to the edge of $\{011\} .(+) 2 \mathrm{~V}=$ very small. $n_{\mathrm{X}}=1.6088 \mathrm{D}, n_{\mathrm{Y}}=1.61 \pm, n_{\mathrm{Z}}=1.90 \pm$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.29 \pm$. Color orange.
$\mathrm{Na}_{4} \mathrm{Fe}(\mathrm{CN})_{6} \cdot 10 \mathrm{H}_{2} \mathrm{O}(?)$ is monoclinic with $a: b: c=0.852: 1: 0.787, \beta=$ $97^{\circ} 34^{\prime}$. Crystals prismatic with indistinct $\{110\}$ cleavage. G. 1.46. Y $=b$. $\mathrm{Z} \wedge c=+74^{\circ}$. ( + ) $2 \mathrm{~V}=81^{\circ} 25^{\prime} \mathrm{Na} ; \mathrm{r}>\mathrm{v}$ weak; $n_{\mathrm{x}}=1.5193 \mathrm{Na}$, $n_{\mathrm{Y}}=1.528$ red, $1.5295 \mathrm{Na}, 1.536$ green, $n_{\mathrm{Z}}=1.5436 \mathrm{Na}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0243$ Na. Color yellow with $\mathrm{Y}>\mathrm{X}>$ Z. Formed from $\mathrm{H}_{2} \mathrm{O}$ solution. PD 7.4, 2.04. 3.51: 1-0095.

[^25]$\mathbf{N a}_{2} \mathbf{P t}(\mathbf{C N})_{4} \cdot 3 \mathbf{H}_{2} \mathrm{O}$ is triclinic ${ }^{88}$ with $a: b: c=1.701: 1: 0.809, \quad \alpha=$ $94^{\circ} 57^{\prime}, \beta=92^{\circ} 18^{\prime}, \gamma=89^{\circ} 1^{\prime}$. Crystals prismatic, twinned on $\{100\}$. Perfect $\{001\}$ and poor $\{110\}$ cleavages. G. 2.633. For $\lambda=578$ : (-)2V $=$ $23^{\circ} 30^{\prime}, \mathrm{r}>$ v strong. $n_{\mathrm{X}}=1.541, n_{\mathrm{Y}}=1.608, n_{\mathrm{Z}}=1.611, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.070$. For $\lambda=546: n_{\mathrm{X}}=1.549, n_{\mathrm{Y}}=1.612, n_{\mathrm{Z}}=1.615$. For $\lambda=436: n_{\mathrm{X}}=$ 1.608, $n_{\mathrm{Y}}=1.641 . n_{\mathrm{Z}}=1.644 . \mathrm{X} \wedge \perp\{001\}=9^{\circ} 30^{\prime} . \mathrm{X} \wedge \perp\{100\}=87^{\circ}$ in (001) $\wedge(0 \overline{1} 0) . \mathrm{Y} \wedge \perp\{001\}=93^{\circ}, \mathrm{Y} \wedge \perp\{100\}=18^{\circ} . \mathrm{Z} \wedge \perp\{001\}$ $=99^{\circ}, Z \wedge \perp\{100\}=108^{\circ}$. Extinction from the trace of the optic plane in $\{001\}$ is at $41^{\circ}$ to (100) in (100) $\wedge(1 \overline{10})$ in Na light; the same extinction angle is $26^{\circ}$ greater in red than in blue light. Colorless.
$\mathrm{K}_{4} \mathbf{F e}(\mathbf{C N})_{6} \cdot \mathbf{3 H}_{2} \mathbf{O}$ is monoclinic with $a: b: c=0.3936: 1: 0.3943, \beta=$ $90^{\circ} 2^{\prime}$. Crystals prismatic; apparently pseudo-tetragonal about $b$; see Fig. $3-8$. Twinning on $\{100\}$ or $\{001\}$. Perfect $\{010\}$ cleavage. G. 1.9. $\mathrm{X} \wedge c=$


Fig. 3-8. Pseudotetragonal habit of potassium ferrocyanide.
$+31^{\circ} 50^{\prime}, \mathrm{Z}=b .(-) 2 \mathrm{~V}=78^{\circ} 10^{\prime} \mathrm{Na}, \mathrm{r}>\mathrm{v}=$ very weak. $n_{\mathrm{Y}}=1.5772$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=$ ?. ${ }^{89}$ Color yellow. PD 2.92, 2.22, 2.09; 1-0923.
$\mathrm{K}_{2} \mathrm{Ni}(\mathbf{C N})_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ is triclinic ${ }^{90}$ with $a: b: c=1.700: 1: 0.832, \alpha=95^{\circ} 28^{\prime}$, $\beta=92^{\circ} 27^{\prime}, \gamma=89^{\circ} 24^{\prime}$. Crystals often twinned and pseudo-hexagonal. $\mathrm{X} \wedge$ $\perp\{110\}=72^{\circ}, \mathrm{X} \wedge \perp\{010\}=79^{\circ}, \mathrm{X} \wedge \perp\{001\}=13^{\circ}$. $\mathrm{Y} \wedge \perp\{110\}$ $=31^{\circ}, \mathrm{Y} \wedge \perp\{010\}=58^{\circ}, \mathrm{Y} \wedge \perp\{001\}=77^{\circ}$. $(-) 2 \mathrm{~V}=21^{\circ}$. For $\lambda=578 \mathrm{~m} \mu: n_{\mathrm{X}}=1.4657, n_{\mathrm{Y}}=1.5915, n_{\mathrm{Z}}=1.5955, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.1298$.

[^26]For $\lambda=546 \mathrm{~m} \mu: n_{\mathrm{X}}=1.4707, n_{\mathrm{Y}}=1.5965, n_{\mathrm{Z}}=1.6005, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.1298 .
$\mathbf{K}_{4} \mathbf{R u}(\mathbf{C N})_{6} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=0.394: 1: 0.395, \beta=90^{\circ} 6^{\prime}$. Crystals $\{010\}$ plates with $\{110\}$ and $\{011\}$, and perfect $\{010\}$ cleavage. $\mathrm{X} \wedge c=+32^{\circ} 10^{\prime} . \mathrm{Z}=b$. (-) $2 \mathrm{~V}=54^{\circ}, n_{\mathrm{Y}}=1.5837 \mathrm{Na}$. Colorless.
$\mathrm{K}_{4} \mathbf{O s}(\mathbf{C N})_{6} \cdot 3 \mathbf{H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=0.393: 1: 0.394, \beta=90^{\circ} 6^{\prime}$. Crystals $\{010\}$ plates with perfect $\{010\}$ cleavage. $\mathrm{X} \wedge c=+30^{\circ} 10^{\prime}$, $\mathrm{Z}=b$. (-) $2 \mathrm{~V}=47^{\circ}, n_{\mathrm{Y}}=1.6071$. Colorless.
$\mathbf{K}_{2} \mathbf{P t}(\mathbf{C N})_{4} \cdot \mathbf{3 H}_{2} \mathbf{O}$ is orthorhombic with $a: b: c=0.879: 1: 0.274$. Crystals short prismatic without cleavage. $\mathrm{Y}=a, \mathrm{Z}=c .(+) 2 \mathrm{E}=78^{\circ}$ red, $40^{\circ}$ blue. $n^{\prime}{ }_{\mathrm{x}}=1.615,{ }^{91} n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}{ }^{\prime}=1.62, n^{\prime}{ }_{\mathrm{Z}}-n^{\prime}{ }_{\mathrm{x}}=0.005$. Colored and fluorescent. PD 8.0, 3.28, 4.00; 1-0084.
$\left(\mathrm{NH}_{4}\right)_{4} \mathrm{Fe}(\mathrm{CN})_{6} \cdot \mathbf{2 \mathrm { NH } _ { 4 }} \mathbf{C l} \cdot \mathbf{3 H _ { 2 }} \mathbf{O}$ is trigonal with $c / a=1.032$. Crystals rhombohedral with no distinct cleavage. G. 1.49. Uniaxial negative with $n_{\mathrm{O}}=1.6067 \mathrm{Li}, 1.6198 \mathrm{Na}, 1.6241 \mathrm{Tl}, n_{\mathrm{E}}=1.5881 \mathrm{Li}, 1.5922 \mathrm{Na}, 1.5964$ $\mathrm{Tl}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0276 \mathrm{Na}$. Color yellow.
$\mathbf{R b}_{2} \mathbf{P t}(\mathbf{C N})_{4} \cdot \mathbf{3} \mathbf{H}_{2} \mathbf{O}(?)$ is monoclinic ${ }^{92}$ with $a: b: c=0.931: 1: 0.533, \beta=$ $99^{\circ} 48^{\prime}$. Crystals $\{100\}$ tablets or prismatic. $\mathrm{X}=b$. Z nearly $=c .(+) 2 \mathrm{~V}=$ moderate, with distinct horizontal dispersion. $n^{\prime}{ }_{\mathrm{x}}=1.6072 \mathrm{C}, 1.6111 \mathrm{He}$ yellow, $n_{\mathrm{Y}}=1.62 \pm, n_{\mathrm{z}}^{\prime}=1.662 \mathrm{C}, 1.696$ He yellow, $n^{\prime}{ }_{\mathbf{Z}}-n^{\prime}{ }_{\mathbf{x}}=0.055$ C, 0.085 He yellow. Color pale green, weakly fluorescent in blue. Alters easily to colorless.
$\mathrm{Na}_{2} \mathrm{Co}(\mathrm{CNS})_{4} \cdot \mathbf{8 H}_{2} \mathrm{O}$ (Julienite) is tetragonal ${ }^{93}$ with $a=19.00, c=$ 5.47 A. U.C. 4. Crystals acicular. G. 1.65. Uniaxial positive with $n_{0}=$ $1.556, n_{\mathrm{E}}=1.645, n_{\mathrm{E}}-n_{\mathrm{O}}=0.089$. Color blue. Crystallizes from water solution. PD 3.55, 3.23, 1.38; 2-0372.

## 9. Anhydrous Halides, efc., of Monovalent and Trivalent Bases. Formula Type $\mathbf{A}_{m} \mathbf{B}_{n} \mathbf{X}_{m+3 n}$

$\mathbf{L i}_{3} \mathbf{F e F}_{6}$ is isometric ${ }^{93 a}$ and isotropic with $n=1.42$. Soluble in HCl .
$\mathbf{L i}_{3} \mathbf{N a}_{3} \mathbf{A l}_{2} \mathbf{F}_{12}$ (Cryolithionite) is isometric with $a=12.097 k X$. U.C. 8 . Crystals dodecahedral; distinct $\{011\}$ cleavage. H. 2.5-3. G. 2.77. M.P. $710^{\circ} \mathrm{C}$. Isotropic with $n=1.3395 \mathrm{Na}$. Colorless to white. PD 1.96, 4.29, 2.21; 2-1282.
$\mathbf{N a}_{3} \mathbf{A l F}_{6}$ (Cryolite) is monoclinic with $a=5.39, b=5.59, c=7.76 k X$,
${ }^{91}$ Indices measured by Bolland (Sitz. Akad. Wiss. Wien CXIX, p. 275, 1910) on "potassium platinum cyanide" of unknown formula.
${ }^{92}$ Baumhauer: Zeit. Krist. XLIX, p. 113 (1911). Bolland (Sitz. Akad. Wiss. Wien CXIX, p. 275, 1910) gives for "rubidium platinum cyanide": $n_{\mathrm{X}}=1.56, n_{\mathrm{Y}}=1.71$. $n_{\mathrm{Z}}=1.95+$.
${ }^{93}$ Preisinger: Tsch. Min. Pet. Mitt. Ser. 3, Bd. 3, p. 376 (1953); Min. Abst. XII, p. 337 (1954).
${ }^{93 a}$ Nielsen: Zeit. anorg. Chem. CCXXIV, p. 84 (1935).
$\beta=90^{\circ} 11^{\prime}$. U.C. 2. Composition varies in synthetic material, toward $2.95 \mathrm{NaF} \cdot \mathrm{AlF}_{3 .}{ }^{94}$ Crystals cubic in aspect. Twinning very common, often repeated. No cleavage, but $\{110\}$ and $\{001\}$ parting. H. 2.5. G. 2.97. M.P. $1020^{\circ} \mathrm{C}$. Inverts to an isometric phase at about $560^{\circ} \mathrm{C}$. $\mathrm{Y}=b,^{95} \mathrm{Z} \wedge$ $c=44^{\circ} .(+) 2 \mathrm{~V}=43^{\circ}, \mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.3376, n_{\mathrm{Y}}=1.3377, n_{\mathrm{Z}}=1.3387$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0011$. Again: $\mathrm{X}=b ; n_{\mathrm{X}}=1.3385, n_{\mathrm{Y}}=1.3388, n_{\mathrm{Z}}=1.3396$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0011$. Colorless to white or stained brown, red or black. Colorless in section. PD 1.94, 2.76, 2.33; 8-73*.
$\mathbf{N a}_{5} \mathbf{A l}_{3} \mathbf{F}_{14}$ (Chiolite) is tetragonal with $a=7.005, c=10.39 k X$. U.C. 2. Perfect $\{001\}$ and distinct $\{011\}$ cleavages. H. 3.5-4. G. 2.99. Uniaxial negative ${ }^{96}$ with $n_{\mathrm{O}}=1.3486, n_{\mathrm{F}}=1.3424, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0062$. White or colorless. PD 2.91, 5.18, 2.32; 2-0749.
$\mathrm{NaBF}_{4}$ (Ferruccite) is orthorhombic ${ }^{97}$ with $a=6.25, b=6.77, c=$ 6.82 kX . U.C. 4. Crystals basal tablets or equant. Good $\{100\},\{010\}$ and $\{001\}$ cleavages. H. 3. G. 2.496. $\mathrm{Y}=b, \mathrm{Z}=a$. $(+) 2 \mathrm{~V}=11^{\circ} 25^{\prime}$, $n_{\mathrm{X}}=1.301, n_{\mathrm{Y}}=1.3012$ calc., $n_{\mathrm{Z}}=1.3068, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0058$. Colorless to white. Taste bitter and acid.

KBF $_{4}$ (Avogadrite) is orthorhombic with $a: b: c=1.5796: 1: 1.283$. Crystals basal tablets sometimes elongated parallel $b$ or $a$. G. 2.505. $\mathrm{X}=c$, $\mathrm{Y}=b .(-) 2 \mathrm{~V}=$ large, $n_{\mathrm{X}}{ }^{98}=1.3231$ (677), $1.3239 \mathrm{Na}, n_{\mathrm{Y}}=1.3236$ (677), $1.3245 \mathrm{Na}, n_{\mathrm{Z}}=1.3247 \mathrm{Na}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0008 \mathrm{Na}$. Colorless. Another phase is isometric. PD 3.37, 2.89, 2.10; 2-0448*.
$\mathrm{CsBF}_{4}$ is isotypic with $\mathrm{KBF}_{4}$ with G. 3.305 and mean $n=1.36 \mathrm{Na}$. It forms mix-crystals with $\mathrm{KBF}_{4}$ at least to about 19 per cent $\mathrm{CsBF}_{4}$. PD 2.27, 3.35, 3.73; 9-394.
$\mathbf{K}_{2} \mathbf{L i A l F}_{6}$ is hexagonal ${ }^{99}$ with $a=5.574, c=13.648 \AA$. U.C. 3. Stable to $470^{\circ} \mathrm{C}$. Basal and rhombohedral cleavages. G. 3.00. Uniaxial negative with $n_{\mathrm{O}}=1.391, n_{\mathrm{E}}=1.390, n_{\mathrm{O}}-n_{\mathrm{E}}=0.001$. Inverts to isometric at $470^{\circ}$; then closely similar to $\mathrm{K}_{2} \mathrm{NaAlF}_{6}$.
$\mathrm{K}_{2} \mathbf{N a A l F}_{6}$ (Elpasolite) is isometric with $a=8.093 k X$. U.C. 4. Crystals equant with $\{111\},\{100\}$. No cleavage. H. 2.5. G. 3. Isotropic with $n=1.376$. Colorless. PD 2.86, 2.02, 2.34; 8-70*.
$\mathbf{K A u B r}_{4}$ is monoclinic ${ }^{77}$ with $a: b: c=0.797: 1: 0.361, \beta=94^{\circ} 26^{\prime}$. Crystals $\{010\}$ or $\{001\}$ tablets or prismatic; often twinned on $\{100\}$. $\mathrm{X} \wedge c=$ $+13^{\circ}, \mathrm{Y}=b$. (-) $2 \mathrm{~V}=$ very small, $n_{\mathrm{X}}<1.74<n_{\mathrm{Y}}<n_{\mathrm{Z}}, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ strong. Marked pleochroism; through $\{010\}$, carmine red and dark brown.

[^27]$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{M n F}_{5}$ is orthorhombic ${ }^{100}$ with $a: b: c=0.576: 1: 0.742$. G. 2.37. $\{010\}$ cleavage. $\mathrm{X}=c, \mathrm{Y}=b .(-) 2 \mathrm{~V}=$ ?, $n_{\mathrm{X}}=1.46, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.50$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.04$.
$\left(\mathbf{N H}_{4}\right)_{3} \mathbf{S c F}_{6}$ is tetragonal ${ }^{100}$ with $c / a=1.02$. G. 1.80. Uniaxial negative with $n_{\mathrm{O}}<1.47, n_{\mathrm{O}}-n_{\mathrm{E}}=$ weak.
$\mathbf{C s}_{3} \mathbf{T l}_{2} \mathbf{C l}_{9}$ is hexagonal with $c / a=0.826$. Uniaxial negative with $n_{\mathbf{O}}=$ $1.772 \mathrm{Li}, 1.784 \mathrm{Na}, 1.792 \mathrm{Tl}, n_{\mathrm{E}}=1.762 \mathrm{Li}, 1.774 \mathrm{Na}, 1.786 \mathrm{Tl}, n_{\mathrm{O}}-$ $n_{\mathrm{E}}=0.010 \mathrm{Na}$.
$\mathbf{K}_{3} \mathbf{C r}(\mathbf{C N})_{6}$ is monoclinic with $a: b: c=1.287: 1: 0.805, \beta=90^{\circ} 3^{\prime}$. Crystals prismatic; lamellar twinning on $\{100\} ;\{100\}$ cleavage. G. 1.71. $\mathrm{Y}=b, \mathrm{Z} \wedge c=0^{\circ} \pm .(+) 2 \mathrm{~V}=46^{\circ}, \mathrm{r}<\mathrm{v}, n_{\mathrm{X}}=1.5176 \mathrm{Li}, 1.5221 \mathrm{Na}$, $1.5268 \mathrm{Tl}, n_{\mathrm{Y}}=1.5198 \mathrm{Li}, 1.5244 \mathrm{Na}, 1.5292 \mathrm{Tl}, n_{\mathrm{Z}}=1.5324 \mathrm{Li}, 1.5373$ $\mathrm{Na}, 1.5423 \mathrm{Tl}, n_{\mathrm{z}}-n_{\mathrm{X}}=0.0152 \mathrm{Na}$. Color clear yellow.
$\mathbf{K}_{3} \mathbf{M n}(\mathbf{C N})_{6}$ is monoclinic with $a: b: c=1.289: 1: 0.801, \beta=90^{\circ} 7^{\prime}$. Crystals prismatic; twinning on $\{100\} ;\{100\}$ cleavage. $\mathrm{Y}=b, \mathrm{Z} \wedge$ $c=0^{\circ} \pm .(+) 2 \mathrm{~V}=43^{\circ}, \mathrm{r}<\mathrm{v}$ marked, $n_{\mathrm{X}}=1.5527 \mathrm{Li}, n_{\mathrm{Y}}=1.5547$, $n_{\mathrm{Z}}=1.5710, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0183$. Weakly pleochroic with X brick red, Y scarlet, Z blood red.
$\mathbf{K}_{3} \mathbf{F e}(\mathbf{C N})_{6}$ is monoclinic with $a: b: c=1.288: 1: 0.801, \beta=90^{\circ} 6^{\prime}$. Crystals prismatic with $\{110\},\{100\},\{322\},\{12 \overline{2}\},\{111\}$ (see Fig. 3-9); often


Fig. 3-9. A crystal habit of potassium ferricyanide. (After Groth.)
twinned on $\{100\}$. Perfect $\{100\}$ cleavage. G. $1.85 . \mathrm{Y}=b, \mathrm{Z} \wedge c=+3^{\circ} 53^{\prime}$. $(+) 2 \mathrm{~V}=49^{\circ}, \mathrm{r}<\mathrm{v}$ marked, $n_{\mathrm{X}}=1.5591 \mathrm{~B}, 1.5660 \mathrm{D}, n_{\mathrm{Y}}=1.5615 \mathrm{~B}$, $1.5689 \mathrm{D}, n_{\mathrm{Z}}=1.5759 \mathrm{~B}, 1.5831 \mathrm{D}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0171 \mathrm{D}$. Pleochroic with X orange to clear red, Y hyacinth to cherry red, Z cherry red, and X $<$ $\mathrm{Z}<\mathrm{Y} . \mathrm{PD} 4.14,3.09,2.94 ; 1-0423$.
$\mathbf{K}_{3} \mathbf{R h}(\mathbf{C N})_{6}$ is monoclinic with $a: b: c=1.286: 1: 0.811, \beta=90^{\circ} 29^{\prime}$.

[^28]Crystals prismatic, often twinned on $\{100\}$; also pyramidal. $\mathrm{Y}=b, \mathrm{Z} \wedge$ $c=0^{\circ} \pm .(+) 2 \mathrm{~V}=39^{\circ}, \mathrm{r}<\mathrm{v} ; n_{\mathrm{X}}=1.5498 \mathrm{Na}, n_{\mathrm{Y}}=1.5513, n_{\mathrm{Z}}=1.5634$, $n_{\mathrm{z}}-n_{\mathrm{X}}=0.0136$. Colorless.
$\mathbf{K}_{2} \mathrm{NaFe}(\mathbf{C N})_{6}$ is monoclinic prismatic. ${ }^{101}$ Crystals equant prismatic. No good cleavage. G. $1.85 c a . \mathrm{Y}=b, \mathrm{Z} \wedge c=40^{\circ} c a .(+) 2 \mathrm{~V}=31^{\circ}, n_{\mathrm{x}}=$ $1.580 \pm 0.003, n_{\mathrm{Y}}=1.581 \pm 0.003, n_{\mathrm{Z}}=1.591 \pm 0.003, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.011$ $c a$. Color orange red, weakly pleochroic yellow to orange. Again: ${ }^{102} n_{\mathrm{x}}=$ $1.5815 \pm 0.0005, n_{\mathrm{z}}=1.590 \pm 0.001$.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{N a F e}(\mathbf{C N})_{6}$ is monoclinic prismatic with $\beta$ about $120^{\circ}$. Crystals equant or vertically long. G. $1.52-1.53 . \mathrm{Y}=b, \mathrm{Z} \wedge c=20^{\circ}$ in obtuse $\beta$. $(+) 2 \mathrm{~V}=10^{\circ}, n_{\mathrm{X}}=1.584 \pm 0.003, n_{\mathrm{Y}}=1.587 \pm 0.003, n_{\mathrm{Z}}=1.598 \pm$ $0.003, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.014$.

## 10. Hydrated Halides, etc., of Monovalent and Trivalent Bases. Formula Type $A_{m} \mathbf{B}_{n} X_{m+3 n} \cdot \mathrm{pH}_{2} \mathrm{O}$

$\mathrm{NaAuCl}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ is orthorhombic ${ }^{103}$ with $a: b: c=0.700: 1: 0.546$. Crystals six-sided prisms having $\{110\},\{010\},\{111\}$ and $\{021\} .(+) 2 \mathrm{~V}=$ ?, $n_{\mathrm{X}}=1.545, n_{\mathrm{Y}}=?, n_{\mathrm{Z}}=1.75+, n_{\mathrm{O}}-n_{\mathrm{X}}=0.205+$. Serves as a microchemical test for gold.
 tablets long parallel $a$, with $\{110\},\{010\}$. ( + ) $2 \mathrm{~V}=$ small, $n_{\mathrm{x}}=1.55$, $n_{\mathrm{Y}}=1.56, n_{\mathrm{Z}}=1.69, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.14$.
$\mathrm{KAuBr}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=0.797: 1: 0.710, \beta=94^{\circ} 24^{\prime}$, Crystals vertically long with $\{100\},\{010\},\{110\},\{111\}$. G. 4.1. $\mathrm{X} \wedge$ $c=-20^{\circ}$. Apparently negative. $n_{\mathrm{X}}=1.67, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ extreme.
$\mathrm{K}_{2} \mathrm{FeCl}_{5} \cdot \mathrm{H}_{2} \mathrm{O}$ (Erythrosiderite) is orthorhombic with ${ }^{104} a=9.924$. $b=13.75, c=6.93 \AA$. U.C. 4. Perfect $\{120\}$ and $\{101\}$ cleavages. G. 2.37. $\mathrm{X}=b, \mathrm{Y}=c .(+) 2 \mathrm{~V}=62^{\circ}, \mathrm{r}>\mathrm{v}$ strong. ${ }^{64} n_{\mathrm{X}}=1.715, n_{\mathrm{Y}}=1.75$, $n_{\mathrm{Z}}=1.80, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.085$. Color ruby red to brownish red; in section weakly pleochroic.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{F e C l}_{5} \cdot \mathbf{H}_{2} \mathbf{O}$ (Kremersite) is orthorhombic with $a: b: c=$ $0.685: 1: 0.702$. Good $\{110\}$ and $\{011\}$ cleavages. Crystals pseudo-octahedral in aspect. G. $2.00 . \mathrm{Y}=c, \mathrm{Z}=b .(+) 2 \mathrm{~V}=78^{\circ} c a ., \mathrm{r}<\mathrm{v}$ strong. ${ }^{48}$ $n_{\mathrm{X}}=1.750, n_{\mathrm{Y}}=1.775, n_{\mathrm{Z}}=1.814, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.064$. Color garnet-red. Pleochroic with X and Z pale yellow-green, Y deep red-orange. PD 5.70, 2.82, 4.95; 1-0187 (?).
$\left(\mathbf{N H}_{4}\right)_{3} \mathbf{R h C l}_{6} \cdot \mathbf{H}_{2} \mathbf{O}$ is orthorhombic ${ }^{78}$ with $a: b: c=0.874: 1: 0.497$. Posi-

[^29]tive elongation. (-) $2 \mathrm{~V}=70^{\circ}, n_{\mathrm{X}}=1.740, n_{\mathrm{Y}}=1.750, n_{\mathrm{Z}}=1.756, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.016$. Color red.
$\left(\mathbf{N H}_{4}\right)_{3} \mathbf{I r C l} \mathbf{l}_{6} \cdot \mathbf{H}_{2} \mathbf{O}$ is orthorhombic ${ }^{81}$ with $a: b: c=0.868: 1: 0.496$. Crystals prismatic with Z parallel length. ( - ) $2 \mathrm{~V}=66^{\circ}, n_{\mathrm{X}}=1.706, n_{\mathrm{Y}}=$ $1.714, n_{\mathrm{Z}}=1.718, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.012$.
$\mathrm{Na}_{3} \mathrm{Fe}(\mathbf{C N})_{6} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ is deliquescent. ${ }^{105}(-) 2 \mathrm{~V}=77^{\circ}$ ca., $n_{\mathrm{X}}=1.531$, $n_{\mathrm{Y}}=1.549, n_{\mathrm{Z}}=1.560, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.029$. Color red.

## 11. Halides, etc., of Monovalent and Tetravalent Bases. Formula Type $\mathbf{A}_{m} \mathbf{B}_{n} \mathbf{X}_{m+4 n} \cdot \mathbf{p H} \mathbf{O}$

$\mathbf{L i}_{2} \mathbf{S i F}_{6} \cdot 2 \mathbf{H}_{2} \mathbf{O}$ is monoclinic. ${ }^{38}$ G. 2.33. Only two indices reported: $n_{1}=$ 1.296, $n_{2}=1.300, n_{2}-n_{1}=0.004$.
$\mathbf{N a}_{2} \mathbf{S i F}_{6}$ (Malladrite) is hexagonal with $c / a=1.333$. Crystals basal plates with small pyramids. G. 2.75. Uniaxial negative with ${ }^{106} n_{\mathrm{O}}=1.3125$, $n_{\mathrm{E}}=1.3089, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0036$. Again: ${ }^{106 a} n_{\mathrm{O}}=1.312, n_{\mathrm{E}}=1.309, n_{\mathrm{O}}-$ $n_{\mathrm{E}}=0.003$. Colorless. Basal sections of artificial crystals may show six biaxial sectors with the optic plane parallel to the prism faces and $\mathrm{Z}=c$. Crystals serve as microchemical test for Na .
$\mathbf{K}_{2} \mathbf{S i F}_{6}$ (Hieratite) is isometric with $a=8.168 k X$. U.C. 4. Crystals often octahedral. Perfect $\{111\}$ cleavage. G. 2.665. Isotropic with ${ }^{106}$ $n=1.339$. Again: ${ }^{106 a} n=1.347$. May contain some Al which raises the index. Forms mix-crystals with $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SiF}_{6}$ and probably with Rb , Cs and Tl salts. It serves as a test for K . By evaporation of a solution at about $10^{\circ} \mathrm{C}$. hexagonal crystals are formed which have $c / a=1.60$. G. 3.08. Perfect basal cleavage and uniaxial negative character with weak birefringence. Colorless. PD 4.70, 2.35, 2.88; 7-217.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{S i F}_{6}$ (Cryptohalite) is isometric with $a=8.337 k X$. U.C. 4. Crystals often octahedral. Perfect $\{111\}$ cleavage. G. 2.028. Isotropic ${ }^{107}$ with $n=1.3682 \mathrm{C}, 1.3696 \mathrm{D}, 1.3723 \mathrm{~F}$. Colorless. By evaporating a solution at about $5^{\circ}$ C., hexagonal crystals form (which are called ${ }^{108}$ bararite in nature); they have $a=5.76, c=4.77 k X$. U.C. 1. Crystals are basal tablets with perfect basal cleavage. G. 2.15. Uniaxial negative ${ }^{107}$ with $n_{\mathrm{O}}=1.406, n_{\mathrm{E}}=1.391, n_{\mathrm{O}}-n_{\mathrm{E}}=0.015 \mathrm{Na} . \mathrm{PD} 4.84,2.42,2.10 ; 7-13$.
$\mathbf{N a}_{2} \mathbf{G e F}_{6}$ is hexagonal with ${ }^{106 a} a=8.99, c=5.12 \AA$. Uniaxial negative with $n_{\mathrm{O}}=1.327, n_{\mathrm{E}}=1.324, n_{\mathrm{O}}-n_{\mathrm{E}}=0.003$. It forms mix crystals with $\mathrm{Na}_{2} \mathrm{SiF}_{6}$ in all proportions. With 28 per cent $\mathrm{Na}_{2} \mathrm{SiF}_{6} n_{\mathrm{O}}=1.331, n_{\mathrm{E}}=$

[^30]$1.329, n_{\mathrm{O}}-n_{\mathrm{E}}=0.002$. With 48 per cent $\mathrm{Na}_{2} \mathrm{SiF}_{6} n_{\mathrm{O}}=1.322, n_{\mathrm{E}}=1.320$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.002$. With 67 per cent $\mathrm{Na}_{2} \mathrm{SiF}_{6} n_{\mathrm{O}}=1.319, n_{\mathrm{E}}=1.317$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.002$.
$\mathbf{K}_{2} \mathbf{G e F}_{6}$ is hexagonal with ${ }^{106 a} a=9.38, c=5.77 \AA$. Uniaxial negative with $n_{\mathrm{O}}=1.383, n_{\mathrm{E}}=1.381, n_{\mathrm{O}}-n_{\mathrm{E}}=0.002$. $\mathrm{PD} 3.77,2.16,4.89$; 7-241.
$\mathbf{N a}_{2} \mathbf{T i F}_{6}$ is hexagonal ${ }^{108 a}$ with $a=9.20, c=5.13 \AA$. Seems to intercrystallize freely with $\mathrm{Na}_{2} \mathrm{GeF}_{6}$. Uniaxial negative with $n_{\mathrm{O}}=1.419, n_{\mathrm{E}}=1.412$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.007$.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{G e F}_{6}$ is hexagonal. ${ }^{109}$ Crystals short prisms or basal plates. G. 2.564. Uniaxial negative with $n_{\mathrm{O}}=1.428, n_{\mathrm{E}}=1.425, n_{\mathrm{O}}-n_{\mathrm{E}}=0.003$. PD 5.07, 3.49, 2.25; 7-240.
$\mathbf{C s}_{2} \mathbf{G e C l}_{6}$ is isometric, ${ }^{110}$ often octahedral, with G. 3.45 and $n=1.68$.
$\mathbf{K}_{2} \mathbf{Z r F}_{6}$ is monoclinic ${ }^{111}$ with $a: b: c=0.573: 1: 0.597, \beta=90^{\circ} 20^{\prime}$. Crystals prismatic with $\{001\}$ cleavage. G. 3.58. Lamellar twinning on $\{100\}$ and $\{001\}$. Soluble in hot $\mathrm{H}_{2} \mathrm{O} . \mathrm{Y}=b, \mathrm{Z} \wedge c=45^{\circ} .(+) 2 \mathrm{~V}=60^{\circ}$, $n_{\mathrm{X}}=1.454, n_{\mathrm{Y}}=1.465, n_{\mathrm{Z}}=1.498, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.044$. Colorless.
$\mathbf{K}_{3} \mathbf{Z r F}_{7}$ is isometric; ${ }^{111 a}$ crystals octahedral. Isotropic with $n=1.408$.
$\left(\mathbf{N H}_{4}\right)_{3} \mathbf{Z r F}_{7}$ is isometric. ${ }^{111 \mathrm{~b}}$ Crystals octahedral. Isotropic with $n=$ 1.433 D. PD 5.44, 4.71, 3.33; 7-24.
$\mathbf{K}_{2} \mathbf{S n C l}_{6}$ is isometric; crystals octahedral with perfect $\{111\}$ cleavage. G. 2.69. Isotropic with $n=1.6517 \mathrm{C}, 1.6574 \mathrm{D}, 1.6717 \mathrm{~F}$. Colorless.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{S n C l}_{6}$ is isometric. Crystals octahedral. G. 2.40. Isotropic with $n=1.690$ D. Colorless. PD 5.81, 5.03, 2.52; 7-198.
$\mathrm{K}_{2} \mathbf{H f F}_{6}$ is monoclinic and isomorphous with $\mathrm{K}_{2} \mathrm{ZrF}_{6}$. Minimum (measured) $n=1.449$ (probably $n_{\mathrm{X}}$ ); maximum 1.461 (probably $n_{\mathrm{Y}}$ ). Colorless.
$\mathbf{K}_{3} \mathbf{H f F}_{7}$ is isometric. ${ }^{11 \mathrm{c}}$ Crystals octahedral. Isotropic with $n=1.403$.
$\left(\mathbf{N H}_{4}\right)_{3} \mathbf{H f F}_{7}$ is isometric. Octahedral. Isotropic with $n=1.426 \mathrm{D}$.
$\mathbf{K}_{2} \mathbf{P t C l}_{6}$ is isometric. ${ }^{106}$ Crystals octahedral or cubic with good $\{111\}$ cleavage. G. 3.6-3.7. Isotropic with $n=1.827$ ( $557 \mathrm{~m} \mu$ ). Color yellow.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{P t C l}_{6}$ is isometric. Crystals octahedral with perfect $\{111\}$ cleavage. G. 3.0. Isotropic ${ }^{112}$ with $n=1.8$ : again, ${ }^{81} n>1.780$, deep yellow. PD 5.70, 4.93, 2.97; 7-218.
$\mathbf{N H}_{4} \mathbf{C H}_{3} \mathbf{P t C l}_{6}$ is isometric and isotropic ${ }^{12}$ with $n=1.74$.

[^31]$\mathbf{L i}_{2} \mathbf{P t}(\mathbf{C N})_{6}$ has $^{113} \mathbf{Z}$ parallel to elongation with one index $n>1.95$ and another $n=1.59$.
$\mathbf{K}_{2} \mathbf{P t}(\mathbf{C N})_{6}$ is rhombohedral with $c / a=1.32$. Crystals have $\{0001\}$, $\{10 \overline{1} 1\},\{2 \overline{2} 01\}$, etc. Uniaxial negative with $n_{0}=1.861(668 \mathrm{~m} \mu), 1.890$ $(588 \mathrm{~m} \mu), n_{\mathrm{E}}=1.781(668 \mathrm{~m} \mu), 1.820(588 \mathrm{~m} \mu), n_{\mathrm{O}}-n_{\mathrm{E}}=0.070(588 \mathrm{~m} \mu)$.
$\mathbf{K}_{2} \mathbf{P t}(\mathbf{C N S})_{6}$ is rhombohedral ${ }^{114}$ with $a=6.733, c=10.26 k X$. U.C. 1. G. 2.49. Uniaxial negative with $n_{\mathrm{O}}=1.861(668 \mathrm{~m} \mu), 1.890(588 \mathrm{~m} \mu)$, $n_{\mathrm{E}}=1.781(668 \mathrm{~m} \mu), 1.820(588 \mathrm{~m} \mu), n_{\mathrm{O}}-r_{\mathrm{E}}=0.070(588 \mathrm{~m} \mathrm{\mu})$.

## 12. Halides, etc., of Monovalent and Pentavalent Bases. Formula Type $\mathbf{A}_{m} \mathbf{B}_{n} \mathbf{X}_{m+5 n}$

$\mathbf{K}_{2} \mathbf{T a F}_{7}$ is monoclinic with ${ }^{15} a: b: c=0.6718: 1: 0.9198, \beta=90^{\circ} 15^{\prime} ;$ crystals acicular parallel to the vertical axis with $\{010\}$ and $\{110\}$ faces prominent. G. 4.06. $\mathrm{X}=b ; \mathrm{Z} \wedge c=32^{\circ}$. (-) $2 \mathrm{~V}=$ ?, $n_{\mathrm{X}}=1.414, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.418, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.004$.
$\mathbf{K}_{2} \mathbf{N b F}_{7}$ is monoclinic with ${ }^{115} a: b: c=0.6711: 1: 0.9209, \beta=90^{\circ} 12^{\prime} ;$ crystals acicular parallel to $c$ and often flattened parallel to (010). G. 3.21. The optic plane and X are probably normal to $\{010\} ; \mathrm{Z} \wedge c=34^{\circ}$. $n_{\mathrm{X}}=1.437, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.440, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.003$.

## 13. Halides, etc., of Divalent and Trivalent (with or without Monovalent) Bases. Formula Type $A_{m} B_{n} X_{2 m+3 n} \cdot \pm \mathrm{pH}_{2} \mathrm{O}$ or $\mathrm{AB}_{m} \mathrm{C}_{n} \mathrm{X}_{1+2 m+3 n} \cdot \pm \mathrm{pH}_{2} \mathrm{O}$

$\mathbf{Z n}\left(\mathbf{B F}_{4}\right)_{2}$ is probably uniaxial ${ }^{116}$ with $n>1.36, n_{1}-n_{2}=0.011$.
$\mathrm{NaCaAlF}_{6} \cdot \mathbf{H}_{2} \mathbf{O}$ is dimorphous; one phase is pachnolite and the other is thomsenolite. Pachnolite is monoclinic with $a=12.12, b=10.39, c=$ $15.68 k X, \beta=90^{\circ} 20^{\prime}$. U.C. 16. Crystals prismatic. Poor basal cleavage. H. 3. G. 2.98. $\mathrm{X}=b,{ }^{64} \mathrm{Z} \wedge c=69^{\circ}$. ( + ) $2 \mathrm{~V}=76^{\circ}, \mathrm{r}<\mathrm{v}$ weak, with strong horizontal dispersion. $n_{\mathrm{X}}=1.411, n_{\mathrm{Y}}=1.413, n_{\mathrm{Z}}=1.420, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.009$. Colorless. PD 3.95, 1.97, 2.79; 5-0356. Thomsenolite is also monoclinic, but with $a=5.57, b=5.50, c=16.10 k X, \beta=96^{\circ} 27^{\prime}$. U.C. 4 . Crystals often prismatic. Perfect basal and distinct prismatic cleavages. H. 2. G. 2.98. $\mathrm{X} \wedge c=-52^{\circ}, \mathrm{Z}=b .^{117}(-) 2 \mathrm{~V}=50^{\circ}, \mathrm{r}<\mathrm{v}$ weak.

[^32]$n_{\mathrm{X}}=1.4072, n_{\mathrm{Y}}=1.4136, n_{\mathrm{Z}}=1.4150, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0078$. Colorless. PD 4.02, 1.96, 2.00; 5-0343. A substance which is probably either pachnolite or thomsenolite ${ }^{118}$ has been made by reaction of powdered cryolite with $\mathrm{CaCl}_{2}$ solution.
$\mathbf{M g}\left(\mathbf{B F}_{4}\right)_{2}$ is hexagonal, rhombohedral. ${ }^{116}$ Uniaxial with $n<1.36, n_{1}-$ $n_{2}=0.014$.
$\mathbf{C a}\left(\mathbf{B F}_{4}\right)_{2}$ is orthorhombic ${ }^{116} .(-) 2 \mathrm{~V}=$ very small. $n_{\mathrm{Y}}<1.36, n_{\mathrm{z}}-$ $n_{\mathrm{X}}=0.002$.
$\mathbf{M n}\left(\mathbf{B F}_{4}\right)_{2}$ is pseudo-trigonal. ${ }^{116}$ Biaxial with 2 V small. $n_{\mathrm{z}}=1.359$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.013$.
$\mathbf{C o}\left(\mathbf{B F}_{4}\right)_{2}$ is almost uniaxial; ${ }^{116}$ pink and weakly pleochroic with $\mathrm{X}>\mathrm{Z}$. $n=1.40 \pm . n_{\mathrm{Z}}-n_{\mathrm{X}}=0.014$.
$\mathrm{Ni}\left(\mathbf{B F}_{4}\right)_{2}$ is pseudo-trigonal. ${ }^{116} 2 \mathrm{~V}$ very small. $n_{\mathrm{X}}>1.47, n_{\mathrm{Y}}=1.48 \pm$, $n_{\mathrm{Z}}<1.50$.
$\operatorname{Sr}\left(\mathbf{B F}_{4}\right)_{2}$ is dimorphous. ${ }^{116}$ One phase is isometric with $n<1.44$. One phase is orthorhombic and biaxial.
$\mathbf{C u}\left(\mathrm{BF}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is monoclinic and closely related to $\mathrm{Cu}\left(\mathrm{ClO}_{4}\right)_{2} .6 \mathrm{H}_{2} \mathrm{O}$. G. 2.175. $\mathrm{X} \wedge c=59^{\circ}, \mathrm{Z}=b$. ( - ) $2 \mathrm{~V}=$ large, with marked crossed dispersion giving anomalous interference colors near extinction in (010) sections or plates. Mean index, $n=1.50 c a$.
$\mathbf{S r}_{3} \mathbf{F e}_{2} \mathbf{F}_{12} \cdot 2 \mathbf{H}_{2} \mathbf{O}$ is orthorhombic ${ }^{119}$ in tablets. G. 3.71. Soluble in hot water. X normal to tablets. $(-) 2 \mathrm{~V}=55^{\circ}$ calc. $n_{\mathrm{X}}=1.473, n_{\mathrm{Y}}=1.480$, $n_{\mathrm{Z}}=1.482, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.009$.
$\mathbf{B a F e F}_{5} \cdot \mathbf{H}_{2} \mathbf{O}$ is orthorhombic ${ }^{119}$ in tablets. G. 3.94. Soluble in hot water. X normal to tablets. $(+) 2 \mathrm{~V}=20^{\circ}$ calc., $n_{\mathrm{X}}=1.502, n_{\mathrm{Y}}=1.503, n_{\mathrm{Z}}=$ $1.513, n_{\mathrm{z}}-n_{\mathrm{X}}=0.011$.
$\mathbf{Y}_{2} \mathbf{P t}_{3}(\mathbf{C N})_{12} \cdot 21 \mathrm{H}_{2} \mathrm{O}$ is orthorhombic with $a: b: c=0.892: 1: 0.616$. Crystals basal plates with perfect $\{001\}$ cleavage. Twinning on $\{110\}$. $\mathrm{Y}=b,{ }^{92} \mathrm{Z}=c .(+) 2 \mathrm{~V}=15^{\circ} \pm \mathrm{Na}, n^{\prime} \mathrm{x}=1.5899 \mathrm{He}$ red, 1.5907 C , $n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=2.058 \mathrm{He}$ red, $2.055 \mathrm{C}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.46 \mathrm{C}$. Color deep red; pleochroic in violet and orange tints.
$\mathrm{Ce}_{2} \mathrm{Pt}_{3}(\mathrm{CN})_{12} \cdot 18 \mathrm{H}_{2} \mathrm{O}$ is monoclinic with ${ }^{120} a: b: c=0.581: 1: 0.553, \beta=$ $107^{\circ} 33^{\prime}$. Crystals prismatic with no good cleavage. Twinning on $\{100\}$. G. 2.66. $(+) 2 \mathrm{~V}=70^{\circ}$ est. $n_{\mathrm{X}}=1.65, n_{\mathrm{Y}}=1.66, n_{\mathrm{Z}}=1.68, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.03 . Color pale yellow with bluish fluorescence.

[^33]$\mathbf{P b}_{3} \mathbf{O}_{2} \mathbf{C l}_{2}$ (Mendipite) is orthorhombic with $a=9.50, b=11.87, c=$ $5.87 k X$. Perfect $\{110\}$ and good $\{100\}$ and $\{010\}$ cleavages. H. 2.5. G. 7.24. $\mathrm{X}=a ; ;^{12} \mathrm{Y}=b$. (+) $2 \mathrm{~V}=$ nearly $90^{\circ}, \mathrm{r}<\mathrm{v}$ strong. $n_{\mathrm{X}}=2.24$, $n_{\mathrm{Y}}=2.27, n_{\mathrm{Z}}=2.31, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.07$. Elongation + . Colorless or nearly so. PD 3.09, 3.04, 2.78; 8-111.
$\mathrm{Hg}_{2} \mathrm{OCl}$ (Terlinguaite) ${ }^{125}$ is monoclinic with $a=11.63, b=5.76, c=$ $9.28 k X, \beta=105^{\circ} 37^{\prime}$. Crystals prismatic. Perfect $\{101\}$ cleavage. H. 2.5. G. 8.725. Optic plane parallel ${ }^{12}$ with $b$ and inclined $-7^{\circ}$ to $c .(-) 2 V=20^{\circ}$, $\mathrm{r}<\mathrm{v}$ extreme. $n_{\mathrm{X}}=2.35 \mathrm{Li}, n_{\mathrm{Y}}=2.64, n_{\mathrm{Z}}=2.66, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.31$. Color yellow, rarely brown. Slightly pleochroic in green and yellow. PD 3.26, 2.51, 2.81; 2-0481.

## 16. Oxyhalides of Trivalent Bases. Formula Type AOX

BiOCl (Bismoclite) is tetragonal with ${ }^{126} a=3.89, c=7.37 k X$. Crystals basal plates with perfect basal cleavage. H. 2-2.5. G. 7.717. Uniaxial negative with $n_{\mathrm{O}}=2.15, n_{\mathrm{E}}=$ ?, $n_{\mathrm{O}}-n_{\mathrm{E}}=$ strong. Color pale cream, grayish, yellowish, brown. Made by slow hydrolysis of $\mathrm{BiCl}_{3}$ in HCl . PD 3.44, 2.68, 2.75; 6-0249.
$\mathbf{B i O}(\mathbf{O H}, \mathrm{Cl})$ (Daubréeite) is tetragonal. BiOCl and BiOOH intercrystallize in all proportions; with $\mathrm{Cl}>\mathrm{OH}$ it is called bismoclite and with $\mathrm{OH}>\mathrm{Cl}$ it is daubréeite. ${ }^{127}$ With $^{126} \mathrm{OH} \approx \mathrm{Cl}: a=3.85, c=7.40 k X$. Perfect basal cleavage. H. 2-2.5. G. 7.56 calc. Uniaxial negative (probably with very little Cl ). $n_{\mathrm{O}}=1.91 \pm 0.01$ and $n_{\mathrm{O}}-n_{\mathrm{E}}=0.01 \mathrm{ca}$. Color pale cream, grayish or yellowish brown. Made by precipitation of $\mathrm{BiCl}_{3}$ solution with ammonia.

## 17. Oxyhalides, etc., of Tetravalent Bases. Formula Type $\mathrm{AOX}_{2} \cdot \mathrm{nH}_{2} \mathrm{O}$

$\mathrm{HfOCl}_{2} \cdot \mathbf{8 H _ { 2 }} \mathbf{O}$ is uniaxial negative with ${ }^{128} n_{\mathrm{O}}=1.557, n_{\mathrm{E}}=1.543$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.014$.
$\mathbf{Z r O C l}_{2} \cdot \mathbf{8} \mathbf{H}_{2} \mathrm{O}$ is tetragonal with ${ }^{129} c / a=0.318$. Crystals prismatic with $\{100\}$ cleavage. Soluble in HCl. Uniaxial positive with $n_{0}=1.552$, $n_{\mathrm{E}}=1.563, n_{\mathrm{E}}-n_{\mathrm{O}}=0.011$. PD 12.8, 3.60, $6.9 ; 1-0024$.

[^34]
## 18. Oxyhalides, etc., of Divalent and Trivalent Bases. Formula Type $\mathrm{ABO}_{2} \mathrm{X}$ or $\mathrm{A}_{4} \mathrm{~B}_{2} \mathrm{O}_{6} \mathrm{X}_{2} \cdot \mathrm{nH}_{2} \mathrm{O}$

$\mathbf{P b S b O}_{2} \mathbf{C l}$ (Nadorite) is orthorhombic ${ }^{130}$ with $a=5.59, b=12.20$, $c=5.43 \AA$, U.C. 4. Crystals $\{100\}$ tablets elongated along $b$ with perfect $\{100\}$ cleavage. Twinning on $\{011\}$ at $91^{\circ} 45^{\prime}$. H. 4. G. 7.02. F. 1.5. Soluble in $\mathrm{HCl} . \mathrm{X}=b ; \mathrm{Y}=c .(+) 2 \mathrm{~V}=$ very large, $\mathrm{r}>\mathrm{v}$ strong. $n_{\mathrm{X}}=2.30 \mathrm{Li}$, $n_{\mathrm{Y}}=2.35, n_{\mathrm{Z}}=2.40, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.10$. Color smoky brown to brownish yellow. Made by fritting. ${ }^{131}$

## 19. Halides, etc., with Ammonia or Amine

$\mathbf{P d}\left(\mathbf{N H}_{3}\right)_{4} \mathbf{C l}_{2} \cdot \mathbf{H}_{2} \mathbf{O}$ is tetragonal. ${ }^{81}$ Uniaxial negative with $n_{o}=1.620$, $n_{\mathrm{E}}=1.557, n_{\mathrm{O}}-n_{\mathrm{E}}=0.063$. Again: ${ }^{77} n_{\mathrm{O}}=1.619, n_{\mathrm{E}}=1.559$. Color pale yellow.
$\left[\mathbf{P t}\left(\mathbf{N H}_{3}\right)_{5} \mathrm{Cl}^{2}\right] \mathrm{Cl}_{3} \cdot \mathbf{H}_{2} \mathrm{O}$ is hexagonal with $a=20.50, c=6.64 \AA$. Uniaxial positive ${ }^{81}$ with $n_{\mathrm{O}}>1.718, n_{\mathrm{E}}<1.722, n_{\mathrm{E}}-n_{\mathrm{O}}<0.004$.
$\mathbf{C o}\left(\mathbf{N H}_{3}\right)_{6} \cdot \mathbf{F e}(\mathbf{C N})_{6}$ is trigonal. ${ }^{132}$ Crystals prismatic. Uniaxial positive with $n_{\mathrm{O}}=1.662, n_{\mathrm{E}}=1.695, n_{\mathrm{E}}-n_{\mathrm{O}}=0.033$.
$\mathbf{I r C l}_{3}\left(\mathbf{N H}_{3}\right)_{4} \cdot \mathbf{H}_{2} \mathbf{O}$ is trigonal with $c / a=0.645$. Crystals prismatic. Uniaxial positive with $n_{\mathrm{O}}=1.6576, n_{\mathrm{E}}=1.6666, n_{\mathrm{E}}-n_{\mathrm{O}}=0.009$.
$\mathbf{R h}\left[\left(\mathbf{N H}_{3}\right)_{5} \mathbf{C l}\right] \mathbf{C l}_{2}$ is orthorhombic and pseudo-tetragonal with $a: b: c=$ 0.784:1:0.0505. Crystals $\{101\}$ domatic with $\{120\}$. Fair $\{120\}$ and $\{010\}$ cleavages. G. 2.08. $\mathrm{Y}=c ; \mathrm{Z}=b$. An optic axis visible through $\{120\}$. $(+) 2 \mathrm{~V}=$ very large, $\mathrm{r}<\mathrm{v}$ distinct. $n_{\mathrm{X}}=1.700, n_{\mathrm{Y}}=1.703, n_{\mathrm{Z}}=1.707$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.007$.
$\mathbf{Z n}\left(\mathbf{N H}_{3}\right)_{2} \mathbf{C l}_{2}$ is orthorhombic ${ }^{133}$ with $a: b: c=0.916: 1: 0.951$. Crystals $\{110\}$ twinned plates or pseudo-tetragonal forms like pyramids on the $b$ axis. Perfect $\{011\}$ and $\{010\}$ cleavages. H. 1. G. 1.95. Soluble in water. $\mathrm{Y}=b ; \mathrm{Z}=c$. $(-) 2 \mathrm{~V}=$ large ( $86^{\circ}$ in glycerine). $n_{\mathrm{Y}}=1.618 c a$. Colorless. Formed in an electric battery. PD 5.80, 3.88, 2.92; 1-0165.
$\mathbf{Z n}\left(\mathbf{N H}_{3}\right)_{6} \mathbf{C l}_{2}$ is hexagonal ${ }^{133}$ prismatic with perfect basal cleavage. H. 1. Soluble in water. Uniaxial negative with $n_{0}=1.539, n_{\mathrm{E}}=1.530 \pm$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.009 \pm$. Colorless. Formed in an electric battery.
$\mathbf{P t}\left(\mathbf{N H}_{3}\right)_{2} \mathbf{O}_{2}(\mathbf{O H})_{2} \mathbf{C l}_{2}$ forms pale yellow crystals ${ }^{81}$ with ( -$) 2 \mathrm{~V}=75^{\circ}$, $n_{\mathrm{X}}=1.690, n_{\mathrm{Y}}=1.730, n_{\mathrm{Z}}=1.756, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.066$.
$\mathbf{K P t C l}_{3} \cdot \mathbf{N H}_{3} \cdot \mathbf{H}_{2} \mathbf{O}$ is orthorhombic ${ }^{104}$ with $a: b: c=0.793: 1: 0.754$. Crystals prismatic with $\{011\}$; no good cleavage. $\mathrm{X}=c ; \mathrm{Y}=b$. (-)2V $=64^{\circ}$ ca. $n_{\mathrm{X}}=1.5438, n_{\mathrm{Y}}=1.5754, n_{\mathrm{Z}}=1.588 \pm, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.044 \pm$. Color
${ }^{130}$ Sillén and Melander: Zeit. Krist. CIII, p. 420 (1941).
${ }^{131}$ Bolfa, Pastant and Roubault: C. R. Acad. Sci. Paris, CCXXVIII, p. 1739 (1949)
${ }^{132}$ Steinmetz: Zeit. Krist. LVII, p. 242 (1922).
${ }^{133}$ Chudoba: Cent. Min. 1929 A, p. 139.
reddish yellow with X yellowish red, Y reddish yellow, Z yellow or red.
$\mathbf{N H}_{3} \mathbf{B F}_{3}$ is orthorhombic. ${ }^{134}$ Crystals often have $\{110\}$ and $\{001\}$. G. 1.864. M. P. $163^{\circ} \mathrm{C} . \mathrm{X}=b ; \mathrm{Y}=a .2 \mathrm{~V}=90^{\circ} \pm 3^{\circ}, n_{\mathrm{X}}=1.335, n_{\mathrm{Y}}=$ $1.34-1.35, n_{\mathrm{Z}}=1.36, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.025 . \mathrm{X}=b, \mathrm{Y}=a$.
$\mathbf{C o}\left(\mathbf{N H}_{3}\right)_{6} \mathbf{C l}_{3}$ is monoclinic with $a: b: c=0.988: 1: 0.650, \beta=91^{\circ} 19^{\prime}$. Crystals $\{010\}$ plates or equant with $\{210\},\{010\},\{10 \overline{1}\}$, etc. No good cleavage. G. 1.704. The optic plane is normal to $\{010\}$; the acute bisectrix is nearly normal to $\{10 \overline{1}\}$. Mean index $n=1.706, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ weak. Color brownish red, pleochroic. PD 3.60, 5.8, 2.48; $1-0522$.
$\mathbf{P d}\left(\mathbf{N H}_{3}\right)_{2} \mathbf{C l}_{2}$ (Trans-) forms dendrites ${ }^{78}$ with $n_{1}=1.718, n_{2}>1.817$.
$\mathbf{P t}\left(\mathbf{N H}_{3}\right)_{2} \mathbf{C l}_{2}$ (Trans-) is monoclinic. Crystals acicular or apparently rhombohedral. ${ }^{81} \mathrm{X} \wedge$ needle length $=19^{\circ} . \mathrm{Z}$ is in long diagonal of rhomb. $n_{\mathrm{X}}=1.706, n_{\mathrm{Y}}=1.778, n_{\mathrm{Z}}>1.790, n_{\mathrm{Z}}-n_{\mathrm{X}}>0.084$. Color yellow.
$\mathbf{P t}\left(\mathbf{N H}_{3}\right)_{2} \mathbf{C l}_{2}$ (Cis-) forms needles ${ }^{81}$ with an extinction angle of $30^{\circ}$. $(-) 2 \mathrm{~V}=70^{\circ}, n_{\mathrm{X}}=1.745, n_{\mathrm{Y}}=1.790, n_{\mathrm{Z}}=1.812, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.067$. Color yellow.
$\mathrm{PtCONH}_{3} \mathrm{Cl}_{2}$ (Cis-) is biaxial ${ }^{81}$ with ( + ) $2 \mathrm{~V}=74^{\circ}, n_{\mathrm{X}}=1.722, n_{\mathrm{Y}}=$ $1.745, n_{\mathrm{Z}}=1.790, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.068$. Color green-brown.

## 20. Compound (and also Acid) Halides, etc.

$\mathbf{A s I}_{3} \cdot \mathbf{3 S}_{8}$ is hexagonal with ${ }^{135} c / a=0.366$. It has ditrigonal pyramidal symmetry. Uniaxial negative with $n_{\mathrm{O}}=2.2756, n_{\mathrm{E}}=1.8501, n_{\mathrm{O}}-n_{\mathrm{E}}=$ 0.4255 for $\lambda=650$ and $n_{\mathrm{O}}=2.3036, n_{\mathrm{E}}=1.8636, n_{\mathrm{O}}-n_{\mathrm{E}}=0.440$ for $\lambda=589$.
$\mathrm{NiF}_{2} \cdot \mathbf{5 H F} \cdot \mathbf{6} \mathrm{H}_{2} \mathrm{O}$ is trigonal ${ }^{14}$ with $c / a=\mathbf{2 . 0 1}$. Crystals flattened prisms with prismatic cleavage. Uniaxial positive with $n_{\mathrm{O}}=1.390 \mathrm{C}, 1.392 \mathrm{D}$, $1.395 \mathrm{~F}, n_{\mathrm{E}}=1.406 \mathrm{C}, 1.408 \mathrm{D}, 1.410 \mathrm{~F}, n_{\mathrm{E}}-n_{\mathrm{O}}=0.016$. Color bluegreen.
$\mathrm{CoF}_{2} \cdot \mathbf{5 H F} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is trigonal ${ }^{14}$ with $c / a=1.04$. Crystals flattened prisms with prismatic cleavage. G. 2.04. Uniaxial positive with $n_{0}=1.382 \mathrm{C}$, $1.384 \mathrm{D}, 1.390 \mathrm{G}^{\prime}, n_{\mathrm{E}}=1.397 \mathrm{C}, 1.399 \mathrm{D}, 1.406 \mathrm{G}^{\prime}, n_{\mathrm{E}}-n_{\mathrm{O}}=0.015 \mathrm{D}$. Color orange-red.
$\mathbf{P t}\left(\mathbf{N H}_{3}\right)_{5}\left(\mathbf{S O}_{4}\right) \mathbf{C l}_{2}$ forms ${ }^{78}$ crystals with symmetrical extinction and common twinning. $n_{1}=1.673, n_{2}=1.710$.
$\left(\mathbf{N H}_{2} \mathbf{O H}\right)_{2} \cdot \mathbf{H}_{2} \mathbf{G e F}_{6} \cdot \mathbf{2} \mathbf{H}_{2} \mathrm{O}$ is monoclinic ${ }^{109}$ with $\beta$ about $100^{\circ}$. Crystals equant with $\{110\},\{100\}$, and $\{011\}$. G. 2.492. $\mathrm{X} \wedge a=80^{\circ} ; \mathrm{Y}=b$. $(-) 2 \mathrm{~V}=60^{\circ} c a ., \mathrm{r}>$ v fairly strong. $n_{\mathrm{X}}=1.418, n_{\mathrm{Y}}=1.438, n_{\mathrm{z}}=1.443$, $n_{\mathrm{z}}-n_{\mathrm{X}}=0.025 \mathrm{Na}$.
$\left(\mathbf{N}_{2} \mathbf{H}_{4}\right)_{2} \cdot \mathbf{H}_{2} \mathbf{G e F}_{6}$ is monoclinic ${ }^{109}$ with $\beta$ about $100^{\circ}$. Crystals prismatic with $\{100\},\{001\}$. G. 2.406. $\mathrm{Y}=b$. Extinction on (110) at $30^{\circ}$. (-) $2 \mathrm{~V}=$

[^35]near $90^{\circ} . n_{\mathrm{X}}=1.452, n_{\mathrm{Y}}=1.460, n_{\mathrm{Z}}=1.464, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.012$. (Indices and 2 V are inconsistent. A.N.W.).
$\mathbf{C u F}_{2} \cdot \mathbf{5 H F} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is monoclinic ${ }^{14}$ with three cleavages. G. 2.41. Loses water easily. Extinction parallel to one cleavage and much inclined to another. Negative elongation. (-) $2 \mathrm{~V}=32^{\circ}, n_{\mathrm{X}}=1.395, n_{\mathrm{Y}}=1.440$, $n_{\mathrm{Z}}=1.444, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.049$. Color greenish blue with $\mathrm{X}<\mathrm{Y}=\mathrm{Z}$.

## IV. Oxides

Oxides are classed as simple, ${ }^{1}$ multiple and compound. Hydroxides are considered separately. The arrangement in order of decreasing A to X ratio may be outlined as follows:
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## A. SIMPLE OXIDES

## $\alpha$. Anhydrous

## 1. Formula Type $A_{2} X$

$\mathbf{L i}_{2} \mathrm{O}$ is isometric with the $\mathrm{CaF}_{2}$ space lattice. Distinct $\{111\}$ cleavage. G. 2.01. M.P. above $1625^{\circ} \mathrm{C}$., but it sublimes below $1000^{\circ} \mathrm{C}$. and oxidizes
${ }^{1}$ Oxides are considred to be "simple" if they contain only one metal or two (or more) metals whose ions are near enough in size to occupy equivalent positions in the crystal structure. Compound oxides contain one (or more) anions besides oxygen (and hydroxyl).
to $\mathrm{Li}_{2} \mathrm{O}_{2}$ at lower temperatures. Soluble in water. Isotropic ${ }^{19}$ with $n=1.644$; also anisotropic (from strain?). Colorless or stained yellow by $\mathrm{Li}_{2} \mathrm{O}_{2}$.
$\mathbf{C u}_{2} \mathbf{O}$ (Cuprite) is isometric with the $\mathrm{CaF}_{2}$ space lattice. Poor octahedral cleavage. H. 3.5-4. G. 5.975. M.P. $1235^{\circ} \mathrm{C}$. Isotropic with $n=2.534 \mathrm{~B}$, $2.558 \mathrm{C}, 2.705 \mathrm{D}, 2.963 \mathrm{~F}$. Color bright red. Made by heating copper in air. PD 2.47, 2.14, 1.51; 5-0667.
$\mathbf{H}_{2} \mathbf{O}$ (Ice) is hexagonal with $a=7.82, c=7.36 k X$. U.C. 12. Complete crystals rare; skeleton crystals (snow) very common in cold winters, often as basal tablets, hexagonal stars, dendrites, etc. H. 1.5, increasing to 4 at $-44^{\circ} \mathrm{C}$. and to about ${ }^{2} 6$ at $-78.5^{\circ} \mathrm{C}$. G. 0.918 . Melts at $0^{\circ} \mathrm{C}$. to water which has G. 1 . and $n=1.333$ and vaporizes (to steam) at $100^{\circ} \mathrm{C}$. Ice is uniaxial positive with ${ }^{3} n_{\mathrm{O}}=1.3071 \mathrm{C}, 1.3091 \mathrm{D}, 1.3133 \mathrm{~F}, n_{\mathrm{E}}=1.3086 \mathrm{C}$, $1.3104 \mathrm{D}, 1.3147 \mathrm{~F}, n_{\mathrm{E}}-n_{\mathrm{O}}=0.0014 \mathrm{~F}$. (data for $-3^{\circ} \mathrm{C}$.). Under varying high pressures six other crystal phases of $\mathrm{H}_{2} \mathrm{O}$ are known; one is isometric ( $a=6.36$; stable at $100^{\circ} \mathrm{C}$.), one tetragonal, and a third orthorhombic. Optic data are lacking. Colorless (to pale blue in mass).

## 2. Formula Type $A X$

$\mathbf{M g O}$ (Periclase) is isometric with the NaCl space lattice. $a=4.203 k X$. U.C. 4. Crystals cubic or octahedral with perfect cubic and poor octahedral cleavages. H. 5.5. G. 3.56. M.P. $2800^{\circ}$ C. Isotropic with ${ }^{4} n=1.7335$ C, $1.7366 \mathrm{D}, 1.7475 \mathrm{~F}$. Colorless, made from fusion. It forms a complete series of mix-crystals with FeO , NiO or CoO ; with 25 per cent FeO the color is yellow; with 50 per cent it is brown. PD 2.11, 1.49, 1.22; 4-0829.

CaO (Lime) is isometric with the NaCl space lattice. $a=4.797 \mathrm{kX}$. Crystals cubic with perfect cubic cleavage. H. 3.5. G. 3.32. M.P. $2570^{\circ}$ C. Soluble in acid. Hydrates easily. Isotropic ${ }^{5}$ with $n=1.833 \mathrm{C}, 1.837 \mathrm{D}$, 1.846 (530). Reversible inversion at about $420^{\circ}$ C., both phases being isotropic. Colorless. PD 2.41, 1.70, 2.78; 4-0777.

MnO (Manganosite) is isometric with $a=4.436 \mathrm{kX}$. U.C. 4. Crystals often octahedral with fair cubic cleavage. H. 5.5. G. 5.36. Isotropic with ${ }^{6}$ $n=2.16$ (red), 2.19 (green). Again: ${ }^{7} n=2.23$. Color emerald green on fresh fracture, becoming black on exposure. Streak brown. Made from fusion. PD 2.99, 3.69, 2.41; 7-58.
$\mathbf{F e O}$ (Wuistite) is isometric with the NaCl space lattice. $a=4.29 \mathrm{kX}$.

[^36]U.C. 4. G. 5.5. M.P. $1370^{\circ}$ C. Isotropic with ${ }^{8} n=2.32$. Color black, nearly opaque. Forms a complete series of mix-crystals with MgO , having rectilinear variation of the refractive index. Thus, with $\mathrm{MgO}: \mathrm{FeO}=33: 67$, $n=2.12$ and with $\mathrm{MgO}: \mathrm{FeO}=64: 36, n=1.95$, and in general, $n=$ $1.737+0.583 x$ where $x=$ atomic proportion $\mathrm{Fe} /(\mathrm{Mg}+\mathrm{Fe})$. PD 2.15, 2.49, 1.52; 6-0615.
$\mathbf{N i O}$ (Bunsenite) is isometric with the NaCl space lattice. $a=4.171 \mathrm{kX}$. U.C. 4. Crystals often octahedral. H. 3.5. G. 6.8. F. 7. Isotropic with ${ }^{9}$ $n=2.27 \mathrm{Li}$. Color deep green or brownish black. Found in slags. PD 2.09, 2.41, 1.48; 4-0835.

SrO is isometric with the NaCl space lattice. $a=5.144 k X$. Crystals cubic with perfect cubic cleavage. G. 4.75 . Isotropic with ${ }^{10} n=1.856 \mathrm{C}$, 1.870 D, 1.880 (535). Colorless. Forms mix-crystals with CaO. PD 2.58, 2.98, 1.83; 6-0520.
$\mathbf{C d O}$ is isometric with the NaCl space lattice. $a=4.689 \mathrm{kX}$. U.C. 4 . Crystals octahedral or cubic with $\{111\}$ (?) cleavage. H. 3. G. 8.15. Isotropic with ${ }^{9} n=2.49 \mathrm{Li}$. Color brown or red to black. PD 2.71, 2.35, 1.66; 5-0640. Found in the muffles of zinc ovens.
$\mathbf{B a O}$ is isometric with the NaCl space lattice. Crystals cubic with perfect cubic cleavage. $a=5.523 k X$. G. 5.72. Isotropic with ${ }^{10} n=1.958 \mathrm{C}$, $1.980 \mathrm{Na}, 2.002$ (520). Again: ${ }^{10 \mathrm{a}} n=2.16 \pm 0.05$. Colorless. PD 3.20, 2.75, 1.95 ; 1-0746.

BeO (Bromellite) is hexagonal ${ }^{11}$ with $a=2.68, c=4.36 k X$. U.C. 2. Crystals prismatic with distinct $\{10 \overline{1} 0\}$ cleavage. H. 9. G. 3.02. Uniaxial positive with $n_{\mathrm{O}}=1.719, n_{\mathrm{E}}=1.733, n_{\mathrm{E}}-n_{\mathrm{O}}=0.014$. Color white. PD 2.36, 2.34, 2.19; 4-0843. Made by sublimation.

ZnO (Zincite) is hexagonal with $a=3.242, c=5.176 k X$. U.C. 2. Perfect $\{10 \overline{1} 0\}$ cleavage; basal parting. H. 4. G. 5.66. M.P. $1670^{\circ}$ C. Soluble in HCl. Uniaxial positive with ${ }^{12} n_{\mathrm{O}}=1.990 \mathrm{Li}, 2.013 \mathrm{Na}, 2.056$ (530); $n_{\mathrm{E}}=2.005 \mathrm{Li}, 2.029 \mathrm{Na}, 2.056$ (530); $n_{\mathrm{E}}-n_{\mathrm{O}}=0.016 \mathrm{Na}$ (natural zincite, $99.63 \% \mathrm{ZnO}$ ). Colorless to deep red. Not pleochroic. Commonly fluorescent in ultraviolet light. A common furnace product. PD 2.48, 2.82, 2.60; 5-0664.

HgO (Montroydite) is orthorhombic with $a=3.513, b=5.504, c=$ $3.296 k X$. Crystals long prismatic or equant or varied. Perfect $\{010\}$

[^37]cleavage. H. 2.5. G. 11.2. $\mathrm{X}=a(?), \mathrm{Z}=c .(+) 2 \mathrm{~V}=$ large. ${ }^{13} n_{\mathrm{X}}=2.37$ $\pm 0.02, n_{\mathrm{Y}}=2.5, n_{\mathrm{Z}}=2.65 \pm 0.02, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.28 \pm 0.04 \mathrm{Li}$. Color deep red; streak yellow-brown; in section orange-red to pale yellow. Made by heating mercury in air. PD 2.87, 2.83, 2.41; 9-381.

PbO (Litharge) is tetragonal with $a=3.986, c=5.011 k X$. U.C. 2. Crystals basal tablets with perfect $\{110\}$ cleavage. H. 2. G. 9.13. F. 1.5. Soluble in $\mathrm{HNO}_{3}$. Uniaxial negative with ${ }^{14} n_{\mathrm{O}}=2.665, n_{\mathrm{E}}=2.535$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.13 \mathrm{Li}$. Color red; light orange red in section. PD 3.12, 2.81, $1.87 ; 5-0561$. Artificial "red lead" is commonly a mixture of litharge and massicot.

PbO (Massicot) is orthorhombic with ${ }^{15} a=5.476, b=5.876, c=$ $4.743 k X$. U.C. 4. Perfect $\{100\}$ cleavage. H. 2. G. 9.56. F. 1.5. Soluble in $\mathrm{HNO}_{3} . \mathrm{Y}=a(?) .2 \mathrm{~V}$ near $90^{\circ}$ with strong dispersion ${ }^{12}$ ( + for red, - for blue). $n_{\mathrm{X}}=2.51, n_{\mathrm{Y}}=2.61, n_{\mathrm{Z}}=2.71, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.20 \mathrm{Li}$. Color yellow with X (or Y ?) light sulfur-yellow, Z deep yellow. A furnace product. PD 3.07, 2.95, 2.74; 5-0570.

CuO (Tenorite) is monoclinic with $a=4.653, b=3.410, c=5.108 \mathrm{kX}$, $\beta=99^{\circ} 32^{\prime}$. U.C. 4. Crystals lath-shaped or basal plates; often twinned; $\{001\}$ and $\{111\}$ cleavages. H. 3.5. G. 6.45. F. 3. Soluble in HCl. $\mathrm{Y}=b$; Z near $c .\left(-\right.$ ?) $2 \mathrm{~V}=$ large, ${ }^{16} n_{\mathrm{Y}}=2.63$ (red), 2.84 (white), 3.18 (blue), $n_{\mathrm{Z}}-n_{\mathrm{X}}=$ strong. Color and streak iron gray to black. Absorption very strong ( $\mathrm{Y}<\mathrm{Z}$ ) and Y light brown, Z nearly opaque brown. Made by heating CuCl in oxygen. PD 2.52, 2.32, 2.53; 5-0661.

## 3. Formula Type $A_{2} X_{3}$

$\mathbf{B}_{2} \mathbf{O}_{3}$ is isometric. ${ }^{17}$ G. 1.805. M.P. $294^{\circ} \mathrm{C}$. Isotropic with $n=1.458$. Like ice in contracting on melting; the glass has G. 1.844 and $n=1.464$. Colorless. Obtained by dehydrating $\mathrm{H}_{3} \mathrm{BO}_{3}$ in a vacuum. $\mathrm{B}_{2} \mathrm{O}_{3}$ also has a hexagonal phase ${ }^{18}$ with $a=4.33, c=8.39 \AA$. G. 2.46. Uniaxial negative with $n_{\mathrm{O}}=1.648, n_{\mathrm{E}}=1.615, n_{\mathrm{O}}-n_{\mathrm{E}}=0.033$. PD 2.10, 2.78, 2.23; 6-0634*.
$\mathbf{Y}_{2} \mathbf{O}_{3}$ is isometric; crystals are rectilinear plates. Isotropic with ${ }^{19} n=$ $1.910 \pm 0.002$. Very hygroscopic. PD 3.06, 1.87, 1.60; 5-0574.
$\mathrm{Al}_{2} \mathrm{O}_{3}$ has three or more crystal phases.
$\boldsymbol{\alpha}-\mathrm{Al}_{2} \mathrm{O}_{3}$ (Corundum) is hexagonal scalenohedral with $a=4.751, c=$ 12.97 kX . Crystals basal plates limited by the rhombohedron or varied.
${ }^{13}$ Larsen: U. S. Geol. Surv. Bull. 679 (1921).
${ }^{14}$ Larsen and Berman: U. S. Geol. Surv. Bull. 848 (1934).
${ }^{15} a b c$ changed to $a c b$ to make $b>a$ with $c$ as the polar axis.
${ }^{16}$ Tunell, Posnjak and Ksanda: Zeit. Krist. XC, p. 120 (1935).
${ }^{17}$ Cole: J. Am. Cer. Soc. XVIII, p. 55 (1935).
${ }^{18}$ Hendricks: J. Wash. Acad. Sci. XXXIV, p. 241 (1944).
${ }^{19}$ Yoder and Keith: Am. Min. XXXVI, p. 519 (1951).

No cleavage, but may have basal parting. H. 9. G. 4. M.P. $2050^{\circ}$ C. Insoluble in acids. Uniaxial negative with ${ }^{20} n_{\mathrm{O}}=1.7653 \mathrm{C}, 1.7686 \mathrm{D}$, $1.7760 \mathrm{~F}, n_{\mathrm{E}}=1.7573 \mathrm{C}, 1.7604 \mathrm{D}, 1.7677 \mathrm{~F}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0082 \mathrm{D}$. Colorless or blue (sapphire), red (ruby) or black (emery). Asterism rather rare, due to oriented needles (of rutile?). Deeply colored crystals are pleochroic with $\mathrm{O}>\mathrm{E}$ and O blue, E emerald green to yellow-green in sapphire and O deep purple, E light yellow in ruby. Ruby is colored by chromium; sapphire by Co and Ti. Corundum is made by melting bauxite. PD 2.09, 2.55, 1.60; 10-173.
$\boldsymbol{\beta}-\mathrm{Al}_{2} \mathbf{O}_{3}$ is hexagonal in triangular or hexagonal plates with perfect basal cleavage. G. 3.31. Uniaxial negative with ${ }^{21} n_{\mathrm{O}}=1.665-1.680, n_{\mathrm{E}}=$ $1.63-1.65, n_{\mathrm{O}}-n_{\mathrm{E}}=0.023-0.045$. Colorless. $\beta-\mathrm{Al}_{2} \mathrm{O}_{3}$ is unstable (or metastable?) unless it contains a little $\mathrm{Na}_{2} \mathrm{O}$; perhaps it is really $\mathrm{Na}_{2} \mathrm{Al}_{22} \mathrm{O}_{34}$. Found in reaction layers of ceramic refractories. PD 1.40, 11.9, 2.68; 10-414.
$\gamma-\mathrm{Al}_{2} \mathrm{O}_{3}$ is isometric ${ }^{22}$ with G. 3.47 and $n=1.696$. It is unstable at ordinary temperatures. PD $1.98,1.40,2.39 ; 10-425$. "Amorphous" $\mathrm{Al}_{2} \mathrm{O}_{3}$ has G. $1.65-1.69$ and $n=1.68$. Colorless.
$\mathbf{C r}_{2} \mathbf{O}_{3}$ is hexagonal scalenohedral with ${ }^{23} a=4.95, c=13.57 \AA . \mathrm{G} .5 .2$. Crystals equant prismatic to basal tablets. Twinning common, often on $\{0001\}$. Distinct rhombohedral cleavage. Uniaxial positive ${ }^{12}$ with $n=$ $2.5 \pm \mathrm{Li}$. Green in thin plates. PD 2.67, 2.48, 1.67; 6-0504*. Miscible in all proportions with $\mathrm{Fe}_{2} \mathrm{O}_{3}$. Found in refractory mixes.
$\boldsymbol{\alpha}-\mathrm{Fe}_{2} \mathrm{O}_{3}$ (Hematite) is hexagonal scalenohedral with $a=5.029, c=$ $13.73 k X$. Crystals rhombohedral or basal plates. May have basal parting. H. 5. G. 5.2. M.P. $1350^{\circ}$ C. Soluble in HCl. Uniaxial negative with ${ }^{24}$ $n_{\mathrm{O}}>2.95 \mathrm{Li}, n_{\mathrm{E}}=2.74, n_{\mathrm{O}}-n_{\mathrm{E}}=0.21+$. Also ${ }^{12} n_{\mathrm{O}}=3.01 \mathrm{Li}, n_{\mathrm{E}}=$ $2.78, n_{\mathrm{O}}-n_{\mathrm{E}}=0.23$. Hematite is steel gray to iron black in crystals; deep red in mass; opaque except in thin flakes which are blood-red with O brownish red, E yellowish red. PD 2.69, 2.51, 1.61; 6-0502. Made by sublimation and by fusion. $\mathrm{Fe}_{2} \mathrm{O}_{3}$ inverts promptly at $678^{\circ} \mathrm{C}$. and is said to invert also at $-40^{\circ} \mathrm{C}$., but optic data on these forms are lacking. It is miscible in all proportions with $\mathrm{Cr}_{2} \mathrm{O}_{3} . \mathrm{Al}_{2} \mathrm{O}_{3}$ can dissolve in $\mathrm{Fe}_{2} \mathrm{O}_{3}$ up to about 12 per cent, but very little $\mathrm{Fe}_{2} \mathrm{O}_{3}$ can enter $\mathrm{Al}_{2} \mathrm{O}_{3}$. By partial deoxidation ( 17.8 per cent FeO ) $n_{\mathrm{E}}=2.71$ and (with 16.1 FeO ) $n_{\mathrm{O}}-$ $n_{\mathrm{E}}=0.16+$. Partially hydrated $\mathrm{Fe}_{2} \mathrm{O}_{3}$, called hydrohematite or turgite,

[^38]is often fibrous; it may have G. 4.5-5 and $n_{\mathrm{O}}=2.5-2.7, n_{\mathrm{E}}=2.3-2.6$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.1-0.2$.
$\mathrm{Sb}_{2} \mathrm{O}_{3}$ has two crystal phases.
$\boldsymbol{\alpha}-\mathrm{Sb}_{2} \mathbf{O}_{3}$ (Senarmontite) is isometric with $a=11.14 k X$. U.C. 16. Crystals octahedral with poor octahedral cleavage. H. 2-2.5. G. 5.5. Isotropic with ${ }^{25} n=2.073 \mathrm{Li}, 2.087 \mathrm{Na}$. Often shows strong anomalous birefringence usually in zones or segments. Colorless or grayish white. PD 3.22, 1.97, 2.79; 5-0534. Made from fusion below $570^{\circ} \mathrm{C}$.
$\boldsymbol{\beta}-\mathbf{S b}_{2} \mathbf{O}_{3}$ (Valentinite) is orthorhombic with $a: b: c=0.394: 1: 0.434$. Crystals prismatic or tabular, often in stellate groups. Perfect prismatic $\{110\}$ and poor $\{010\}$ cleavages. H. 2.5-3. G. 5.76. $\mathrm{X}=a, \mathrm{Y}=c$ and $\mathrm{Z}=b$ for red light; $\mathrm{X}=a, \mathrm{Y}=b, \mathrm{Z}=c$ for green light. ( - ) $2 \mathrm{~V}=$ very small, ${ }^{25}$ about $0^{\circ}$ for yellow, $\mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=2.18, n_{\mathrm{Y}}=2.35, n_{\mathrm{Z}}=2.35$, $n_{\mathrm{Z}}-n_{\mathrm{Y}}=0.17$. Colorless to white or stained. PD 3.14, 1.80, 4.59; 3-0530. Formed by sublimation or quenching melts heated above $570^{\circ} \mathrm{C}$. Valentinite is the stable phase at lower temperatures.
$\boldsymbol{\alpha}-\mathrm{As}_{2} \mathbf{O}_{3}$ (Claudetite) is monoclinic with $a: b: c=0.409: 1: 0.349 . \beta=$ $94^{\circ} 20^{\prime}$. Crystals $\{010\}$ plates resembling gypsum. Perfect $\{010\}$ cleavage. Flexible. H. 2.5. G. 4.15. $\mathrm{Y}=b,{ }^{25} \mathrm{Z} \wedge c=6^{\circ} c a$. $(+) 2 \mathrm{~V}=58^{\circ}$ calc., $\mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.87, n_{\mathrm{Y}}=1.92, n_{\mathrm{Z}}=2.01, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.14$. Colorless to white. It is the stable phase at an unknown temperature above $100^{\circ} \mathrm{C}$.
$\boldsymbol{\beta}-\mathbf{A s}_{2} \mathbf{O}_{3}$ (Arsenolite) is isometric with $a=11.05 \mathrm{kX}$. U.C. 16. Crystals octahedral with perfect octahedral cleavage. H. 1.5. G. 3.87. Isometric with $^{25} n=1.748 \mathrm{Li}, 1.755 \mathrm{Na}$. May show anomalous birefringence. Color white or stained. PD 3.20, 6.39, 2.54; 4-0566. Made by sublimation below about $200^{\circ} \mathrm{C}$.
$\mathrm{Bi}_{2} \mathrm{O}_{3}$ has four crystal phases.
$\gamma-\mathrm{Bi}_{2} \mathrm{O}_{3}$ (Sillenite) is isometric with $a=10.08 \mathrm{kX}$. Massive. Soft. G. 8.8. Isotropic with ${ }^{26} n>2.42$. Color olive drab to green. Transparent in thin flakes. PD 3.22, 1.74, 2.73; 6-0312.
$\alpha-\mathrm{Bi}_{2} \mathbf{O}_{3}$ (Bismite) is monoclinic with $a=5.83, b=8.14, c=7.48, \beta=$ $112^{\circ} 56^{\prime}$. U.C. 4. Massive. H. 4.5. G. $9.2+$. M.P. $860^{\circ}$ C. Biaxial with strong dispersion and indices above 2.43. Color grayish green to bright yellow. Transparent in very thin fragments. PD 3.23, 2.68, 1.67; 6-0307.

Two other phases of $\mathrm{Bi}_{2} \mathrm{O}_{3}$ are known, but optic data are not available.

## 4. Formula Type $\mathrm{AX}_{\mathbf{2}}$

$\mathbf{U O _ { 2 }}$ (Uraninite) is isometric with $a=5.47 \AA$. Crystals octahedral or cubic; rarely dodecahedral; usually massive. Fracture uneven to conchoidal. H. 5-6. G. 10.95 (artif). In nature the mineral commonly oxidizes, usually

[^39]to about $\mathrm{U}_{3} \mathrm{O}_{8}$; this decreases the specific gravity to about $8-10$; often altered to an amorphous "metamict" state (pitchblende) with about $2-5 \mathrm{H}_{2} \mathrm{O}$ and G. about 6-8. F. $=7$. Soluble in $\mathrm{HNO}_{3}$. Not magnetic. Usually opaque; otherwise dark green, yellowish or dark brown. Streak brownish black, gray or olive green. In polished sections light gray with a brownish tint. Reflection percentages: red 12.5, orange 12.5, green 15. PD 3.16, 1.93, 2.74; 5-0550. Made by fusion of uranium oxide in borax ${ }^{26 a}$ and in other ways.
$\mathbf{T h O}_{2}$ (Thorianite) is isometric with $a=5.61 k X$. U.C. 4. Crystals often cubic with poor cubic cleavage. H. 6.5. G. 9.7. M.P. $3050^{\circ} \mathrm{C}$. Isotropic with a variable index, averaging ${ }^{13} n=2.20$. Color dark gray to black; reddish brown in thin splinters. PD 3.23, 1.69, 1.98; 4-0556. Forms a complete series of mix-crystals with $\mathrm{UO}_{2}$. Strongly radioactive. Made by fusion in borax.
$\mathrm{TiO}_{2}$ has three crystal phases, rutile, anatase and brookite.
$\boldsymbol{\alpha}-\mathbf{T i O}_{2}$ (Rutile) is tetragonal with $a=4.58, c=2.95$. U.C. 2. Crystals prismatic, often acicular; vertically striated. Twinning common on $\{011\}$ or varied. Distinct $\{110\}$ and poor $\{100\}$ cleavages. H. 6-6.5. G. 4.23. M.P. $1825^{\circ}$ C. Uniaxial positive with ${ }^{27} n_{\mathrm{O}}=2.6505$ (546), 2.6211 (579), 2.5890 (623), 2.5555 (691), $n_{\mathrm{E}}=2.9467$ (546), 2.9085 (579), 2.8712 (623), 2.8294 (691), $n_{\mathrm{E}}-n_{\mathrm{O}}=0.2874$ (579). The indices vary also with change of temperature, as follows: at $25^{\circ}$ C. $n_{\mathrm{O}}=2.6124, n_{\mathrm{E}}=2.8993, n_{\mathrm{E}}-n_{\mathrm{O}}=$ 0.2869 ; at $110^{\circ} \mathrm{C} . n_{\mathrm{O}}=2.6087, n_{\mathrm{E}}=2.8920, n_{\mathrm{E}}-n_{\mathrm{O}}=0.2833$; at $300^{\circ} \mathrm{C}$. $n_{\mathrm{O}}=2.5992, n_{\mathrm{E}}=2.8770, n_{\mathrm{E}}-n_{\mathrm{O}}=0.2778$. Color usually brown or red, but colorless in thin flakes. Colored crystals pleochroic with $0<\mathrm{E}$. PD $3.25,1.69,2.49 ; 4-0551^{*}$.
$\boldsymbol{\beta} \mathbf{- T i O}_{2}$ (Anatase or Octahedrite) is tetragonal with $a=3.73, c=$ 9.37 kX . U.C. 4. Crystals pyramidal or rarely tabular $\{001\}$. Perfect basal and $\{011\}$ cleavages. H. 5.5-6. G. 3.90. Uniaxial negative with ${ }^{27} n_{\mathrm{O}}=$ $2.5612, n_{\mathrm{E}}=2.4880, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0732$ at $25^{\circ} \mathrm{C} . \mathrm{Na} ; n_{\mathrm{O}}=2.5580, n_{\mathrm{E}}=$ $2.4872, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0708$ at $150^{\circ} \mathrm{C}$. Na and $n_{\mathrm{O}}=2.5520, n_{\mathrm{E}}=2.4853$, $n_{\mathrm{o}}-n_{\mathrm{E}}=0.0667$ at $450^{\circ} \mathrm{C}$. Na. Often biaxial with small 2 V (due to strain?). Color variable, but often brown (or yellow, blue or green); pleochroism usually weak and may be either $\mathrm{O}<\mathrm{E}$ or $\mathrm{O}>\mathrm{E}$. PD 3.51, 1.89, 2.38; 4-0477*. Made by reaction of $\mathrm{TiCl}_{4}$ or $\mathrm{TiF}_{4}$ with $\mathrm{H}_{2} \mathrm{O}$ vapor below $760^{\circ} \mathrm{C}$.

The $\gamma$-phase (brookite), to be described later, is orthorhombic.
$\mathbf{S n O}_{2}$ (Cassiterite) is tetragonal with $a=4.72, c=3.17 k X$. U.C. 2. Crystals short prismatic, pyramidal, or long prismatic. Common $\{011\}$ twinning. Poor $\{100\}$ cleavage. H. 6-7. G. 6.99. Uniaxial positive with ${ }^{28}$ ${ }^{26 a}$ Hillebrand: U. S. Geol. Surv. Bull. 113, p. 37 and 41 (1893).
${ }^{27}$ Schröder: Zeit. Krist. LXVII, p. 485 (1928).
${ }^{28}$ Ecklebe: N. Jahrb. Min. Bl. Bd. LXVI, p._ 47 (1932).
$n_{\mathrm{O}}=2.0239, n_{\mathrm{E}}=2.1188, n_{\mathrm{E}}-n_{\mathrm{O}}=0.0949$ for $\lambda=496 ; n_{\mathrm{O}}=2.0006$,
$n_{\mathrm{E}}=2.0972, n_{\mathrm{E}}-n_{\mathrm{O}}=0.0966$ for $\lambda=585 ; n_{\mathrm{O}}=1.9899, n_{\mathrm{E}}=2.0874$,
$n_{\mathrm{E}}-n_{\mathrm{O}}=0.0975$ for $\lambda=653$. Also: $n_{\mathrm{O}}=2.0007, n_{\mathrm{E}}=2.0980, n_{\mathrm{E}}-n_{\mathrm{O}}$
$=0.0973$ at $16^{\circ} \mathrm{C}$. for $\lambda=578$, and $n_{\mathrm{O}}=2.0409, n_{\mathrm{E}}=2.1275, n_{\mathrm{E}}-n_{\mathrm{O}}=$
0.0866 at $535^{\circ} \mathrm{C}$. Color of crystals yellow to brown; rarely red, gray or white; color in section colorless to brown; less commonly red or green. Absorption $\mathrm{O}<\mathrm{E} . \mathrm{PD} 3.35,2.64,1.77$; 5-0467. Made from fusion.
$\mathbf{P b O}_{2}$ (Plattnerite) is tetragonal with $a=4.931, c=3.367$. U.C. 2. Crystals prismatic; often dense or fibrous. No cleavage. H. 5.5. G. 8.9-9.36. Decomposes at $290^{\circ} \mathrm{C}$. Uniaxial negative with ${ }^{13} n_{\mathrm{o}}=2.30 \pm .05 \mathrm{Li}$; weak birefringence. Color jet black. In transmitted light cloudy and nearly opaque. Basal sections may show six biaxial segments. When made by fusion of lead oxide in potash the color is dark brown. PD 3.50, 2.80, 1.86; $8-185$. Made by fusing PBO in KOH .
$\mathrm{SeO}_{2}$ is tetragonal or hexagonal when crystallized in selenium. G. 3.96. Acicular. Uniaxial positive: ${ }^{29} n>1.76, n_{\mathrm{E}}-n_{\mathrm{O}}=$ strong. PD 3.73, 3.01, 4.17; 4-0429. Another phase is monoclinic.
$\mathbf{G e O}_{2}$ is tetragonal with ${ }^{30} a=4.395, c=2.852 k X$. U.C. 2 . Crystals short prisms. Insoluble. G. 6.24. Uniaxial positive with $n_{\mathrm{O}}=1.99, n_{\mathrm{E}}=2.05-$ 2.10 (est.), $n_{\mathrm{E}}-n_{\mathrm{O}}=0.006-0.011$ (est.). Colorless. PD 3.11, 2.40, 1.62; $9-379^{*}$. Another phase is hexagonal ${ }^{31}$ with $a=4.972, c=5.648 k X$. Crystals rhombohedrons resembling cubes. G. 4.28. Soluble. Uniaxial positive with $n_{\mathrm{O}}=1.695, n_{\mathrm{E}}=1.735, n_{\mathrm{E}}-n_{\mathrm{O}}=0.040$. When fused to glass ${ }^{31 \mathrm{a}}$ it has G. 3.638, H. $4.5-5$ and $n=1.603 \mathrm{C} ; 1.607 \mathrm{D}, 1.6176$ F. Colorless. PD $3.43,2.37,4.32$; 4-0497/8* (which polymorph?).
$\mathbf{S i O}_{2}$ (Quartz, etc.) has surprisingly many crystal phases. The hightemperature phase ( $\boldsymbol{\beta}$-cristobalite) is isometric; crystals octahedral or cubic or skeletal with common twinning on \{111\}. H. 6-7. G. 2.27-2.35. M.P. $1710^{\circ} \mathrm{C}$. Insoluble in HCl . Isotropic above $200^{\circ}$ to $275^{\circ} \mathrm{C}$. with $n=$ 1.486. It is stable above $1470^{\circ} \mathrm{C}$. and metastable to about $250^{\circ} \mathrm{C}$. PD 4.15, $2.53,1.64 ; 4-0359^{*}$ (at $500^{\circ} \mathrm{C}$.). If the slow inversion to tridymite does not occur at about $1470^{\circ}$ C., the substance inverts very easily to a tetragonal(?) phase ( $\alpha$-cristobalite) at a temperature between 275 and $200^{\circ} \mathrm{C}$.; low cristobalite is uniaxial negative with $n_{\mathrm{O}}=1.487, n_{\mathrm{E}}=1.484, n_{\mathrm{O}}-n_{\mathrm{E}}=$ 0.003. Complex lamellar twinning is common. Colorless. PD 4.04, 2.49, 2.85; 4-0379*.

The moderate temperature phase of $\mathrm{SiO}_{2}$, called tridymite, is hexagonal above $117^{\circ} \mathrm{C}$. (with $c / a=1.653$ ) and orthorhombic ( $\alpha$-tridymite) below that temperature with $a=9.88, b=17.1, c=16.3 \AA$. U.C. 64 . It is the

[^40]stable phase of $\mathrm{SiO}_{2}$ between $870^{\circ}$ and $1470^{\circ} \mathrm{C}$. It inverts to quartz below $870^{\circ} \mathrm{C}$. and to cristobalite above $1470^{\circ} \mathrm{C}$. but these changes are very sluggish and tridymite may exist for long periods as a metastable form. This has permitted measurement of the melting point $\left(1670^{\circ} \mathrm{C}\right.$.) and the study of the mineral at ordinary temperatures. $\alpha$-Tridymite may invert on heating to a phase called $\beta_{1}$-tridymite at $117^{\circ} \mathrm{C}$. and to another phase called $\beta_{2}$-tridymite at $163^{\circ} \mathrm{C}$. But both these phases are hexagonal and uniaxial, the change at $163^{\circ} \mathrm{C}$. being perhaps from hemihedral to holohedral symmetry. On cooling the inversions show some lag. Crystals of tridymite are usually six-sided basal plates with common wedge-like twinning in sectors (as seen on 001) as in aragonite and cordierite, the optic plane being normal to the external boundary. $\alpha$-Tridymite has indistinct prismatic cleavage and basal parting. H. 7. G. 2.27. $\mathrm{Y}=a, \mathrm{Z}=c .(+) 2 \mathrm{~V}=35^{\circ} . n_{\mathrm{X}}=1.469$, $n_{\mathrm{Y}}=1.469, \quad n_{\mathrm{Z}}=1.473, \quad n_{\mathrm{Z}}-n_{\mathrm{X}}=0.004$. Again: ${ }^{32} \quad(+) 2 \mathrm{~V}=76^{\circ} 15^{\prime}$, $n_{\mathrm{X}}=1.471, n_{\mathrm{Y}}=1.472, n_{\mathrm{Z}}=1.474, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.003$. Also $:^{33} n_{\mathrm{X}}=$ $1.470, n_{\mathrm{Y}}=1.480, n_{\mathrm{Z}}=1.483, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.004$. Colorless. PD 4.30, 4.08, $3.81 ; 3-0227^{*}$. Made from fusion in fluxes. Tridymite seems to vary in composition.

The low-temperature phase of $\mathrm{SiO}_{2}$ is $\alpha$-quartz; it is trigonal trapezohedral with $a=4.903, c=5.393 \AA$. U.C. 3 . Crystals usually short prismatic terminated by two rhombohedrons; often twinned. No cleavage. $H$. 7. G. 2.65. Insoluble in acids except HF. Uniaxial positive with $n_{0}=$ $1.5419 \mathrm{C}, 1.5442 \mathrm{D}, 1.5497 \mathrm{~F}, n_{\mathrm{E}}=1.5509 \mathrm{C}, 1.5533 \mathrm{D}, 1.5590 \mathrm{~F}, n_{\mathrm{E}}-n_{\mathrm{O}}$ $=0.0091$. Composition and indices very constant in natural as well as artificial crystals. Refringence and birefringence decrease very slowly with increase of temperature. PD 3.34, 4.26, 1.82; 5-0490*. At $573^{\circ}$ C. low-temperature $\alpha$-quartz inverts to $\beta$-quartz and this change is revessed ${ }^{34}$ promptly on cooling. $\beta$-quartz is hexagonal trapezohedral with $a=5.01, c=5.47 \AA$. U.C. 3. It has good $\{10 \overline{1} 1\}$ and $\{10 \overline{1} 0\}$ cleavages. At $580^{\circ}$ C. it has $n_{0}=$ $1.5329 \mathrm{D}, n_{\mathrm{E}}=1.5405, n_{\mathrm{E}}-n_{\mathrm{O}}=0.0066$. PD 3.42, 1.85, 1.57; 7-346*. Quartz undergoes a second inversion at $870^{\circ} \mathrm{C}$. to tridymite, which inverts at $1470^{\circ} \mathrm{C}$. to cristobalite, but these changes are very sluggish.
$\mathbf{S i O}_{2}$ (Keatite or Silica K) has been made ${ }^{35}$ at $380-585^{\circ}$ C. and 500018000 pounds per square inch water-vapor pressure. It is tetragonal with $a=7.46, c=8.59 \AA$ Å. U.C. 12. G. 2.50. Uniaxial negative with $n_{\mathrm{O}}=1.522$, $n_{\mathrm{E}}=1.513, n_{\mathrm{O}}-n_{\mathrm{E}}=0.009$. Stable to $1100^{\circ} \mathrm{C}$.
$\mathbf{S i O}_{2}$ (Coesite or silica $\mathbf{C}$ ) has been crystallized from a mixture of equal parts of $\mathrm{Na}_{2} \mathrm{SiO}_{3}$ and $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{HPO}_{4}$ at $500-800^{\circ} \mathrm{C}$. and 35000 atmospheres. ${ }^{36}$
${ }^{32}$ Heide: Cent. Min. 1823, p. 69.
${ }^{33}$ Barth and Kvalhein: Norsk Videns. Akad. Oslo, XXII p. 1 (1944).
${ }^{34}$ Wyckoff: Am. J. Sci. CCXI, p. 101 (1926).
${ }^{35}$ Keat: Science, CXX, p. 328 (1954).
${ }^{36}$ Coes: Science, CXVIII, p. 131 (1953).

It is monoclinic ${ }^{36 \mathrm{a}}$ with $a=7.23, b=12.52, c=7.23 \AA, \beta=120^{\circ}$. U.C. 17. H. 8. G. 3.01. Insoluble in HF, but dissolved in fused $\left(\mathrm{NH}_{4}\right) \mathrm{HF}_{2}$. Changes to silica glass and cristobalite at $1700^{\circ} \mathrm{C}$. Biaxial with oblique extinction in the common six-sided plates. $(+) 2 \mathrm{~V}=54^{\circ} . n_{\mathrm{x}}=1.599$ (calc.)? $n_{\mathrm{Z}}=1.604, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.014$ ( $n_{\mathrm{Y}}=1.593$, calc. from these data). PD 3.09, 3.43, 6.20; 8-18*. Pseudo-tetragonal twins ${ }^{36 \mathrm{a}}$ on $\{021\}$.
$\mathrm{SiO}_{2}$ glass has G. 2.19 and $n=1.4588$. The natural substance, called lechatelierite is produced when lightning strikes quartz sand and fuses tiny tubes (fulgurites) in it.

A fibrous variety of $\mathrm{SiO}_{2}$ called Chalcedony, has the same crystal structure as quartz, ${ }^{37}$ but has H. 6 and G. 2.55-3.63, apparently with $n_{0}=$ $1.537(1.533-1.539), n_{\mathrm{E}}=1.530, n_{\mathrm{O}}-n_{\mathrm{E}}=0.007$, but the sign is uncertain and the substance may be biaxial, since the fibers in some cases seem to have $\pm$ elongation, parallel to Y or extinction at $29^{\circ}$.
$\mathbf{T e} \mathbf{O}_{2}$ (Tellurite) is orthorhombic with $a=5.50, b=11.75, c=5.59 \AA$. U.C. 8. H. 2. G. 5.91. $\mathrm{X}=b, \mathrm{Y}=a$. (-) $2 \mathrm{~V}=$ large. $n_{\mathrm{X}}=2.00 \mathrm{Li}, n_{\mathrm{Y}}=$ $2.18, n_{\mathrm{Z}}=2.35, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.35$. Color white. Made from fusion. Another phase is tetragonal. PD 3.28, 3.72, 3.01; 9-433*.
$\gamma-\mathbf{T i O}_{2}$ (Brookite) is orthorhombic with $a=5.436, b=9.166, c=$ $5.135 k X$. U.C. 8. Crystals $\{010\}$ platelets or prismatic; rarely pyramidal. Poor $\{120\}$ cleavage. H. 5.5-6. G. $4.14 \pm .06$. Very high refringence and birefringence and also extraordinary dispersion of the optic axes so that the optic plane is (001) for red and yellow light ${ }^{38}$ (with $\mathrm{r}<\mathrm{v}$ ) and (100) for green and blue light (with $\mathrm{r}>\mathrm{v}$ ); the optic angle is $0^{\circ}$ at about $\lambda=555$ at $25^{\circ} \mathrm{C} . \mathrm{Z}=b$ in all cases. Brookite shows abnormal interference colors and no good extinction.
$\mathrm{At}^{27} 25^{\circ}$ C. $n_{\mathrm{X}}=2.5831, n_{\mathrm{Y}}=2.5843, n_{\mathrm{Z}}=2.7004, n_{\mathrm{Z}}-n_{\mathrm{Y}}=0.1173 \mathrm{Na}$.
At $300^{\circ}$ C. $n_{\mathrm{X}}=2.5880, n_{\mathrm{Y}}=2.5897, n_{\mathrm{Z}}=2.6762, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0882 \mathrm{Na}$.
At $600^{\circ}$ C. $n_{\mathrm{X}}=2.5924, n_{\mathrm{Y}}=2.5981, n_{\mathrm{Z}}=2.6610, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0686 \mathrm{Na}$.

| $\lambda$ | 671.6 | 589 | 579.1 | $555 \pm$ | 546.1 | 491.6 | $n_{\mathrm{F}}-n_{\mathrm{C}}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $(+) 2 \mathrm{E}$ | $58^{\circ} 7^{\prime}$ |  | $25^{\circ} 48^{\prime}$ | $0^{\circ}$ |  | $68^{\circ} 16^{\prime}$ |  |
| $n_{\mathrm{X}}$ | 2.5405 | 2.5831 | 2.5895 |  | 2.6154 | 2.6717 | 0.1341 |
| $n_{\mathrm{Y}}$ | 2.5443 | 2.5843 | 2.5904 |  | 2.6159 | 2.6770 | 0.1373 |
| $n_{\mathrm{Z}}$ | 2.6519 | 2.7004 | 2.7091 |  | 2.7402 | 2.8090 | 0.1623 |
| $n_{\mathrm{Z}}-n_{\mathrm{X}}$ | 0.1114 | 0.1173 | 0.1196 |  | 0.1248 | 0.1373 | 0.0282 |

Color brown, yellowish, reddish, black. In section weakly pleochroic in

[^41]yellow or brown tints; for example: X and Y orange, Z lemon yellow or X cinnamon brown, Y and Z clove brown. PD 3.47, 2.90, 1.38; 3-0380*. Brookite inverts to rutile at about $700^{\circ} \mathrm{C}$. Another phase is anatase. Both of these other phases have already been discussed.
$\mathbf{Z r O}_{2}$ (Baddeleyite) is monoclinic with $a=5.21, b=5.26, c=$ 5.575 kX . $\beta=99^{\circ} 7^{\prime}$. Crystals varied, often twinned. Good basal and poor $\{010\}$ and $\{110\}$ cleavages. H. 6.5. G. $5.6 \pm$. M.P. $2700^{\circ} \mathrm{C} . \mathrm{X} \wedge c=13^{\circ}$, $\mathrm{Y}=b .(-) 2 \mathrm{~V}=30^{\circ}, \mathrm{r}>\mathrm{v} . n_{\mathrm{X}}=2.13, n_{\mathrm{Y}}=2.19, n_{\mathrm{Z}}=2.20, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.07 . Colorless to brown with X yellow, brown or green, Y oil green or reddish brown, Z brown. PD 3.16, 2.84, 2.62; 7-343. Made from fusion of $\mathrm{ZrO}_{2}$ in borax. It inverts to a tetragonal phase at about $1008^{\circ} \mathrm{C}$., and to a hexagonal phase at about $1900^{\circ} \mathrm{C}$.; an isometric phase ${ }_{39}$ has been reported; optic properties unknown.

## 5. Formula Type $A_{2} X_{\overline{5}}$

$\mathbf{P}_{2} \mathbf{O}_{5}$ has at least three crystal phases. ${ }^{39 \mathrm{a}}$ One phase is tetragonal; G. 2.89 $c a$.; uniaxial positive with $n_{\mathrm{O}}=1.599, n_{\mathrm{E}}=1.624, n_{\mathrm{E}}-n_{\mathrm{O}}=0.025$. Colorless. A metastable phase is orthorhombic with a good cleavage parallel with the optic plane and a poor cleavage normal thereto. $(-) 2 \mathrm{~V}=65^{\circ}$. $n_{\mathrm{X}}=1.545, n_{\mathrm{Y}}=1.578, n_{\mathrm{Z}}=1.589, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.044$. Another metastable phase is hexagonal with G. 2.28-2.32. Uniaxial positive with $n_{0}=$ $1.469, n_{\mathrm{E}}=1.471, n_{\mathrm{E}}-n_{\mathrm{O}}=0.002$. PD 5.40, $5.20,3.02 ; 1-0213^{*}$.

## $\beta$. Hydrated

## 1. Formula Type $A X_{\mathbf{2}} \cdot \boldsymbol{n H}_{\mathbf{2}} \mathrm{O}$

$\mathbf{S b}_{2} \mathbf{O}_{4} \cdot n \mathbf{H}_{2} \mathbf{O}$ (or $\mathrm{Sb}_{3} \mathrm{O}_{6}(\mathrm{OH})$ ?) Stibiconite(?) is isometric. Massive or in powder or crusts. H. 4-5.5. G. 5-5.58. Isotropic with a remarkably great range in refractive index, ${ }^{13}$ from $n=1.60$ to 2.00 , perhaps due to variations in content of water. PD $2.96,5.93,1.81 ; 10-388$. Often mixed with birefringent fibrous material, perhaps cervantite. Color pale yellow to yellowish or reddish white. An isometric compound, $\mathrm{Sb}_{3} \mathrm{O}_{6}(\mathrm{OH})$, with $a=10.28 \AA$, has been made by heating antimonic acid.
$\mathbf{2 U O} \mathbf{N}_{2} \cdot \mathbf{7 H _ { 2 }} \mathbf{O}$ (?) (Ianthinite) is orthorhombic with $a: b: c=$ $0.9996: 1: 1.2964$. Crystals basal plates or prismatic along $b$. Perfect $\{001\}$ cleavage. H. $2-3$. G. 4.94. $\mathrm{X}=c ; \mathrm{Y}=b$. (-) $2 \mathrm{~V}=$ small. $n_{\mathrm{X}}=1.674$, $n_{\mathrm{Y}}=1.90, n_{\mathrm{Z}}=1.92, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.246$. Again: ${ }^{40} n_{\mathrm{Y}}=1.88, n_{\mathrm{Z}}=1.91$. Color violet-black (alters on edges to yellow). Pleochroic with X colorless, Y violet, Z dark violet. PD 7.60, 3.79, 3.59; 8-307*. [Composition quite
${ }^{39}$ Bauer: N. Jahrb. Min. Bl. Bd. LXXV, p. 159 (1939).
${ }^{39 a}$ Hill, Faust and Reynolds: Am. J. Sci. CCXLII, p. 542 (1944).
${ }^{40}$ Branche, Chervet and Guillemin: Bull. Soc. Fr. Min. LXXIV, p. 457 (1951).
uncertain-another analysis leads to the formula ${ }^{41} 3 \mathrm{CaO} \cdot 2 \mathrm{CO}_{2} \cdot 7\left(\mathrm{UO}_{2.83}\right)$ - $10 \mathrm{H}_{2} \mathrm{O}$.]

## 2. Formula Type $A X_{3} \cdot \mathbf{n H}_{2} \mathrm{O}$

$4 \mathrm{UO}_{3} \cdot \mathbf{5 H}_{2} \mathrm{O}$ is orthorhombic. ${ }^{41}$ Perfect $\{001\}$, good $\{010\}$ and poor $\{100\}$ cleavages. $\mathrm{H} .3-4 . \mathrm{Y}=b ; \mathrm{Z}=c .(-) 2 \mathrm{~V}=48^{\circ}, n_{\mathrm{X}}=1.79$ calc., $n_{\mathrm{Y}}=1.89$, $n_{\mathrm{Z}}=1.91, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.12$. Strong pleochroism.
$4 \mathrm{UO}_{3} \cdot 9 \mathrm{H}_{2} \mathrm{O}$ (Schoepite) is orthorhombic with $a=14.40, b=16.89$, $c=14.75 \mathrm{kX}$. Crystals often tabular or short prisms. Perfect $\{001\}$ cleavage. H. 2-3. G. 6.5. $\mathrm{X}=c ; \mathrm{Y}=b .(-) 2 \mathrm{~V}=89^{\circ}, \mathrm{r}>\mathrm{v} .{ }^{42} n_{\mathrm{X}}=1.690$, $n_{\mathrm{Y}}=1.714, n_{\mathrm{Z}}=1.733, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.045$. Color yellow. PD 7.49, 3.26, 3.64; 8-396.
$\mathbf{7} \mathrm{UO}_{3} \cdot \mathbf{1 1 H}_{2} \mathrm{O}$ (Becquerelite) is orthorhombic with ${ }^{43} a=13.93, b=$ $14.84, c=12.34 \AA$. Crystals $\{010\}$ tablets long parallel with $c$. Perfect $\{010\}$ cleavage. H. $2-3$. G. 5.2. $\mathrm{X}=b ; \mathrm{Y}=c .(-) 2 \mathrm{~V}=31^{\circ}, \mathrm{r}>\mathrm{v} .{ }^{44}$ $n_{\mathrm{X}}=1.735, n_{\mathrm{Y}}=1.820, n_{\mathrm{Z}}=1.830, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.095$. Color amber to brownish yellow; pleochroic with X colorless, Y light yellow, Z dark yellow. Made at room temperature ${ }^{45}$ from solutions. PD 7.50, 3.22, 3.75; 8-299.
$\mathbf{W O}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ (or $\mathrm{H}_{2} \mathrm{WO}_{4}$ ) (Tungstite) is orthorhombic. Crystals tiny scales or prisms with perfect basal cleavage. H. 2.5. G. 5.5(?). F. 7. Soluble in KOH or $\mathrm{NH}_{4} \mathrm{OH}$ but not in acids. $\mathrm{X}=c ; \mathrm{Z}=b . .^{46}(-) 2 \mathrm{~V}=27^{\circ}, \mathrm{r}<\mathrm{v}$ distinct. $n_{\mathrm{X}}=1.82, n_{\mathrm{Y}}=?, n_{\mathrm{Z}}=2.04, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.22,{ }^{46}$ absorption $\mathrm{X}<\mathrm{Y}<\mathrm{Z}$. Again: ${ }^{13} n_{\mathrm{X}}=2.09, n_{\mathrm{Y}}=2.24, n_{\mathrm{Z}}=2.26, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.17$, absorption $\mathbf{Z}<\mathbf{Y}<\mathbf{X}$. This difference may be due to the fact that the indices change as the water is driven off; tungstite begins to lose water at $120^{\circ} \mathrm{C}$. and so attempts to determine the indices with melts which become liquid only above this temperature may give inaccurate results. Color golden yellow to green. Luster pearly. Absorption $\mathrm{Y}<\mathrm{X}<\mathrm{Z}$. PD 3.49, 2.68, 2.56; 6-0242. Made by heating hydrotungstite to $100^{\circ} \mathrm{C}$. for several days.
$\mathrm{WO}_{3} \cdot \mathbf{2 \mathrm { H } _ { 2 } \mathrm { O }}$ (or $\mathrm{H}_{2} \mathrm{WO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ ) (Hydrotungstite) is monoclinic(?) with poor $\{010\}$ cleavage. Crystals platy. Multiple twinning on $\{1 \overline{1} 0\}$ very common. H. 2. G. 4.6. Soluble in $\mathrm{NH}_{4} \mathrm{OH}$, but not in acids. $\mathrm{X} \wedge$ normal to $\{001\}=3^{\circ} c a . ; \mathrm{Y}=b .(-) 2 \mathrm{~V}=52^{\circ} c a . ; \mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.70, n_{\mathrm{Y}}=1.95$, $n_{\mathrm{Z}}=2.04, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.34$. Color green with X colorless, Y yellow-green, Z dark green. Made from a solution ${ }^{46}$ of $\left(\mathrm{NH}_{4}\right)_{6} \mathrm{~W}_{7} \mathrm{O}_{24} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ in water treated with HCl. PD 3.46, 2.30, 3.30; 6-0244.
${ }^{41}$ Bignand: Bull. Soc. Fr. Min. Crist. LXXVIII, p. 1 (1955).
${ }^{42}$ Walker: Am. Min. VIII, p. 67 (1923).
${ }^{43} a b c$ changed to $a c b$ to make $b>a>c$.
${ }^{44}$ Palache and Berman: Am. Min. XVIII, p. 20 (1933).
${ }^{45}$ Gruner: Am. Min. XXXVIII, p. 342 (1953).
${ }^{46}$ Kerr and Young: Am. Min. XXIX, p. 192 (1944).

## B. HYDROXIDES AND OXIDES CONTAINING HYDROXYL

## 1. Formula Type AX

$\mathbf{L i O H}$ is tetragonal with ${ }^{47} a=3.55, c=4.33 k X$. U.C. 2. Perfect basal and distinct prismatic cleavages. G. 1.46. Uniaxial negative with $n_{\mathrm{O}}=$ $1.464, n_{\mathrm{E}}=1.452, n_{\mathrm{O}}-n_{\mathrm{E}}=0.012$ for $\lambda=589$. Colorless. PD 2.73, 3.47, 1.78; 4-0708.
$\mathbf{N a O H}$ is orthorhombic(?) in grains or basal plates with perfect $\{001\}$ and poor prismatic cleavages, the latter at an angle of about $90^{\circ}$. Extinction $^{48}$ on (001) bisects the angle between the cleavages. G. 2.13. $\mathrm{Z}=c$. $(-) 2 \mathrm{~V}=50^{\circ} \pm 10^{\circ} . n_{\mathrm{X}}=1.457, n_{\mathrm{Y}}=1.470, n_{\mathrm{Z}}=1.472, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.015 . Colorless. PD 2.35, 1.70, 1.65; 1-1173.
$\mathbf{N a O H} \cdot 2 \mathrm{H}_{2} \mathrm{O}(?)$ is orthorhombic(?) in $\{001\}$ blades long parallel to $a$ with $\{110\}$ and domes. ${ }^{48}$ Good basal cleavage. Angle between prism faces is $92^{\circ} \pm 2^{\circ} . \mathrm{X}=c, \mathrm{Y}=a .(-) 2 \mathrm{~V}=45^{\circ} \pm 5^{\circ} . n_{\mathrm{X}}=1.435, n_{\mathrm{Y}}=1.470$, $n_{\mathrm{Z}}=1.475$, all $\pm .004, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.040$. Colorless. PD 5.90, 2.49, 2.69; 3-89*(?).

KOH is orthorhombic with $^{49} a=3.95, b=4.03, c=11.4 \AA$. Prismatic cleavage angle of $94^{\circ}$. G. 2.05. $\mathrm{X}=a, \mathrm{Y}=c,(+) 2 \mathrm{~V}=$ large, $n_{\mathrm{x}}=1.486$, $n_{\mathrm{Y}}=1.492, n_{\mathrm{Z}}=1.497, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.011$. Colorless. PD 2.69, 1.98, 2.93; 1-1054.

## 2. Formula Type $A X_{2}$

$\mathrm{Sr}(\mathrm{OH})_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ is tetragonal with $c / a=0.64$. Crystals basal plates with $\{001\}$ and $\{110\}$ cleavages; twinning common on $\{110\},\{101\}$ or $\{210\}$. G. 1.885. Uniaxial negative with $n_{\mathrm{O}}=1.499, n_{\mathrm{E}}=1.476, n_{\mathrm{O}}-n_{\mathrm{E}}=$ 0.023. Colorless. PD 2.02, 4.29, 2.76; 1-1263.
$\mathbf{M g}(\mathbf{O H})_{2}$ (Brucite) is hexagonal with $a=3.125, c=4.75 k X$. Crystals basal plates with perfect basal cleavage. H. 2.5. G. 2.39. F. 7. Soluble in HCl . Uniaxial positive ${ }^{50}$ with $n_{\mathrm{O}}=1.559, n_{\mathrm{E}}=1.580, n_{\mathrm{E}}-n_{\mathrm{O}}=0.021$. Again: $n_{\mathrm{O}}=1.5662, n_{\mathrm{E}}=1.5853, n_{\mathrm{E}}-n_{\mathrm{O}}=0.0191 .{ }^{51}$ Color white. Often anomalously biaxial with small 2 V , or showing abnormal interference colors due to marked change in birefringence with wave length. PD 2.37, 4.77, 1.79; 7-239. After heating above $400^{\circ} \mathrm{C} . \mathrm{MgO}$ remains, ${ }^{52}$ which is uniaxial negative with G. 3.666, $n_{\mathrm{O}}=1.644, n_{\mathrm{E}}=1.634, n_{\mathrm{O}}-n_{\mathrm{E}}=0.010$.
${ }^{47}$ Ernst: Zeit. phys. Chem. XX, p. 65 (1933).
${ }^{48}$ Morey and Burlew: Am. J. Sci. XXXV, p. 185 (1938).
${ }^{49}$ Ernst and Schober: Nachr. Akad. Wiss. Göttingen, Math. Phys. Kl. Abt. 1947, No. 2, p. 49. Chem. Abst. XLIII, p. 7771 (1944).
${ }^{50}$ Bauer: N. Jahrb. Min. Bl. Bd. II, p. 73 (1883).
${ }^{51}$ Westphal, in Ehringhaus: N. Jahrb. Min. Bl. Bd. XLI, p. 371 (1917).
${ }^{52}$ Westphal: Inaug. Diss. Leipzig, 1913.
$\mathbf{C a}(\mathbf{O H})_{2}$ (Portlandite ${ }^{53}$ ) is hexagonal with $a=3.585, c=4.895 \mathrm{kX}$. U.C. 1. Crystals basal plates with perfect basal cleavage. H. 2. G. 2.23. Uniaxial negative with ${ }^{53 \mathrm{a}} n_{\mathrm{O}}=1.574, n_{\mathrm{E}}=1.545, n_{\mathrm{O}}-n_{\mathrm{E}}=0.029 \mathrm{Na}$. Colorless. PD 2.63, 4.90, 1.93; 4-0733.
$\mathbf{M n}(\mathbf{O H})_{2}$ (Pyrochroite) is hexagonal with $a=3.34, c=4.68 \mathrm{k} X$. Crystals basal tablets or rhombohedral with perfect basal cleavage. H. 2.5. G. 3.25. Uniaxial negative with $n_{\mathrm{O}}=1.723, n_{\mathrm{E}}=1.681, n_{\mathrm{O}}-n_{\mathrm{E}}=0.042$. May have small 2 V . Colorless, but easily altered to brown, and then absorption is $\mathrm{O}>\mathrm{E}$. PD 4.72, 1.37, 2.45; 8-171.
$\mathbf{Z n}(\mathbf{O H})_{2}$ is orthorhombic with $a: b: c=0.605: 1: 0.576$. Crystals prismatic or varied with no distinct cleavage. $\mathrm{X}^{54}=c, \mathrm{Y}=b ;(-) 2 \mathrm{~V}=$ $50^{\circ} 40^{\prime}, \mathrm{r}>$ v distinct; $n_{\mathrm{X}}=1.5705, n_{\mathrm{Y}}=1.5777, n_{\mathrm{Z}}=1.5796, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.0091. Again: ${ }^{55} \mathrm{X}=b, \mathrm{Y}=a, 2 \mathrm{~V}=$ large. Also: ${ }^{56} \mathrm{Z}=c$, ( - )2V large, $\mathrm{r}>\mathrm{v} ; n_{\mathrm{X}}=1.570, n_{\mathrm{Y}}=1.578, n_{\mathrm{Z}}=1.580, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.010$. PD 4.38, 3.27, 2.71; 1-0360.
$\mathbf{B a}(\mathbf{O H})_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=0.999: 1: 1.278, \beta=98^{\circ} 56^{\prime}$. Crystals complex, often flattened parallel to $\{001\}$ or long parallel to $a$ with perfect basal cleavage. G. 2.18. Loses $\mathrm{H}_{2} \mathrm{O}$ at $78^{\circ}$ C. (then G. 4.50) and fuses at $780^{\circ} \mathrm{C}$. X nearly normal to $\{001\} . \mathrm{Z}=b$. (-) $2 \mathrm{~V}=8^{\circ} 33^{\prime} \mathrm{Na}$. $n_{\mathrm{X}}=1.471, n_{\mathrm{Y}}=1.5017, n_{\mathrm{Z}}=1.502, n_{\mathrm{O}}-n_{\mathrm{X}}=0.031$. Colorless. PD 6.00, 4.62, 2.78; 1-0151.
$\mathbf{B O}(\mathbf{O H})$ has three crystal phases. ${ }^{57}$ The high temperature $\alpha$-phase may be grown from the vapor. It is orthorhombic ${ }^{58}$ with $a=1.507, b=8.015$, $c=1.503 \AA$. Crystals basal plates with a prism angle of $78^{\circ} 30^{\prime}$. Perfect basal cleavage. G. 1.86. $\mathrm{X}=c ; \mathrm{Y}=a$. (-) $2 \mathrm{~V}^{57}=23^{\circ}, n_{\mathrm{X}}<1.376, n_{\mathrm{Y}}=$ $1.514, n_{\mathrm{Z}}=1.521$. $n_{\mathrm{Z}}-n_{\mathrm{X}}>0.145$. Again: ${ }^{58} n_{\mathrm{X}}=1.378, n_{\mathrm{Y}}=1.503$, $n_{\mathrm{Z}}=1.507, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.129$. Another ( $\beta$ ) phase is monoclinic ${ }^{57}$ with $a: b: c=0.804: 1: 1.785, \beta=120^{\circ} 12^{\prime}$. G. 2.044. Perfect basal and distinct $\{101\}$ cleavages. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=5^{\circ}$ red, $4.5^{\circ}$ blue. $(-) 2 \mathrm{~V}=35^{\circ}, \mathrm{r}<\mathrm{v}$. $n_{\mathrm{X}}=1.434, n_{\mathrm{Y}}=1.570, n_{\mathrm{Z}}=1.588, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.154$. Again: ${ }^{53} n_{\mathrm{X}}=$ $1.450, n_{\mathrm{Y}}=1.574, n_{\mathrm{Z}}=1.579, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.129$. A third phase ("most stable") is isometric, ${ }^{57}$ often dodecahedral. G. 2.486. Isotropic with $n=$ 1.619. All phases react rapidly with acetone, methyl alcohol or acetonitrile; they are colorless or white. PD 3.12, 5.93, 3.49; 9-15 (which phase?).

[^42]$\mathrm{AlO}(\mathbf{O H})$ (Boehmite) is orthorhombic ${ }^{59}$ with $a=3.69, b=12.24, c=$ $2.86 k X$, U.C. 4, structure like that of lepidocrocite. Crystals thin, lenticular, flattened on $\{001\}$; usually massive. H. 3.5-4. G. 3.01-3.06 (3.11 calc.). $\{010\}$ cleavage. Probably $\mathrm{X}=a$ (elongation), $\mathrm{Y}=c, \mathrm{Z}=b$. ( $+2 \mathrm{~V}^{60}=$ about $80^{\circ}, n_{\mathrm{X}}=1.646,\left[n_{\mathrm{Y}}(\right.$ calc. $\left.)=1.652\right], n_{\mathrm{Z}}=1.661, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.015$. Again: ${ }^{61}(-) 2 \mathrm{~V}=$ small, $n_{\mathrm{X}}=n_{\mathrm{Y}}=1.649, n_{\mathrm{Z}}=1.665, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.016$. Earlier reports give mean index $n=1.624$ to 1.645 , but the reasons for such variation are unknown, and the reports are considered doubtful. Colorless or white. PD 6.11, 3.16, 2.35; 5-0190.
$\operatorname{AlO}(\mathbf{O H})$, made by heating $\mathrm{Al}(\mathrm{OH})_{3}$ to about $200^{\circ} \mathrm{C}$. for 50 hours, is amorphous with $n=1.565$. When made by hydrating $\mathrm{Al}_{2} \mathrm{O}_{3}$ in steam at 125 atmospheres it has G. 3.06, $n=1.65$ and $n_{\mathrm{Z}}-n_{\mathrm{X}}=$ weak-not like diaspore nor boehmite.
$\mathbf{F e O}(\mathbf{O H})$ (Lepidocrocite) is orthorhombic ${ }^{62}$ with $a=3.87, b=12.51$, $c=3.06 k X$. U.C. 4. Crystals $\{010\}$ scales; or fibrous along $a$. Perfect $\{010\}$ and good $\{001\}$ cleavages. H. 5. G. 4.09 . $\mathrm{X}=b, \mathrm{Y}=c .(-) 2 \mathrm{~V}=83^{\circ}$, $n_{\mathrm{X}}=1.94, n_{\mathrm{Y}}=2.20, n_{\mathrm{Z}}=2.51, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.57$. Color ruby-red to reddish brown. Pleochroic with X nearly colorless (to clear yellow in thicker grains), Y and Z orange to yellow to red orange (in thicker grains). Absorption $\mathrm{X}<\mathrm{Y}<\mathrm{Z}$. PD 6.26, 3.29, 2.47; 8-98.
$\mathbf{M n O}(\mathrm{OH})$ (Manganite) is monoclinic ${ }^{63}$ with $a=8.86, b=5.24, c=$ $5.70 k X, \beta=90^{\circ}$. U.C. 8. Pseudo-orthorhombic. Crystals striated prisms often grouped. Perfect $\{010\}$ and good $\{001\}$ cleavages. H. 4. G. 4.33. $\mathrm{Y}=$ $b, \quad \mathrm{Z}=c^{14}, \quad$ again, ${ }^{64} \quad \mathrm{Z} \wedge c=4^{\circ} . \quad(+) 2 \mathrm{~V}=$ small, $\quad \mathrm{r}>\mathrm{v}, \quad$ very strong. $n_{\mathrm{X}}=2.25 \mathrm{Li}, n_{\mathrm{Y}}=2.25 \pm .02, n_{\mathrm{Z}}=2.53, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.28$. Mass color steel gray to iron black; color in flakes for X and Y reddish brown, Z red brown with X and $\mathrm{Y}<\mathrm{Z}$. PD 3.40, 2.64, 2.28; 8-99. Alters readily to pyrolusite.
$\mathbf{L a O O H}{ }^{65}$ is anisotropic with ill-defined crystal form and low birefringence. $n=1.798 \pm .006$. The principal X-ray powder-pattern lines that differ from lines due to $\mathrm{La}_{2} \mathrm{O}_{3}$ are at $d=2.959,2.042,3.533,3.243$. Made hydrothermally.
$\mathbf{N d O O H}{ }^{65}$ forms lathlike crystals with positive elongation and parallel extinction. Birefringence low to moderate; $n=1.850 \pm .008$. The principal

[^43]powder lines are at $d=6.005,2.974,3.007,1.981$. Made hydrothermally.
SmOOH ${ }^{65}$ forms lathlike crystals with parallel extinction and positive elongation. Birefringence moderate; $n=1.860 \pm .008$. The principal powder lines are at $d=1.948,5.894,2.929,4.040,1.169$. Made hydrothermally.

YOOH ${ }^{65}$ forms fibrous crystal grains with parallel extinction, positive elongation. Birefringence low to moderate; $n=1.845 \pm .008$. The principal X-ray powder lines are at $d=2.891,3.986,5.671,4.076,2.783$. Made hydrothermally.

## 3. Formula Type $A X_{3}$

$\mathrm{Al}(\mathrm{OH})_{3}$ (Gibbsite) is monoclinic with $a=8.624, b=5.060, c=$ $9.700 k X, \beta=94^{\circ} 34^{\prime}$. U.C. 4. Crystals often six sided basal plates. Perfect basal cleavage. H. 2.5-3.5. G. 2.40. $\mathrm{X}=b, \mathrm{Z} \wedge c^{13}=-25^{\circ}$. ( + ) $2 \mathrm{~V}=$ $0^{\circ} \pm . n_{\mathrm{X}}=1.566, n_{\mathrm{Y}}=1.566, n_{\mathrm{Z}}=1.587, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.021$. Above $56^{\circ} \mathrm{C}$. $\mathrm{Y}=b$ and $\mathrm{Z} \wedge c=-45^{\circ}$ (red). Again: ${ }^{66} n_{\mathrm{X}}=n_{\mathrm{Y}}=1.577, n_{\mathrm{Z}}=1.595$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.018$. Color white with pearly luster. PD 4.85, 4.37, 2.39; 7-324. Also called hydrargillite. See also bayerite.
$\mathrm{Al}(\mathrm{OH})_{3}$ (Bayerite) is produced by rapid precipitation ${ }^{66}$ of alumina from solution. X-ray study shows that it is not the same as gibbsite. It is weakly birefringent with a mean index $n=1.583$ if dried at $110^{\circ} \mathrm{C}$. and 1.55 if dried with alcohol and ether. PD 4.73, 2.22, 4.37; 8-96.
$\mathbf{B}(\mathbf{O H})_{3}$ (Sassolite) is triclinic ${ }^{57}$ with $a=7.04, b=7.04, c=6.56 \mathrm{kX}$, $\alpha=92^{\circ} 30^{\prime}, \beta=101^{\circ} 10^{\prime}, \gamma=120^{\circ}$. U.C. 4. Crystals basal six-sided tablets or, rarely, acicular. Perfect basal cleavage. Flexible. H. 1. G. 1.48. Decomposes at $185^{\circ}$ C. Soluble in water. X inclined $2^{\circ}$ from normal to (001). $\mathrm{X} \wedge c=16^{\circ}$. The optic plane makes an angle on (001) of $17^{\circ} \pm 2^{\circ}$ with (100) and $43^{\circ} \pm 2^{\circ}$ with ( $1 \overline{1} 0$ ). ( $-2 \mathrm{~V}=10^{\circ} . n_{\mathrm{X}}=1.337, n_{\mathrm{Y}}=1.461$, $n_{\mathrm{Z}}=1.462, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.125$. Again: ${ }^{13} \quad n_{\mathrm{X}}=1.340, n_{\mathrm{Y}}=1.456, n_{\mathrm{Z}}=$ $1.459, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.119$. Color white or stained. PD 3.18, 6.04, 1.59; 9-335.
$\mathbf{L a}(\mathbf{O H})_{3}{ }^{65}$ is uniaxial positive with positive elongation. $n_{0}=1.740$, $n_{\mathrm{E}}=1.768 \pm .005$. Stable below about $480^{\circ} \mathrm{C}$. and $10,000 \mathrm{lbs}$. per sq. in. pressure of water vapor. A high-density form stable at higher pressures and temperatures has low to moderate birefringence and $n=1.760 \pm .015$. PD 2.962, 3.662, 2.071, 5.067, and 2.110.
$\mathbf{N d}(\mathbf{O H})_{3}{ }^{65}$ is uniaxial positive with positive elongation. $n_{0}=1.740$, $n_{\mathrm{E}}=1.768 \pm .005$. Stable to a little above $400^{\circ} \mathrm{C}$. under hydrothermal conditions. A high-density form stable at higher temperature and pressures above 10,000 lbs. per sq. in. water-vapor pressure has low birefringence and $n=1.78 \pm .02$. PD 3.930, 2.614, 2.970, 7.885, 3.375.

[^44]$\mathbf{S m}(\mathrm{OH})_{3}{ }^{65}$ is uniaxial positive with positive elongation. $n_{\mathrm{O}}=1.740$, $n_{\mathrm{E}}=1.768 \pm .005$. Stable below nearly $400^{\circ} \mathrm{C}$. under hydrothermal conditions. A high-density form stable at higher temperature and pressures above $10,000 \mathrm{lbs}$. per sq. in. water-vapor pressure has low birefringence and $n=1.780 \pm .015$. PD 2.583, 3.723, 3.089, 5.566, 2.089 .
$\mathbf{Y}(\mathbf{O H})_{3}{ }^{65}$ is uniaxial positive with positive elongation. $n_{0}=1.676$, $n_{\mathrm{E}}=1.714 \pm .005$. Stable at $300^{\circ} \mathrm{C}$. under 2000 lbs . per sq. in. pressure of water vapor, and at increasing temperatures as the pressure is increased, to about $380^{\circ} \mathrm{C}$. and $18,000 \mathrm{lbs}$. per sq. in. water-vapor pressure. There seems to be no dense polymorph analogous to those of the corresponding compounds of La, Nd, and Sm. PD 8.12, 4.09, 3.07; 9-62.

## 4. Miscellaneous Hydroxides

$\mathrm{Na}_{2} \mathrm{Sn}(\mathrm{OH})_{6}$ is hexagonal ${ }^{66 \mathrm{a}}$ with $a=5.956, c=14.13 \AA$. U.C. 3. G. 3. Crystals basal plates. Decomposes at about $250^{\circ}$ C. Uniaxial positive with $n_{\mathrm{O}}=1.568, n_{\mathrm{E}}=1.582, n_{\mathrm{E}}-n_{\mathrm{O}}=0.014$. PD 2.52, 4.75, 1.85; 1-1115.
$\mathrm{Ca}_{3} \mathrm{Al}_{2}(\mathbf{O H})_{12}$ (Hydrogrossularite) $^{66 \mathrm{~b}}$ is isometric with $a=12.56 \AA$., in dodecahedral or octahedral crystals. Isotropic, with $n=1.604 \pm .002$. Isomorphous with grossularite in the garnet group. Made hydrothermally. PD 2.71, 1.62, 3.03; 3-0801*.
$4 \mathrm{CaO} \cdot 3 \mathrm{Al}_{2} \mathrm{O}_{3} \cdot 3 \mathrm{H}_{2} \mathrm{O}^{66 \mathrm{~b}}$ is biaxial. ( - ) $2 \mathrm{~V}=$ large, and $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.005$. PD 3.59, 3.24, 1.572, 2.084, 2.156, 3.007.

## C. MULTIPLE OXIDES

$\alpha$. Anhydrous

## 1. Formula Type $A_{m} B_{n} X_{p}$ with $(m+n): p \approx 1: 1$

$\mathbf{K A l O}_{2}$ is isometric. ${ }^{67}$ Crystals octahedral. Extremely hygroscopic. Isotropic with $n=1.603$. Colorless. It may take some $\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{Fe}_{2} \mathrm{O}_{10}$ in solid solution raising the index to 1.625 . PD 2.72, 1.57, 1.21; 2-0897.
$\mathrm{LiFeO}_{2}$ is isometric ${ }^{68}$ above $600^{\circ} \mathrm{C}$. and anisotropic when crystallized below that temperature. The isometric form does not invert on cooling. Its crystals are octahedral with G. 4.368 and $n=2.40 \pm .04 \mathrm{Li}$. PD 2.07, 1.47, 2.39; 2-1237*.
$\mathbf{L i}_{2} \mathbf{T i O}_{3}$ is isometric. ${ }^{69}$ G. 3.42. Isotropic with $n=2.087 \mathrm{Na}$. PD 2.07,

[^45]$1.46,1.19 ; 8-249$. It forms mix-crystals in all proportions with 3 MgO , the refractive index decreasing regularly from 2.087 to 1.7366 (the index of MgO ).
$\mathbf{L i A l O}_{2}$ forms plates or grains with G. 2.554. M.P. $1900-2000^{\circ}$ C. Uniaxial negative ${ }^{70}$ with $n_{\mathrm{O}}=1.624, n_{\mathrm{E}}=1.606, n_{\mathrm{O}}-n_{\mathrm{E}}=0.018$. It may take some $\mathrm{SiO}_{2}$ in crystal solution lowering the indices even to $n_{\mathrm{O}}=1.586$, $n_{\mathrm{E}}=1.570, n_{\mathrm{O}}-n_{\mathrm{E}}=0.016$. PD 1.39, 2.37, 1.52; 1-1306.
$\mathbf{N a A l O}_{2}$ is orthorhombic(?), ${ }^{21}$ often twinned. M.P. $1650^{\circ}$ C. ( - ) $2 \mathrm{~V}=$ $30^{\circ} . n_{\mathrm{X}}=1.566, n_{\mathrm{Y}}=1.575, n_{\mathrm{Z}}=1.580, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.014$. Colorless. PD 2.59, 2.54, 2.93; 2-0985.
$\mathbf{N a}_{2} \mathbf{Z r O}_{3}$ is probably orthorhombic. ${ }^{71}$ Crystals six-sided plates produced by pseudo-hexagonal twinning. G. 4.0. ( - ) $2 \mathrm{~V}=$ ?. $n_{\mathrm{X}}=1.720$, $n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}>1.80, n_{\mathrm{Z}}-n_{\mathrm{X}}>0.08$. Made by fusion at $1110^{\circ} \mathrm{C}$. and slow cooling. PD 2.31, 1.66, 1.62; 8-242.
$\mathrm{HAlO}_{2}$ (Diaspore) is orthorhombic with $a=4.40, b=9.39, c=2.84 \mathrm{kX}$. U.C. 4. Crystals often $\{010\}$ platelets elongated along $c$; also foliated massive. Perfect $\{010\}$ and good $\{110\}$ cleavages. H. 6.5-7. G. 3.3-3.5. $\mathrm{X}=c$, $\mathrm{Y}=b ;^{72}(+) 2 \mathrm{~V}=84-85^{\circ} . n_{\mathrm{X}}=1.702, n_{\mathrm{Y}}=1.722, n_{\mathrm{Z}}=1.750, n_{\mathrm{Z}}-n_{\mathrm{X}}$ $=0.048$. Colorless or faintly tinted, but it may contain up to about 5 per cent $\mathrm{Fe}_{2} \mathrm{O}_{3}$ and then it is pleochroic with brown color and $\mathrm{X}<\mathrm{Y}<\mathrm{Z}$. PD 3.99, 2.32, 2.13; 5-0355.
$\mathrm{HFeO}_{2}$ (Goethite) is orthorhombic with $a=4.64, b=10.0, c=3.03 \mathrm{kX}$. U.C. 4. Prismatic and striated or tabular or fibrous. Perfect $\{010\}$ and good $\{100\}$ cleavages. H. 5-5.5. G. 4.28 (crystals), 3.3-4.3 (massive). $\mathrm{Y}=a$ (red) and $c$ (yellow), $\mathrm{Z}=c$ (red) and $a$ (yellow). ( - ) $2 \mathrm{~V}=$ small to medium ${ }^{72 a}$ ( $0^{\circ}$ at $\lambda=610-620$ ), $\mathrm{r}>\mathrm{v}$ strong. $n_{\mathrm{X}}=2.260 \mathrm{Na}, n_{\mathrm{Y}}=2.393$, $n_{\mathrm{Z}}=2.398, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.138$. The optic angle changes with change of temperature, being $0^{\circ}$ at $610-620^{\circ} \mathrm{C}$. Pleochroic with X yellow, Y brownish yellow, Z orange yellow. PD 4.21, 2.69, 2.44; 8-97. Fibrous varieties show anomalous optical effects probably due to impurities between the fibers. Impure aggregates may be apparently isotropic with $n=2.00 \pm$ to $2.15 \pm$.
$\mathbf{N a C a}_{4} \mathbf{A l}_{3} \mathbf{O}_{9}$ is orthorhombic (pseudo-isometric) ${ }^{21}$ in six- or eight-sided polyhedrons with common twinning. Dissociates at $1508^{\circ} \mathrm{C}$. to CaO and liquid. $(-) 2 \mathrm{~V}=$ medium. $n_{\mathrm{X}}=1.702 \pm 0.003, n_{\mathrm{Y}}=1.708$ ca., $n_{\mathrm{Z}}=$ 1.710, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.008$. Colorless. PD 2.67, 1.55, 2.19; 2-0929.
$\mathbf{N a}_{4} \mathbf{C a}_{3} \mathbf{A l}_{10} \mathbf{O}_{20}$ is stable to $1630^{\circ}$ C. Granular. (+)2V $=$ ?; mean index ${ }^{21}$ $n=1.592, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.005 c a$. Colorless. PD 2.57, 4.19, 3.90; 2-1003.

[^46]
## 2. Formula Type $A_{m} B_{n} X_{p}$ with ( $m+n$ ): $\mathbf{p} \approx 3: 4$

$\mathrm{LiAl}_{5} \mathbf{O}_{8}$ is isometric with the spinel ${ }^{72 \mathrm{~b}}$ space lattice. G. 3.606. Isotropic with $n=1.735$ D. Colorless. PD 2.39, 1.40, 1.98; 3-0911.

## Spinel Group

The spinel group has about a dozen end-member formulas but these are not all miscible in all proportions, indeed $\mathrm{Fe}^{\prime \prime \prime}$ replaces Al or Cr probably only to a limited extent, but Al can be replaced by Cr in any proportion. All the crystals of the spinel group are isometric. All may contain an excess of the trivalent base. The chief compounds are:
$\left.\begin{array}{ll}\mathrm{MgAl}_{2} \mathrm{O}_{4} & \text { Spinel proper } \\ \mathrm{FeAl}_{2} \mathrm{O}_{4} & \text { Hercynite } \\ \mathrm{MgCr}_{2} \mathrm{O}_{4} & \text { Magnesiochromite } \\ \mathrm{FeCr}_{2} \mathrm{O}_{4} & \text { Chromite } \\ \mathrm{ZnAl}_{2} \mathrm{O}_{4} & \text { Gahnite } \\ \mathrm{MnAl}_{2} \mathrm{O}_{4} & \text { Galaxite } \\ \mathrm{CoAl}_{2} \mathrm{O}_{4} & \text { Artificial }\end{array}\right\}$ Spinel
$\left.\begin{array}{ll}\mathrm{FeFe}_{2} \mathrm{O}_{4} & \text { Magnetite proper } \\ \mathrm{MgFe}_{2} \mathrm{O}_{4} & \text { Magnesioferrite } \\ \mathrm{MnFe}_{2} \mathrm{O}_{4} & \text { Jacobsite } \\ \mathrm{ZnFe}_{2} \mathrm{O}_{4} & \text { Franklinite } \\ \mathrm{CdFe}_{2} \mathrm{O}_{4} & \text { Artificial }\end{array}\right\}$ Magnetite
$\mathbf{M g A l}_{2} \mathrm{O}_{4}$ (Spinel) is isometric with $a=8.080 k X$. U.C. 8. Crystals often octahedral. Twinning on $\{111\}$ common. Poor octahedral cleavage; cubic cleavage (or parting?) is usual in boules. ${ }^{73}$ H. 8. G. 3.55 ( 3.578 calc.). M.P. $2135^{\circ} \mathrm{C}$. Isotropic with $n=1.7161$ (623), 1.7190 (578), 1.7322 (436) for the pure substance. PD 2.44, 2.02, 1.43; 5-0672*. The natural mineral is very rarely pure; $\mathrm{MgAl}_{2} \mathrm{O}_{4}$ is miscible in all proportions with $\mathrm{FeAl}_{2} \mathrm{O}_{4}$ and $\mathrm{ZnAl}_{2} \mathrm{O}_{4}$ and probably with $\mathrm{MnAl}_{2} \mathrm{O}_{4}$ and $\mathrm{CoAl}_{2} \mathrm{O}_{4}$. Miscibility is possible ${ }^{73}$ in artificial crystals with $\mathrm{MgCr}_{2} \mathrm{O}_{4}, \mathrm{FeCr}_{2} \mathrm{O}_{4}, \mathrm{ZnCr}_{2} \mathrm{O}_{4}$ and $\mathrm{MnCr}_{2} \mathrm{O}_{4}$, but in nature these do not seem to form complete series. With 75 mol . per cent ${ }^{74}$ $\mathrm{Al}_{2} \mathrm{Al}_{4} \mathrm{O}_{9}$ (to 25 per cent $\mathrm{MgAl}_{2} \mathrm{O}_{4}$ ) $n=1.7261$ (623), 1.7288 (578), 1.7428 (436). With 9 per cent $\mathrm{MgFe}_{2} \mathrm{O}_{4}$ in solution $n=1.76 \mathrm{Na} . \mathrm{SiSiO}_{4}$ in solution may lower the index to 1.718 . Colorless or blue or red from $\mathrm{Mn}, \mathrm{Fe}$, etc.; blue varieties are said to have higher indices than red types. ${ }^{75}$ Crystals are

[^47]often birefringent, probably from strain. $\mathrm{MgAl}_{2} \mathrm{O}_{4}$ glass has $n=1.67-1.68$. Made from fusion for use as a gem.
$\mathrm{FeAl}_{2} \mathrm{O}_{4}$ (Hercynite) is isometric with $a=8.119 \mathrm{kX}$. U.C. 8. Crystals octahedral. Usually massive. H. 7.5. G. 4.39. M.P. $1750^{\circ}$ C. Isotropic ${ }^{76}$ with $n=1.83$. Color black; streak dark grayish green. Properties of the $\mathrm{MgAl}_{2} \mathrm{O}_{4}-\mathrm{FeAl}_{2} \mathrm{O}_{4}-\mathrm{ZnAl}_{2} \mathrm{O}_{4}$ system are shown in Fig. 4-1. PD 2.45, 2.02, 1.43; 3-0894*.


Fig. 4-1. Gahnite-Hercynite-Spinel System.
$\mathbf{M g C r}_{2} \mathbf{O}_{4}$ (Magnesiochromite) is isometric. G. 4.39. M.P. $>1800^{\circ} \mathrm{C}$. Isotropic ${ }^{15}$ with $n=1.90$. Again: $n=2.035$. Forms mix-crystals with $\mathrm{MgAl}_{2} \mathrm{O}_{4}, \mathrm{FeCr}_{2} \mathrm{O}_{4}$, etc. Color pale gray-green. PD 2.49, 1.47, 1.59; 9-353.

[^48]$\mathrm{FeCr}_{2} \mathrm{O}_{4}$ (Chromite) is isometric with $a=8.344 k X$. U.C. 8. No cleavage. H. 5.5. G. 5.09. M.P. $>1800^{\circ}$ C. Forms mix-crystals with $\mathrm{MgCr}_{2} \mathrm{O}_{4}$, $\mathrm{FeAl}_{2} \mathrm{O}_{4}$, etc. Isotropic with $n=2.12$. With much $\mathrm{MgAl}_{2} \mathrm{O}_{4}, n=1.83$. Color black; streak brown. Opaque except in thin splinters. Made by fusing the mixed oxides. PD 2.51, 1.91, 1.61; 4-0759*.
$\mathrm{ZnAl}_{2} \mathbf{O}_{4}$ (Gahnite) is isometric with $a=8.085 k X$. U.C. 8. Crystals octahedral. H. 7.5. G. 4.62. Isotropic with ${ }^{15} n=1.805$. Again: $:^{77} n=1.782$ (natural material, probably impure). Color green to black, rarely blue. PD 2.44, 2.86, 1.43; 5-0669.
$\mathrm{MnAl}_{2} \mathrm{O}_{4}$ (Galaxite) is isometric with $a=8.271 \mathrm{kX}$. U.C. 8. Massive. H. 7.5. G. 4.03. Isotropic with $n=1.848$ calc. Natural galaxite ${ }^{78}$ $\left(\mathrm{Mn}_{.90} \mathrm{Fe}_{.05} \mathrm{Mg}_{.05}\right)\left(\mathrm{Al}_{.77} \mathrm{Fe}_{.23}\right)_{2} \mathrm{O}_{4}$ has G. 4.234 and $n=1.923$. Color brown to black. PD 2.49, 2.92, 1.46; 10-310.
$\mathrm{CoAl}_{2} \mathrm{O}_{4}$ is isometric with $^{79} n>1.78$ (red), $n=1.74$ (blue). This is the "cobalt blue" pigment of commerce.
$\mathrm{FeFe}_{2} \mathrm{O}_{4}$ (Magnetite) is isometric with $a=8.374 k X$. U.C. 8. Crystals often octahedral or dodecahedral. Good octahedral parting. H. 5.5-6.5. G. 5.175. M.P. $1590^{\circ}$ C. Isotropic with $n=2.42 \mathrm{Na}$. Color black; streak black. Opaque except in very thin splinters. Strongly magnetic. PD 2.53, 1.48, 2.97; 7-322. Apparently miscible in all proportions with $\mathrm{MgFe}_{2} \mathrm{O}_{4}$, $\mathrm{ZnFe}_{2} \mathrm{O}_{4}, \mathrm{NiFe}_{2} \mathrm{O}_{4}$ and $\mathrm{MnFe}_{2} \mathrm{O}_{4}$. Also $\mathrm{FeFe}_{2} \mathrm{O}_{4}$ may be changed artificially in whole or in part to $\mathrm{Fe}_{2} \mathrm{O}_{3}$ (maghemite or oxymagnite). Oxymagnite has about the structure of magnetite; has G. 4.74 calc., H .5 , and is isotropic with $n=2.52-2.74$. Color brown to yellow. PD 2.52, 1.48, 2.95; 4-0755.
$\mathbf{M g F e}_{2} \mathrm{O}_{4}$ (Magnesioferrite) is isometric with $a=8.366 \mathrm{kX}$. U.C. 8. Crystals usually octahedral; often massive or granular. No cleavage. H. 6-6.5. G. 4.5. M.P. $1580^{\circ}-1610^{\circ}$ C. Soluble in HCl. Isotropic ${ }^{80}$ with $n=$ 2.39 Na . Color red. Strongly magnetic. PD 2.74, 2.10, 1.70; 8-479.
$\mathbf{Z n F e}_{2} \mathbf{O}_{4}$ (Franklinite) is isometric ${ }^{80 a}$ with $a=8.423 k X$. U.C. 8. Crystals often octahedral. H. 5.5. G. 5.2. Poor octahedral parting. Isotropic ${ }^{13}$ with $n=2.36$ ca. Li. Color iron black; streak reddish brown to black. Opaque except in very thin splinters. Weakly magnetic. PD 2.55, 1.50, $1.99 ; 10-467$.
$\mathrm{CdFe}_{2} \mathrm{O}_{4}$ is isometric ${ }^{80}$ with G. 5.8. Isotropic with $n=2.39 \pm .02 \mathrm{Li}$. PD 2.62, 3.08, 1.67; 1-1083.
$\mathbf{Z n G a} \mathbf{a}_{2} \mathbf{O}_{4}$ is isometric. G. 6.15 calc. Isotropic with $n=1.74$. PD 1.48, 2.52, 1.67; 3-1155.

[^49]$\mathbf{M g}_{2} \mathbf{T i O}_{4}$ is isometric with M.P. $1732^{\circ}$ C. Isotropic ${ }^{81}$ with $n=1.959$. PD 2.55, 2.10, 1.50; 3-0858.
$\mathbf{C a}_{3} \mathbf{A l}_{2} \mathbf{O}_{6}$ is isometric. ${ }^{82}$ Conchoidal fracture. H. 6. Isotropic with $n=$ 1.710. Also reported as pseudo-isometric ${ }^{21}$ and isotropic or nearly so. Colorless. PD 2.70, 1.91, 1.56; 8-516.
$\mathbf{S r}_{3} \mathbf{A l}_{2} \mathbf{O}_{6}$ is isometric ${ }^{83}$ in trapezohedrons. Isotropic with $n=1.728$. PD 2.81, 1.62, 1.99; 9-44*.
$\mathbf{B a}_{3} \mathbf{A l}_{2} \mathbf{O}_{6}$ Spherulitic tablets ${ }^{97}$ soluble in water. G. 4.54. Biaxial with $n_{\mathrm{Y}}=1.735, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.009$.

Ca $_{5} \mathbf{A l}_{6} \mathbf{O}_{14}$ is isometric. ${ }^{82}$ H. 5. M.P. $1455^{\circ}$ C. No cleavage. Isotropic with $n=1.608$. As glass $n=1.662$. With 1 per cent $\mathrm{Na}_{2} \mathrm{O}, n=1.59$. With 2 per cent $\mathrm{K}_{2} \mathrm{O}, n=1.593$. Another phase is probably orthorhombic. $2 \mathrm{~V}=$ large. $n_{\mathrm{X}}=1.687, n_{\mathrm{Z}}=1.692, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.005$.
$\mathbf{B a A l}_{2} \mathbf{O}_{4}$ is isometric. Crystals dodecahedral with no cleavage. G. 3.99. M.P. $1820^{\circ} \pm 20^{\circ}$ C. Soluble in water. Isotropic with ${ }^{84} n=1.683 \pm .002$. Colorless. PD 3.17, 4.56, 2.62; 2-0545.
$\mathbf{C a F e}_{2} \mathbf{O}_{4}$ is tetragonal or hexagonal. ${ }^{85}$ It dissociates at $1216^{\circ} \mathrm{C}$. Crystals long acicular. Uniaxial negative with $n_{\mathrm{O}}=2.465 \mathrm{Li}, 2.58 \mathrm{Na}, n_{\mathrm{E}}=2.345$ $\mathrm{Li}, 2.43 \mathrm{Na}, n_{\mathrm{o}}-n_{\mathrm{E}}=0.15 \mathrm{Na}$. Color in mass black; deep red in powder, not pleochroic. Formed from glass at $1190^{\circ} \mathrm{C}$. It may take as much as 10 per cent $\mathrm{CaAl}_{2} \mathrm{O}_{4}$ in crystal solution; then it has $n_{\mathrm{O}}=2.25 \mathrm{Li}, n_{\mathrm{E}}=2.13$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.12$. PD 2.66, 2.52, 1.51; 8-100.
$\mathbf{M n M n}_{2} \mathrm{O}_{4}$ (Hausmannite) is tetragonal with $a=5.75, c=9.42 \mathrm{kX}$. U.C. 4. Crystals pseudo-octahedral; granular. Perfect basal cleavage. H. 5.5. G. 4.84. Uniaxial negative with $^{86} n_{\mathrm{O}}=2.45 \pm .02 \mathrm{Li}, n_{\mathrm{E}}=2.15 \pm$ $.02 n_{\mathrm{O}}-n_{\mathrm{E}}=0.30 \pm .04$. Color brownish black; not pleochroic. Streak chestnut-brown. Opaque except in thin splinters. Made by heating MnO in air. PD 2.47, 2.74, 1.54; 8-17*.
$\mathbf{Z n M n}_{2} \mathbf{O}_{4}$ (Hetaerolite) is tetragonal with $a=5.74, c=9.15 k X$. U.C. 4. Crystals pyramidal, also massive. Poor basal cleavage. H. 6. G. 5.18. Uniaxial negative with ${ }^{13} n_{\mathrm{O}}=2.35, n_{\mathrm{E}}=2.10, n_{\mathrm{O}}-n_{\mathrm{E}}=0.25$. Color black; streak dark brown. Opaque except in thin splinters which are reddish brown with $\mathrm{O}<\mathrm{E}$. Made from fusion. PD 2.46, 2.70, 1.52; 7-354.
$\mathbf{P b}_{3} \mathbf{O}_{4}$ (Minium) is tetragonal ${ }^{86 \mathrm{a}}$ with $a=8.80, c=6.56 \AA$. H. 2.5. G. 8.9-9.2. F. 1.5. Uniaxial negative. Mean index ${ }^{15} n=2.42 \pm 0.02$ Li. $n_{\mathrm{O}}-$

[^50]$n_{\mathrm{E}}=$ weak. Color red. Streak orange yellow. Strongly pleochroic in thin section, with O nearly colorless, E deep reddish brown. Commonly shows abnormal green interference colors. PD 3.38, 2.90, 2.79; 8-19. Made by heating PbO in air.
$\mathrm{MgBeAl}_{4} \mathbf{O}_{8}$ is uniaxial negative with ${ }^{87} n_{\mathrm{O}}=1.722-1.725, n_{\mathrm{E}}=1.715-$ 1.718, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.007$. Colorless. PD 2.43, 2.05, 1.43; 8-11.
$\mathrm{PbAl}_{2} \mathbf{O}_{4}(?)$ is uniaxial negative with ${ }^{88} n_{\mathrm{O}}=1.91, n_{\mathrm{E}}=1.85, n_{\mathrm{O}}-n_{\mathrm{E}}=$ 0.06. PD 3.09, 4.44, 2.23; 3-0562.
$\mathrm{BeAl}_{2} \mathrm{O}_{4}$ (Chrysoberyl) is orthorhombic with $a=5.47, b=9.39, c=$ $4.42 k X$. U.C. 4. Crystals basal tablets or varied; twinning on $\{130\}$ common. Good prismatic cleavage. H. 8.5. G. 3.75. M.P. between $1855^{\circ}$ and $1880^{\circ}$ C. $\mathrm{X}=c, \mathrm{Y}=b .(+) 2 \mathrm{~V}=70^{\circ}, \mathrm{r}>\mathrm{v} . n_{\mathrm{X}}=1.732, n_{\mathrm{Y}}=?, n_{\mathrm{z}}=1.741$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.009$ (artificial). Averages with some iron: ${ }^{99} n_{\mathrm{X}}=1.746, n_{\mathrm{Y}}=$ 1.748, $n_{\mathrm{Z}}=1.756, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.010$. Optic angle variable, may be as low as $10^{\circ}$. At high temperature $\mathrm{Y}=a$. Color green; rarely yellow or red. Pleochroic with (for example) X columbine-red, Y orange yellow, Z emeraldgreen. One variety, a gem stone called alexandrite, is emerald-green in day light but columbine-red in artificial light. Made from fusion. PD 2.09, 1.62, 3.23; 10-82.
$\mathrm{CaAl}_{2} \mathbf{O}_{4}$ is orthorhombic ${ }^{90}$ or monoclinic. Prismatic to fibrous. Distinct prismatic cleavage. Pseudo-hexagonal twinning on $\{130\}$. H. 6.5. G. 2.98. M.P. $1600^{\circ}$ C. Soluble in HCl . $\mathrm{X}=c ; \mathrm{Y}=b$. (-) $2 \mathrm{~V}=56^{\circ} . n_{\mathrm{X}}=1.643$, $n_{\mathrm{Y}}=1.655, n_{\mathrm{Z}}=1.663, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.020$. Colorless. Formed from fusion. It may take as much as 15 per cent $\mathrm{CaFe}_{2} \mathrm{O}_{4}$ in crystal solution; then it has $n_{\mathrm{X}}=1.70 \pm, n_{\mathrm{Z}}=1.72 \pm, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.020 \pm$. Important in cements.
$\mathbf{S r A l}_{2} \mathbf{O}_{4}$ has pseudo-hexagonal twinning ${ }^{83}$ with perfect cleavage in one direction. Biaxial with $n_{\mathrm{X}}=1.649, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.663, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.014$. PD 3.14, 3.05, 2.98; 9-39.
$\mathbf{C a}_{2} \mathbf{F e}_{2} \mathbf{O}_{5}$ is orthorhombic. ${ }^{91}$ It dissociates at $1436^{\circ} \mathrm{C} .(+) 2 \mathrm{~V}=\bmod -$ erate. $n_{\mathrm{X}}=2.20 \mathrm{Li}, 2.25 \mathrm{Na}, n_{\mathrm{Y}}=2.22 \mathrm{Li}, n_{\mathrm{Z}}=2.29 \mathrm{Li}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.09$ Li. Color yellow-brown with $\mathrm{X}>\mathrm{Y}=\mathrm{Z}$. It forms mix-crystals with $\mathrm{Ca}_{2} \mathrm{Al}_{2} \mathrm{O}_{5}$ at least to $\mathrm{Ca}_{6} \mathrm{Al}_{4} \mathrm{Fe}_{2} \mathrm{O}_{15}$.
$\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{Fe}_{2} \mathrm{O}_{10}$ (Brownmillerite) is orthorhombic. ${ }^{92}$ G. 3.77. M.P. $1415^{\circ}$ C. $(-) 2 \mathrm{~V}=75^{\circ}$ calc. $n_{\mathrm{X}}=1.96 \mathrm{Li}, n_{\mathrm{Y}}=2.01, n_{\mathrm{Z}}=2.04, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ ${ }^{87}$ Geller, Yavorsky, Steierman and Creamer: J. Res. Nat. Bur. Stand. XXXVI, p. 277 (1946). [Min. Abst. XI, p. 369 (1951).]
${ }^{88}$ Geller and Bunting: J. Res. Nat. Bur. Stand. XXXI, p. 255 (1943).
${ }^{89}$ Palache, Berman and Frondel: Dana's System of Mineralogy I, p. 718 (1944).
${ }^{90}$ Rankin and Merwin: J. Am. Chem. Soc. XXXVIII, p. 568 (1916). Carstens: Zeit. Krist. LXIII, p. 473 (1926).
${ }^{91}$ Agrell: J. Iron Steel Inst. London CLII, p. 19 (1945).
${ }^{92}$ Bogue: Chemistry of Portland Cement, 1947.
0.08. It may have MgO in solid solution; then $n_{\mathrm{X}}=1.92, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=$ 1.97, G. 3.72. Pleochroic with X yellow-brown, Z brown. Also said to be monoclinic with a very small extinction angle. Found in Portland cement.
$\mathbf{C a}_{6} \mathbf{A l}_{4} \mathbf{F e}_{2} \mathbf{O}_{15}$ is orthorhombic. ${ }^{93}$ Crystals tabular. Decomposes at $1365^{\circ}$ C. $(-) 2 \mathrm{~V}=$ small. $n_{\mathrm{X}}=1.94, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.99, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.05$. Found in Portland cement mixes.
$\mathrm{CaCr}_{2} \mathbf{O}_{4}$ is orthorhombic(?). M.P. $2000^{\circ}$ C. 士. Biaxial. ${ }^{94}$ Extinction parallel with cleavage and elongation. Refractive indices very high. Green and pleochroic. Found in chrome-dolomite refractories. Polymorphous. PD 5.51, 2.76, 2.29; 9-151*.
$\mathrm{CaAl}_{4} \mathrm{O}_{7}$ has two crystal phases. ${ }^{76}$ The $\alpha$-phase is monoclinic. ${ }^{95}$ H. 6.5. Melts incongruently at about $1765^{\circ} \mathrm{C}$. $\mathrm{Z} \wedge$ elongation ${ }^{96}=39^{\circ}$. ( + ) $2 \mathrm{~V}=$ $0^{\circ}-5^{\circ} . n_{\mathrm{X}} \approx n_{\mathrm{Y}}=1.617, n_{\mathrm{Z}}=1.651, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.035$. The $\beta$-phase is probably orthorhombic; it is unstable. Prismatic cleavage. H. 5.5-6. Z parallel elongation. (-) $2 \mathrm{~V}=35^{\circ}, \mathrm{r}>\mathrm{v}$ strong. $n_{\mathrm{X}}=1.662, n_{\mathrm{Y}}=1.671$, $n_{\mathrm{Z}}=1.674, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.012$. Colorless. Made from fusion. PD 3.52, 2.61, 4.44;7-82.
$\mathrm{SrAl}_{4} \mathbf{O}_{7}$ is monoclinic(?) in prisms with extinction ${ }^{84}$ reaching $45^{\circ}$. $(+) 2 \mathrm{~V}=$ large. $\quad n_{\mathrm{X}}=1.614, \quad n_{\mathrm{Y}}=?, \quad n_{\mathrm{Z}}=1.640, \quad n_{\mathrm{Z}}-n_{\mathrm{X}}=0.026$, $\therefore n_{\mathrm{Y}}=1.625 \mathrm{ca}$.
$\mathbf{C a}_{3} \mathbf{F e}_{2} \mathbf{O}_{6}$ is monoclinic. ${ }^{91}$ Crystals acicular with a small extinction angle to Z. $n_{\mathrm{X}}$ decidedly greater than $1.73 ; n_{\mathrm{Z}}-n_{\mathrm{X}}=0.017 c a$. Metallic and dead black in reflected light. Opaque to deep ruby red in tiny needles.
$\mathbf{C a}_{2} \mathbf{G e O}_{4}$ is triclinic. ${ }^{98}$ Crystals are white or slightly greenish. $n_{\mathrm{x}}=$ $1.724, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.739, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.015$.

## 3. Formula Type $A_{m} B_{n} X_{p}$ with $(m+n): p \approx 2: 3$

$\mathrm{SrTiO}_{3}$ is isometric with ${ }^{99} a=3.90 \AA$. Conchoidal fracture. H. 6-6.5. G. 5.12. M.P. $2080^{\circ}$ C. Isotropic with $n=2.380 \mathrm{C}, 2.409 \mathrm{D}, 2.488 \mathrm{~F}$. $n_{\mathrm{F}}-n_{\mathrm{C}}=0.108$. Color often dark blue to black; but when fully oxidized water-white. Slight impurities cause various colors including yellow, red and blue. PD 2.76, 1.95, 1.59; 5-0634.

[^51]$\mathrm{CaAl}_{12} \mathbf{O}_{19}$ is hexagonal with $a=5.536, c=21.825$. G. 3.54-3.9. Uniaxial negative ${ }^{100}$ with $n_{\mathrm{O}}=1.757, n_{\mathrm{E}}=1.750, n_{\mathrm{O}}-n_{\mathrm{E}}=0.007$ (with very little $\mathrm{SiO}_{2}, \mathrm{TiO}_{2}$, and $\mathrm{Fe}_{2} \mathrm{O}_{3}$ ). With ${ }^{100} \mathrm{SiO}_{2} 2.08, \mathrm{TiO}_{2} 8.78, \mathrm{Fe}_{2} \mathrm{O}_{3} 0.75$ per cent., $n_{\mathrm{O}}=1.790, n_{\mathrm{E}}=1.780, n_{\mathrm{O}}-n_{\mathrm{E}}=0.010$. Colorless to blue or green. PD 1.39, 2.48, 2.11; 7-85.
$\mathbf{S r A l}_{12} \mathbf{O}_{19}$ has perfect basal cleavage. It is uniaxial negative with $n_{\mathrm{O}}=$ 1.702, $n_{\mathrm{E}}=1.694, n_{\mathrm{O}}-n_{\mathrm{E}}=0.008$. Colorless. PD 2.63, 2.48, 2.11; 10-66.
$\mathbf{B a A l}_{12} \mathbf{O}_{19}$ is hexagonal with basal cleavage. G. 3.69. Uniaxial negative with $^{84} n_{\mathrm{O}}=1.702, n_{\mathrm{E}}=1.694, n_{\mathrm{O}}-n_{\mathrm{E}}=0.008$.
$\mathrm{Na}_{2} \mathrm{Al}_{12} \mathbf{O}_{19}$ is hexagonal with G. 3.33. Uniaxial negative with ${ }^{101} n_{\mathrm{O}}=$ $1.686, n_{\mathrm{E}}=1.650, n_{\mathrm{O}}-n_{\mathrm{E}}=0.036$. Again: $n_{\mathrm{O}}=1.670, n_{\mathrm{E}}=1.633$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.037$. Colorless.
$\mathrm{K}_{2} \mathrm{Al}_{12} \mathrm{O}_{19}$ ( $\beta$-alumina) is hexagonal. G. 2.40. Uniaxial negative with ${ }^{101}$ $n_{\mathrm{O}}=1.696, n_{\mathrm{E}}=1.660, n_{\mathrm{O}}-n_{\mathrm{E}}=0.036$. Again: ${ }^{102} n_{\mathrm{O}}=1.668, n_{\mathrm{E}}=$ $1.64, n_{\mathrm{O}}-n_{\mathrm{E}}=0.028$. Colorless. PD 1.40, 2.51, 2.69; 1-1301.
$\mathrm{FeTiO}_{3}$ (Ilmenite) is hexagonal with $a=5.083, c=14.04 k X$. Crystals often basal tablets. H. 5.5-6. G. $4.72 \pm .04$. Uniaxial negative with high indices and very strong birefringence. Color iron black; streak black. Opaque except in very thin splinters, which transmit only red light. Percentage reflection for all colors: 18. Probably forms a complete series of mix-crystals with $\mathrm{MgTiO}_{3}$ and also with $\mathrm{MnTiO}_{3}$. PD 2.74, 1.72, 2.54; 3-0781.
$\mathrm{MgTiO}_{3}$ (Geikielite) is hexagonal with $a=5.086, c=14.093 \mathrm{kX} . \mathrm{H}$. $5-6$. G. 4.05. M.P. $1630^{\circ}$ C. Rhombohedral cleavage. Uniaxial negative with $^{13} n_{\mathrm{O}}=2.31, n_{\mathrm{E}}=1.95, n_{\mathrm{O}}-n_{\mathrm{E}}=0.36$. Again ${ }^{81} n_{\mathrm{O}}=2.28, n_{\mathrm{E}}=$ 1.95. Color brownish black; in thin section purplish red with $O<E$, faint. PD 2.72, 2.22, 2.53; 6-0494.
$\mathrm{MnTiO}_{3}$ (Pyrophanite) is hexagonal with $a=5.126, c=14.333$. Crystals fine scales. Perfect $\{02 \overline{2} 1\}$ cleavage. H. 5-6. G. 4.54. Uniaxial negative with ${ }^{13} n_{\mathrm{O}}=2.481 \mathrm{Na}, n_{\mathrm{E}}=2.210 \mathrm{Na}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.271 \mathrm{Na}$. Also $n_{\mathrm{o}}=2.441 \mathrm{Li}$. Color deep blood-red; yellowish red in section; not pleochroic. PD 2.79, 2.58, 1.75; 2-0846.
$\mathbf{A l}_{2} \mathbf{T i O}{ }_{5}$ is orthorhombic with ${ }^{103} a=9.60, b=9.63, c=3.60 \AA . \mathrm{G} .3 .62$. M.P. $1890^{\circ}$ C. Parallel extinction. $n_{\mathrm{X}}=1.98, n_{\mathrm{Z}}=2.04, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.06$. Again: $n_{\mathrm{X}}=2.025, n_{\mathrm{Z}}=2.06, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.035-0.04$. PD 2.66, 1.60, 4.74; 9-252.
${ }^{100}$ Filonenko: C. R. Acad. Sci. U.R.S.S. XLVIII, p. 430 (1945) [Min. Abst. IX, p. 282].
${ }^{101}$ Tropov and Stukalova: Dokl. Akad. Sci. U.S.S.R. XXIV, p. 459 (1939).
${ }^{102}$ Kato and Yamaguchi: J. Jap. Ceram. Assoc. LI, p. 465, 543, 586, 640 (1943), [Chem. Abst. XLV, p. 7755 (1951)].
${ }^{103}$ Yamaguchi: J. Jap. Ceram. Assoc. LII, p. 6 (1944) [Chem. Abst. XLV, p. 7925 (1951)].
$\mathbf{C a}_{3} \mathbf{T i}_{2} \mathbf{O}_{7}$ has parallel extinction and positive elongation. ${ }^{104}$ Uniaxial (or nearly so) and negative. $n_{\mathrm{O}}=2.22, n_{\mathrm{E}}=2.16, n_{\mathrm{O}}-n_{\mathrm{E}}=0.06$. PD 1.95, 4.9, 9.7; 6-0698.
$\mathbf{B a T i O}_{3}$ has at least three crystal phases. ${ }^{105}$ The stable phase above $120^{\circ}$ C. is isometric ${ }^{105 a}$ with $n=2.40$ at $20^{\circ}$ C., 2.46 at $120^{\circ}$ C. and 2.42 at $140^{\circ} \mathrm{C}$. Another phase is tetragonal, but optic data are not known. A third phase (stable below $5^{\circ} \mathrm{C}$.) is biaxial orthorhombic with ${ }^{106}(-) 2 \mathrm{~V}=$ large, $n_{\mathrm{X}}=2.395, n_{\mathrm{Y}}=2.401, n_{\mathrm{Z}}=2.406, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.011$ at $20^{\circ} \mathrm{C}$. $(-$ ? $) 2 \mathrm{~V}=$ large, $n_{\mathrm{X}}=2.40, n_{\mathrm{Y}}=2.405, n_{\mathrm{Z}}=2.410, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.010$ at $90^{\circ} \mathrm{C}$. $(-?) 2 \mathrm{~V}=$ large, $n_{\mathrm{X}}=2.456, n_{\mathrm{Y}}=2.46, n_{\mathrm{Z}}=2.466, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.010$ at $115^{\circ} \mathrm{C}$. The birefringence is ${ }^{107} 0.056$ at $20^{\circ} \mathrm{C} ., 0.038$ at $90^{\circ} \mathrm{C}$. and 0.018 at $115^{\circ}$ C. PD 2.83, 2.31, 2.00; 5-0626.
$\mathbf{C a T i O}_{3}$ (Perovskite) is pseudo-isometric and orthorhombic (or monoclinic?). Crystals apparently cubic, rarely octahedral. Poor $\{001\}$ cleavage. H. 5.5. G. 4.01, increasing to 4.88 when Ce replaces some Ca. Isotropic or weakly birefringent. $\mathrm{Y}=c, \mathrm{X}=a$ in the orthorhombic interpretation or $\mathrm{Y}=b, \mathrm{Z} \wedge c($ or $a)=45^{\circ}$ in the monoclinic interpretation. $(+) 2 \mathrm{~V}=$ $90^{\circ} \pm, \mathrm{r}>\mathrm{v}$, mean index ${ }^{13} n=2.38$ (or, with $\mathrm{Ce}, 2.30-2.37$; with Cb , $2.33 \pm .02$ ). Often contains rare earths and may contain $\mathrm{Cb}, \mathrm{Na}, \mathrm{Fe}, \mathrm{Mg}$, etc. Color black or brown or yellow. Black samples opaque except in thin splinters. PD 2.70, 1.91, 1.56; 9-365*.
$\mathbf{P b Z r O}_{3}$ is orthorhombic ${ }^{105 a}$ (like one phase of $\mathrm{BaTiO}_{3}$ ). $\mathrm{X}=a, \mathrm{Y}=b$, $\mathrm{Z}=c$. (-) 2 V near $90^{\circ} . n_{\mathrm{Z}}$ about $2.2, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.039$. (Therefore, $n_{\mathrm{Y}} \approx$ 2.180 and $n_{\mathrm{X}}=2.161$. A.N.W.). PD 2.94, 1.70, 1.46; 3-0655.
$\mathbf{M g T i}_{2} \mathbf{O}_{5}$ is biaxial with ${ }^{108}$ M.P. $1652^{\circ}$ C., $n_{\mathrm{X}}=2.19, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=2.32$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.13$. Again $:^{81}(-) 2 \mathrm{~V}=70^{\circ}$ calc., $n_{\mathrm{X}}=2.11, n_{\mathrm{Y}}=2.19, n_{\mathrm{Z}}=$ $2.23, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.12$. Formed in slags rich in titanium. PD 3.51, 2.75, 1.88; 9-16.
$\mathrm{Fe}_{2} \mathbf{T i O}_{5}$ (Pseudobrookite) is orthorhombic with $a=9.79, b=9.93$, $c=3.725 k X$. U.C. 4. Crystals $\{100\}$ tablets or prismatic and vertically striated. Distinct $\{010\}$ cleavage. H. 6. G. 4.39. $\mathrm{X}=b, \mathrm{Y}=c .(+) 2 \mathrm{~V}=$ $50^{\circ} \pm, \mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=2.38 \mathrm{Li}, n_{\mathrm{Y}}=2.39, n_{\mathrm{Z}}=2.42, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.04$. Color brown with $\mathrm{X}<\mathrm{Y}>\mathrm{Z}$. Formed as a sublimation product. PD 3.48, 2.75, 4.90; 9-162.
$\mathbf{T i T i}_{2} \mathbf{O}_{5}$ (Anosovite) is orthorhombic with ${ }^{108} a=3.747, b=9.465, c=$
${ }^{104}$ Fisk: J. Am. Ceram. Soc. XXXIV, p. 9 (1951) [Chem. Abst. XLV, p. 2643 (1951)].
${ }^{105}$ Matthias and von Hippel: Phys. Rev. LXXIII, p. 268 (1948).
${ }^{105 a}$ Jona, Shirane and Pepinsky: Phys. Rev. XCVII, p. 1581 (1955).
${ }^{106}$ Bush, Fleury and Merz: Helv. Phys. Acta, XXI, p. 212 (1948).
${ }^{107}$ Merz: Phys. Rev. LXXVI, p. 1221 (1949).
${ }^{108}$ Belyankin and Lapin: Dokl. Akad. Sci. U.S.S.R. LXXX, p. 421 (1951) [Min. Abst. XI, p. 415]. Also Rusakov and Zhdanov: Dokl. Akad. Sci. U.S.S.R. LXXVI, p. 411 (1951) [Min. Abst. XI, p. 415].
1.95. Uniaxial negative with ${ }^{112} n_{\mathrm{O}}=1.522, n_{\mathrm{E}}=1.502, n_{\mathrm{O}}-n_{\mathrm{E}}=0.020$. Again: ${ }^{119} n_{\mathrm{O}}=1.519, n_{\mathrm{E}}=1.506, n_{\mathrm{O}}-n_{\mathrm{E}}=0.013$. Also reported with $(-) 2 \mathrm{~V}=7^{\circ}$. Colorless.
$\mathrm{Ca}_{3} \mathrm{Al}_{2} \mathrm{O}_{6} \cdot 10-12 \mathrm{H}_{2} \mathrm{O}$ is hexagonal. Uniaxial negative with ${ }^{112}$ notable variation in the indices (due to variation in $\mathrm{H}_{2} \mathrm{O}$ ?); for example: with $11 \mathrm{H}_{2} \mathrm{O}, n_{\mathrm{O}}=1.530, n_{\mathrm{E}}=1.510, n_{\mathrm{O}}-n_{\mathrm{E}}=0.020$; with ${ }^{115} ? \mathrm{H}_{2} \mathrm{O}: n_{\mathrm{O}}=$ $1.520, n_{\mathrm{E}}=1.504, n_{\mathrm{O}}-n_{\mathrm{E}}=0.016$. Colorless. This is said to be an intimate mixture ${ }^{112}$ of $\mathrm{Ca}_{2} \mathrm{Al}_{2} \mathrm{O}_{5} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ and $\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{O}_{7} \cdot 13 \mathrm{H}_{2} \mathrm{O}$ in equal portions. PD 7.65, 3.77, 2.86; 2-0083.

## 3. Formula Type $A_{m} B_{n} X_{p} \cdot \mathbf{x H}_{2} \mathrm{O}$ with ( $m+n$ ):p $\boldsymbol{1 : 2}$

( $\mathbf{C a}, \mathrm{Na}_{2}$ ) $\mathrm{U}_{2} \mathrm{O}_{7} \cdot \mathrm{nH}_{2} \mathrm{O}$ (Clarkeite) often contains some Pb and K and there may be a complete $\mathrm{Ca}-\mathrm{Na}_{2}$ series. ${ }^{120} \mathrm{H}_{2} \mathrm{O}$ is common, but was probably absent in the synthetic product. H. 4-5. G. 6.39. The mean refractive index is above 2.00 for the Ca compound and about 1.84 for the Na compound. An intermediate sample found in nature as an alteration product of uraninite $\left(\mathrm{UO}_{2}\right)$ has $(-) 2 \mathrm{~V}=30-50^{\circ}, n_{\mathrm{X}}=1.997, n_{\mathrm{Y}}=2.098, n_{\mathrm{Z}}=$ $2.180, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.117$. Color yellow to brown. Made from uranyl nitrate solutions and $\mathrm{CaCO}_{3}$ or CaO at about $260^{\circ} \mathrm{C} . \mathrm{PD} 3.17,3.34,5.77 ; 8-315$.
$\mathbf{C u O} \cdot \mathrm{UO}_{3} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ (Vandenbrandeite) is triclinic. Crystals basal plates or laths. Perfect $\{001\}$ cleavage with distinct cleavage normal to it and another poor cleavage. H. 4. G. 5.03. An optic axis nearly normal to $\{001\}$; $\mathrm{Z} \wedge$ elongation ${ }^{121}=40^{\circ} \pm .(-$ ? $) 2 \mathrm{~V}=$ large. $n_{\mathrm{X}}=1.77 \pm .02, n_{\mathrm{Y}}=1.78$ $\pm .02, n_{\mathrm{Z}}=1.80 \pm .02, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.03$. Again: ${ }^{121 \mathrm{a}} n_{\mathrm{X}}=1.765 \pm .005$, $n_{\mathrm{Y}}=1.792 \pm .002,2 \mathrm{~V}$ near $90^{\circ}$ for triclinic natural material with $a=7.84$, $b=5.43, c=6.09 k X, \alpha=91^{\circ} 52^{\prime}, \beta=102^{\circ} 00^{\prime}, \gamma=89^{\circ} 37^{\prime}$. PD 4.44, 5.26, 2.97; 8-325*.

## 4. Formula Type $A_{m} B_{n} X_{p} \cdot \mathrm{xH}_{2} \mathrm{O}$ with $(m+n): p \approx 2: 5$

$\mathbf{P b O} \cdot 4 \mathrm{UO}_{3} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ (?) (Fourmarierite) is orthorhombic with ${ }^{122} a: b: c=$ $0.982: 1: 0.811$. Crystals $\{010\}$ plates, long parallel to $c$. Perfect $\{010\}$ cleavage. H. 3-4. G. $6.05 . \mathrm{X}=b ; \mathrm{Y}=a$. (-)2V large, $\mathrm{r}>\mathrm{v}$ strong. ${ }^{15}$ $n_{\mathrm{X}}=1.85, n_{\mathrm{Y}}=1.92, n_{\mathrm{Z}}=1.94, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.09$. Color red to brown; pleochroic with X colorless, Y pale yellow, Z yellow. Made from solution at $100^{\circ}$ C. PD 3.08, 3.43, $1.90 ; 8-303^{*}$.
$\mathbf{P b O} \cdot 3 \mathrm{UO}_{3} \cdot 2 \mathrm{H}_{2} \mathbf{O}$ (?) (Curite) is orthorhombic with $a=12.52, b=$ $12.98, c=8.35 \AA$. Crystals prismatic; usually massive. $\{100\}$ cleavage. H. 4-5. G. 7.2. $\mathrm{X}=b ; \mathrm{Y}=a$. $(-) 2 \mathrm{~V}=$ large, $\mathrm{r}>\mathrm{v}$ strong. $n_{\mathrm{x}}=2.06$,

[^52]$n_{\mathrm{Y}}=2.11, n_{\mathrm{Z}}=2.15, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.09$. Again: ${ }^{122 \mathrm{a}} n_{\mathrm{X}}=2.05, n_{\mathrm{Y}}=2.08$, $n_{\mathrm{Z}}=2.12, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.07$. Color orange-red; pleochroic with X pale yellow, Y light red-orange, Z dark red-orange. Made from solution ${ }^{123}$ at $180^{\circ}$ C. and higher, PD 6.28, 3.97, 3.14; 8-292.

## D. COMPOUND OXIDES

$\mathbf{N a C a C b}_{2} \mathbf{O}_{6} \mathbf{F}$ (Pyrochlore) is isometric hexoctahedral. $a=10.37 \AA$. Crystals octahedral; also granular. Octahedral cleavage (or parting?) distinct to poor. H. 5-5.5. G. $4.5 \pm$. Isotropic with ${ }^{13} n=1.96$, increasing with tenor of Ta. Forms a continuous series of mix-crystals with $\mathrm{NaCaTa} \mathrm{O}_{6} \mathrm{~F}$ (microlite) and usually contains other elements including $\mathrm{K}, \mathrm{Mg}, \mathrm{Fe}, \mathrm{Mn}$, $\mathrm{Ce}, \mathrm{La}, \mathrm{Ti}$, etc. Colorless, yellow, brown. May show weak anomalous birefringence or a zonal structure in shades of brown or yellow. The index probably decreases with alteration by hydration; on ignition $n$ increases to $2.0-2.2$. PD 1.84, 1.57, 1.19; 3-1100.
$(\mathbf{N a}, \mathrm{Ca})_{2} \mathbf{T a}_{2} \mathrm{O}_{6}(\mathbf{O}, \mathbf{O H}, \mathrm{~F})$ (Microlite) is isometric ${ }^{124} . a=10.42 \AA$. Crystals octahedral with poor octahedral cleavage. G. 6.12. Isotropic with ${ }^{124} n=2.055$. Forms mix-crystals with $\mathrm{NaCaCb}_{2} \mathrm{O}_{6} \mathrm{~F}$, and usually contains other elements including $\mathrm{K}, \mathrm{Mg}, \mathrm{Fe}, \mathrm{Mn}, \mathrm{Ce}, \mathrm{La}, \mathrm{Ti}$, etc. Colorless, yellow, brown, etc. The index probably decreases with alteration by hydration; on ignition (changing from the metamict to the crystalline state) $n$ increases to 2.0-2.2. PD 1.57, 1.84, 3.00; 3-1139.
$\mathrm{Mg}_{6} \mathrm{Al}_{2}(\mathrm{OH})_{16} \mathrm{CO}_{3} \cdot \mathbf{4 H _ { 2 }} \mathbf{O}$ (Hydrotalcite) is hexagonal with $a=6.13$, $c=46.15 \AA$. U.C. 3. Crystals basal tablets. Massive or lamellar. Perfect basal cleavage. H. 2. G. 2.06. Uniaxial negative with ${ }^{125} n_{0}=1.511$, $n_{\mathrm{E}}=1.495, n_{\mathrm{O}}-n_{\mathrm{E}}=0.016$. Also small 2 V due to strain. Again: ${ }^{125}$ $n_{\mathrm{O}}=1.510-1.518, n_{\mathrm{E}}=1.494-1.504, n_{\mathrm{O}}-n_{\mathrm{E}}=0.012-0.017$. Colorless. Found in boiler deposits.
$\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{O}_{6} \mathrm{Cl}_{2} \cdot 10 \mathrm{H}_{2} \mathrm{O}$ is hexagonal ${ }^{125 a}$ in basal plates with $c / a=2.067$. Uniaxial negative with $n_{\mathrm{O}}=1.550, n_{\mathrm{E}}=1.535, n_{\mathrm{O}}-n_{\mathrm{E}}=0.015$. Again: $:^{117}$ $n_{\mathrm{O}}=1.552, n_{\mathrm{E}}=1.533, n_{\mathrm{O}}-n_{\mathrm{E}}=0.019$. Colorless. Below $36^{\circ} \mathrm{C}$. it is monoclinic and pseudo-hexagonal in basal plates with complex twinning and $a: b: c=0.579: 1: 1.378, \beta=92^{\circ} 40^{\prime}$. G. 1.89 . $\mathrm{Y}=b$; an optic axis is nearly normal to (001).
$\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{O}_{6} \mathrm{Br}_{2} \cdot 8-\mathbf{1 0 H}_{2} \mathrm{O}$ is hexagonal. ${ }^{117}$ Crystals basal plates. Uniaxial negative. With $8 \mathrm{H}_{2} \mathrm{O}: n_{\mathrm{O}}=1.570, n_{\mathrm{E}}=1.558, n_{\mathrm{O}}-n_{\mathrm{E}}=0.012$. With $10 \mathrm{H}_{2} \mathrm{O}: n_{\mathrm{O}}=1.556, n_{\mathrm{E}}=1.546, n_{\mathrm{O}}-n_{\mathrm{E}}=0.010$. Colorless.
${ }^{122 \mathrm{a}}$ Branche, Chervet and Guillemin, Bull. Soc. Fr. Min. Crist. LXXIV, p. 457 (1951).
${ }^{123}$ Gruner: Am. Min. XXXVIII, p. 342 (1953).
${ }^{124}$ Pecora, Switzer, Barbosa and Myers: Am. Min. XXXV, p. 899 (1950).
${ }^{125}$ Frondel: Am. Min. XXVI, p. 295 (1941).
${ }^{125 a}$ Wells: J. Res. Nat. Bur. Stand. I, p. 951 (1928).
$\mathbf{C a}_{4} \mathbf{A l}_{2} \mathbf{O}_{6} \mathbf{I}_{2} \cdot \mathbf{8} \mathbf{H}_{2} \mathbf{O}$ is hexagonal. ${ }^{117}$ Crystals platy spherulites. Uniaxial negative with $n_{\mathrm{O}}=1.575 \pm 0.002, n_{\mathrm{E}}=1.572 \pm 0.002, n_{\mathrm{O}}-n_{\mathrm{E}}=0.003$. Colorless.
$\mathrm{Ca}_{4} \mathbf{A l}_{2} \mathbf{O}_{6} \cdot \mathbf{C O}_{2} \cdot \mathbf{1 1 H}_{2} \mathbf{O}$ forms hexagonal plates. Uniaxial negative ${ }^{126}$ with $n_{0}=1.552, n_{\mathrm{E}}=1.532, n_{\mathrm{O}}-n_{\mathrm{E}}=0.020$. Colorless.
$\mathrm{Ca}_{4} \mathbf{A l}_{2} \mathrm{O}_{6}\left(\mathbf{N O}_{3}\right)_{2} \cdot \mathbf{1 0 H}_{\mathbf{2}} \mathbf{O}$ forms hexagonal plates often in spherulitic groups. Uniaxial positive with ${ }^{117} n_{\mathrm{O}}=1.502, n_{\mathrm{E}}=1.532, n_{\mathrm{E}}-n_{\mathrm{O}}=0.030$. Colorless.
$\mathrm{Ca}_{4} \mathbf{A l}_{2} \mathrm{O}_{6} \cdot\left(\mathrm{ClO}_{3}\right)_{2} \cdot \mathbf{1 0} \mathrm{H}_{2} \mathrm{O}$ forms hexagonal plates often in spherulitic groups. Uniaxial (positive?) with ${ }^{117} n_{\mathrm{O}}=1.519-1.521, n_{\mathrm{E}}=1.521, n_{\mathrm{E}}-$ $n_{0}=0.002-0.000$. Colorless.
$\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{O}_{7} \cdot\left(\mathbf{C H}_{3} \cdot \mathbf{C O}_{2}\right)_{2} \cdot \mathbf{8} \mathrm{H}_{\mathbf{2}} \mathrm{O}$ forms thin hexagonal plates mostly in spherulitic groups. Uniaxial negative with $^{117} n_{\mathrm{O}}=1.549, n_{\mathrm{E}}=1.538$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.011$. Colorless.
$\mathbf{C a}_{4} \mathbf{A l}_{2} \mathrm{O}_{7} \cdot \mathbf{S O}_{3} \cdot \mathbf{1 2} \mathrm{H}_{2} \mathbf{O}$ forms hexagonal plates often in spherulitic groups. Uniaxial negative with ${ }^{127} n_{\mathrm{O}}=1.504, n_{\mathrm{E}}=1.488, n_{\mathrm{O}}-n_{\mathrm{E}}=0.016$.
$\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{O}_{7} \cdot \mathbf{S i O}_{2} \cdot \mathbf{1 2 H}_{2} \mathrm{O}$ is hexagonal. Uniaxial negative with ${ }^{128} n_{\mathrm{O}}=$ $1.538, n_{\mathrm{E}}=1.523, n_{\mathrm{O}}-n_{\mathrm{E}}=0.015$.
$\mathrm{Ca}_{5} \mathrm{Al}_{2} \mathrm{O}_{8}\left(\mathrm{IO}_{3}\right)_{2} \cdot \mathbf{2 2 \mathrm { H } _ { 2 } \mathrm { O }}$ forms long needles, probably hexagonal. Uniaxial negative with $n_{\mathrm{O}}=1.521, n_{\mathrm{E}}=1.496, n_{\mathrm{O}}-n_{\mathrm{E}}=0.025$.
$\mathbf{C a}_{6} \mathbf{A l}_{2} \mathbf{O}_{9} \cdot\left(\mathbf{I O}_{3}\right)_{2} \cdot \mathbf{3 3} \mathbf{H}_{2} \mathbf{O}$ forms long needles, probably hexagonal. Very weakly birefringent with mean $n=1.471$.
$\mathbf{M g}_{4} \mathrm{Al}_{10} \mathrm{Si}_{2} \mathbf{O}_{23}$ (Sapphirine) is monoclinic with $a=9.70, b=14.55$, $c=10.05 \AA, \beta=111^{\circ} 27^{\prime}$. H. 7.5. G. 3.4-3.5. Incongruent melting ${ }^{128}$ at $1475^{\circ} \mathrm{C} . \mathrm{Y}=b ; \mathrm{Z} \wedge c=6^{\circ}-9^{\circ} . \mathrm{Mg}$ may be replaced, at least in part, by Fe. With very little Fe (only 0.65 per cent FeO ): ( - ) $2 \mathrm{~V}=68^{\circ} 49^{\prime}$, $n_{\mathrm{X}}=1.7055, n_{\mathrm{Y}}=1.7088, n_{\mathrm{Z}}=1.7112$ (red), $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0057$. With $3.09 \mathrm{FeO}:(-) 2 \mathrm{~V}=50^{\circ} 30^{\prime}, n_{\mathrm{X}}=1.714, n_{\mathrm{Y}}=1.719, n_{\mathrm{Z}}=1.720 \mathrm{Na}$, $n_{\mathrm{z}}-n_{\mathrm{X}}=0.006$. With $9.08 \mathrm{FeO}:(-) 2 \mathrm{~V}$ rather large, $n_{\mathrm{X}}=1.729 \mathrm{Na}$, $n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.734, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.005$. Color pale blue (darker with Fe ). Made from fusion.

[^53]
## V. Carbonates, Nitrates, and Halates

All artificially produced carbonates, nitrates and halates whose optical properties
have been measured are included. An outline classification follows:
A. Acid Carbonates . . . . . . . . . . . . . . . . . . . . . . . . . . 87
B. Normal Carbonates . . . . . . . . . . . . . . . . . . . . . . . . 90

1. Formula Type $\mathrm{A}_{2} \mathrm{CO}_{3}$ (and $\mathrm{ABCO}_{3}$ ) . . . . . . . . . . . . . . . . 90
$\alpha$. Anhydrous . . . . . . . . . . . . . . . . . . . . . . . . . 90
B. Hydrated . . . . . . . . . . . . . . . . . . . . . . . . . . 90
2. Formula Type $\mathrm{ACO}_{3}$. . . . . . . . . . . . . . . . . . . . . . 91

ג. Anhydrous . . . . . . . . . . . . . . . . . . . . . . . . . 91
乃. Hydrated . . . . . . . . . . . . . . . . . . . . . . . . . . 94
3. Formula Type $\mathrm{AB}\left(\mathrm{CO}_{3}\right)_{2}$. . . . . . . . . . . . . . . . . . . . . 95
4. Formula Type $\mathrm{A}_{2}\left(\mathrm{CO}_{3}\right)_{3} \cdot n \mathrm{H}_{2} \mathrm{O}$. . . . . . . . . . . . . . . . . . 95
5. Formula Type $\mathrm{A}_{m} \mathrm{~B}_{n}\left(\mathrm{CO}_{3}\right)_{p}$ with $(m+n): p \approx 3: 2$. . . . . . . . 96
$\alpha$. Anhydrous . . . . . . . . . . . . . . . . . . . . . . . . . 96
8. Hydrated . . . . . . . . . . . . . . . . . . . . . . . . . . 96
C. Carbonates Containing Hydroxyl or Halogen or Extra Oxygen . . . . . 97

1. Formula Type $\mathrm{A}_{\boldsymbol{m}}\left(\mathrm{CO}_{3}\right)_{p} \mathbf{Z}_{q}$. . . . . . . . . . . . . . . . . . . . 97
2. Formula Type $\mathrm{A}_{\boldsymbol{m}} \mathrm{B}_{n}\left(\mathrm{CO}_{3}\right)_{p} \mathrm{Z}_{q}$. . . . . . . . . . . . . . . . . . . 98
D. Compound Carbonates . . . . . . . . . . . . . . . . . . . . . . . 100
E. Nitrates and Nitrites . . . . . . . . . . . . . . . . . . . . . . . . 100
3. Formula Type $\mathrm{ANO}_{3}$. . . . . . . . . . . . . . . . . . . . . . . 100
. Anhydrous . . . . . . . . . . . . . . . . . . . . . . . . . 100
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## A. ACID CARBONATES

$\left(\mathbf{N H}_{4}\right) \mathbf{H C O}_{3}$ (Teschemacherite) is orthorhombic with $a=7.29 ; b=$ $10.79, c=8.76 k X$. Space group Pccn. U.C. 8. Crystals prismatic or equant. Perfect $\{110\}$ cleavages at $68^{\circ}$. H. 1.5. G. 1.57. F. 5.5, but volatile.


Fig. 5-1. A crystal habit of $\mathrm{NaHCO}_{3}$.
Fig. 5-2. $\mathrm{NaHCO}_{3}$ crystals drawn from a photomicrograph.
Fig. 5-3. Optic orientation of $\mathrm{NaHCO}_{3}$ twin.
$\mathrm{X}=a,^{1,2} \mathrm{Y}=b .(-) 2 \mathrm{~V}=41^{\circ} 38^{\prime}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{X}}=1.4227, n_{\mathrm{Y}}=1.5358$, $n_{\mathrm{Z}}=1.5545, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.1318 \mathrm{Na}$. Colorless. Made from $\mathrm{H}_{2} \mathrm{O}$ solution in closed vessels. PD 3.00, 5.34, 3.62; 9-415.
$\mathbf{N a H C O}_{3}$ (Nahcolite) is monoclinic with $a=7.51, b=9.70, c=3.53 k X$, $\beta=93^{\circ} 19^{\prime}$. Space group $P 2_{1} / n$. Crystals $\{010\}$ tablets with $\{110\},\{111\}$ and $\{11 \overline{1}\}$; see Figs. 5-1, 5-2, 5-3; often twinned on $\{101\}$. Perfect $\{101\}$, good $\{111\}$ and poor $\{100\}$ cleavages. H. 2.5. G. 2.21. $\mathrm{X} \wedge c=+27.5^{\circ}$, $\mathrm{Y}=b .(-) 2 \mathrm{~V}=75^{\circ}$ ca., $\mathrm{r}>\mathrm{v}$ weak. $n_{\mathrm{X}}=1.380, n_{\mathrm{Y}}=1.500, n_{\mathrm{Z}}=$ $1.586, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.206$. Again: ${ }^{3} n_{\mathrm{X}}=1.376, n_{\mathrm{Y}}=1.500, n_{\mathrm{Z}}=1.582$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.206$. Since the extinction angle is about half the angle between the $c$ axes in $\{101\}$ twins, the substance may be recognized by the peculiar condition that both parts of the twin go to extinction simultaneously. ${ }^{4}$ The substance is colorless. It is commonly called baking soda. PD 2.94, 2.61, 2.21; 3-0653.
$\mathrm{KHCO}_{3}$ (Kalicinite) is monoclinic with $a=15.01, b=5.69, c=$ $3.68 k X, \beta=104^{\circ} 30^{\prime}$. U.C. 4. Space group $P 2_{1} / a$. Crystals often prismatic, with $\{100\},\{001\}$ and $\{101\}$ cleavages. Soft. G. 2.16. F. easy. Soluble in water. $\mathrm{X} \wedge c=+30^{\circ} ; \mathrm{Y}=b$. (-) $2 \mathrm{~V}=81.5^{\circ} . n_{\mathrm{X}^{5}}=1.380 \mathrm{Na}, n_{\mathrm{Y}}=$ $1.482, n_{\mathrm{Z}}=1.573, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.193 \mathrm{Na}$. Also: $n_{\mathrm{X}}=1.379 \mathrm{C}, 1.383 \mathrm{~F}$, $n_{\mathrm{Y}}=1.4794 \mathrm{C}, 1.487 \mathrm{~F}, n_{\mathrm{Z}}=1.569 \mathrm{C}, 1.581 \mathrm{~F}$. Colorless to white. Made by passing $\mathrm{CO}_{2}$ into an aqueous solution of $\mathrm{K}_{2} \mathrm{CO}_{3}$. PD 2.84, 3.68, 2.62; 1-0976.
$\mathrm{Na}_{3} \mathrm{H}\left(\mathrm{CO}_{3}\right)_{2} \cdot \mathbf{2 H}_{2} \mathrm{O}$ (Trona) is monoclinic with ${ }^{5 \mathrm{a}} a=20.41, b=3.49$, $c=10.31 \AA, \beta=106^{\circ} 20^{\prime}$. Space group $C 2 / c$ or $C c$. Crystals $\{001\}$ tablets


Fig. 5-4. A crystal habit of $\mathrm{HNa}_{3}\left(\mathrm{CO}_{3}\right)_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$.
elongated along $b$. Perfect $\{100\}$ and good $\{10 \overline{1}\}$ cleavages. H. 3. G. 2.13. $\mathrm{X}=b ;{ }^{6} \mathrm{Z} \wedge c=83^{\circ}$. (-) $2 \mathrm{~V}=72^{\circ}, \mathrm{r}<\mathrm{v}$ marked. $n_{\mathrm{X}}{ }^{6}=1.412, n_{\mathrm{Y}}=$ 1.492, $n_{\mathrm{Z}}=1.540, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.128$. Again: ${ }^{5 \mathrm{a}} n_{\mathrm{X}}=1.418, n_{\mathrm{Y}}=1.492$,
${ }^{1}$ Lang: Sitz. Akad. Wiss. Wien, XLV (II), p. 112 (1862).
${ }^{2}$ Larsen: U. S. Geol. Surv. Bull. 679, 1921.
${ }^{3}$ H. E. Merwin: pers. comm., Mar., 25, 1931.
${ }^{4}$ H. L. Robson: pers. comm., Dec. 3, 1930.
${ }^{5}$ Merwin: Intern. Crit. Tables VII, 1930.
${ }^{50}$ Brown, Peiser and Turner-Jones: Acta Cryst. II, p. 167 (1949).
${ }^{6}$ Larsen and Berman: U. S. Geol. Surv. Bull. 848 (1934).
$n_{\mathrm{Z}}=1.543, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.125$. Colorless. Made from solution in water containing much NaCl and $\mathrm{Na}_{2} \mathrm{SO}_{4}$ at $50^{\circ}-85^{\circ} \mathrm{C}$. PD 3.06, 2.66, 9.42; 2-0601*.
$\mathrm{MgKH}\left(\mathrm{CO}_{3}\right)_{2} \cdot \mathbf{4} \mathrm{H}_{2} \mathrm{O}$ is triclinic. Crystals $\{010\}$ tablets with $\{110\}$ and $\{101\}$. Extinction angle on $\{010\}$ is $32^{\circ}$. ( $-2 \mathrm{~V}=65^{\circ}$ calc. $\mathrm{r}>\mathrm{v}$; $n_{\mathrm{X}}{ }^{7}=1.430, n_{\mathrm{Y}}=1.51, n_{\mathrm{Z}}=1.542, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.112$. Colorless. Made by treating a suspension of $\mathrm{MgCO}_{3} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ in a solution of KCl or $\mathrm{K}_{2} \mathrm{SO}_{4}$ with $\mathrm{CO}_{2}$.

## B. NORMAL CARBONATES

## 1. Formula Type $\mathrm{A}_{2} \mathrm{CO}_{3}$ (and $\mathrm{ABCO}_{3}$ )

## $\alpha$. Anhydrous

$\mathbf{L i N a C O} \mathbf{O}_{3}$ is hexagonal ${ }^{8}$ in prismatic crystals. Uniaxial negative with $n_{\mathrm{O}}=1.538, n_{\mathrm{E}}=1.406, n_{\mathrm{O}}-n_{\mathrm{E}}=0.132$. Colorless.
$\mathbf{L i}_{2} \mathrm{CO}_{3}$ is monoclinic with $a: b: c=1.672: 1: 1.244, \beta=114^{\circ} 25^{\prime}$. Crystals prismatic. Perfect $\{001\}$ and distinct $\{101\}$ cleavages. Common twinning on $\{100\}$. G. 2.11. M.P. $618^{\circ} . \mathrm{X} \wedge c$ nearly $0^{\circ} ; \mathrm{Z}=b$. (-) $2 \mathrm{~V}=15^{\circ} \mathrm{ca}$., $n_{\mathrm{X}}=1.428, n_{\mathrm{Y}}=1.567, n_{\mathrm{Z}}=1.572, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.144$ Na. Colorless. Made from fusion or by heating a saturated solution. PD 2.83, 4.18, 2.93; 9-359.
$\mathbf{N a}_{2} \mathrm{CO}_{3}$ made from fusion shows lamellar twinning. ${ }^{9} \cdot(-) 2 \mathrm{~V}=34^{\circ} \pm 3^{\circ}$, $n_{\mathrm{X}}=1.415, n_{\mathrm{Y}}=1.535, n_{\mathrm{Z}}=1.546, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.131$. Colorless. PD 2.36, 2.96, 2.60; 1-1166.
$\mathbf{K}_{2} \mathbf{C O}_{3}$ made from fusion shows lamellar twinning with very oblique extinction. ${ }^{9}(-) 2 \mathrm{~V}=35^{\circ} \pm 5^{\circ}, \quad n_{\mathrm{X}}=1.426 \pm .004, \quad n_{\mathrm{Y}}=1.531 \pm .002$, $n_{\mathrm{Z}}=1.541 \pm .002, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.115 \pm .006$. Colorless. PD 2.80, 2.61, 2.97; 1-1001.

## $\beta$. Hydrated

$\mathrm{Na}_{2} \mathrm{CO}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ (Thermonatrite) is orthorhombic with ${ }^{10} a=6.44, b=$ $10.72, c=5.24 \mathrm{kX}$. U.C. 4. Space group Pmmm. Crystals basal laminæ or $\{010\}$ tablets; often forms crusts. Poor $\{010\}$ cleavage. H. 1.5. G. 2.25. F. 1.5. $\mathrm{X}=b ;^{3} \mathrm{Y}=c .(-) 2 \mathrm{~V}=48^{\circ}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{X}}{ }^{2}=1.420, n_{\mathrm{Y}}=1.506$, $n_{\mathrm{Z}}=1.524, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.104$. Again: ${ }^{3} n_{\mathrm{X}}=1.420, n_{\mathrm{Y}}=1.509, n_{\mathrm{Z}}=$ $1.525, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.105$. Colorless or white. Made from solution in water at temperatures between $32^{\circ}$ and $112^{\circ}$ C. PD 2.77, 2.37, 2.75; 8-448.

[^54]$\mathbf{N a}_{2} \mathrm{CO}_{3} \cdot \mathbf{2 . 5 \mathrm { H } _ { 2 } \mathrm { O }}$ is orthorhombic with ${ }^{11} a: b: c=0.794: 1: 0.439$. Crystals acicular prismatic (often in sheaves), terminated by two planes making an angle of $134^{\circ}$. G. 2.05. $\mathrm{X}=c .(-) 2 \mathrm{~V}=$ large, $n_{\mathrm{X}}=1.435, n_{\mathrm{Y}}=1.492$, $n_{\mathrm{Z}}=1.547$, all $\pm .003, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.112$. Colorless. Formed from evaporation of a solution of Solvay soda at $18^{\circ}-25^{\circ} \mathrm{C}$.
 and an extinction angle of $15^{\circ}-20^{\circ} .(+) 2 \mathrm{~V}=66^{\circ}, n_{\mathrm{X}}=1.474, n_{\mathrm{Y}}=1.483$, $n_{\mathrm{Z}}=1.510, n_{\mathrm{z}}-n_{\mathrm{X}}=0.036 . \mathrm{K}_{2} \mathrm{CO}_{3} \cdot n \mathrm{H}_{2} \mathrm{O}$ (probably the same) has ${ }^{13}$ $(+) 2 \mathrm{~V}=60^{\circ}-65^{\circ} c a ., n_{\mathrm{X}}=1.476 \pm .003, n_{\mathrm{Y}}=1.486 \pm .003, n_{\mathrm{Z}}=1.514$ $\pm .003, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.038$. PD 2.76, 3.01, 6.90; 1-1014.
$\mathrm{Na}_{2} \mathrm{CO}_{3} \cdot \mathbf{1 0 H}_{2} \mathbf{O}$ (Natron) is monoclinic with $a: b: c=1.483: 1: 1.400$, $\beta=121^{\circ} 8^{\prime}$. Crystals $\{010\}$ tablets with distinct $\{001\}$ and poor $\{010\}$ cleavages. H. 1-1.5. G. 1.46-1.47. M.P. $34.5^{\circ}$. $\mathrm{X}=b ;^{2} \mathrm{Z} \wedge c=+41^{\circ} c a$. $(-) 2 \mathrm{~V}=71^{\circ}, \mathrm{r}>\mathrm{v}$ weak with crossed dispersion. $n_{\mathrm{X}}=1.405, n_{\mathrm{Y}}=1.425$, $n_{\mathrm{Z}}=1.440, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.035$. Colorless to white or stained. Effloresces rapidly in dry air, changing to the monohydrate. PD 2.89, 5.3, 4.03; 1-0938.

## 2. Formula Type $\mathrm{ACO}_{3}$

$\alpha$. Anhydrous
$\mathbf{M g C O}_{3}$ (Magnesite) is hexagonal-scalenohedral with $a=4.58, c=$ $14.92 k X$. Space group $R \overline{3} c$. Crystals rare; usually massive. Perfect $\{10 \overline{1} 1\}$ cleavage. H. 4. G. 3.00. Uniaxial negative with ${ }^{14} n_{\mathrm{O}}=1.700, n_{\mathrm{E}}=1.509$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.191$. Colorless or white when pure. $\mathrm{MgCO}_{3}$ is miscible in all proportions with $\mathrm{FeCO}_{3}$ and $\mathrm{ZnCO}_{3}$ and $\mathrm{CoCO}_{3}$, but has only limited miscibility with $\mathrm{CaCO}_{3}$ and $\mathrm{MnCO}_{3}$. In crystals with $\mathrm{Mg}: \mathrm{Fe}=1: 1$, $n_{\mathrm{O}}=1.788, n_{\mathrm{E}}=1.570, n_{\mathrm{O}}-n_{\mathrm{E}}=0.218$. Made by heating $\mathrm{CaCO}_{3}$ with $\mathrm{MgCl}_{2}$ or $\mathrm{MgSO}_{4}$ solution in a closed tube at $160-200^{\circ} \mathrm{C}$. PD 2.74, 2.10, 1.70; 8-479.
$\mathrm{CaCO}_{3}$ has three crystal phases; the commonest one is calcite; another is aragonite; a rare one is vaterite.
$\mathrm{CaCO}_{3}$ (Calcite) is hexagonal-scalenohedral with ${ }^{14 \mathrm{a}} a=4.9898, c=$ $17.060 \AA$ at $18^{\circ} \mathrm{C}$. Space group $R \overline{3} c$. The cell commonly used in morphological descriptions ${ }^{14 \mathrm{~b}}$ has $a^{\prime}=4 a$ and $c^{\prime}=c$, in which the cleavage is $\{10 \overline{1} 1\}$ [the cleavage is $\{10 \overline{1} 4\}$ with reference to the actual unit cell].

[^55]Crystals are extremely varied in habit: 328 crystal-forms are known and 296 more are considered uncertain. ${ }^{14 c}$ Perfect $\{10 \overline{1} 1\}$ cleavage. Parting common on $\{01 \overline{1} 2\}$, rare on $\{0001\}$. See Figs. $5-5$ and 5-6. H. 3. G. 2.71. F. 7, but calcite dissociates at $900^{\circ} \mathrm{C}$. Under pressures above 110 atmos-


Fig. 5-5.


Fig. 5-6.

Figs. 5-5, 5-6. Crystal habits of $\mathrm{CaCO}_{3}$, calcite.
pheres it melts at $1290^{\circ} \mathrm{C}$. Soluble in cold dilute HCl with effervescence. Uniaxial negative with $n_{\mathrm{O}}=1.6544 \mathrm{C}, 1.6584 \mathrm{D}, 1.6678 \mathrm{~F}, n_{\mathrm{E}}=1.4846 \mathrm{C}$, $1.4864 \mathrm{D}, 1.4908 \mathrm{~F}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.1720 \mathrm{D}$. Colorless. Easily made from bicarbonate solution. $\mathrm{CaCO}_{3}$ is miscible probably in all proportions with $\mathrm{MnCO}_{3}$, but only in very limited amounts with $\mathrm{FeCO}_{3}, \mathrm{ZnCO}_{3}, \mathrm{CoCO}_{3}$, or $\mathrm{MgCO}_{3}$. Made by precipitation from solution. PD 3.04, 2.29, 2.10; 5-0586.
$\mathrm{MnCO}_{3}$ (Rhodochrosite) is hexagonal-scalenohedral with $a=4.73$, $c=15.51 k X$. Space group $R \overline{3} c$. Crystals rhombohedral, but rare. Perfect $\{10 \overline{1} 1\}$ cleavage. H. 3.5-4. G. 3.70, but varying with variations in composition ( $\mathrm{Ca}, \mathrm{Fe}, \mathrm{Mg}$ replacing some Mn ). Uniaxial negative with ${ }^{14} n_{\mathrm{O}}=1.816$, $n_{\mathrm{E}}=1.597, n_{\mathrm{O}}-n_{\mathrm{E}}=0.219$ (when pure). With $\mathrm{Mn}: \mathrm{Fe}=1: 1, n_{\mathrm{O}}=$ $1.845, n_{\mathrm{E}}=1.615$. With $\mathrm{Mn}: \mathrm{Ca}=1: 1$, $n_{\mathrm{O}}=1.737, n_{\mathrm{E}}=1.542$. Color pink, red, gray, brown. Colorless (or pale red) in section. Made by heating $\mathrm{CaCO}_{3}$ with $\mathrm{MnCl}_{2}$ or $\mathrm{MnSO}_{4}$ solution in a closed tube at $150-200^{\circ} \mathrm{C}$. PD 2.84, 3.66, 1.76; 7-268.

[^56]$\mathrm{FeCO}_{3}$ (Siderite) is hexagonal-scalenohedral with $a=4.71, c=$ $15.43 k X$. Space group $R \overline{3} c$. Crystals rhombohedral or varied. Perfect $\{10 \overline{1} 1\}$ cleavage. H. 4 ca. G. 3.96 (pure), decreasing with $\mathrm{Mn}, \mathrm{Mg}, \mathrm{Ca}$ replacing some Fe. Uniaxial negative with ${ }^{14} n_{\mathrm{O}}=1.875, n_{\mathrm{E}}=1.633$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.242$. With $\mathrm{Fe}: \mathrm{Mg}=1: 1, n_{\mathrm{O}}=1.788, n_{\mathrm{E}}=1.570$. Color brown, gray, green, etc. In section colorless to yellow or brown. PD 2.79, $1.73,3.59 ; 8-133$. Made by reaction of $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{CO}_{3}$ and $\mathrm{FeCl}_{2}$ at red heat.
$\mathrm{CoCO}_{3}$ (Cobaltocalcite) is hexagonal-scalenohedral with $a=4.67$, $c=15.13 \mathrm{kX}$. Space group $R \overline{3} c$. Usually massive. H. 4. G. 4.13. Uniaxial negative ${ }^{2}$ with $n_{\mathrm{O}}=1.855, n_{\mathrm{E}}=1.60, n_{\mathrm{O}}-n_{\mathrm{E}}=0.255$. Color rose-red, altering to gray, brown or black. In transmitted light O is violet red, E rose-red. PD $2.77,1.71,3.65 ; 1-1020$. Made by heating $\mathrm{CoCl}_{2}$ with carbonates at $150^{\circ} \mathrm{C}$. in a closed tube.
$\mathbf{Z n C O}_{3}$ (Smithsonite) is hexagonal-scalenohedral with $a=4.65, c=$ 14.95 kX . Space group $R \overline{3} c$. Crystals rhombohedral; often massive. Good $\{10 \overline{1} 1\}$ cleavage. H. 4-4.5. G. 4.43 but varying (4.0-4.45) with composition and condition. Uniaxial negative with ${ }^{15} n_{\mathrm{o}}=1.842 \mathrm{Li}, 1.848 \mathrm{Na}, 1.855 \mathrm{Tl}$, $n_{\mathrm{E}}=1.619 \mathrm{Li}, 1.621 \mathrm{Na}, 1.624 \mathrm{Tl}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.227 \mathrm{Na}$. Color gray or varied. In section colorless or nearly so. May contain some $\mathrm{Ca}, \mathrm{Fe}, \mathrm{Mg}, \mathrm{Cu}$, etc. replacing Zn. PD 2.75, 3.55, 1.70; 8-449.
$\mathrm{CaCO}_{3}$ (Vaterite) is hexagonal with $a=4.12, c=8.56 \mathrm{kX}$; in platelets or skeletal groups resembling snowflakes. G. 2.64. Uniaxial positive with ${ }^{16}$ $n_{\mathrm{O}}=1.550, n_{\mathrm{E}}=1.640-1.650, n_{\mathrm{E}}-n_{\mathrm{O}}=0.090-0.100$. Colorless or white. PD 2.73, 3.29, 3.58; 1-1033. Made by causing crystallization of gelatinous $\mathrm{CaCO}_{3}$ at $5^{\circ}$ in the presence of much $\mathrm{K}_{2} \mathrm{CO}_{3}$.
$\mathrm{CaCO}_{3}$ (Aragonite) is orthorhombic with $a=4.94, b=7.94, c=$ 5.72 kX . Space group Pmen. U.C. 4. Crystals often prismatic, varied with common twinning. Good $\{010\}$ cleavage. H. 3.5-4. G. 2.94. $\mathrm{X}=c,{ }^{17}$ $\mathrm{Y}=a$. $(-) 2 \mathrm{~V}=18^{\circ} 4^{\prime} \mathrm{C}, 18^{\circ} 8^{\prime} \mathrm{D}, 18^{\circ} 20^{\prime} \mathrm{F} . n_{\mathrm{X}}=1.5279 \mathrm{C}, 1.5300 \mathrm{D}$, $1.5346 \mathrm{~F}, n_{\mathrm{Y}}=1.6772 \mathrm{C}, 1.6810 \mathrm{D}, 1.6900 \mathrm{~F}, n_{\mathrm{Z}}=1.6815 \mathrm{C}, 1.6854 \mathrm{D}$, $1.6947 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.1554$ D. Colorless. Metastable at ordinary temperatures; inverts to calcite at about $400^{\circ} \mathrm{C}$. May contain some $\mathrm{Pb}, \mathrm{Sr}, \mathrm{Zn}$ replacing Ca. PD 3.40, 1.98, 3.27; 5-0453. Made from solutions of calcium salts with alkali carbonates.
$\mathbf{S r C O}_{3}$ (Strontianite) is orthorhombic with $a=5.12, b=8.40, c=$ 6.08 kX . Space group Pmcn. U.C. 4. Crystals prismatic or varied. Common twinning. Good $\{110\}$ cleavage. H. 3.5. G. 3.75, but often less due to presence of some Ca replacing Sr (e.g. 3.63 with 6 per cent of CaO ). $\mathrm{X}=c$,

[^57]$\mathrm{Y}=b$. (-) $2 \mathrm{~V}=7^{\circ} 7^{\prime}$ calc. ${ }^{18} \mathrm{Na}, \mathrm{r}<\mathrm{v}$ very weak. $n_{\mathrm{x}}=1.5181 \mathrm{Li}$, $1.5199 \mathrm{Na}, 1.5219 \mathrm{Tl}, n_{\mathrm{Y}}=1.6624 \mathrm{Li}, 1.6666 \mathrm{Na}, 1.6704 \mathrm{Tl}, n_{\mathrm{Z}}=1.6640$ $\mathrm{Li}, 1.6685 \mathrm{Na}, 1.6728 \mathrm{Tl}, n_{\mathrm{z}}-n_{\mathrm{X}}=0.1486 \mathrm{Na}$. Colorless. Inverts to a hexagonal phase at $929^{\circ} \mathrm{C}$. and fuses at $1497^{\circ} \mathrm{C}$. The natural substance nearly always contains some Ca. PD $3.54,3.45,2.05 ; 5-0418$. Forms a complete series ${ }^{19}$ with $\mathrm{BaCO}_{3}$.
$\mathrm{BaCO}_{3}$ (Witherite) is orthorhombic with $a=5.25, b=8.83, c=$ $6.54 k X$. Space group Pmcn. U.C. 4. Crystals twinned on $\{110\}$ to pseudohexagonal forms usually pyramidal. H. 3-3.5. G. 4.29. $\mathrm{X}=c, \mathrm{Y}=b$. $(-) 2 \mathrm{~V}=16^{\circ}, \mathrm{r}>\mathrm{v}$ very weak. $n_{\mathrm{X}}{ }^{20}=1.529, n_{\mathrm{Y}}=1.676, n_{\mathrm{Z}}=1.677$. $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.148$. Colorless. Inverts to a hexagonal phase at $811^{\circ} \mathrm{C}$. and to an isometric phase at $982^{\circ} \mathrm{C}$. which melts at $1740^{\circ} \mathrm{C}$. Artificial crystals form a complete series with $\mathrm{SrCO}_{3}$ and a series up to $\mathrm{Ca}: \mathrm{Ba} \approx 1: 2$ with $\mathrm{CaCO}_{3}$. PD 3.72, 3.68, 2.15; 5-0378.
$\mathrm{PbCO}_{3}$ (Cerussite) is orthorhombic with $a=5.17, b=8.48, c=$ $6.13 k X$. Space group Pmcn. U.C. 4. Crystals varied, often $\{010\}$ tablets, pyramidal or equant. Pseudo-hexagonal twinning very common. Good $\{110\}$ and $\{021\}$ cleavages. H. $3-3.5$. G. $6.55 . \mathrm{X}=c, \mathrm{Y}=b .(-) 2 \mathrm{~V}=9^{\circ}$ $\mathrm{Na}, \mathrm{r}>\mathrm{v}$ strong. Uniaxial at $15^{\circ} \mathrm{C}$. for $\lambda=415 \mathrm{~m} \mu . n_{\mathrm{x}^{21}}=1.8037$, $n_{\mathrm{Y}}=2.0763, n_{\mathrm{Z}}=2.0780, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.2743 \mathrm{Na}$. Colorless or stained. Often present in commercial "white lead." PD 3.59, 3.50, 2.49; 5-0417.

## $\beta$. Hydrated

$\mathbf{M g C O}_{3} \cdot \mathbf{3} \mathbf{H}_{2} \mathrm{O}$ (Nesquehonite) is orthorhombic with $a=7.68, b=$ $11.93, c=5.39 k X$. Space group Pmmm. U.C. 4. Crystals prismatic with perfect $\{110\}$ and poor $\{001\}$ cleavages. H. 2.5. G. 1.85. Soluble in cold HCl with effervescence. $\mathrm{X}=a . \mathrm{Y}=c$. Optic axes nearly normal to the $\{110\}$ cleavages. $(-) 2 \mathrm{~V}=53^{\circ}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{X}}=1.417$ calc., ${ }^{22} n_{\mathrm{Y}}=$ $1.503 \pm 0.001, n_{\mathrm{Z}}=1.527 \pm 0.001, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.110$. Colorless. PD 6.50, $3.86,2.61$; 1-0130. Made by reaction of alkali carbonates with a Mg salt.
$\mathbf{M g C O}_{3} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ (Lansfordite) is monoclinic with $a=12.48, b=7.55$, $c=7.34 k X, \beta=101^{\circ} 46^{\prime}$. Space group $P 2_{1} / m$. U.C. 4. Crystals prismatic with perfect $\{001\}$ cleavage. H. 2.5. G. 1.69. Soluble in cold HCl with effervescence. $(-) 2 \mathrm{~V}^{22}=59^{\circ} 48^{\prime}, n_{\mathrm{X}}=1.456, n_{\mathrm{Y}}=1.469, n_{\mathrm{Z}}=1.508$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.052$. Colorless. Made (with nesquehonite) by reaction of alkali carbonates with $\mathrm{MgCl}_{2}$.
${ }^{18}$ Indices measured by Beykirch: N. Jahrb. Min. Bl. Bd. XIII, p. 427 (1901) on crystals with 5.95 per cent CaO .
${ }^{19}$ Cork and Gerhard: Am. Min. XVI, p. 71 (1931).
${ }^{20}$ Mallard: Bull. Soc. Fr. Min. XVIII, p. 7 (1895).
${ }^{21}$ Dübigk: N. Jahrb. Min. Bl. Bd. XXXVI, p. 214 (1913).
${ }^{22}$ Fenoglio: Per. Min. VI, p. 1 (1935).
$\mathbf{C a C O}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=1.02: 1: ?, \beta=108^{\circ}$ ?. Crystals basal plates or short prisms. G. 1.77. $\mathrm{Y}=b, \mathrm{Z} \wedge c=+17^{\circ}$ with distinct inclined dispersion. $(-) 2 \mathrm{~V}=38^{\circ} . n_{\mathrm{X}}=1.460, n_{\mathrm{Y}}=1.535, n_{\mathrm{Z}}=1.545$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.085$. Colorless. Formed at $0^{\circ}$ from aqueous solutions containing $\mathrm{CaCO}_{3}$ and also KOH . Changes easily by dehydration to $\mathrm{CaCO}_{3} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ and $\mathrm{CaCO}_{3} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ ? and then $\mathrm{CaCO}_{3}$.

## 3. Formula Type $\mathrm{AB}\left(\mathrm{CO}_{3}\right)_{2}$

$\mathbf{C a M g}\left(\mathbf{C O}_{3}\right)_{2}$ (Dolomite) is hexagonal with $a=4.83, c=15.92 \mathrm{kX}$. Space group $R \overline{3}$. U.C. 3. Crystals rhombohedral or prismatic. Twinning varied, not rare. Perfect $\{10 \overline{1} 1\}$ cleavage. H. 3.5-4. G. 2.85, increasing to about 3 with $\mathrm{Mg}: \mathrm{Fe}=1: 1$. Uniaxial negative with ${ }^{23} n_{\mathrm{O}}=1.679, n_{\mathrm{E}}=$ $1.502, n_{\mathrm{O}}-n_{\mathrm{E}}=0.177$. Colorless. PD 2.88, 1.78, 1.80; $5-0622 . \mathrm{CaMg}\left(\mathrm{CO}_{3}\right)_{2}$ forms a continuous series with $\mathrm{CaFe}\left(\mathrm{CO}_{3}\right)_{2}$ and a considerable (perhaps continuous) series with $\mathrm{CaMn}\left(\mathrm{CO}_{3}\right)_{2}$. With $\mathrm{Mg}: \mathrm{Fe}=1: 1$, $n_{\mathrm{o}}=1.721$, $n_{\mathrm{E}}=1.528, n_{\mathrm{O}}-n_{\mathrm{E}}=0.193$. But Ca can be replaced also (in part) by some Fe and Mn . Made from solutions of Ca and Mg carbonates under pressure of at least 10 atmospheres of $\mathrm{CO}_{2}$.
$\mathbf{C a F e}\left(\mathbf{C O}_{3}\right)_{2}$ (Ferrodolomite) is hexagonal with $a=4.82, c=16.11 \mathrm{kX}$. Crystals rhombohedral, often with $\{0001\}$. Perfect $\{10 \overline{1} 1\}$ cleavage. H. 3.5-4. G. 3.2. F. 7. Uniaxial negative with $n_{\mathrm{O}}=1.765, n_{\mathrm{E}}=1.555$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.210$. Colorless to brown.
$\mathbf{C a B a}\left(\mathrm{CO}_{3}\right)_{2}$ (Alstonite) is orthorhombic with $a=4.99, b=8.77, c=$ $6.11 k X .{ }^{24}$ Crystals commonly pseudo-hexagonal pyramids or prisms by twinning. Poor $\{110\}$ cleavage. H. $4-4.5$. G. 3.67 (may be 3.70 with some Sr replacing Ca ). $\mathrm{X}=c, \mathrm{Y}=a .(-) 2 \mathrm{~V}=7^{\circ}, \mathrm{r}>\mathrm{v}$ weak. ${ }^{25} n_{\mathrm{X}}=1.525$, $n_{\mathrm{Y}}=1.673, n_{\mathrm{Z}}=1.673, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.148$. Colorless, white or pink. It may contain some Sr , replacing Ba. PD 3.68, 3.12, 2.13; 3-0322*.

## 4. Formula Type $\mathrm{A}_{2}\left(\mathrm{CO}_{3}\right)_{3} \cdot \mathrm{nH}_{2} \mathrm{O}$

(La,Ce) $)_{2}\left(\mathrm{CO}_{3}\right)_{3} \cdot \mathbf{8 H _ { 2 }} \mathbf{O}$ (Lanthanite) is orthorhombic with $a=9.50$, $b=17.1, c=9.00 \mathrm{kX}$. U.C. 8. Thin to thick basal tablets. Perfect $\{010\}$ cleavage. H. 2.5-3. G. 2.7. $\mathrm{X}=b,{ }^{2} \mathrm{Y}=c$. ( $-2 \mathrm{~V}=63^{\circ}$ ca., $\mathrm{r}<\mathrm{v}$ very weak. $n_{\mathrm{X}}=1.53$ ca., $n_{\mathrm{Y}}=1.587, n_{\mathrm{Z}}=1.613, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.083 c a$. Colorless. Made by reaction of ( $\mathrm{La}, \mathrm{Ce}$ ) hydroxide with $\mathrm{NaHCO}_{3}$ solution and $\mathrm{CO}_{2}$.

[^58]
## 5. Formula Type $A_{m} B_{n}\left(\mathrm{CO}_{3}\right)_{p}$ with $(m+n): p \approx 3: 2$

## $\alpha$. Anhydrous

$\mathbf{N a}_{2} \mathbf{M g}\left(\mathrm{CO}_{3}\right)_{2}$ is hexagonal ${ }^{8}$ with $c / a=3.33$ and distinct prismatic cleavage. G. 2.734. M.P. $677^{\circ}$ C. under a pressure of $1240 \mathrm{~kg} / \mathrm{cm}^{2}$. Uniaxial negative with $n_{\mathrm{O}}=1.594, n_{\mathrm{E}}=1.54, n_{\mathrm{O}}-n_{\mathrm{E}}=0.054$. Colorless. PD 2.61, 1.89, 2.73; 4-0737.
$\mathbf{N a}_{2} \mathbf{C a}\left(\mathbf{C O}_{3}\right)_{2}$ is hexagonal ${ }^{8}$ in basal plates with perfect basal cleavage. G. 2.54. M.P. $812^{\circ} \mathrm{C}$. in $\mathrm{CO}_{2}$ gas. Uniaxial negative with $n_{\mathrm{O}}=1.547$, $n_{\mathrm{E}}=1.504, n_{\mathrm{o}}-n_{\mathrm{E}}=0.043$. May have small optic angle due to strain. Stable in air. Colorless.
$\mathrm{K}_{2} \mathbf{M g}\left(\mathrm{CO}_{3}\right)_{2}$ is probably hexagonal ${ }^{8}$ with prismatic cleavage. G. 2.671. Uniaxial negative with $n_{\mathrm{O}}=1.597, n_{\mathrm{E}}=1.47, n_{\mathrm{O}}-n_{\mathrm{E}}=0.127$. Colorless. The glass has G. 2.39 and $n=1.496$.
$\mathrm{K}_{2} \mathrm{Ca}\left(\mathrm{CO}_{3}\right)_{2}$ (Fairchildite) is hexagonal in basal plates with distinct basal cleavage. G. 2.465. M.P. $813^{\circ} \mathrm{C}$. in $\mathrm{CO}_{2}$ gas. Uniaxial negative with ${ }^{12}$ $n_{\mathrm{O}}=1.530, n_{\mathrm{E}}=1.48 \mathrm{ca} ., n_{\mathrm{O}}-n_{\mathrm{E}}=0.05 \pm$. Colorless. PD 3.19, 2.64, $6.64 ; 6-0321^{*}$. Seems to form complete series with similar compounds containing $\mathrm{Na}, \mathrm{Ba}$ or Sr . Made by treating $\mathrm{CaCO}_{3}$ with strong solutions of KOH or $\mathrm{K}_{2} \mathrm{CO}_{3}$ (59 per cent at $19^{\circ}$ ).

## $\beta$. Hydrated

$\mathbf{N a}_{6} \mathbf{Z n}_{8}\left(\mathrm{CO}_{3}\right)_{11} \cdot \mathbf{8 H} \mathbf{2} \mathbf{O}$ is isometric. ${ }^{26}$ Crystals tetrahedral. Isotropic with $n=1.540$. Colorless.
$\mathrm{K}_{6} \mathrm{Ca}_{2}\left(\mathrm{CO}_{3}\right)_{5} \cdot \mathbf{6} \mathrm{H}_{2} \mathrm{O}$ (Buetschliite) is probably hexagonal. ${ }^{12}$ Crystals barrel-shaped along $c$. Uniaxial negative with $n_{\mathrm{O}}=1.595, n_{\mathrm{E}}=1.455$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.140$. Colorless. PD 2.86, 3.03, 2.69; 6-0428. Made by hydration of fairchildite.
$\mathbf{N a}_{2} \mathrm{Ca}\left(\mathrm{CO}_{3}\right)_{2} \cdot \mathbf{2 H}_{2} \mathbf{O}$ (Pirssonite) is orthorhombic with $a=11.32, b=$ $20.06, c=6.00 \AA$. U.C. 8. Crystals short prismatic or $\{010\}$ tablets, etc. H. 3-3.5. G. 2.35. $\mathrm{X}=a, \mathrm{Y}=c .{ }^{27}(+) 2 \mathrm{~V}=31^{\circ} 11^{\prime} \mathrm{Li}, 31^{\circ} 26^{\prime} \mathrm{Na}, 31^{\circ} 27^{\prime}$ $\mathrm{Tl}, \mathrm{r}<\mathrm{v}$ slight. $n_{\mathrm{x}}=1.5043 \mathrm{Na}, n_{\mathrm{Y}}=1.5056 \mathrm{Li}, 1.5095 \mathrm{Na}, 1.5115 \mathrm{Tl}$, $n_{\mathrm{z}}=1.5710 \mathrm{Li}, 1.5751 \mathrm{Na}, 1.5789 \mathrm{Tl}, n_{\mathrm{z}}-n_{\mathrm{x}}=0.0694$. Colorless. PD 2.50, 5.10, 2.65; 2-1051.
$\mathrm{K}_{2} \mathrm{Mg}\left(\mathrm{CO}_{3}\right)_{2} \cdot \mathbf{4 H}_{2} \mathrm{O}$ is orthorhombic. ${ }^{7}$ Crystals plates or tablets with six sides. $(+) 2 \mathrm{~V}=65^{\circ} \quad c a ., \mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.465, n_{\mathrm{Y}}=1.485, n_{\mathrm{Z}}=1.535$, $n_{\mathrm{Z}}-n_{\mathrm{x}}=0.070$. Colorless. Made by treating $\mathrm{MgKH}\left(\mathrm{CO}_{3}\right)_{2}$ with $\mathrm{MgCO}_{3}$ in solution.
$\mathbf{N a} \mathbf{a}_{2} \mathrm{Ca}\left(\mathrm{CO}_{3}\right)_{2} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ (Gaylussite) is monoclinic with $a: b: c=$ 1.4897:1:1.4441, $\beta=101^{\circ} 33^{\prime}$. Crystals often elongated along $a$ with $\{001\}$,

[^59]$\{011\},\{111\}$, etc. Perfect $\{110\}$ cleavage. H. 2.5-3. G. 1.99. $\mathrm{X}=b$; $\mathrm{Z} \wedge c^{27}=-15^{\circ}$. (-) $2 \mathrm{~V}=34^{\circ}, \mathrm{r}<\mathrm{v}$ and crossed dispersion. $n_{\mathrm{X}}=1.4435$, $n_{\mathrm{Y}}=1.5156, n_{\mathrm{Z}}=1.5233, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0798 \mathrm{Na}$. Colorless. It is a stable phase in the system $\mathrm{Na}_{2} \mathrm{CO}_{3}-\mathrm{CaCO}_{3}-\mathrm{H}_{2} \mathrm{O}$. PD 6.41, 3.18, 2.70; 2-0122.
$\mathbf{N a}_{2} \mathrm{Cu}\left(\mathrm{CO}_{3}\right)_{2} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ (Chalconatrite) is monoclinic(?). Crystals sixsided plates; also laths. H. low. G. 2.27. Y parallel length of laths; Z normal to plates and apparently $\mathrm{Z} \wedge c$ very small. $(+$ ? $) 2 \mathrm{~V}=$ large. ${ }^{27 \mathrm{a}} n_{\mathrm{X}}=1.483$, $n_{\mathrm{Y}}=1.530, \quad n_{\mathrm{Z}}=1.576, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.093$. Color greenish blue and pleochroic with X nearly colorless, Y pale blue, Z blue. Made by grinding copper acetate in a solution of sodium carbonate, then filtering, washing, and drying. PD 6.92, 4.15, 3.68; 10-442*.

## C. CARBONATES CONTAINING HYDROXYL OR HALOGEN OR EXTRA OXYGEN

## 1. Formula Type $\boldsymbol{A}_{m}\left(\mathrm{CO}_{3}\right)_{p} \mathbf{Z}_{q}$

$\mathrm{Pb}_{2} \mathrm{Cl}_{2}\left(\mathrm{CO}_{3}\right)$ (Phosgenite) is tetragonal with $a=8.139, c=8.856 \AA$. U.C. 4. Crystals prismatic or varied. H. 2-3 varying with the crystal direction. G. 6.13. Distinct $\{001\}$ and $\{110\}$ cleavages. Uniaxial positive ${ }^{28}$ with $n_{\mathrm{O}}=2.1181, n_{\mathrm{E}}=2.1446, n_{\mathrm{E}}-n_{\mathrm{O}}=0.0265 \mathrm{Na}$. Color white, brown, rose, gray, greenish. In thick sections it may show O reddish and E greenish. PD 2.82, 2.23, 3.64; 9-494.
$(\mathbf{B i O})_{2}\left(\mathbf{C O}_{3}\right)$ (Bismutite) is tetragonal with $a=3.859, c=13.658 \mathrm{kX}$. U.C. 2. Usually massive or in crusts. Basal cleavage. H. 2.5-3.5. G. 8.15, but varying to 6.1. Refractive index varies ${ }^{29}$ from 2.12 to about 2.30, due to varying non-essential water content; birefringence moderate. Fibers have parallel extinction and positive elongation. Color usually yellow, but may be gray, green or brown. PD 2.95, 2.14, 1.62; 4-0666.
$\mathrm{Pb}_{3}(\mathrm{OH})_{2}\left(\mathrm{CO}_{3}\right)_{2}$ (Hydrocerussite) is hexagonal with $a=8.97, c=$ 23.8 kX . U.C. 3. Crystals thin to thick tabular or pyramidal. Perfect basal cleavage. H. 3.5. G. 6.8. Uniaxial negative with ${ }^{2} n_{\mathrm{O}}=2.09, n_{\mathrm{E}}=1.94$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.15$. Colorless. Chief component of "white lead." PD 2.63, 3.60, 3.28; 10-401*.
$\mathrm{Cu}_{3}(\mathrm{OH})_{2}\left(\mathrm{CO}_{3}\right)_{2}$ (Azurite) is monoclinic with $a=4.96, b=5.83, c=$ $10.27 k X, \beta=92^{\circ} 25^{\prime}$. Space group $P 2_{1} / c$. U.C. 2. Crystals varied, often with many forms. Good $\{011\}$ and poor $\{100\}$ cleavages. H. 3.5-4. G. 3.77. $\mathrm{X}=b,{ }^{2} \mathrm{Z} \wedge c=-12^{\circ} 36^{\prime} .(+) 2 \mathrm{~V}=67^{\circ}, \mathrm{r}>\mathrm{v} . n_{\mathrm{X}}=1.730, n_{\mathrm{Y}}=1.754$, $n_{\mathrm{Z}}=1.836, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.106 \mathrm{Na}$. Color pale to dark blue. In section pale

[^60]blue with $\mathrm{X}<\mathrm{Y}<\mathrm{Z}$. PD 3.50, 5.15, 2.53; 3-0360*. Made by heating copper sulphate or nitrate with calcite in a closed tube.
$\left(\mathbf{U O}_{2}\right)\left(\mathbf{C O}_{v}\right)$ (Rutherfordine) is orthorhombic with ${ }^{29 \mathrm{a}} a=4.85, b=$ $9.21, c=4.30 \AA$. Often finely fibrous. Soft. G. 4.82. Perfect $\{010\}$ and good $\{001\}$ cleavages. $\mathrm{X}=b ; \mathrm{Y}=c$ (elongation). (十) $2 \mathrm{~V}=53^{\circ}$ calc. $n_{\mathrm{X}}=$ $1.715, n_{\mathrm{Y}}=1.730, n_{\mathrm{Z}}=1.795, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.080$. Color yellow, weakly pleochroic. Artificial crystals studied. ${ }^{29 b}$ PD 4.56, 4.25, 3.19; 9-163.
$\mathrm{Ni}_{3}(\mathrm{OH})_{4}\left(\mathrm{CO}_{3}\right) \cdot \mathbf{4 H _ { 2 } \mathrm { O }}$ (Zaratite) is probably isometric with ${ }^{30} a=$ $6.15 k X$. U.C. 1. H. 3.5. G. 2.66. Forms incrustations. Isotropic with $n=$ 1.58-1.60. Often mixed with fibrous material with positive elongation, parallel extinction and variable indices (due to strain or another phase). Color emerald green. Made by the action of $\mathrm{NiCl}_{2}$ on $\mathrm{MgCO}_{3} \cdot 3 \mathrm{H}_{2} \mathrm{O}$.
$\mathrm{Cu}_{2}(\mathbf{O H})_{2}\left(\mathrm{CO}_{3}\right)$ (Malachite) is monoclinic with $a=9.49, b=12.00$, $c=3.24 \AA, \beta=98^{\circ} 42^{\prime}$. U.C. 4. Space group $P 2_{1} / a$. Crystals rare, often twinned; massive. Perfect $\{\overline{2} 01\}$ and fair $\{010\}$ cleavages. H. 3.5-4. G. 4.0, but often less, even to 3.6. $\mathrm{X} \wedge c=23.5^{\circ} ; \mathrm{Y}=b$. (-) $2 \mathrm{~V}=43^{\circ} \pm 2^{\circ}$, $\mathrm{r}<\mathrm{v}$ distinct. $n_{\mathrm{X}}{ }^{2}=1.655, n_{\mathrm{Y}}=1.875, n_{\mathrm{Z}}=1.909, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.254$. Color green with X nearly colorless, Y yellow green, Z deep green. PD 2.86, $3.69,5.06 ; 10-399$. Formed on a copper anode by electrolysis of soluble carbonates.
$\mathbf{M g}_{4}(\mathbf{O H})_{2}\left(\mathrm{CO}_{3}\right)_{3} \cdot \mathbf{3} \mathrm{H}_{2} \mathrm{O}$ (Hydromagnesite) is monoclinic with ${ }^{31} a: b: c$ $=1.121: 1: 0.947, \beta=113^{\circ} 32^{\prime}$. (Possibly orthorhombic.) Crystals $\{100\}$ plates long parallel $c$. Perfect $\{010\}$ cleavage. H. 2.5. G. 2.236. $\mathrm{X} \wedge c=$ $47^{\circ} 9^{\prime} ; \mathrm{Z}=b .(+) 2 \mathrm{~V}=$ moderate, $n_{\mathrm{X}}=1.523, n_{\mathrm{Y}}=1.527, n_{\mathrm{Z}}=1.545$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.022 \mathrm{Na}$. Colorless. PD 5.79, 2.90, 2.15; 8-179. Made from solution of magnesium sulfate or nitrate with alkali carbonates.
$\mathbf{Z n}_{5}(\mathbf{O H})_{6}\left(\mathbf{C O}_{3}\right)_{2}$ (Hydrozincite) is monoclinic with $a=13.452, b=$ $6.307, c=5.357 k X, \beta=95^{\circ} 30^{\prime}$. Space group $C 2 / m$ or $C m$ or C2. U.C. 2. Crystals rare, usually massive. Perfect $\{100\}$ cleavage. H. 2-2.5. G. 4.0 ca.; mostly $3.5-3.8$ for massive samples. $\mathrm{X}=b$. $\mathrm{Z} \wedge c=13^{\circ},{ }^{6}$ also $\mathrm{Z} \wedge c=$ $40^{\circ} .{ }^{32}(-) 2 \mathrm{~V}=40^{\circ}, \mathrm{r}<\mathrm{v}$ distinct. $n_{\mathrm{X}}=1.640, n_{\mathrm{Y}}=1.736, n_{\mathrm{Z}}=1.750$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.110 .^{2}$ Color white, gray, pale yellow, brown, pink. Colorless in section. $5 \mathrm{ZnO} \cdot 2 \mathrm{CO}_{2} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ easily made from solution of zinc salts and alkali carbonates.

## 2. Formula Type $\mathrm{A}_{\boldsymbol{m}} \mathrm{B}_{n}\left(\mathrm{CO}_{3}\right)_{p} \mathbf{Z}_{q}$

$\mathbf{N a} \mathbf{3}_{3} \mathbf{M g C l}\left(\mathbf{C O}_{3}\right)_{2}$ (Northupite) is isometric with $a=13.99 k X$. U.C. 16. Space group Fd3. Crystals octahedral. No cleavage. H. 3.5-4. G. 2.366.
${ }^{29 a}$ Clark and Christ: Am. Min. XLI, p. 844 (1956).
${ }^{29 \mathrm{~b}}$ Cromer and Harper: Acta Cryst. VIII, p. 847 (1955).
${ }^{30}$ Fenoglio: Per. Min. V, p. 265 (1935).
${ }^{31}$ Rogers: Am. J. Sci. VI, p. 37 (1923).
${ }^{32}$ Prider: Min. Mag. XXVI, p. 60 (1941).

Soluble in acid with effervescence. Isotropic with ${ }^{27} n=1.5117 \mathrm{Li}, 1.5144$ Na, 1.5180 Tl. Again: ${ }^{33} n=1.510$. Colorless. PD 2.69, 2.48, 8.00; 2-0916. Made by reaction of $\mathrm{MgCl}_{2}$ and $\mathrm{Na}_{2} \mathrm{CO}_{3}$ and NaCl . Forms a complete series of mix-crystals with $\mathrm{Na}_{6} \mathrm{Mg}_{2} \mathrm{SO}_{4}\left(\mathrm{CO}_{3}\right)_{4}$.
$\mathbf{N a}_{3} \mathbf{M g B r}\left(\mathrm{CO}_{3}\right)_{2}$ is isometric with $a=14.17 k X$. Crystals octahedral. G. 2.67. Isotropic with ${ }^{27} n=1.515$. Colorless.
$\mathbf{C a}(\mathbf{B i O})_{2}\left(\mathrm{CO}_{3}\right)_{2}$ (Beyerite) is tetragonal with $a=3.78, c=21.77 \mathrm{kX}$. U.C. 2. Space group $I 4 / \mathrm{mmm}$. Crystals rectangular basal plates. H. 2-3. G. 6.56. No cleavage. Uniaxial negative with $n_{0}=2.13 \pm .02, n_{\mathrm{E}}=$ $1.99 \pm .02, n_{\mathrm{O}}-n_{\mathrm{E}}=0.14$. Color yellow. In section pale yellow to colorless; not pleochroic. May be slightly biaxial (due to strain?). PD 2.84, 2.14, 1.75; 4-0693. Made by heating $\mathrm{BiNO}_{3}, \mathrm{CaCO}_{3}$ and urea in dilute $\mathrm{HNO}_{3}$ in a bomb at $220^{\circ} \mathrm{C}$.
$\mathrm{NaAl}\left(\mathrm{CO}_{3}\right)(\mathbf{O H})_{2}$ (Dawsonite) is orthorhombic with $a=6.72, b=$ 10.34, $c=5.56 \AA$. U.C. 4. Space group Ima. Crystals platy to acicular along $c$. H. 3. G. 2.44. Perfect $\{110\}$ cleavage. $\mathrm{X}=a{ }^{34} \mathrm{Y}=c$. (-) $2 \mathrm{~V}=$ $76^{\circ} 46^{\prime} \mathrm{Na}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{X}}=1.466, n_{\mathrm{Y}}=1.542, n_{\mathrm{Z}}=1.596, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.130. Again: ${ }^{35} n_{\mathrm{X}}=1.462, n_{\mathrm{Y}}=1.537, n_{\mathrm{Z}}=1.589, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.127$. Colorless. Made by reaction of solutions of sodium aluminate and bicarbonate with excess of $\mathrm{CO}_{2}$.
$\left(\mathbf{N H}_{4}\right)_{4}\left(\mathbf{U O}_{2}\right)\left(\mathbf{C O}_{3}\right)_{3}$ is monoclinic with $a: b: c=0.964: 1: 0.867, \beta=$ $99^{\circ} 17^{\prime}$. Crystals prismatic with perfect $\{001\}$ cleavage. G. 2.77. ( -$) 2 \mathrm{~V}^{36}=$ ?, $n_{\mathrm{X}^{\prime}}^{\prime}=1.60, n_{\mathrm{z}}^{\prime}=1.625, n_{\mathrm{z}^{\prime}}^{\prime}-n_{\mathrm{X}^{\prime}}^{\prime}=0.025$. Color yellow.
$\mathbf{N a} 2 \mathbf{C a}\left(\mathrm{UO}_{2}\right)\left(\mathbf{C O}_{3}\right)_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ (Andersonite) is hexagonal with $a=18.04$, $c=23.90 \AA$. U.C. 6. Space group $R \overline{3}$ or $R 3$. Crystals pseudo-cubic. G. 2.8. Uniaxial positive ${ }^{37}$ with $n_{\mathrm{O}}=1.520, n_{\mathrm{E}}=1.540, n_{\mathrm{E}}-n_{\mathrm{O}}=0.020$. Color in mass bright green; in section: O colorless, E pale yellow. PD 13.0, 7.97, 5.68; 4-0080. Made by evaporating a solution containing $\mathrm{K}_{2} \mathrm{CO}_{3}$ and nitrates of $\mathrm{Na}, \mathrm{Ca}$ and U .
$\mathbf{M g}_{2}\left(\mathbf{U O}_{2}\right)\left(\mathbf{C O}_{3}\right)_{3} \cdot \mathbf{1 8} \mathbf{H}_{2} \mathrm{O}$ (Bayleyite) is monoclinic with $a=26.65, b=$ 15.31, $c=6.53 \AA, \beta=93^{\circ} 4^{\prime}$. Space group $P 2_{1} / a$. U.C. 4. Crystals prismatic or acicular divergent groups. G. 2.05. $\mathrm{X} \wedge c^{37}=15^{\circ}$. ( - ) $2 \mathrm{~V}=30^{\circ}$ calc. $n_{\mathrm{X}}=1.455, n_{\mathrm{Y}}=1.490, n_{\mathrm{Z}}=1.500, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.045$. Color yellow with X pinkish, Y and Z pale yellow. Fluorescent in yellowish-green. PD 7.66, 13.1, 3.83; 4-0130. Made from solutions of uranyl nitrate, magnesium nitrate and potassium carbonate.
$\mathbf{C a M g}\left(\mathrm{UO}_{2}\right)\left(\mathrm{CO}_{3}\right)_{3} \cdot \mathbf{1 2 \mathrm { H } _ { 2 } \mathrm { O }}$ (Swartzite) is monoclinic with $a=11.12$,
${ }^{33}$ Shiba and Watanabe: C. R. Acad. Sci., Paris, CXCIII, p. 1421 (1931).
${ }^{34}$ Graham: Trans. Roy. Soc. Canada, II (3), p. 165 (1908).
${ }^{35}$ Pelloux: Per. Min. III, p. 69 (1932).
${ }^{36}$ Optic data from Bolland: Sitz. Akad. Wiss. Wien CXIX, IIb, p. 275 (1910) on "ammonium uranyl carbonate" of unknown formula.
${ }^{37}$ Axelrod et al.: Am. Min. XXXVI, p. 1 (1951).
$b=14.72, c=6.47 \AA, \beta=99^{\circ} 26^{\prime}$. Space group $P 2_{1} / m$ or $P 2_{1}$. U.C. 2 . Crystals prismatic. G. 2.3 . ( - ) $2 \mathrm{~V}=40^{\circ}$ calc. ${ }^{37} n_{\mathrm{X}}=1.465, n_{\mathrm{Y}}=1.51$. $n_{\mathrm{Z}}=1.540, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.075$. Color green; in transmitted light X colorless, Y and Z yellow. PD 8.76, 5.50, 7.31; 4-0111. Obtained by seeding an evaporating solution of $\mathrm{K}_{2} \mathrm{CO}_{3}$ and nitrates of $\mathrm{Ca}, \mathrm{Mg}$ and U .

## D. COMPOUND CARBONATES

$\mathbf{N a}_{6} \mathbf{M g}_{2}\left(\mathbf{S O}_{4}\right)\left(\mathbf{C O}_{3}\right)_{4}$ (Tychite) is isometric with $a=13.87 \mathrm{kX}$. U.C. 8. Space group Fd3. No cleavage. H. 3.5-4. G. 2.588. Isotropic with ${ }^{38} n=$ 1.510. Colorless. Made from reaction of $\mathrm{MgSO}_{4}$ solution with a mixed solution of $\mathrm{Na}_{2} \mathrm{CO}_{3}$ and $\mathrm{Na}_{2} \mathrm{SO}_{4}$.
$\mathbf{N a}_{6} \mathbf{M g}_{2}\left(\mathbf{C r O}_{4}\right)\left(\mathbf{C O}_{3}\right)_{4}$ is isometric with G. 2.506. Isotropic with ${ }^{38} n=$ 1.555. Made from reaction of $\mathrm{MgCrO}_{4}$ solution with a mixed solution of $\mathrm{Na}_{2} \mathrm{CO}_{3}$ and $\mathrm{Na}_{2} \mathrm{SO}_{4}$.
$\mathrm{Ag}_{2}\left(\mathbf{C O}_{3}\right) \cdot \mathbf{4 \mathrm { NH } _ { 3 }} \cdot \mathbf{H}_{2} \mathrm{O}$ is orthorhombic ${ }^{39}$ with $a: b: c=0.577: 1: 0.768$, and pseudo-hexagonal. Crystals prismatic or pyramidal. Perfect $\{010\}$ and $\{021\}$ cleavages with distinct $\{001\}$ and $\{110\}$ partings. Common twinning on $\{110\} . \mathrm{Y}=b, \mathrm{Z}=c .(+) 2 \mathrm{~V}=10^{\circ}, \mathrm{r}<\mathrm{v}$ strong, the substance being uniaxial in the extreme red and having $2 \mathrm{E}=36^{\circ}$ for $435 \mathrm{~m} \mu$. $n_{\mathrm{X}}=1.66, n_{\mathrm{Y}}=1.66, n_{\mathrm{Z}}=1.68, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.023 \mathrm{Na}$. Colorless. Unstable in air.
$\mathrm{Pb}_{4}\left(\mathrm{SO}_{4}\right)\left(\mathrm{CO}_{3}\right)_{2}(\mathbf{O H})_{2}$ (Leadhillite) is monoclinic with $a=9.07, b=$ 11.55, $c=20.70 k X, \beta=90^{\circ} 30^{\prime}$. U.C. 8. Space group $P 2_{1} / a$. Crystals often pseudo-hexagonal in thin to thick \{001\} plates and apparently rhombohedral. Twinning on $\{140\}$ very common; also other types. Perfect basal cleavage. H. 2.5-3. G. 6.55. $\mathrm{X} \wedge c=-5.5^{\circ}, \mathrm{Z}=b$. ( - ) 2 V about $10^{\circ}$ at room temperature; becomes uniaxial (for Na ) at about $125^{\circ} \mathrm{C}$. $n_{\mathrm{X}}{ }^{2}=1.87 \pm 0.01, n_{\mathrm{Y}}=2.00 \pm 0.01, n_{\mathrm{Z}}=2.01 \pm 0.01, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.14$ $c a$. Colorless, gray, pale green, blue or yellow. Colorless in sections. Made by heating $\mathrm{PbSO}_{4}$ and $\mathrm{PbCO}_{3}$ with water in a closed tube at $180^{\circ} \mathrm{C}$.

## E. NITRATES AND NITRITES

## 1. Formula Type $\mathrm{ANO}_{3}$

## $\alpha$. Anhydrous

$\mathbf{L i N O}_{3}$ is hexagonal with a rhombohedral angle of $74^{\circ} 20^{\prime}$. G. 2.33. Very hygroscopic. Uniaxial negative with ${ }^{39 \mathrm{a}}$ extreme birefringence. $n_{\mathrm{O}}=1.735$,

[^61]$n_{\mathrm{E}}=1.435, n_{\mathrm{O}}-n_{\mathrm{E}}=0.300$. Colorless. Formed from hot water solution. PD 3.60, 2.13, 2.79; 8-466.
$\mathbf{N a N O}_{3}$ (Soda-Niter) is hexagonal with $a=5.07, c=16.81 k X$. U.C. 6. Space group $R \overline{3} c$. Crystals rhombohedral, resembling calcite; massive. Perfect rhombohedral cleavage. H. 1.5-2. G. 2.27. F. 1; deflagrates on heating. Deliquescent. Uniaxial negative with extreme birefringence. ${ }^{40} n_{\mathrm{O}}=$ $1.5793 \mathrm{~B}, 1.5874 \mathrm{D}, 1.5954 \mathrm{E}, 1.6260 \mathrm{H}, n_{\mathrm{E}}=1.3346 \mathrm{~B}, 1.3361 \mathrm{D}, 1.3374 \mathrm{E}$, $1.3440 \mathrm{H}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.2513 \mathrm{D}$. Index on cleavage, $n_{\mathrm{E}}^{\prime}=1.467$. Merwin ${ }^{5}$ gives: $n_{\mathrm{O}}=1.5848 \mathrm{D}, n_{\mathrm{E}}=1.3360, n_{\mathrm{O}}-n_{\mathrm{E}}=0.2488$. Colorless or white. PD 3.03, 2.31, 1.90; 7-271. Made from water solution.
$\mathrm{CsNO}_{3}$ is hexagonal with $c / a=1.236$. Crystals prismatic with pyramids. Distinct basal cleavage. G. 3.69. Uniaxial positive with weak birefringence decreasing with lowering temperature. $n_{O^{26}}=1.558, n_{\mathrm{E}}=1.560, n_{\mathrm{E}}-$ $n_{\mathrm{O}}=0.002$. Colorless. Inverts to an isometric phase at $161^{\circ} \mathrm{C} . \mathrm{PD} 3.15$, 4.47, 2.57; 9-403. Made from water solution at $14^{\circ} \mathrm{C}$.
$\mathrm{KNO}_{3}$ (Niter) is orthorhombic with $a=5.42, b=9.17, c=6.45 \mathrm{kX}$. U.C. 4. Space group Pnma. Isostructural with aragonite. Crystals prismatic or acicular. Twinning on $\{110\}$ common. Perfect $\{011\}$ and distinct $\{010\}$ and $\{110\}$ cleavages. H. 2. G. 2.1. F. 1. Deflagrates vividly on coal with violet flame color. $\mathrm{X}=c, \mathrm{Y}=a .(-) 2 \mathrm{~V}=6^{\circ} 11^{\prime} \mathrm{B}, 7^{\circ} 12^{\prime} \mathrm{D}, 8^{\circ} 5^{\prime} \mathrm{E}$, $10^{\circ} 22^{\prime} \mathrm{H}, \mathrm{r}<\mathrm{v} . n_{\mathrm{x}}=1.3328 \mathrm{~B}, 1.3346 \mathrm{D}, 1.3365 \mathrm{E}, n_{\mathrm{Y}}=1.4988 \mathrm{~B}$, $1.5056 \mathrm{D}, 1.5124 \mathrm{E}, 1.5385 \mathrm{H}, n_{\mathrm{Z}}=1.4994 \mathrm{~B}, 1.5064 \mathrm{D}, 1.5135 \mathrm{E}, n_{\mathrm{z}}-$ $n_{\mathrm{X}}=0.1718 \mathrm{D}$. Merwin $^{5}$ gives: $n_{\mathrm{X}}=1.332 \mathrm{D}, n_{\mathrm{Y}}=1.5038, n_{\mathrm{Z}}=1.5042$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.1722$ D. Colorless or white. PD 3.78, 3.73, 3.03; 5-0377*. Easily made from water solution. Inverts at $129^{\circ} \mathrm{C}$. to a rhombohedral phase isostructural with $\mathrm{NaNO}_{3}$. Other phases are known.
$\mathbf{K N O}_{3}$ and $\mathbf{R b N O}$ form mix-crystals ${ }^{41}$ from 0 to at least 50 per cent $\mathrm{RbNO}_{3}$ in which 2 E decreases from $10^{\circ} 51^{\prime}$ with $\mathrm{r}<\mathrm{v}$ in pure $\mathrm{KNO}_{3}$ to $0^{\circ}$ at about 32 per cent $\mathrm{RbNO}_{3}$; with more $\mathrm{RbNO}_{3}$ the optic angle opens in 010 attaining $2^{\circ} 48^{\prime}$ with $\mathrm{r}>\mathrm{v}$ in crystals with 37 per cent $\mathrm{RbNO}_{3}$. The density increases from 2.11 for pure $\mathrm{KNO}_{3}$ to 2.35 for 50 per cent $\mathrm{RbNO}_{3}$.
$\mathbf{R b N O}_{3}$ is orthorhombic with $a: b: c=1.737: 1: 0.711$; very nearly hexagonal. Crystals prismatic with poor $\{001\}$ cleavage. G. 3.12. $\mathrm{Y}=b$, $\mathrm{Z}=c . \quad(-) 2 \mathrm{~V}=$ small; ${ }^{42} \mathrm{r}>\mathrm{v} . \quad n_{\mathrm{X}}=1.51, \quad n_{\mathrm{Y}}=1.52, \quad n_{\mathrm{Z}}=1.524$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.014$. Colorless. PD 3.10, 2.53, 1.96; 4-0608*. Made from water solution at $17^{\circ} \mathrm{C}$.
$\mathbf{N H}_{4} \mathbf{N O}_{3}$ (Ammonia-Niter) is orthorhombic with $a=4.96, b=5.45$, $c=5.75 \AA$. Space group Pmmn. Crystals pseudo-tetragonal long prisms.

[^62]
## 3. Formula Type $\mathrm{A}_{\boldsymbol{m}} \mathbf{B}_{n}\left(\mathrm{NO}_{3}\right)_{p} \cdot \mathbf{q} \mathbf{H}_{2} \mathbf{O}$

$\mathbf{M g}_{3} \mathrm{Ce}_{2}\left(\mathbf{N O}_{3}\right)_{12} \cdot \mathbf{2 4} \mathbf{H}_{2} \mathbf{O}$ is hexagonal. ${ }^{53}$ Crystals rhombohedral. Uniaxial negative with $n_{\mathrm{O}}=1.5204 \mathrm{C}, 1.5249 \mathrm{D}, 1.5346 \mathrm{~F}, n_{\mathrm{E}}=1.5135 \mathrm{C}, 1.5176 \mathrm{D}$, $1.5267 \mathrm{~F}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0073 \mathrm{D} ; \mathrm{F}-\mathrm{C}$ for $n_{\mathrm{O}}=0.0142$.
$\mathbf{M g}_{3} \mathbf{N d}_{2}\left(\mathrm{NO}_{3}\right)_{12} \cdot \mathbf{2 4 \mathrm { H } _ { 2 } \mathrm { O }}$ is hexagonal. ${ }^{53}$ Crystals rhombohedral. Uniaxial negative with $n_{\mathrm{O}}=1.5228 \mathrm{C}, 1.5266 \mathrm{D}, 1.5368 \mathrm{~F}, n_{\mathrm{E}}=1.5156 \mathrm{C}, 1.5192 \mathrm{D}$, $1.5286 \mathrm{~F}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0074 ; \mathrm{F}-\mathrm{C}$ for $n_{\mathrm{O}}=0.0140$.
$\mathbf{M g}_{3} \mathbf{P r}_{2}\left(\mathbf{N O}_{3}\right)_{12} \cdot \mathbf{2 4 H}_{2} \mathbf{O}$ is hexagonal. ${ }^{53}$ Crystals rhombohedral. Uniaxial negative with $n_{\mathrm{O}}=1.5215 \mathrm{C}, 1.5255 \mathrm{D}, 1.5356 \mathrm{~F}, n_{\mathrm{E}}=1.5144 \mathrm{C}, 1.5182 \mathrm{D}$, $1.5277 \mathrm{~F}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0073 ; \mathrm{F}-\mathrm{C}$ for $n_{\mathrm{O}}=0.0141$.
$\mathbf{M g}_{3} \mathbf{L a}_{2}\left(\mathbf{N O}_{3}\right)_{12} \cdot \mathbf{2 4 H}_{2} \mathrm{O}$ is hexagonal. ${ }^{53}$ Crystals rhombobedral. Uniaxial negative with $n_{\mathrm{O}}=1.5180 \mathrm{C}, 1.5220 \mathrm{D}, 1.5319 \mathrm{~F}, n_{\mathrm{E}}=1.5112 \mathrm{C}, 1.5150 \mathrm{D}$, $1.5242 \mathrm{~F}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0070 \mathrm{D} ; \mathrm{F}-\mathrm{C}$ for $n_{\mathrm{O}}=0.0139$.

## F. NITRATES CONTAINING HYDROXYL OR HALOGEN

$\mathrm{Ca}_{4} \mathrm{Al}_{2}\left(\mathrm{NO}_{3}\right)_{2}(\mathbf{O H})_{12} \cdot \mathbf{4 H _ { 2 }} \mathbf{O}$ is hexagonal in basal plates often in spherulites. Uniaxial negative ${ }^{54}$ with weak birefringence when immersed in water, but uniaxial positive ${ }^{55}$ in immersion liquids; $n_{\mathrm{O}}=1.502 \pm 0.005, n_{\mathrm{E}}=$ $1.532 \pm 0.005, n_{\mathrm{E}}-n_{\mathrm{O}}=0.030$. Colorless.
$\mathbf{C a}(\mathbf{O H})\left(\mathrm{VO}_{3}\right) \cdot \mathrm{H}_{2} \mathrm{O}$ is orthorhombic ${ }^{56}$ in needles along $c$ and flattened on $\{100\} ;\{100\},\{010\}$ and $\{001\}$ cleavages. $\mathrm{X}=c, \mathrm{Y}=b,(-) 2 \mathrm{~V}=44^{\circ}$ calc. $\quad n_{\mathrm{X}}=1.447 \pm 0.002, \quad n_{\mathrm{Y}}=1.564 \pm 0.002, \quad n_{\mathrm{Z}}=1.583 \pm 0.002$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.136$. Colorless.
$\mathrm{Cu}_{2}(\mathbf{O H})_{3}\left(\mathbf{N O}_{3}\right)$ (Gerhardtite) is orthorhombic with $a: b: c=$ $0.9206: 1: 1.1498$. Crystals thick basal tablets with pyramidal striations. Perfect $\{001\}$ and good $\{100\}$ cleavages. H. 2. G. 3.43. $\mathrm{X}=a, \mathrm{Y}=b$. $(+) 2 \mathrm{~V}=$ very large, ${ }^{6} \mathrm{r}>$ v strong. $n_{\mathrm{X}}=1.703, n_{\mathrm{Y}}=1.713, n_{\mathrm{Z}}=1.722$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.019$. Color green, with X and Y green, Z blue. PD 6.85, 3.44, $2.45 ; 3-0068$. Made by heating a solution of the normal nitrate and in other ways. A monoclinic phase is also known.
$\mathbf{H g}(\mathbf{O H})\left(\mathbf{N O}_{3}\right) \cdot \mathbf{0 . 5} \mathrm{H}_{2} \mathrm{O}$ is orthorhombic with $a: b: c=0.698: 1: 0.519$. Crystals $\{010\}$ plates with $\{001\},\{100\},\{110\}$, etc. Perfect $\{010\}$, good $\{100\}$ and distinct $\{120\}$ cleavages. For mercury "oxydulnitrat" Bolland ${ }^{52}$ gives parallel extinction and $n_{\mathrm{X}}=1.69, n_{\mathrm{Y}}=1.72, n_{\mathrm{Z}}=1.92, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.23 . $(+) 2 \mathrm{~V}=70^{\circ}$ calc. (PD: $5.60,3.47,3.75 ; 1-0196$ for " $\mathrm{HgNO}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ ").

[^63]
## G. NITRATES CONTAINING URANYL OR AMMONIA

$\mathbf{U O}_{2}\left(\mathbf{N O}_{3}\right)_{2} \cdot \mathbf{6 H} \mathbf{2} \mathbf{O}$ is orthorhombic ${ }^{57}$ with $a=11.58, b=13.20, c=8.04$ A. U.C. 4. G. $2.74-2.81$. M.P. $60^{\circ}$ C. Crystals usually vertically long. $\mathrm{X}=$ $c, \mathrm{Y}=b .(-) 2 \mathrm{~V}=46^{\circ}, \mathrm{r}>\mathrm{v}$ weak. $n_{\mathrm{X}}=1.482, n_{\mathrm{Y}}=1.494, n_{\mathrm{Z}}=1.572$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.090$. Again: ${ }^{58} n_{\mathrm{X}}=1.485, n_{\mathrm{Y}}=1.497, n_{\mathrm{Z}}=1.58, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.095 . Color yellow with X light yellow, Y yellow, Z yellow-green; also color siskin-green with yellowish green fluorescence and X clear yellow, Y greenish yellow, Z deep citron-yellow. PD 5.70, 4.33, 6.60; 1-0176.
$\mathrm{K}_{2}\left(\mathbf{U O}_{2}\right)\left(\mathbf{N O}_{3}\right)_{4}$ is monoclinic ${ }^{59}$ with $a: b: c=0.639: 1: 0.619, \beta=90^{\circ} \pm$. Crystals basal plates or prismatic. G. 3.36. $n_{1}$ (vibration parallel to $b$ ) $=$ 1.5422, $n_{2}$ (vibration in (010) at $26^{\circ} 34^{\prime}$ from $a$ toward $c$ in the acute angle $\beta)=1.5349$. Color green.
$\left(\mathbf{N H}_{4}\right)_{2}\left(\mathbf{U O}_{2}\right)\left(\mathbf{N O}_{3}\right)_{4} \cdot \mathbf{2 H} \mathbf{H} \mathbf{O}$ is monoclinic with ${ }^{59} a: b: c=0.842: 1: 0.559$, $\beta=85^{\circ} 5^{\prime}$. Crystals resemble cubes modified by pyramids. No cleavage. G. 2.78. Dissociates at $140^{\circ}$ C. Volatile. $\mathrm{Z}=b$. (-) $2 \mathrm{~V}=45^{\circ}$ calc. $n_{\mathrm{X}}=$ $1.508, n_{\mathrm{Y}}=1.619, n_{\mathrm{Z}}=1.639, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.131$. Color sulfur-yellow.
$\mathbf{C a}\left(\mathbf{N H}_{3}\right)_{4}\left(\mathbf{N O}_{3}\right)_{2}$ is biaxial with ${ }^{60}(-?) 2 \mathrm{~V}=45^{\circ}, n_{\mathrm{X}}=1.475, n_{\mathbf{Y}}=$ ?, $n_{\mathrm{Z}}=1.510, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.035 \mathrm{Na}$.

## H. COMPOUND NITRATES

$\mathbf{N a}_{3}\left(\mathbf{S O}_{4}\right)\left(\mathbf{N O}_{3}\right) \cdot \mathbf{H}_{2} \mathbf{O}$ (Darapskite) is monoclinic with $a: b: c=$ 1.5258:1:0.7514, $\beta=102^{\circ} 55^{\prime}$. Crystals pseudo-tetragonal $\{100\}$ tablets. Perfect $\{010\}$ cleavage and $\{100\}$ cleavage or parting. H. 2.5. G. 2.20. $\mathrm{X}=b, \mathrm{Z} \wedge c=12^{\circ}$. (-) $2 \mathrm{~V}=27^{\circ} \pm 1^{\circ}, \mathrm{r}>\mathrm{v}$ moderate. ${ }^{2} n_{\mathrm{X}}=1.391 \pm$ $0.005, n_{\mathrm{Y}}=1.481 \pm 0.003, n_{\mathrm{Z}}=1.486 \pm 0.003, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.095$. Colorless. Made by heating a water solution of $\mathrm{Na}_{2} \mathrm{SO}_{4}$ and $\mathrm{NaNO}_{3}$ at tempera-. ture between $14^{\circ}$ and $50^{\circ} \mathrm{C}$.

## I. NITRITES

$\mathbf{K}_{2} \mathbf{P b C u}\left(\mathbf{N O}_{2}\right)_{6}$ is isometric. ${ }^{61}$ Crystals cubic with smaller dodecahedral and trisoctahedral faces. Isotropic with $n=$ or somewhat greater than 1.80. Made by adding $\mathrm{KNO}_{2}$ to a solution of $\mathrm{Na}_{2} \mathrm{PbCu}\left(\mathrm{NO}_{2}\right)_{6}$.

[^64]$\mathbf{N a N O}_{2}$ is orthorhombic ${ }^{62}$ with $a: b: c=0.640: 1: 0.967$. Crystals $\{010\}$ tablets, prismatic or columnar along $b$ with perfect $\{101\}$ cleavage. G. 2.15. $\mathrm{X}=a, \mathrm{Y}=b .(+) 2 \mathrm{~V}=75^{\circ} . n_{\mathrm{X}}=1.354, n_{\mathrm{Y}}=1.460, n_{\mathrm{Z}}=1.648, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.294$. Again: ${ }^{63} n_{\mathrm{X}}=1.340, n_{\mathrm{Y}}=1.425, n_{\mathrm{Z}}=1.655, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.315 . Colorless. PD 2.98, 2.79, 2.04; 6-0392.
$\mathbf{K}_{2} \mathbf{C d}\left(\mathbf{N O}_{2}\right)_{4}$ is orthorhombic with $a: b: c=0.537: 1: 1.924$; pseudohexagonal. Crystals columnar prismatic or $\{010\}$ tablets with distinct $\{110\}$ cleavage. $\mathrm{Y}=b, \mathrm{Z}=c .(+) 2 \mathrm{~V}=48^{\circ} . n_{\mathrm{X}}=1.556$ calc., $n_{\mathrm{Y}}=1.565$, $n_{\mathrm{Z}}=1.608, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.052 \mathrm{Na}$. Color pale yellow.
$\mathbf{K}_{2} \mathbf{P t}\left(\mathbf{N O}_{2}\right)_{4}$ is monoclinic with $^{64} a=7.74, b=12.87, c=9.24 \AA ., \beta=$ $96^{\circ} 15^{\prime}$. G. 3.13. Acute bisectrix, X, nearly normal to a poor cleavage. Extinction on $\{110\}$ at $6^{\circ}$ to $c$ in acute angle $\beta$. (-) $2 \mathrm{E}=102^{\circ} ; 2 \mathrm{~V}=55^{\circ} 28^{\prime}$ calc. For $\lambda=578: n_{\mathrm{X}}=1.590, n_{\mathrm{Y}}=1.670, n_{\mathrm{Z}}=1.685, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.095$. For $\lambda=546: n_{\mathrm{X}}=1.605, n_{\mathrm{Y}}=1.676, n_{\mathrm{Z}}=1.710 . n_{\mathrm{Z}}-n_{\mathrm{X}}=0.105$.
$\mathbf{S r}\left(\mathbf{N O}_{2}\right)_{2} \cdot \mathbf{H}_{2} \mathbf{O}^{65}$ is isometric. Crystals cubic with poor $\{111\}$ cleavage. G. 2.99. Isotropic with $n=1.589 \mathrm{Na}$. Colorless. Formed from cold water solution.
$\mathrm{Na}_{2} \mathrm{Ru}\left(\mathrm{NO}_{2}\right)_{5} \cdot 2 \mathrm{H}_{2} \mathbf{O}$ is monoclinic with $a: b: c=1.508: 1: 1.022, \beta=$ $97^{\circ} 47^{\prime}$. Crystals prismatic with no good cleavage. Twinning on $\{100\}$ of the Carlsbad type. $\mathrm{Y}=b, \mathrm{Z} \wedge c=84^{\circ} 18^{\prime} \mathrm{Na}, 84^{\circ} 34^{\prime} \mathrm{Tl} .(+) 2 \mathrm{~V}=24^{\circ} 50^{\prime}$ $\mathrm{Li}, 25^{\circ} 14^{\prime} \mathrm{Na}, 25^{\circ} 37^{\prime} \mathrm{Tl} . n_{\mathrm{X}}=1.5889 \mathrm{Na}, n_{\mathrm{Y}}=1.5847 \mathrm{Li}, 1.5943 \mathrm{Na}$, $1.6041 \mathrm{Tl}, n_{\mathrm{Z}}=1.7163 \mathrm{Na}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.1274 \mathrm{Na}$ : Color orange with X yellow, Z orange.

## J. NITRITES CONTAINING HALOGEN

$\mathbf{K}_{2} \mathbf{P t I}_{2}\left(\mathbf{N O}_{2}\right)_{2} \cdot 2 \mathbf{H}_{2} \mathbf{O}$ is tetragonal with $c / a=0.589$. Perfect $\{100\}$ and distinct $\{001\}$ cleavages. Uniaxial negative with $n_{\mathrm{O}}=1.7909, n_{\mathrm{E}}=1.6527$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.1382$. Color reddish yellow with O orange, E greenish yellow.
$\mathbf{K}_{2} \mathbf{P t B r}_{2}\left(\mathbf{N O}_{2}\right)_{2} \cdot \mathbf{H}_{2} \mathbf{O}$ is triclinic with $a: b: c=0.992: 1: 1.317, \alpha=90^{\circ} 58^{\prime}$, $\beta=91^{\circ} 43^{\prime}, \gamma=91^{\circ} 7^{\prime}$. Crystals $\{001\}$ (or $\{20 \overline{\}}\}$ ) tablets, or complex. Common twinning on $\{001\}$. One optic axis is nearly normal to $\{001\}$; the other, visible through $\{20 \overline{1}\}$, makes an angle of $30^{\circ} 5^{\prime}$ with a normal to this face. $\mathrm{X} \wedge$ normal to $\{001\}=47^{\circ} 55^{\prime} ; \mathrm{X} \wedge$ normal to $\{20 \overline{1}\}=63^{\circ} 10^{\prime}$; $\mathrm{Z} \wedge$ normal to $\{001\}=42^{\circ} 7^{\prime} ; \mathrm{Z} \wedge$ normal to $\{20 \overline{1}\}=32^{\circ} 27^{\prime} .(+) 2 \mathrm{~V}=$ $72^{\circ} 21^{\prime}$. Axis A, visible through $\{001\}$, is very little dispersed with $\mathrm{r}>\mathrm{v}$. Axis B, visible through $\{20 \overline{1}\}$, shows strong inclined dispersion with $\mathrm{r}<\mathrm{v}$. $n_{\mathrm{X}}=1.626, n_{\mathrm{Y}}=1.6684, n_{\mathrm{Z}}=1.757, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.131 \mathrm{Na}$. Color yellow.

[^65]
## K. NITRITES CONTAINING AMMONIA

$\mathbf{K C o}\left(\mathbf{N H}_{3}\right)_{2}\left(\mathbf{N O}_{2}\right)_{4}$ is orthorhombic with $a: b: c=0.878: 1: 0.519$. Crystals show $\{010\},\{110\},\{101\}$. G. 2.067. Again ${ }^{58}$ G. 2.172. Good $\{110\}$ cleavage. $\mathrm{Y}=a, \mathrm{Z}=c .(+) 2 \mathrm{~V}=$ moderate, $\mathrm{r} \gg \mathrm{v} . n_{\mathrm{X}}=1.702, n_{\mathrm{Y}}=$ $1.713, n_{\mathrm{Z}}=1.760, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.058$.
$\mathbf{N H}_{4} \mathbf{C o}\left(\mathbf{N H}_{3}\right)_{2}\left(\mathbf{N O}_{2}\right)_{4}$ is orthorhombic ${ }^{66}$ with $a: b: c=0.868: 1: 0.511$. Crystals prismatic with $\{110\},\{101\}$. G. 1.972. No cleavage seen. For vibrations along $c, n>1.74$ and $<1.78$; for vibrations along either $a$ or $b$, $n=1.73 \pm$. Therefore $n_{\mathrm{X}}$ and $n_{\mathrm{Y}}$ nearly $=1.73, n_{\mathrm{Z}}>1.74$ and $<1.78$, $\mathrm{Z}=c$ and $(+) 2 \mathrm{~V}$ not large.
$\mathbf{R h}\left(\mathbf{N H}_{3}\right)_{3}\left(\mathbf{N O}_{2}\right)_{3}$ has symmetrical extinction. ${ }^{67}(+) 2 \mathrm{~V}=69^{\circ}$, $n_{\mathrm{X}}=$ $1.700, n_{\mathrm{Y}}=1.720, n_{\mathrm{Z}}=1.780, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.080$. Color of crystals light yellow.
$\mathbf{P t}\left(\mathbf{N H}_{3}\right)_{2} \mathbf{C l N O}_{2}($ trans- $)$ forms irregular crystals ${ }^{67}$ with ( - ) $2 \mathrm{~V}=46^{\circ}$ calc. $n_{\mathrm{X}}=1.764, n_{\mathrm{Y}}=1.786, n_{\mathrm{Z}}=1.790, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.026$.
$\mathbf{P t}\left(\mathbf{N H}_{3}\right)_{2} \mathbf{B r N O} \mathbf{O}_{2}$ (trans-) has symmetrical extinction ${ }^{67}$ with $n_{\mathrm{X}}=1.778$, $n_{\mathrm{Y}}>1.780, n_{\mathrm{Z}}>1.780$.
$\mathbf{P t}\left(\mathbf{N H}_{3}\right)_{2} \mathbf{C l}\left(\mathbf{N O}_{2}\right)_{3}$ is monoclinic ${ }^{68}$ with $a: b: c=0.97: 1: 0.56, \beta=96^{\circ}$. Crystals acicular. ( $+2 \mathrm{~V}=66^{\circ} . n_{\mathrm{X}}=1.755, n_{\mathrm{Y}}=1.797, n_{\mathrm{Z}}=1.89$ calc., $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.135$. Color of crystals pale green.
$\mathbf{P t}\left(\mathbf{N H}_{3}\right)_{2}\left(\mathbf{N O}_{2}\right)_{2}(c i s-)$ is monoclinic ${ }^{68}$ with $a: b: c=0.821: 1: 1.030, \beta=$ $101^{\circ} 20^{\prime}$. Crystals acicular. Twinning common. $\mathrm{X} \wedge c=42^{\circ}-45^{\circ}$ in obtuse $\beta ; \mathrm{Y}=b .(+) 2 \mathrm{~V}=80^{\circ} . n_{\mathrm{X}}=1.711, n_{\mathrm{Y}}=1.742, n_{\mathrm{Z}}=1.790$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.079$. Color pale yellow.
$\mathbf{P t}\left(\mathbf{N H}_{3}\right)_{2}\left(\mathbf{N O}_{2}\right)_{2}$ (trans-) has an extinction angle ${ }^{68}$ of $20^{\circ}$. (-) $2 \mathrm{~V}=32^{\circ}$. $n_{\mathrm{X}}=1.531, n_{\mathrm{Y}}=1.779, n_{\mathrm{Z}}=1.80 \mathrm{ca} ., n_{\mathrm{Z}}-n_{\mathrm{X}}=0.269 \mathrm{ca}$. Colorless.
$\mathbf{K R h}\left(\mathbf{N H}_{3}\right)_{2}\left(\mathbf{N O}_{2}\right)_{4} \cdot \mathbf{0 . 5 H} \mathbf{H} \mathbf{O}$ is triclinic ${ }^{67}$ with $a: b: c=1.205: 1: 0.903$, $\alpha=95^{\circ} 18^{\prime}, \beta=118^{\circ} 36^{\prime}, \gamma=85^{\circ} 11^{\prime}$. ( -$) 2 \mathrm{~V}=62^{\circ}$. $n_{\mathrm{X}}=1.612, n_{\mathrm{Y}}=$ $1.690, n_{\mathrm{Z}}=1.716, n_{\mathrm{z}}-n_{\mathrm{X}}=0.104$. Color of crystals light yellow.

## L. HALATES

The halates include chlorates, bromates and iodates as well as hypochlorites, perchlorates, perbromates and periodates. A few complex and compound salts are known.

[^66]
## 1. Formula Type $\mathrm{A}_{\boldsymbol{m}}\left(\mathrm{XO}_{2}\right)_{\mathbf{2}} \cdot \boldsymbol{n} \mathbf{H}_{\mathbf{2}} \mathbf{O}$

$\mathbf{C a}\left(\mathbf{C l O}_{2}\right)_{2} \cdot 2 \mathbf{H}_{2} \mathrm{O}$ is tetragonal. ${ }^{68 \mathrm{a}}$ Uniaxial positive with $n_{\mathrm{O}}=1.53, n_{\mathrm{E}}=$ $1.63, n_{\mathrm{E}}-n_{\mathrm{O}}=0.10$. Colorless.
$\mathbf{C a}_{3}\left(\mathbf{C l O}_{2}\right)_{2}(\mathbf{O H})_{4}$ is tetragonal. ${ }^{68 \mathrm{a}}$ Uniaxial positive with $n_{\mathrm{O}}=1.51, n_{\mathrm{E}}=$ $1.585, n_{\mathrm{E}}-n_{\mathrm{O}}=0.075$. Colorless.

## 2. Formula Type $\mathrm{AXO}_{3}(\mathrm{OH})_{n}$ with $n=0$ or 1

$\mathbf{N a C l O}_{3}$ is isometric and tetartohedral. Crystals cubic or tetartohedral with no cleavage. Penetration twins common on $\{100\}$. G. 2.49. Soluble in water. Isotropic with $n=1.5127 \mathrm{C}, 1.5151 \mathrm{D}, 1.5216 \mathrm{~F}$. Rotates the plane of polarization for 1 mm . of thickness $2.3^{\circ} \mathrm{B}, 3.1^{\circ} \mathrm{D}, 4.6^{\circ} \mathrm{F}$. Colorless. Made from water solution. PD 2.94, 3.29, 1.76; 5-0610.
$\mathbf{N a B r O}_{3}$ is isometric tetartohedral. Crystals tetartohedral, etc. G. 3.3. Soluble in water. Isotropic with $n=1.6117$ for $672 \mathrm{~m} \mu,{ }^{69} 1.617$ for $579 \mathrm{~m} \mu$, 1.6268 for $492 \mathrm{~m} \mu$; again ${ }^{70} n=1.5943+\mathrm{Na}$. Weakly birefringent in some cases (due to strain?). Rotates the plane of polarization for 1 mm . of thickness $1.4^{\circ} \mathrm{B}, 2.1^{\circ} \mathrm{D}, 3.75^{\circ} \mathrm{F}$. Colorless. Made from water solution. PD 3.00, 1.79, 4.74; 6-0377.
$\mathbf{A g B r O}_{3}$ is tetragonal with $c / a=0.941$. Crystals prismatic columnar or pyramidal. Poor $\{110\}$ cleavage. G. 5.1-5.2. Uniaxial positive with $n_{\mathrm{O}}=$ $1.8466 \mathrm{Na}, 1.860$ (green), $n_{\mathrm{E}}=1.920 \mathrm{Na}, 1.9405$ (green), $n_{\mathrm{E}}-n_{\mathrm{O}}=$ 0.0734 Na . Color white. PD 2.95, 3.04, 3.48; 6-0385.
$\mathbf{K B r O}_{3}$ is hexagonal rhombohedral with $c / a=1.357$. Crystals rhombohedral. Poor basal cleavage. G. 3.32. Uniaxial negative with ${ }^{26} n_{0}=1.68$, $n_{\mathrm{E}}=1.54, n_{\mathrm{O}}-n_{\mathrm{E}}=0.14$ PD 3.21, 3.01, 4.39; 7-242.
$\mathrm{KClO}_{3}$ is monoclinic with $a=7.085, b=5.585, c=4.647 \AA \AA^{, 71} \beta 109^{\circ} 38^{\prime}$. (Pseudo-trigonal and closely related to calcite and soda niter.) Crystals lamellar to equant basal tablets. Perfect basal and $\{110\}$ cleavages. Lamellar twinning on $\{001\}$. G. 2.32. Soluble in water. $\mathrm{Y} \wedge a=58.5^{\circ}$ in obtuse angle $\beta ;^{71} \mathrm{Z}=b$. (-) $2 \mathrm{~V}=28^{\circ}$, with distinct horizontal dispersion. $n_{\mathrm{X}}=1.415, n_{\mathrm{Y}}=1.517, n_{\mathrm{Z}}=1.523, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.108$. Again: ${ }^{72}$ $\mathrm{X} \wedge c=+56^{\circ} 10^{\prime},(-) 2 \mathrm{~V}=26^{\circ} 45^{\prime} . \quad n_{\mathrm{X}}=1.4099, n_{\mathrm{Y}}=1.5174, n_{\mathrm{Z}}=$ $1.5241, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.1142$. Colorless. PD 3.45, 2.79, 2.86; 1-0599. Made from water solution.
$\mathrm{KIO}_{3}$ is monoclinic with $a: b: c=1.009: 1: 1.439, \beta=90^{\circ} 45^{\prime}$. Crystals commonly twinned in pseudo-cubic form with $\{110\},\{001\},\{100\}$, etc. No cleavage seen. G. 3.89 (or 3.98). M.P. $560^{\circ} \mathrm{C} .(-) 2 \mathrm{~V}=$ small, ${ }^{26} \mathrm{r}>\mathrm{v}$.

[^67]$n_{\mathrm{X}}=1.700, n_{\mathrm{Y}}=1.828, n_{\mathrm{Z}}=1.832, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.132 . \mathrm{PD} 3.16,4.48$, 2.23; 1-0776.
$\mathbf{C u}(\mathbf{O H}) \mathbf{I O}_{3}$ is orthorhombic ${ }^{73}$ with $a: b: c=0.712: 1: 1.707$. Crystals basal tablets with $\{010\},\{110\}$ and $\{101\}$. Distinct $\{100\}$ cleavage. $\mathrm{X}=a$, $\mathrm{Y}=b$. (-) $2 \mathrm{~V}=$ small, $\mathrm{r}>\mathrm{v}$ (uniaxial in blue). $n_{\mathrm{X}}=1.775 \pm 0.01$, $n_{\mathrm{Y}}=2.046 \pm 0.005, n_{\mathrm{Z}}=2.052 \pm 0.005, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.277$. Color green with X colorless, Y green, Z yellowish green. Dimorphous with salesite which is also orthorhombic with $a=4.78, b=10.77, c=6.70 \AA$ with perfect $\{110\}$ cleavages. H. 3. G. $4.77(-) 2 \mathrm{~V}=0^{\circ}-5^{\circ}, \mathrm{r}>\mathrm{v}$, extreme. $n_{\mathrm{X}}=1.786, \quad n_{\mathrm{Y}}=2.070, \quad n_{\mathrm{Z}}=2.075, \quad n_{\mathrm{Z}}-n_{\mathrm{X}}=0.289$. Color bluish green.

## 3. Formula Type $\mathrm{A}\left(\mathrm{XO}_{3}\right)_{2} \cdot \mathrm{nH}_{2} \mathrm{O}$

$\mathbf{M g}\left(\mathrm{BrO}_{3}\right)_{2} \cdot \mathbf{6 H}_{2} \mathrm{O}$ is isometric; crystals octahedral. G. 2.29. Loses water at $200^{\circ} \mathrm{C}$. Isotropic with $n=1.5139 \mathrm{Na}$. Colorless.
$\mathbf{Z n}\left(\mathrm{BrO}_{3}\right)_{2} \cdot \mathbf{6 H} \mathbf{2} \mathbf{O}$ is isometric. Crystals octahedral. G. 2.56. M.P. $100^{\circ} \mathrm{C}$. Isotropic with $n=1.5452 \mathrm{Na}$. Color white.
$\mathbf{S r}\left(\mathbf{C l O}_{3}\right)_{2}$ is orthorhombic with $a: b: c=0.916: 1: 0.597$. Crystals pyramidal. G. 3.15. Decomposes at $120^{\circ} \mathrm{C} . \mathrm{X}=c, \mathrm{Y}=a$. (-)2V $=72^{\circ} 21^{\prime}$, $\mathrm{r}>\mathrm{v} . n_{\mathrm{X}}=1.5636 \mathrm{~B}, 1.5670 \mathrm{D}, 1.5717 \mathrm{~F}, n_{\mathrm{Y}}=1.6002 \mathrm{~B}, 1.6047 \mathrm{D}$, $1.6116 \mathrm{~F}, n_{\mathrm{z}}=1.6210 \mathrm{~B}, 1.6257 \mathrm{D}, 1.6337 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0587 \mathrm{D}$. Colorless.
$\mathbf{B a}\left(\mathrm{ClO}_{3}\right)_{2} \cdot \mathbf{H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=1.142: 1: 1.198, \beta=93^{\circ} 34^{\prime}$. Crystals columnar prisms with perfect $\{011\}$ and good $\{100\}$ cleavages. G. 3.18. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=-24^{\circ}$. $(+) 2 \mathrm{~V}=55.5^{\circ}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{X}}=1.562$, $n_{\mathrm{Y}}=1.577, n_{\mathrm{Z}}=1.635, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.073$. Colorless. PD 6.00, 2.32, 3.35; 1-0155.
$\mathbf{C a}\left(\mathrm{IO}_{3}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is orthorhombic. M.P. $42^{\circ} \mathrm{C} .(+) 2 \mathrm{~V}=$ nearly $90^{\circ}$ calc. $n_{\mathrm{X}}=1.604, n_{\mathrm{Y}}=1.644, n_{\mathrm{Z}}=1.686, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.082$. Colorless.
$\mathbf{C a}\left(\mathbf{I O}_{3}\right)_{2}$ (Lautarite) is monoclinic prismatic with $a=7.18, b=11.38$, $c=7.32 k X, \beta=106^{\circ} 22^{\prime}$. U.C. 4. Space group $P 2_{1} / c$. Crystals short prismatic. Good $\{011\}$ cleavage. H. 3.5-4. G. 4.59. $\mathrm{X} \wedge c=+25^{\circ}, \mathrm{Y}=b .^{6}$ $(+) 2 \mathrm{~V}=$ nearly $90^{\circ}, \mathrm{r}>\mathrm{v}$ moderate. $n_{\mathrm{X}}=1.792, n_{\mathrm{Y}}=1.840, n_{\mathrm{Z}}=$ $1.888, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.096$. Colorless. PD 4.27, 3.04, 3.24; $1-0386$. Made by fusing $\mathrm{CaIO}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ in $\mathrm{NaNO}_{3}$.
$3 \mathrm{Cu}\left(\mathrm{IO}_{3}\right)_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ (Bellingerite) is triclinic pinacoidal ${ }^{74}$ with $a=7.22$, $b=7.82, c=7.92 \AA, \alpha 105^{\circ} 6^{\prime}, \beta 96^{\circ} 58^{\prime}, \gamma 92^{\circ} 55^{\prime}$. U.C. 1. Space group $P \overline{1}$. Crystals thick $\{100\}$ tablets with $\{110\},\{2 \overline{1} 0\},\{0 \overline{1} 2\},\{010\}$, etc. H. 4. G. 4.89. On $\{100\}$ extinction is very nearly parallel with the zone edge [0 $\overline{1} 1]$ and $\mathrm{X}^{\prime} \wedge[001]=37^{\circ} .(+) 2 \mathrm{~V}=$ medium, $\mathrm{r}>$ v strong. $n_{\mathrm{X}}=$

[^68]${ }^{74}$ Berman and Wolfe: Am. Min. XXV, p. 505 (1940).
1.890, $n_{\mathrm{Y}}=1.90, n_{\mathrm{Z}}=1.99, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.10$. Color light green with X and Y light bluish green, Z blue-green.

## 4. Formula Type $\mathrm{A}\left(\mathrm{XO}_{3}\right)_{3} \cdot \boldsymbol{n H}_{2} \mathrm{O}$

$\mathbf{S m}\left(\mathrm{BrO}_{3}\right)_{3} \cdot \mathbf{9 H}_{2} \mathrm{O}$ is hexagonal ${ }^{75}$ with $c / a=0.562$. G. 2.845. Uniaxial negative with $n_{\mathrm{O}}=1.605 \mathrm{D}, 1.609 \mathrm{E}, 1.614 \mathrm{~F}, n_{\mathrm{E}}=1.551 \mathrm{D}, 1.555 \mathrm{E}$, $1.560 \mathrm{~F}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.054 \mathrm{D}$.
$\mathbf{G d}\left(\mathbf{B r O}_{3}\right)_{3} \cdot \mathbf{9 H}_{2} \mathrm{O}$ is hexagonal ${ }^{75}$ with $c / a=0.570$. G. 2.892. Uniaxial negative with $n_{\mathrm{O}}=1.605 \mathrm{D}, 1.609 \mathrm{E}, 1.614 \mathrm{~F}, n_{\mathrm{E}}=1.551 \mathrm{D}, 1.555 \mathrm{E}$, $1.560 \mathrm{~F}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.054 \mathrm{D}$.

## 5. Formula Type $\mathrm{AXO}_{4} \cdot \mathbf{n H}_{2} \mathrm{O}$

$\mathrm{KIO}_{4}$ is tetragonal. Crystals pyramidal. G. 3.62. It is stable to $200^{\circ} \mathrm{C}$. but loses oxygen at $300^{\circ}$ forming $\mathrm{KIO}_{3}$. Uniaxial positive ${ }^{76}$ with $n_{0}=$ $1.6151 \mathrm{C}, 1.6205 \mathrm{D}, 1.6346 \mathrm{~F}, n_{\mathrm{E}}=1.6416 \mathrm{C}, 1.6479 \mathrm{D}, 1.6651 \mathrm{~F}, n_{\mathrm{F}}-n_{\mathrm{O}}$ $=0.0274$ D. PD 3.41, 5.22, 2.12; 8-472.
$\mathrm{LiClO}_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ is hexagonal ${ }^{77}$ with $a=15.42, c=5.42 \mathrm{kX}$. Crystals prismatic with distinct basal and $\{11 \overline{2} 0\}$ cleavages. G. 1.89. M.P. $95^{\circ} \mathrm{C}$. Uniaxial negative with $n_{\mathrm{O}}=1.483, n_{\mathrm{E}}=1.448, n_{\mathrm{O}}-n_{\mathrm{E}}=0.035$. Colorless. PD 4.23, 2.85, 3.86; 8-156.
$\mathrm{NaClO}_{4}$ is orthorhombic ${ }^{78}$ and apparently isostructural with $\mathrm{CaSO}_{4}$. G. 2.50. Optic orientation not reported. $(+) 2 \mathrm{~V}=$ small. $n_{\mathrm{X}}=1.4606$, $n_{\mathrm{Y}}=1.4617, n_{\mathrm{Z}}=1.4730, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0124$. Colorless. PD 3.54, 3.97, 2.96; 8-494*.
$\mathrm{KClO}_{4}$ is orthorhombic ${ }^{79}$ with $a: b: c=0.781: 1: 1.281$. Crystals thick basal tablets with perfect basal and $\{110\}$ cleavages. G. $2.524 . \mathrm{Y}=a, \mathrm{Z}=b$. $(+) 2 \mathrm{~V}=50^{\circ} 15^{\prime} \mathrm{C}, 49^{\circ} 48^{\prime} \mathrm{D}, 48^{\circ} 48^{\prime} \mathrm{F} . n_{\mathrm{X}}=1.4712 \mathrm{C}, 1.4731 \mathrm{D}, 1.4774 \mathrm{~F}$, $n_{\mathrm{Y}}=1.4718 \mathrm{C}, 1.4737 \mathrm{D}, 1.4779 \mathrm{~F}, n_{\mathrm{Z}}=1.4750 \mathrm{C}, 1.4769 \mathrm{D}, 1.4812 \mathrm{~F}$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0038$ D. Colorless. PD 3.49, 3.15, 2.89; 7-211*. Made by reaction of $\mathrm{K}_{2} \mathrm{SO}_{4}$ with $\mathrm{Ba}\left(\mathrm{ClO}_{4}\right)_{2}$. Miscible in all proportions with $\mathrm{KMnO}_{4}$.
$\mathbf{N H}_{4} \mathrm{ClO}_{4}$ is orthorhombic ${ }^{79}$ with $a: b: c=0.793: 1: 1.281$. Crystals short prisms or basal tablets with perfect $\{110\}$ and distinct $\{001\}$ cleavages. G. 1.95. $\mathrm{Y}=c, \mathrm{Z}=b$. $(+) 2 \mathrm{~V}=69^{\circ} 34^{\prime} \mathrm{C}, 69^{\circ} 54^{\prime} \mathrm{D}, 70^{\circ} 45^{\prime} \mathrm{F}, \mathrm{r}>\mathrm{v}$ distinct. $n_{\mathrm{X}}=1.4798 \mathrm{C}, 1.4818 \mathrm{D}, 1.4865 \mathrm{~F}, n_{\mathrm{Y}}=1.4813 \mathrm{C}, 1.4833 \mathrm{D}$, $1.4881 \mathrm{~F}, n_{\mathrm{Z}}=1.4859 \mathrm{C}, 1.4881 \mathrm{D}, 1.4931 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0063 \mathrm{D}$. Colorless. PD 4.58, 3.61, 3.25; 8-451*. Made by reaction of $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SO}_{4}$ with $\mathrm{Ba}\left(\mathrm{ClO}_{4}\right)_{2}$.

[^69]$\mathbf{R b C l O}_{4}$ is orthorhombic ${ }^{79}$ with $a: b: c=0.796: 1: 1.288$. Crystals thick basal tablets to prismatic and apparently sphenoidal with distinct basal and $\{110\}$ cleavages. G. $3.014 . \mathrm{Y}=a, \mathrm{Z}=b .(+) 2 \mathrm{~V}=55^{\circ} 12^{\prime} \mathrm{C}, 55^{\circ} 4^{\prime} \mathrm{D}$, $54^{\circ} 33^{\prime} \mathrm{F}$; r $>$ v weak. $n_{\mathrm{X}}=1.4674 \mathrm{C}, 1.4692 \mathrm{D}, 1.4732 \mathrm{~F}, n_{\mathrm{Y}}=1.4684 \mathrm{C}$, $1.4701 \mathrm{D}, 1.4742 \mathrm{~F}, n_{\mathrm{Z}}=1.4715 \mathrm{C}, 1.4731 \mathrm{D}, 1.4774 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.0039 D. Colorless. PD 3.85, 2.73, 2.32; 2-0309 (at $300^{\circ} \mathrm{C}$ ).
$\mathrm{CsClO}_{4}$ is orthorhombic ${ }^{79}$ with $a: b: c=0.817: 1: 1.287$. Crystals basal tablets or short prisms with perfect basal and \{110\} cleavages. G. 3.327. $\mathrm{Y}=a, \mathrm{Z}=b .(-) 2 \mathrm{~V}=62^{\circ} 30^{\prime} . n_{\mathrm{X}}=1.4734 \mathrm{C}, 1.4752 \mathrm{D}, 1.4797 \mathrm{~F}$, $n_{\mathrm{Y}}=1.4770 \mathrm{C}, 1.4788 \mathrm{D}, 1.4835 \mathrm{~F}, n_{\mathrm{Z}}=1.4786 \mathrm{C}, 1.4804 \mathrm{D}, 1.4852 \mathrm{~F}$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0052$. Colorless. PD 3.99, 2.83, 2.41; 2-0923 (at $230^{\circ} \mathrm{C}$ ). Made by reaction of $\mathrm{Cs}_{2} \mathrm{SO}_{4}$ with $\mathrm{Ba}\left(\mathrm{ClO}_{4}\right)_{2}$.
$\mathrm{TlClO}_{4}$ is orthorhombic ${ }^{87}$ with $a: b: c=0.798: 1: 1.290$. Crystals domatic with $\{110\}$ cleavage. G. $4.96 . \mathrm{Y}=c, \mathrm{Z}=b .(+) 2 \mathrm{~V}=$ small. $n_{\mathrm{X}}=1.6370$ $\mathrm{Li}, 1.6427 \mathrm{D}, 1.6557 \mathrm{Cd}, n_{\mathrm{Y}}=1.6389 \mathrm{Li}, 1.6445 \mathrm{D}, 1.6578 \mathrm{Cd}, n_{\mathrm{Z}}=$ $1.6484 \mathrm{Li}, 1.6541 \mathrm{D}, 1.6681 \mathrm{Cd}, n_{\mathrm{z}}-n_{\mathrm{X}}=0.0114$. Colorless. PD 3.21, 3.05, 4.42; 9-406.

## 6. Formula Type $\mathbf{A}\left(\mathrm{XO}_{4}\right)_{2} \cdot \mathbf{n H}_{2} \mathrm{O}$

$\mathbf{M g}\left(\mathbf{C l O}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathbf{O}$ is hexagonal ${ }^{81}$ with $a=15.52, c=5.26 \mathrm{kX}$. Crystals slender prisms with distinct basal cleavage. G. 1.98. Uniaxial negative with $n_{\mathrm{O}}=1.482, n_{\mathrm{E}}=1.458, n_{\mathrm{O}}-n_{\mathrm{E}}=0.024$. Also may be biaxial ( 2 V up to $16^{\circ}$ ) with twinning as in aragonite. Colorless. PD 2.85, 4.18, 3.91; 1-0969.
$\mathbf{M n}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathbf{H}_{2} \mathrm{O}$ is hexagonal ${ }^{81}$ with $a=15.70, c=5.30 k X$. Crystals prismatic with distinct basal cleavage. G. 2.10. Uniaxial negative with $n_{\mathrm{O}}=1.492, n_{\mathrm{E}}=1.475, n_{\mathrm{O}}-n_{\mathrm{E}}=0.017$.
$\mathrm{Fe}\left(\mathrm{ClO}_{4}\right)_{2} \cdot \mathbf{6 H}_{2} \mathbf{O}$ is hexagonal ${ }^{81}$ with $a=15.58, c=5.24 k X$. Crystals prismatic with distinct basal cleavage. G. 2.15. Uniaxial negative with $n_{\mathrm{O}}=1.493, n_{\mathrm{E}}=1.478, n_{\mathrm{O}}-n_{\mathrm{E}}=0.015$. Also may be biaxial with very small 2 V and twinning as in aragonite. Color green.
$\mathbf{C o}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is hexagonal ${ }^{81}$ with $a=15.52, c=5.20 \mathrm{kX}$. Crystals prismatic with distinct basal cleavage. G. 2.20. Uniaxial negative with $n_{\mathrm{O}}=1.510, n_{\mathrm{E}}=1.490, n_{\mathrm{O}}-n_{\mathrm{E}}=0.020$. Also may be biaxial with very small 2 V and twinning as in aragonite. Color red or pink with O pale pink, slightly yellowish, E deep pink.
$\mathrm{Ni}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is hexagonal ${ }^{81}$ with $a=15.46, c=5.17 k X$. Crystals prismatic with distinct basal cleavage. G. 2.25. Uniaxial negative with $n_{\mathrm{O}}=1.518, n_{\mathrm{E}}=1.498, n_{\mathrm{O}}-n_{\mathrm{E}}=0.020$. Color greenish blue with O green, E dark bluish green.

[^70]$\mathbf{Z n}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is hexagonal ${ }^{81}$ with $a=15.52, c=5.20 k X$. Crystals prismatic with distinct basal cleavage. G. 2.25. Uniaxial negative with $n_{\mathrm{O}}=1.508, n_{\mathrm{E}}=1.487, n_{\mathrm{O}}-n_{\mathrm{E}}=0.021$.
$\mathbf{C d}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is hexagonal ${ }^{81}$ with $a=15.92, c=5.30 \mathrm{kX}$. Crystals prismatic with distinct basal cleavage. G. 2.37. Uniaxial negative with $n_{\mathrm{O}}=1.489, n_{\mathrm{E}}=1.480, n_{\mathrm{O}}-n_{\mathrm{E}}=0.009$.
$\mathbf{H g}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is hexagonal rhombohedral. ${ }^{81} \mathrm{G} .2 .79$. Uniaxial negative with $n_{\mathrm{O}}=1.511, n_{\mathrm{E}}=1.509, n_{\mathrm{O}}-n_{\mathrm{E}}=0.002$.
$\mathrm{Cu}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is monoclinic ${ }^{81}$ with G. 2.245. Crystals prismatic or $\{100\}$ tablets. $\mathrm{X} \wedge c=23^{\circ} ; \mathrm{Z}=b$. (+) $2 \mathrm{~V}=54^{\circ} . n_{\mathrm{X}}=1.495, n_{\mathrm{Y}}=$ $1.505, n_{\mathrm{Z}}=1.522, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.027$. Marked crossed dispersion giving anomalous interference colors near extinction in (010) sections.
$\mathbf{B a}\left(\mathbf{C l O}_{4}\right)_{2} \cdot 3 \mathbf{H}_{2} \mathrm{O}$ is hexagonal ${ }^{82}$ with $c / a=1.33$. Crystals prismatic. Hygroscopic. G. 2.91. Uniaxial negative with $n_{\mathrm{O}}=1.5330, n_{\mathrm{E}}=1.5323$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.0007$. PD 2.90, 3.65, 2.14; 1-0931.
$\mathbf{C a}\left(\mathbf{I O}_{4}\right)_{2} \cdot \mathbf{6 H} \mathbf{H}_{2} \mathrm{O}$ is orthorhombic ${ }^{83}$ with $a: b: c=0.647: 1: 0.277$. Crystals pyramidal or prismatic with $\{131\},\{110\},\{010\},\{100\}$, etc. Poor $\{110\}$ cleavage. $\mathrm{Y}=a, \mathrm{Z}=c .(+) 2 \mathrm{~V}=88^{\circ} \pm, \mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.604, n_{\mathrm{Y}}=1.644$, $n_{\mathrm{Z}}=1.686, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.082 \mathrm{D}$.

## 7. Miscellaneous Halates

$\mathbf{C o}\left(\mathbf{C l O}_{4}\right)_{2} \cdot 6 \mathbf{N H}_{3}$ is isometric. Crystals octahedral with distinct octahedral cleavage. Isotropic with $n=1.430 \mathrm{Na}$.
$\mathbf{N i}\left(\mathbf{C l O}_{4}\right)_{2} \cdot 6 \mathbf{N H}_{3}$ is isometric. Crystals octahedral with distinct octahedral cleavage. Isotropic with $n=1.437 \mathrm{Na}$. PD 4.04, 2.85, 2.19; 2-0284.
$\mathbf{C o}\left(\mathrm{ClO}_{4}\right)_{3} \cdot 6 \mathrm{NH}_{3}$ is isometric ${ }^{84}$ in modified octahedrons. G. 2.065. Isotropic with $n=1.570$. Color yellow-brown.
$\mathbf{C o C l}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{NH}_{3}$ is rhombohedral ${ }^{84}$ with $c / a=1.93$. Crystals basal plates with poor $\{10 \overline{1} 1\}$ cleavage. G. 1.905. Uniaxial negative with $n_{0}=$ $1.610, n_{\mathrm{E}}=1.600, n_{\mathrm{O}}-n_{\mathrm{E}}=0.010$. Color orange.
$\mathrm{Ca}_{4} \mathrm{Al}_{2}\left(\mathrm{ClO}_{3}\right)_{2}(\mathbf{O H})_{12} \cdot \mathbf{4 H _ { 2 }} \mathbf{O}$ (?) is hexagonal ${ }^{54}$ in plates often in spherulites. Uniaxial negative in water, but changes ${ }^{85}$ slowly to uniaxial positive in immersion liquids. $n_{\mathrm{O}}=1.521 \pm 0.002, n_{\mathrm{E}}=1.521 \pm 0.002, n_{\mathrm{O}}-n_{\mathrm{E}}=$ very weak.
$\mathrm{Ca}_{5} \mathrm{Al}_{2}\left(\mathbf{I O}_{3}\right)_{2}(\mathbf{O H})_{15} \cdot \mathbf{1 4 H} \mathbf{H} \mathbf{O}(?)$ is probably hexagonal. ${ }^{54}$ Uniaxial negative with $n_{\mathrm{O}}=1.521 \pm 0.003, n_{\mathrm{E}}=1.496 \pm 0.003, n_{\mathrm{O}}-n_{\mathrm{E}}=0.025$.
$\mathrm{Ca}_{6} \mathrm{Al}_{2}\left(\mathbf{I O}_{3}\right)_{2}(\mathbf{O H})_{18} \cdot \mathbf{2 4 H} \mathbf{O} \mathbf{O}$ ? $)$ seems to be hexagonal. ${ }^{54}$ Uniaxial negative with $n_{\mathrm{O}}=1.471 \pm 0.002, n_{\mathrm{E}}=1.471 \pm 0.002, n_{\mathrm{O}}-n_{\mathrm{E}}=$ very weak.

[^71]$\mathrm{Al}\left(\mathrm{NO}_{3}\right)\left(\mathbf{I O}_{3}\right)_{2} \cdot \mathbf{6 H} \mathbf{H} \mathbf{O}$ is rhombohedral ${ }^{86}$ with $c / a=1.206$. Crystals basal tablets limited by $\{10 \overline{1} 0\},\{10 \overline{1} 1\}$ and $\{10 \overline{1} 2\}$. No cleavage. Twinning on $\{10 \overline{1} 1\}$. G. 2.78. Soluble in water. Uniaxial positive with $n_{0}=1.6516$, $n_{\mathrm{E}}=1.6987$. Colorless; transparent to porcelain-like.
$\mathrm{H}_{2} \mathrm{~K}_{2} \mathrm{TeI}_{2} \mathrm{O}_{10} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ is rhombohedral with $c / a=1.933$. Crystals rhombohedral with $\{0001\}$. Common twinning on $\{10 \overline{1} 1\}$. No good cleavage. Uniaxial negative with $n_{\mathrm{O}}=2.142, n_{\mathrm{E}}=2.030, n_{\mathrm{O}}-n_{\mathrm{E}}=0.112 \mathrm{Na}$.
$\mathrm{Ca}_{2}\left(\mathrm{ClO}_{4}\right)_{2}(\mathbf{O H})_{2} \cdot \mathbf{2 H}_{2} \mathrm{O}$ is orthorhombic ${ }^{87}$ in needles along $c$, flattened on $\{100\}$ with $\{100\},\{001\}$, and $\{010\}$ cleavages. $\mathrm{X}=c, \mathrm{Y}=b,(-) 2 \mathrm{~V}=$ ?. $n_{\mathrm{X}}=1.532 \pm 0.002, n_{\mathrm{Y}}=1.535 \pm 0.002, n_{\mathrm{Z}}=$ ?.
$\mathrm{Ca}_{4}\left(\mathrm{ClO}_{4}\right)_{2}(\mathbf{O H})_{6} \cdot \mathbf{1 2 H}_{2} \mathbf{O}$ is orthorhombic ${ }^{87}$ in needles a'ong $c$ flattened on $\{100\}$ with $\{100\}$ and $\{010\}$ cleavages. $\mathrm{Y}=b, \mathrm{Z}=c$. $(-) 2 \mathrm{~V}=66^{\circ} 26^{\prime}$. $n_{\mathrm{X}}=1.490$ calc., $n_{\mathrm{Y}}=1.499 \pm 0.002, n_{\mathrm{Z}}=1.503 \pm 0.002, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.013 .
${ }^{86}$ Sztrokay: Zeit. Krist. XC, p. 38 (1935).
${ }^{87}$ Pehrman and Mylius: Acta Acad. Abo, Math. Phys. VIII, No. 9 (1935).
$\mathrm{Na}_{2} \mathbf{B}_{4} \mathrm{O}_{7} \cdot 10 \mathrm{H}_{2} \mathrm{O}$ (Borax) is monoclinic with $a=11.82, b=10.61, c=$ $12.30 k X, \beta=107^{\circ} 35^{\prime}$. Crystals prismatic, resembling pyroxene. Twinning occurs on $\{100\}$. Perfect $\{100\}$ and distinct $\{110\}$ cleavages. H. 2. G. 1.70. $\mathrm{Y}=b,{ }^{9} \mathrm{Z} \wedge c=-56^{\circ}$ (red), $-55^{\circ} 50^{\prime} \mathrm{Na},-54^{\circ} 39^{\prime}$ (green). ( - ) $2 \mathrm{~V}=$ $39^{\circ} 28^{\prime}$ (red), $39^{\circ} 10^{\prime} \mathrm{Na}, 38^{\circ} 35^{\prime}$ (green). $n_{\mathrm{X}}=1.4445 \mathrm{C}, 1.4467 \mathrm{D}, 1.4517 \mathrm{~F}$, $n_{\mathrm{Y}}=1.4669 \mathrm{C}, 1.4694 \mathrm{D}, 1.4750 \mathrm{~F}, n_{\mathrm{Z}}=1.4669 \mathrm{C}, 1.4724 \mathrm{D}, 1.4778 \mathrm{~F}$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0257$ D. Colorless. PD 2.57, 2.84, 4.86; 1-1097. Made from an aqueous solution of boric acid and sodium carbonate at ordinary temperature. Borax glass is isotropic with $n=1.5147 \mathrm{Na}$.
$\mathrm{CaB}_{2} \mathrm{O}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is monoclinic ${ }^{10}$ with $a: b: c=1.2058: 1: 1.2063, \quad \beta=$ $104^{\circ} 11^{\prime}$. U.C. 2. Crystals equant with $\{111\},\{100\},\{001\},\{201\},\{110\}$, etc. Perfect $\{001\}$ cleavage. H. 2.5. G. 1.88. F. 1. $\mathrm{X}=b, \mathrm{Z} \wedge c=-3^{\circ}$. $(-) 2 \mathrm{~V}=77^{\circ} \pm 5^{\circ}$ calc. $\mathrm{r}>\mathrm{v} . n_{\mathrm{X}}=1.505(1.506), n_{\mathrm{Y}}=1.511, n_{\mathrm{Z}}=$ 1.515 (1.514), $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.010$ (0.008). Colorless. Made from Portland cement mixed with four parts of $\mathrm{Ca}_{2} \mathrm{~B}_{6} \mathrm{O}_{11} \cdot 5 \mathrm{H}_{2} \mathrm{O}$.
$\mathrm{NaCaB}_{5} \mathrm{O}_{9} \cdot \mathbf{5 H}_{2} \mathbf{O}$ (Probertite) is monoclinic with $a=13.88, b=12.56$, $c=6.609 \AA, \beta=107^{\circ} 40^{\prime}$. U.C. 2. Crystals often in groups of needles. Perfect $\{110\}$ cleavage. H. 3.5. G. 2.14. Fuses easily with swelling. $Y=b,{ }^{8}$ $\mathrm{Z} \wedge c=-12^{\circ} .(+) 2 \mathrm{~V}=73^{\circ}, \mathrm{r}>\mathrm{v} . \quad n_{\mathrm{X}}=1.514, \quad n_{\mathrm{Y}}=1.524, \quad n_{\mathrm{Z}}=$ $1.543, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.029$. Again $:^{8} n_{\mathrm{X}}=1.515, n_{\mathrm{Y}}=1.525, n_{\mathrm{Z}}=1.544$. Colorless or white. PD 9.1, 2.78, 2.90; 4-0107. Made by heating a mixture of two parts of $\mathrm{NaCaB}_{5} \mathrm{O}_{9} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ and one part of $\mathrm{Na}_{2} \mathrm{~B}_{4} \mathrm{O}_{7} \cdot 10 \mathrm{H}_{2} \mathrm{O}$ to about $60^{\circ} \mathrm{C}$.
$\mathrm{NaCaB}_{5} \mathrm{O}_{9} \cdot \mathbf{8 H}_{2} \mathrm{O}$ (Ulexite) is triclinic with $a=8.71, b=12.72, c=$ $6.69 k X, \alpha=90^{\circ} 16^{\prime}, \beta=109^{\circ} 8^{\prime}, \gamma=105^{\circ} 7^{\prime}$. U.C. 2. Often in fibrous masses or crusts. Perfect $\{010\}$, good $\{1 \overline{1} 0\}$ and poor $\{110\}$ cleavages. H . 2.5. G. 1.96. $\mathrm{Y} \wedge c^{8}=$ about $20^{\circ}$. ( $+2 \mathrm{~V}=73^{\circ} \pm 1^{\circ}, n_{\mathrm{X}}=1.493, n_{\mathrm{Y}}=$ $1.505, n_{\mathrm{Z}}=1.519, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.026$. White or colorless. PD 12.3, 4.15, 7.8; 9-483.
$\mathrm{K}_{2} \mathrm{CaB}_{8} \mathrm{O}_{14} \cdot \mathbf{1 2 \mathrm { H } _ { 2 } \mathrm { O } \text { is orthorhombic. } { } ^ { 1 1 } \text { Crystals prismatic. G. 1.80. } n _ { \mathrm { X } } =}$ $1.449, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.476, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.027$. Colorless.
$\mathbf{M g B}_{4} \mathbf{O}_{7} \cdot \mathbf{9 H}_{2} \mathbf{O}$ is hexagonal. Uniaxial negative with ${ }^{12} n_{\mathrm{O}}=1.485, n_{\mathrm{E}}=$ $1.442, n_{\mathrm{O}}-n_{\mathrm{E}}=0.043$. Colorless.
$\mathbf{K B}_{5} \mathbf{O}_{3} \cdot \mathbf{4 H}_{2} \mathrm{O}$ is orthorhombic hemimorphic ${ }^{13}$ (Class $\mathrm{C}_{2 \mathrm{v}}$ ) with $a: b: c=$ $0.9905: 1: 0.8105$. Crystals pyramidal with $\{111\},\{100\},\{001\}$, etc. Perfect $\{010\}$ and distinct $\{100\}$ cleavages. Crystals generally twinned on
${ }^{9}$ Dufet: Eull. Soc. Fr. Min. X, p. 218 (1887).
${ }^{10}$ Peacock and Vigfusson: Univ. Toronto Stud., Geol. Ser. XLII, p. 113 (1939).
${ }^{11}$ Gode: Latv. P. S. R. Zin. Akad. Vestis, 1952, No. 1 (54), p. 89 [Chem. Abst. XLVII, p. 8570 (1953)].
${ }^{12}$ Nikolaev and Chelishcheva: Dokl. Akad. Sci. U.S.S.R. VIII, p. 127 (1940). [Min. Abst. VIII, p. 257 (1941)].
${ }^{13}$ W. R. Cook, Cleveland, Ohio: pers. comm. March 20, April 5 and May 23, 1956.
$\{01 \overline{1}\}$, occasionally on $\{00 \overline{1}\}$. H. 2.5. G. 1.74. $\mathrm{X}=c ; \mathrm{Y}=b .(+) 2 \mathrm{~V}=70^{\circ}$ calc. $n_{\mathrm{X}}=1.422, n_{\mathrm{Y}}=1.436, n_{\mathrm{Z}}=1.480, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.058$. Colorless. PD 5.50, 3.50, 3.30; 3-0107(?).
$\mathbf{N H}_{4} \mathbf{B}_{5} \mathbf{O}_{8} \cdot \mathbf{4} \mathbf{H}_{2} \mathbf{O}$ is orthorhombic (Class $\mathrm{C}_{2 \mathrm{v}}$ ) with $^{13} a=11.324, b=$ $11.029, c=9.235 \AA$. Crystals pyramidal with $\{100\},\{111\},\{001\}$, etc. Distinct $\{100\}$ and $\{010\}$ cleavages. Often twinned on $\{01 \overline{1}\}$; less often on $\{00 \overline{1}\}$. H. 2.5. G. 1.57. $\mathrm{X}=c ; \mathrm{Y}=b .(+) 2 \mathrm{~V}=30^{\circ}$ calc. $\mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{X}}=1.427, n_{\mathrm{Y}}=1.431, n_{\mathrm{Z}}=1.486, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.059$. Colorless. Crystallizes readily from solution. As in the case of many other K and $\mathrm{NH}_{4}$ salts, $\mathrm{KB}_{5} \mathrm{O}_{8} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ and $\mathrm{NH}_{4} \mathrm{~B}_{5} \mathrm{O}_{8} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ intercrystallize freely, the $a$ axis increasing steadily in length, becoming equal to the $b$ axis with about $25 \%$ $\mathrm{NH}_{4}$ and notably longer in the pure $\mathrm{NH}_{4}$ salt which is here described with $a>b$ to emphasize this condition.
$\left(\mathrm{NH}_{4}\right)_{2} \mathbf{B}_{10} \mathrm{O}_{16} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ (Ammonioborite) is ${ }^{13 \mathrm{a}}$ monoclinic(?) Forms platy groups. X is normal to the plates. Z makes an angle of $7^{\circ}$ to $13^{\circ}$ with the elongation of the plates. $(+) 2 \mathrm{~V}=60^{\circ}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{X}}=1.470, n_{\mathrm{Y}}=$ $1.487, n_{\mathrm{Z}}=1.540, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.070$. Color white. Made by evaporating at $95^{\circ}$ a water solution of $\mathrm{NH}_{4} \mathrm{~B}_{5} \mathrm{O}_{8} \cdot 4 \mathrm{H}_{2} \mathrm{O}$.
$\mathbf{C a B}_{6} \mathbf{O}_{10} \cdot 4 \mathbf{H}_{2} \mathbf{O}$ forms a powder with ${ }^{14} n_{\mathrm{X}}=1.505, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.550$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.045$. Colorless.
$\mathbf{M g B}_{6} \mathbf{O}_{10} \cdot \mathbf{7 . 5 H _ { 2 }} \mathbf{O}$ is uniaxial negative with ${ }^{12} n_{\mathrm{O}}=1.5081, n_{\mathrm{E}}=1.463$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.045$. Colorless.

## B. BORATES CONTAINING HALOGEN OR HYDROXYL

$\mathbf{N a}_{2} \mathrm{BO}_{2} \mathbf{C l} \cdot 2 \mathrm{H}_{2} \mathbf{O}$ (Teepleite) is tetragonal with ${ }^{15} a=7.27, c=4.84 k X$. U.C. 2. Crystals basal tablets. H. 3-3.5. G. 2.07. Uniaxial negative with $n_{\mathrm{O}}=1.521, n_{\mathrm{E}}=1.503, n_{\mathrm{O}}-n_{\mathrm{E}}=0.018$. Colorless or white. PD. 2.68, 2.01, 2.88; 2-0926.
$\mathbf{M g}_{3} \mathbf{B}_{7} \mathbf{O}_{13} \mathbf{C l}$ (Boracite) is orthorhombic with $a=16.97, b=16.97, c=$ $12.10 k X$ (pure); with some Fe replacing $\mathrm{Mg}: a=17.11, b=17.11, c=$ 12.10. U.C. 16. Crystals often cubic in aspect. No cleavage. H. 7-7.5. G. 2.93 (with some $\mathrm{Fe}, 2.97 c a$.). ( $+2 \mathrm{~V}=82.5^{\circ} .^{16} n_{\mathrm{X}}=1.658, n_{\mathrm{Y}}=1.662$, $n_{\mathrm{Z}}=1.668, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.010$. Again: ${ }^{17} n_{\mathrm{X}}=1.6622, n_{\mathrm{Y}}=1.6670, n_{\mathrm{Z}}=$ $1.6730, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0108$. Colorless to white (pure); with some Fe it is yellow or light to dark green. PD 2.06, 3.04, 2.72; 5-0710. When heated to

[^72]or above $265^{\circ} \mathrm{C}$. it becomes isometric and isotropic with ${ }^{17} n=1.6776$ (for $\lambda=501.6$ ) at $290^{\circ}$ and 1.6796 at $502^{\circ}$. PD 2.05, 3.01, 2.70; 3-1034.
$\mathrm{CaB}_{3} \mathrm{O}_{4}(\mathrm{OH})_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ (Colemanite) is monoclinic with $a=8.72, b=$ $11.29, c=6.06 k X, \beta=110^{\circ} 7^{\prime}$. U.C. 2. Crystals equant with $\{110\},\{001\}$, etc. Also massive. Perfect 010 and distinct 001 cleavages. H. 4.5. G. 2.42. $\mathrm{X}=b,{ }^{18} \mathrm{Y} \wedge c=-6^{\circ}$. $(+) 2 \mathrm{~V}=55^{\circ}, \mathrm{r}>\mathrm{v}$ weak. $n_{\mathrm{X}}=1.5863, n_{\mathrm{Y}}=$ $1.5920, n_{\mathrm{Z}}=1.6140, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0277$. Colorless, white or yellowish. PD 3.13, 5.64, 3.85; 6-0331. Made from solution at $70^{\circ} \mathrm{C}$.
$\mathrm{CaMgB}_{6} \mathrm{O}_{8}(\mathbf{O H})_{6} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ (Hydroboracite) is monoclinic with $a: b: c=$ 1.765:1:1.233, $\beta=102^{\circ} 39^{\prime}$. Crystals $\{010\}$ lamellar fibers along $c$. Perfect $\{010\}$ and $\{100\}$ cleavages. H. 2. G. 2.17. $\mathrm{X} \wedge c=33^{\circ}, \mathrm{Y}=b$. (+) $2 \mathrm{~V}=$ $60^{\circ}-66^{\circ}, \mathrm{r}<\mathrm{v}$ weak. ${ }^{19} n_{\mathrm{X}}=1.520-1.523, n_{\mathrm{Y}}=1.534-1.535, n_{\mathrm{Z}}=1.569-$ $1.571, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.048-0.050$. Colorless to white. Made from a solution at $50^{\circ} \mathrm{C}$.
$\mathrm{CaMgB}_{6} \mathrm{O}_{8}(\mathrm{OH})_{6} \cdot \mathbf{8 \mathrm { H } _ { 2 } \mathrm { O }}$ (Inderborite) is monoclinic with $a: b: c=$ 1.635:1:1.317, $\beta=90^{\circ} 48^{\prime}$. Good \{100\} cleavage. H. 3.5. G. 2.00. $\mathrm{X} \wedge c=$ $2.5^{\circ} ; \mathrm{Z}=b ; ;^{20}(-) 2 \mathrm{~V}=77^{\circ}, n_{\mathrm{X}}=1.483 \pm 0.002, n_{\mathrm{Y}}=1.512 \pm 0.002$, $n_{\mathrm{Z}}=1.530 \pm 0.002, n_{\mathrm{z}}-n_{\mathrm{X}}=0.047$. Again: $2^{1}(-) 2 \mathrm{~V}=80^{\circ}-86^{\circ}, n_{\mathrm{X}}=$ 1.496, $n_{\mathrm{Y}}=1.521, n_{\mathrm{Z}}=1.54, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.044$. Also $:{ }^{22} n_{\mathrm{X}}=1.480$, $n_{\mathrm{Y}}=1.509, n_{\mathrm{Z}}=1.527, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.047$. Colorless.
$\mathrm{CaB}_{3} \mathrm{O}_{4}(\mathrm{OH})_{3} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ (Inyoite) is monoclinic with $a: b: c=0.883: 1: 0.695$, $\beta=114^{\circ} 1^{\prime}$. Crystals short prisms to basal tablets; also massive. Good $\{001\}$ cleavage; also $\{010\}$. H. 2. G. 1.875. X $\wedge c=+37^{\circ}$, $\mathrm{Y}=b .{ }^{23}(-) 2 \mathrm{~V}=70^{\circ}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{X}}=1.495, n_{\mathrm{Y}}=1.51, n_{\mathrm{Z}}=1.520$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.025$. Again: ${ }^{14} n_{\mathrm{X}}=1.491, n_{\mathrm{Y}}=1.505, n_{\mathrm{Z}}=1.518, n_{\mathrm{Z}}-n_{\mathrm{X}}$ $=0.0027$. Colorless. PD 3.03, 7.59, 2.29; 6-0361.
$\mathrm{CaB}_{3} \mathrm{O}_{4}(\mathrm{OH})_{3} \cdot \mathbf{2 \mathrm { H } _ { 2 } \mathrm { O }}$ (Meyerhofferite) is triclinic with $a=6.60, b=$ 8.33, $c=6.48 k X, \alpha=91^{\circ}, \beta=101^{\circ} 31^{\prime}, \gamma=86^{\circ} 55^{\prime}$. U.C. 1. Crystals $\{100\}$ plates elongated along $c$. Perfect $\{010\}$ cleavage. H. 2. G. 2.12. On $\{010\} \mathrm{X}^{\prime} \wedge c=30^{\circ}$; on $\{100\} \mathrm{Z}^{\prime} \wedge c=25^{\circ}$. (-) $2 \mathrm{~V}=78^{\circ}, n_{\mathrm{X}^{23}}=1.500$, $n_{\mathrm{Y}}=1.535, n_{\mathrm{Z}}=1.560, n_{\mathrm{O}}-n_{\mathrm{X}}=0.060$. Colorless or white. PD 8.39, 6.51, 3.17; 6-0032.
$\mathrm{MgB}_{3} \mathrm{O}_{4}(\mathrm{OH})_{3} \cdot \mathbf{1 5 H}_{2} \mathrm{O}$ (Inderite) is triclinic with $a=8.14, b=10.47$, $c=6.33 \AA, \alpha=96^{\circ} 56^{\prime}, \beta=106^{\circ} 28^{\prime}, \gamma=106^{\circ} 3^{\prime}$. U.C. 1. Tabular with perfect $\{010\}$ and good $\{110\}$ cleavages; also prismatic. H. 3. G. 1.86.
${ }^{18}$ Mülheims: Zeit. Krist. XIV, p. 230 (1888).
${ }^{19}$ Schaller: Festschrift Goldschmidt, p. 256 (1928); Nikolaiev and Selivanova: Dokl. Akad. Sci. U.S.S.R. XX, p. 29 (1938). [Min. Abst. VII, p. 476 (1940)].
${ }^{20}$ Ikornikova and Godlevsky: Dokl. Akad. Sci. U.S.S.R. XXXIII, p. 257 (1941).
${ }^{21}$ Gorshkov: Dokl. Akad. Sci. U.S.S.R. XXXIII, p. 254 (1941).
${ }^{22}$ Kurnakova: Dokl. Akad. Sci. U.S.S.R. L, p. 241 (1945) [Chem. Abst. XLIII, p. 2128 (1949)].
${ }^{23}$ Schaller: U. S. Geol. Surv. Bull. 610, p. 35 and 41 (1916).

X nearly $=b ; ;^{24} \mathrm{Z} \wedge c^{14}=-22^{\circ}$. (-) $2 \mathrm{~V}=63^{\circ} \pm 3^{\circ}, \mathrm{r}>\mathrm{v}$ weak, $n_{\mathrm{X}}=$ $1.488 \pm 0.002, n_{\mathrm{Y}}=1.508 \pm 0.002, n_{\mathrm{Z}}=1.515 \pm 0.002, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.027$. Again: $\mathrm{Z} \wedge c=5^{\circ},(+) 2 \mathrm{~V}=$ large. $n=1.488$ and 1.505. Colorless, white, or pink. PD 5.00, $7.36,3.18 ; 8-164^{*}$. Made from solution at $35^{\circ} \mathrm{C}$.

## C. COMPOUND BORATES

$5 \mathrm{CaO} \cdot \mathbf{S i O}_{2} \cdot \mathbf{B}_{2} \mathrm{O}_{3}\left[=\mathrm{Ca}_{2} \mathbf{S i O}_{4} \cdot \mathbf{C a}_{3}\left(\mathrm{BO}_{3}\right)_{2}\right.$ ? ] is biaxial. ${ }^{25}$ Polysynthetic twinning is very common, suggesting monoclinic or triclinic symmetry. M.P. $1419^{\circ}$ C. (-) $2 \mathrm{~V}=$ moderate. $n_{\mathrm{X}}=1.666 \pm 0.003, n_{\mathrm{Y}}=1.682 \pm$ $0.003, n_{\mathrm{Z}}=1.690 \pm 0.003, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.024 \pm 0.006$. Colorless.

[^73]
## VII. Sulfates

Sulfates, chromates, selenates, and the related sulfites, thiosulfates, pyrosulfates, pyrosulfites, sulfamates, thionates, dichromates, etc., are included with sulfates. The classification is as follows:
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## A. ANHYDROUS SULFITES, SELENITES, THIOSULFATES, THIONATES, SULFAMATES, ETC.

$\mathbf{N a}_{2} \mathbf{S O}_{3}$ is hexagonal ${ }^{1}$ in prisms and tablets. Uniaxial negative with $n_{0}=$ $1.565 \pm, n_{\mathrm{E}}=1.515 \pm, n_{\mathrm{O}}-n_{\mathrm{E}}=0.050 \pm$. Colorless. PD 2.58, 2.73, 3.75; 5-0653.
$\mathrm{NaHSO}_{3}$ occurs in formless grains ${ }^{1}$ with ( + ) $2 \mathrm{~V}=65^{\circ} \pm, n_{\mathrm{x}}=1.474$, $n_{\mathrm{Y}}=1.526, n_{\mathrm{Z}}=1.685 \pm, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.211 \pm$. Colorless.
$\mathbf{R b}_{2} \mathbf{S}_{2} \mathbf{O}_{3}$ is hexagonal ${ }^{2}$ (trigonal) with $a=10.02, c=6.35 \mathrm{kX}$. U.C. 3. Uniaxial positive with $n_{\mathrm{O}}=1.46 \mathrm{ca} ., n_{\mathrm{E}}=1.51, n_{\mathrm{E}}-n_{\mathrm{O}}=0.0504$. Specific rotation about $2^{\circ}$ per mm .

[^74]$\mathbf{N a}_{10} \mathbf{C u}_{2} \mathbf{A g}_{4}\left(\mathbf{S}_{2} \mathbf{O}_{3}\right)_{8} \cdot \mathbf{6 N H} \mathbf{N H}_{3}$ is tetragonal with $c / a=0.84$. Crystals prismatic with poor $\{001\}$ cleavage. Uniaxial negative with $n_{0}=$ ?, $n_{\mathrm{E}}=$ $1.7 \pm$. Color deep blue with X pale sapphire-blue, Z deep cobalt-blue.
$\mathbf{4}\left(\mathbf{N H}_{4}\right)_{2} \mathbf{S}_{2} \mathrm{O}_{3} \cdot \mathbf{A g B r} \cdot \mathbf{N H}_{4} \mathbf{B r}$ is tetragonal with $c / a=0.63$. Uniaxial negative with $n_{\mathrm{O}}=1.6769, n_{\mathrm{E}}=1.6294, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0475$.
$\mathbf{K}_{2} \mathbf{S}_{2} \mathbf{O}_{6}$ is hexagonal (trigonal) with $c / a=0.647$. Crystals hexagonal prisms. G. 2.28. Uniaxial positive ${ }^{2}$ with $n_{\mathrm{O}}=1.4532 \mathrm{C}, 1.4550 \mathrm{D}, 1.4595 \mathrm{~F}$, $n_{\mathrm{E}}=1.5119 \mathrm{C}, 1.5153 \mathrm{D}, 1.5239 \mathrm{~F}, n_{\mathrm{E}}-n_{\mathrm{O}}=0.0603 \mathrm{D}$.
$\mathbf{R b}_{2} \mathbf{S}_{2} \mathbf{O}_{6}$ is hexagonal (trigonal) with $c / a=0.631$. Crystals hexagonal prisms. Uniaxial positive with ${ }^{3} n_{\mathrm{O}}=1.4544 \mathrm{C}, 1.4565 \mathrm{D}, 1.4613 \mathrm{~F}, n_{\mathrm{E}}=$ $1.5034 \mathrm{C}, 1.5068 \mathrm{D}, 1.5153 \mathrm{~F}, n_{\mathrm{E}}-n_{\mathrm{O}}=0.0503 \mathrm{D}$.
$\mathrm{Cs}_{2} \mathrm{~S}_{2} \mathrm{O}_{6}$ is hexagonal (trigonal) with $c / a=0.632$. Crystals prismatic. Uniaxial positive with ${ }^{1} n_{\mathrm{O}}=1.5207 \mathrm{C}, 1.5230 \mathrm{D}, 1.5285 \mathrm{~F}, n_{\mathrm{E}}=1.5405 \mathrm{C}$, $1.5438 \mathrm{D}, 1.5518 \mathrm{~F}, n_{\mathrm{E}}-n_{\mathrm{O}}=0.0208 \mathrm{D}$.
$K_{2} \mathbf{S}_{3} \mathbf{O}_{6}$ is orthorhombic with $a: b: c=0.717: 1: 0.409$. Crystals prismatic or tabular. No distinct cleavage. G. $2.34 . \mathrm{X}=c ; \mathrm{Y}=b$. ( $-2 \mathrm{~V}=72^{\circ}$ (68 ${ }^{\circ}$ Na. For $^{4} \lambda=691: n_{\mathrm{X}}=1.4903, n_{\mathrm{Y}}=1.5591, n_{\mathrm{Z}}=1.596, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.1061 . For $\lambda=589: n_{\mathrm{X}}=1.4934, n_{\mathrm{Y}}=1.5641, n_{\mathrm{Z}}=1.602, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.1086 . For $\lambda=436: n_{\mathrm{X}}=1.5040, n_{\mathrm{Y}}=1.5805, n_{\mathrm{Z}}=1.621, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.117 .
$\mathbf{R} b_{2} \mathbf{S}_{3} \mathbf{O}_{6}$ is orthorhombic with $a: b: c=0.706: 1: 0.418$. Crystals prismatic. G. 2.83. $\mathrm{X}=c, \mathrm{Y}=b$. (-) $2 \mathrm{~V}=62^{\circ} 33^{\prime} . n_{\mathrm{X}}=1.4874, n_{\mathrm{Y}}=1.5580$, $n_{\mathrm{Z}}=1.5867, n_{\mathrm{z}}-n_{\mathrm{X}}=0.0993$.
$\mathbf{H N H}_{2} \mathbf{S O}_{3}$ is orthorhombic ${ }^{5}$ with $a: b: c=0.995: 1: 1.149$. Crystals $\{010\}$ tablets with $\{111\},\{120\},\{201\}$, etc. No cleavage seen. $\mathrm{X}=c ; \mathrm{Y}=b$. (-) $2 \mathrm{~V}=63^{\circ}$ or $64^{\circ}$ with weak dispersion. ${ }^{6} n_{\mathrm{X}}=1.553, n_{\mathrm{Y}}=1.563, n_{\mathrm{Z}}=$ 1.568 , all $\pm 0.003$ (for $\lambda=546$ ), $n_{\mathrm{z}}-n_{\mathrm{X}}=0.015$. PD 3.37, 3.70, 4.01; 8-483.
$\mathbf{L i N H}_{2} \mathrm{SO}_{3}{ }^{7}$ is probably orthorhombic. Crystals acicular. Deliquescent. $(-) 2 \mathrm{~V}=48^{\circ}, \mathrm{r} \ll \mathrm{v} . n=1.507, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.007$.
$\mathbf{N a N H}_{2} \mathbf{S O}_{3}$ forms prismatic needles ${ }^{7}$ with octagonal cross-section. (-)2V $=82^{\circ}-84^{\circ} . n_{\mathrm{X}}=1.494, n_{\mathrm{Y}}=1.498 \pm$ calc., $n_{\mathrm{Z}}=1.501, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.007$.
$\mathrm{KNH}_{2} \mathbf{S O}_{3}$ forms rhombic tablets. ${ }^{7}(+) 2 \mathrm{~V}=26^{\circ} . n_{\mathrm{X}}=1.487, n_{\mathrm{Y}}=$ $1.490 \pm$ calc., $n_{\mathrm{Z}}=1.515, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.028$.
$\mathbf{N H}_{4} \mathbf{N H}_{2} \mathbf{S O}_{3}$ forms needles ${ }^{7}$ normal to X . (-) $2 \mathrm{~V}=84^{\circ}$, $\mathrm{r}>\mathrm{v} . n_{\mathrm{X}}=$ $1.526, n_{\mathrm{Y}}=1.532, n_{\mathrm{Z}}=1.538, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.012$. Again ${ }^{6} n_{\mathrm{Y}}=1.537$.

[^75]$\mathbf{R b N H}_{2} \mathbf{S O}_{3}$ forms six-sided rhombic plates. ${ }^{7}(-) 2 \mathrm{~V}=65^{\circ}, \mathrm{r}>$ v. $n=$ $1.537, n_{\mathrm{z}}-n_{\mathrm{X}}=0.015$.
$\mathbf{B e}\left(\mathbf{N H}_{2} \mathbf{S O}_{3}\right)_{2}$ forms tabular crystals. ${ }^{7}$ Soluble in water. $(-) 2 \mathrm{~V}=60^{\circ}$, $n_{\mathrm{X}}=1.552, n_{\mathrm{Y}}=1.563$ calc., $n_{\mathrm{Z}}=1.567, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.015$.
$\mathbf{M g}\left(\mathbf{N H}_{2} \mathbf{S O}_{3}\right)_{2}$ forms very small crystals; ${ }^{7}$ also cryptocrystalline. Soluble in water. $(+) 2 \mathrm{~V}=68^{\circ}-70^{\circ}, \mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.510, n_{\mathrm{Y}}=1.517$ calc., $n_{\mathrm{Z}}=$ $1.535, n_{\mathrm{z}}-n_{\mathrm{X}}=0.025$.
$\mathbf{B a}\left(\mathbf{N H}_{2} \mathbf{S O}_{3}\right)_{2}$ forms long prismatic crystals. ${ }^{7}$ (-)2V $=48^{\circ}-50^{\circ}$, $\mathrm{r} \gg \mathrm{v} . n=1.599, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.022$.
$\mathbf{K}_{2} \mathbf{S}_{4} \mathbf{O}_{6}$ is monoclinic ${ }^{8}$ with $a=22.05, b=7.99, c=10.09 k X . \beta=$ $102^{\circ} 5^{\prime}$. U.C. 8. Crystals tablets or prismatic. Perfect $\{100\}$ cleavage. G. 2.30. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=33^{\circ}$ in obtuse angle $\beta$. $(+) 2 \mathrm{~V}=66^{\circ} \mathrm{C}, 69^{\circ} \mathrm{F}$, $\mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.5896, n_{\mathrm{Y}}=1.6057, n_{\mathrm{Z}}=1.6435($ all $\pm 0.0002), n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.0539. Colorless. PD 3.37, 2.92, 3.17; 2-0441.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{S}_{2} \mathbf{O}_{8}$ is monoclinic ${ }^{8 a}$ with $a: b: c=1.296: 1: 1.187, \beta=103^{\circ} 48^{\prime}$. Crystals basal tablets or elongated along $b$. Poor $\{001\}$ cleavage. G. 1.98. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=+27^{\circ} .(+) 2 \mathrm{~V}=24^{\circ}, \mathrm{r}<\mathrm{v}$ moderate. $n_{\mathrm{X}}=1.4981, n_{\mathrm{Y}}=$ 1.5016, $n_{\mathrm{Z}}=1.5866, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0885$. Colorless. Made from aqueous solution.
$\mathbf{R} b_{2} \mathbf{S}_{2} \mathbf{O}_{8}$ is monoclinic with ${ }^{8 \mathrm{a}} a: b: c=1.281: 1: 1.188, \beta=103^{\circ} 28^{\prime}$. Crystals basal tablets or elongated along $b$. No good cleavage. G. 3.13. $\mathrm{Y}=b$; $\mathrm{Z} \wedge c=+26.5^{\circ} .(+) 2 \mathrm{~V}=35^{\circ}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{X}}=1.4812, n_{\mathrm{Y}}=1.4888$, $n_{\mathrm{Z}}=1.5719, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0907$. Made from warm solution.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{C r}_{2} \mathbf{O}_{7}$ is monoclinic prismatic with $a: b: c=1.0277: 1: 1.767, \beta=$ $93^{\circ} 42^{\prime}$. Crystals basal or $\{101\}$ plates or columns along $b$. Distinct $\{101\}$ cleavage. G. 2.15. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=+35^{\circ}$ (in obtuse angle $\beta$ ). ${ }^{8 \mathrm{~b}}(+) 2 \mathrm{H}=$ $104^{\circ}$ red. $n_{\mathrm{X}}=1.725, n_{\mathrm{Y}}=1.80 \mathrm{ca} ., n_{\mathrm{Z}}=1.905, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.180$.
$\mathbf{K}_{2} \mathbf{S}_{2} \mathbf{O}_{8}$ is triclinic with ${ }^{8 \mathrm{a}} a: b: c=0.576: 1: 0.574, \alpha=98^{\circ} 33^{\prime}, \beta=94^{\circ} 2^{\prime}$, $\gamma=88^{\circ} 39^{\prime}$. Crystals $\{010\}$ tablets. Twinning on $\{010\}$. Distinct $\{010\}$ cleavage. G. 2.48. The optic axes are in the positive octant. ( $+2 \mathrm{~V}=$ $29^{\circ} 32^{\prime} . n_{\mathrm{X}}=1.4609, n_{\mathrm{Y}}=1.4669, n_{\mathrm{Z}}=1.5657, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.1048$. Made from solution at ordinary temperature.
$\mathbf{K}_{2} \mathbf{C r}_{2} \mathbf{O}_{7}$ is dimorphous. A metastable phase is monoclinic ${ }^{9}$ with $a=7.47$, $b=7.35, c=12.97 \AA . \beta=91^{\circ} 55^{\prime}$. U.C. 4. Crystals basal plates with $\{111\},\{101\},\{110\}$, etc. G. 2.736. For $\lambda=758:(+) 2 \mathrm{~V}=64^{\circ} 14^{\prime}, n_{\mathrm{X}}=$ $1.715, n_{\mathrm{Y}}=1.762, n_{\mathrm{Z}}=1.892, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.177$. Pleochroic. A second (stable) phase (Lopezite) is triclinic pinacoidal with $a=7.50, b=7.37$, $c=13.40 \AA . \alpha=82^{\circ} 0^{\prime}, \beta=90^{\circ} 51^{\prime}, \gamma=83^{\circ} 47^{\prime}$. Crystals prismatic or

[^76]$\{010\}$ tablets. Twinning, as on $\{010\}$. Perfect $\{010\}$, distinct $\{100\}$ and $\{001\}$ cleavages. G. 2.69. The optic plane is nearly normal to (001) between (100) and ( $0 \overline{1} 0$ ). X makes angles of $86^{\circ} 27^{\prime}, 68^{\circ} 6^{\prime}$ and $13^{\circ} 43^{\prime}$ with normals to $\{100\},\{0 \overline{1} 0\}$ and $\{00 \overline{1}\}$; Z makes angles of $77^{\circ} 5^{\prime}, 23^{\circ} 5^{\prime}$ and $76^{\circ} 21^{\prime}$ with normals to $\{100\},\{0 \overline{1} 0\}$ and $\{00 \overline{1}\} .(+) 2 \mathrm{~V}=52^{\circ} 24^{\prime} \mathrm{Li}, 51^{\circ} 53^{\prime} \mathrm{Na} ; n_{\mathrm{x}}=$ $1.7202, n_{\mathrm{Y}}=1.7380, n_{\mathrm{Z}}=1.8197, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0995$. Color aurora red; pleochroic with X red, Z yellow. Made from warm solution.
$\mathrm{CaS}_{4} \mathbf{O}_{6}$ is biaxial with ${ }^{1}(+) 2 \mathrm{~V}=32^{\circ} \pm, n_{\mathrm{X}}=1.535 \pm, n_{\mathrm{Y}}=1.540 \pm$, $n_{\mathrm{Z}}=1.675 \pm, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.140 \pm$. Colorless.

## B. ANHYDROUS ACID SULFATES

$\mathrm{KHSO}_{4}$ (Mercallite) is orthorhombic with $a: b: c=0.861: 1: 1.934$. Crystals basal tablets. No cleavage. G. 2.32. $\mathrm{X}=b, \mathrm{Y}=c .{ }^{10}(+) 2 \mathrm{~V}=$ $56^{\circ}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{X}}=1.445, n_{\mathrm{Y}}=1.460$ calc., $n_{\mathrm{Z}}=1.491$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.046. Colorless when pure; also sky-blue (due to copper?). Easily made from water solution.
$\mathbf{N H}_{4} \mathbf{H S O}_{4}$ is orthorhombic with $a: b: c=0.613: 1: 0.744$. Crystals long prismatic or thick $\{010\}$ tablets. Perfect $\{100\}$ cleavage. G. 1.82. $\mathrm{Y}=b$, $\mathrm{Z}=c .(+) 2 \mathrm{~V}=60^{\circ} \pm$, with weak dispersion. ${ }^{1} n_{\mathrm{X}}=1.463, n_{\mathrm{Y}}=1.473$, $n_{\mathrm{Z}}=1.510, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.047$. Colorless. PD 4.75, 3.69, 2.61; $1-0290$.
$\mathbf{R b H S O}_{4}$ is orthorhombic with $a: b: c=0.75: 1: 0.60 . \mathrm{X}=c, \mathrm{Y}=b$. $(+) 2 \mathrm{~V}=55^{\circ} 52^{\prime}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{Y}}=1.473$.
$\mathrm{K}_{8} \mathbf{H}_{6}\left(\mathbf{S O}_{4}\right)_{7}$ (Misenite) is monoclinic with $a: b: c=3.2196: 1: 2.1842$, $\beta=102^{\circ} 5^{\prime}$. Occurs as fibrous masses or needles. Distinct $\{010\}$ cleavage. G. 2.32. ( $+2 \mathrm{~V}=$ large. ${ }^{11} \mathrm{X} \wedge c=+29^{\circ} ; \mathrm{Z}=b . n_{\mathrm{X}}=1.475, n_{\mathrm{Y}}=1.480$, $n_{\mathrm{Z}}=1.487, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.012$. Colorless. PD 3.85, 3.40, 3.01; 1-0477.
$\mathbf{K}_{3} \mathbf{H}\left(\mathbf{S O}_{4}\right)_{2}$ is monoclinic ${ }^{12}$ with $a: b: c=1.722: 1: 3.767, \beta=90^{\circ} 11^{\prime}$. Crystals tabular or pyramidal. Twinning on $\{110\}$; or on $\{310\}$ in pseudohexagonal trillings. Distinct $\{001\}$ cleavage. G. 2.59. $\mathrm{X} \wedge c=-35^{\circ}$; $\mathrm{Z}=b$. (-) $2 \mathrm{~V}=60^{\circ} 42^{\prime} . n_{\mathrm{X}}=1.4793, n_{\mathrm{Y}}=1.4899, n_{\mathrm{Z}}=1.5259, n_{\mathrm{Z}}-n_{\mathrm{X}}$ $=0.0466 \mathrm{Na}$. Colorless. Made from an aqueous solution of $\mathrm{KHSO}_{4}$ from which $\mathrm{K}_{2} \mathrm{SO}_{4}$ was first separated.
$\left(\mathbf{N H}_{4}\right)_{3} \mathbf{H}\left(\mathbf{S O}_{4}\right)_{2}$ (Letovicite) is monoclinic with ${ }^{12} a: b: c=1.739: 1: 2.647$, $\beta=102^{\circ} 6^{\prime}$. Crystals basal tablets. Twinning often on $\{110\}$ or $\{310\}$. Distinct $\{001\}$ cleavage. G. 1.83. $\mathrm{X} \wedge c=78^{\circ}, \mathrm{Z}=b$. On artificial crystals ${ }^{13} n_{\mathrm{X}}=1.499, n_{\mathrm{Z}}=1.526$. Again: ${ }^{13}(-) 2 \mathrm{~V}=75^{\circ}, n_{\mathrm{X}}=1.501, n_{\mathrm{Y}}=$

[^77]1.516, $n_{\mathrm{Z}}=1.526, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.024$. Inverts to a uniaxial phase. Colorless. Made by cooling a solution of $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SO}_{4}$ and $\mathrm{H}_{2} \mathrm{SO}_{4}$.

## C. ANHYDROUS NORMAL SULFATES, CHROMATES, AND SELENATES

## 1. Formula Type $\mathbf{A}_{2} \mathrm{XO}_{4}$

$\mathrm{LiKSO}_{4}$ is hexagonal with $c / a=1.676$. Crystals columnar prismatic, basal tablets or plainly hemimorphic. Twinning often obscures the hemimorphism. Poor basal cleavage. H. 3. G. 2.39. Uniaxial negative ${ }^{14}$ with $n_{\mathrm{O}}=1.4703 \mathrm{C}, 1.4723 \mathrm{D}, 1.4765 \mathrm{~F}, n_{\mathrm{E}}=1.4697 \mathrm{C}, 1.4717 \mathrm{D}, 1.4759 \mathrm{~F}$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.0006 \mathrm{D}$. Rotates the plane of polarization. Colorless. Formed from an acid solution. Inverts at about $435^{\circ} \mathrm{C}$. PD 3.94, 3.09, 2.57; 1-0459.
$\mathrm{LiNaSO}_{4}$ is hexagonal ${ }^{15}$ with $a=7.64, c=9.76 \AA$. G. 2.54. Uniaxial positive with $n_{\mathrm{O}}=1.490, n_{\mathrm{E}}=1.495, n_{\mathrm{E}}-n_{\mathrm{O}}=0.005$. Colorless. Made from water solution.
$(\mathrm{K}, \mathbf{N a})_{3} \mathrm{Na}\left(\mathrm{SO}_{4}\right)_{2}$ (Aphthitalite) is hexagonal with $a=5.65, c=$ 7.29 kX . Crystals tabular with marked trigonal development; bladed aggregates, etc. Fair $\{10 \overline{1} 0\}$ and poor $\{0001\}$ cleavages. H. 3. G. 2.7. F. 1.5. Uniaxial positive with $n_{\mathrm{O}}=1.491, n_{\mathrm{E}}=1.499, n_{\mathrm{E}}-n_{\mathrm{O}}=0.008$ for ${ }^{16}$ $\mathrm{K}: \mathrm{Na}=2.46: 1 ; n_{\mathrm{O}}=1.487, n_{\mathrm{E}}=1.492, n_{\mathrm{E}}-n_{\mathrm{O}}=0.005$ for $\mathrm{K}^{17}: \mathrm{Na}=$ 1:1.5. New data follow:

| $\mathrm{Na}: \mathrm{K}$ |  |  |  |  |  |  |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: |
| ratio | $n_{\mathrm{O}}$ | $n_{\mathrm{E}}$ | $n_{\mathrm{E}}-n_{\mathrm{O}}$ | $a$ | $c$ | G |
| $\mathrm{Na}_{4} \mathrm{~K}$ | 1.485 | 1.490 | 0.005 | 5.49 | 7.26 | 2.71 |
| NaK | 1.490 | 1.495 | 0.005 | 5.64 | 7.27 |  |
| $\mathrm{NaK}_{2}$ | 1.491 | 1.4965 | 0.0055 |  |  |  |
| $\mathrm{NaK}_{3}$ | 1.493 | 1.498 | 0.005 | 5.66 | 7.33 | 2.697 |
| $\mathrm{NaK}_{4}$ | 1.4935 | 1.500 | 0.0065 | 5.67 | 7.39 |  |

It may have a small optic angle. Colorless unless stained by iron oxide. PD 2.81, 2.02, 2.92; 6-0461*. Easily made from dry fusions and also from aqueous solutions; the former have all ratios between K and Na ; the latter are 71 to 75 mol . per cent $\mathrm{K}_{2} \mathrm{SO}_{4}$ at $25^{\circ} \mathrm{C}$. The refringence ${ }^{17}$ and birefringence increase a little with increase in the tenor of K . Continuity from $\mathrm{Na}_{2} \mathrm{~K}_{8}\left(\mathrm{SO}_{4}\right)_{5}$ to $\mathrm{K}_{2} \mathrm{SO}_{4}$ is improbable. ${ }^{17 \mathrm{a}}$

[^78]$\mathbf{N a K}_{3}\left(\mathbf{C r O}_{4}\right)_{2}$ is hexagonal with $c / a=1.286$. Crystals basal tablets or rhombohedral. Distinct basal cleavage. G. 2.767. Uniaxial positive with $n_{\mathrm{O}}=1.7278 \mathrm{Na}, n_{\mathrm{E}}=1.7361, n_{\mathrm{E}}-n_{\mathrm{O}}=0.0083$. Strong dispersion giving an unusual interference figure. Also monoclinic, pseudo-hexagonal, biaxial positive. 2 V small, Z nearly normal to (001); $\mathrm{Y}=b$. Color in plates 1 mm . thick, X orange yellow, Z lemon yellow.
$\mathrm{Na}_{2} \mathrm{SO}_{4}$ (Thenardite) is orthorhombic with ${ }^{18} a=9.75, b=12.29, c=$ $5.85 k X$. U.C. 8. Crystals dipyramidal, short prismatic, or basal plates. Distinct basal cleavage. H. 2.5-3. G. 2.66. F. 1.5-2. $\mathrm{Y}=c ; \mathrm{Z}=a .(+) 2 \mathrm{~V}=$ $83^{\circ} 35^{\prime} \mathrm{Na}, \mathrm{r}>\mathrm{v}$ weak. $n_{\mathrm{X}}=1.471, n_{\mathrm{Y}}=1.477, n_{\mathrm{Z}}=1.484, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.013. Again: ${ }^{18} n_{\mathrm{X}}=1.4669 \mathrm{Na}, n_{\mathrm{Y}}=1.4731, n_{\mathrm{Z}}=1.4809, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.014 . Colorless. PD 2.78, 4.66, 3.18; 5-0631*. Made from aqueous solution at about $50^{\circ} \mathrm{C} . \mathrm{NaSO}_{4}$ inverts ${ }^{19}$ at about $160^{\circ}-180^{\circ} \mathrm{C}$. to a phase ("IV")

which is probably monoclinic with $n_{\mathrm{X}}<1.46, n_{\mathrm{Y}}=?, n_{\mathrm{Z}}=1.480$, $n_{\mathrm{z}}-n_{\mathrm{X}}>0.02$. It inverts again at about $185^{\circ} \mathrm{C}$. to an orthorhombic phase ("III") thought to be isomorphous with $\mathrm{K}_{2} \mathrm{SO}_{4}$; it has G. 2.696, all indices between 1.480 and 1.485 ; very stable at ordinary temperature. PD 2.80, 3.91, 3.76; 8-31. $\mathrm{Na}_{2} \mathrm{SO}_{4}$ inverts finally at $241^{\circ} \mathrm{C}$. to a hexagonal phase (" I ") probably isomorphous with the high temperature phase of $\mathrm{K}_{2} \mathrm{SO}_{4}$; it is uniaxial negative with both indices below 1.475 and very weak birefringence; it was found at Mont Pelée by Lacroix and called metathenardite. These inversions occur very slowly, so that several phases may be found together after heating and cooling. On cooling, if the change at $241^{\circ} \mathrm{C}$. is avoided, an irreversible inversion occurs at $236^{\circ} \mathrm{C}$. to a phase ("II") with very strong birefringence, having $n_{\mathrm{x}}$ much less than 1.465 , $n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.480$; not stable at low pressure.
$\mathrm{K}_{2} \mathrm{SO}_{4}$ (Arcanite) is orthorhombic with $a=5.731, b=10.008, c=$

[^79]${ }^{19}$ Kracek: J. Phys. Chem. XXXIII, p. 1281 (1929) and Kracek and Gibson, ibid., XXXIV, p. 188 (1930). See also reference 17
$7.424 k X$. Crystals nearly equant or $\{010\}$ tablets. Often pseudo-hexagonal by twinning on $\{110\}$. Good $\{010\}$ and $\{001\}$ cleavages. G. 2.66. Soluble in water. $\mathrm{Y}=a, \mathrm{Z}=c .^{20}(+) 2 \mathrm{~V}=67^{\circ} 20^{\prime} \mathrm{D}, \mathrm{r}>\mathrm{v}$ very weak. $n_{\mathrm{X}}=$ $1.4916 \mathrm{C}, 1.4935 \mathrm{D}, 1.4982 \mathrm{~F}, n_{\mathrm{Y}}=1.4928 \mathrm{C}, 1.4947 \mathrm{D}, 1.4995 \mathrm{~F}, n_{\mathrm{Z}}=$ $1.4954 \mathrm{C}, 1.4973 \mathrm{D}, 1.5023 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0038 \mathrm{D}$. Colorless. PD 2.90, $3.00,2.89 ; 5-0613^{*}$. Inverts to a uniaxial negative phase at about $650^{\circ} \mathrm{C}$. Miscible in all proportions with $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SO}_{4}, \mathrm{KCr}_{2} \mathrm{O}_{4}$ and probably with $\mathrm{Rb}_{2} \mathrm{SO}_{4}$ and $\mathrm{Cs}_{2} \mathrm{SO}_{4}$.


Fig. 7-2. A combination of crystal forms in $\mathrm{K}_{2} \mathrm{SO}_{4}$.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{S O}_{4}$ (Mascagnite) is orthorhombic with $a=5.98, b=10.62$, $c=7.78 k X$, U.C. 4. Crystals $\{010\}$ tablets or nearly equant. Twinning on $\{110\}$ often gives pseudo-hexagonal habit. Good $\{001\}$ cleavage. H. 2. G. 1.77. F. 1. Volatile. $\mathrm{Y}=b, \mathrm{Z}=a .^{21}(+) 2 \mathrm{~V}=52^{\circ} 12^{\prime} \mathrm{Na}, \mathrm{r}>\mathrm{v}$ very weak. $n_{\mathrm{X}}=1.5177 \mathrm{Li}, 1.5209 \mathrm{Na}, n_{\mathrm{Y}}=1.5199 \mathrm{Li}, 1.5230 \mathrm{Na}, n_{\mathrm{Z}}=$ $1.5297 \mathrm{Li}, 1.5330 \mathrm{Na}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0128 \mathrm{Na} . \mathrm{PD} 4.33,4.39,3.06 ; 10-343^{*}$. Colorless or stained gray to yellow. Made from aqueous solution. Miscible in all proportions with $\mathrm{K}_{2} \mathrm{SO}_{4}, \mathrm{Rb}_{2} \mathrm{SO}_{4}, \mathrm{Tl}_{2} \mathrm{SO}_{4}$ or $\mathrm{Cs}_{2} \mathrm{SO}_{4}$.
$\mathbf{N H}_{4} \mathbf{L i S O}_{4}$ is orthorhombic ${ }^{22}$ with $a: b: c={ }^{23} 0.595: 1: 0.583$. Crystals $\{010\}$ plates with horizontal striations on prism faces. Perfect \{010\} cleavage. G. 1.20. $\mathrm{Y}=a ; \mathrm{Z}=b$. ( + ) $2 \mathrm{~V}=36^{\circ} 32^{\prime}$ red, $49^{\circ} 4^{\prime}$ green. $n_{\mathrm{Y}}=1.437 \mathrm{Li}, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ very weak. Colorless. Made from cold water solution. A pseudo-hexagonal phase is also known with one perfect cleavage. G. 1.16. Common twinning. ( + ) $2 \mathrm{E}=63^{\circ} 30^{\prime}$ red, $61^{\circ} 32^{\prime}$ green. Made from hot water solution.

[^80]$\mathbf{R b}_{2} \mathbf{S O}_{4}$ is orthorhombic with ${ }^{21} a: b: c=0.572: 1: 0.749$. Crystals varied, nearly equant or $\{100\}$ tablets. Common pseudo-hexagonal forms from twinning on $\{110\}$. Distinct $\{010\}$ and poor $\{001\}$ cleavages. G. 3.61. $\mathrm{X}=b ; \mathrm{Y}=c .(+) 2 \mathrm{~V}=38^{\circ} 40^{\prime} \mathrm{Li}, 41^{\circ} 55^{\prime} \mathrm{Na}, 43^{\circ} 35^{\prime} \mathrm{Tl}$ (but variations are found). $n_{\mathrm{X}}=1.5108 \mathrm{Li}, 1.5131 \mathrm{Na}, 1.5153 \mathrm{Tl}, n_{\mathrm{Y}}=1.5109 \mathrm{Li}, 1.5133$ $\mathrm{Na}, 1.5155 \mathrm{Tl}, n_{\mathrm{Z}}=1.5120 \mathrm{Li}, 1.5144 \mathrm{Na}, 1.5166 \mathrm{Tl}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0013$ Na at room temperature. At $180^{\circ}$ C. $n_{\mathrm{X}}=1.5075 \mathrm{Na}, n_{\mathrm{Y}}=1.5085, n_{\mathrm{Z}}=$ $1.5096, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0021$. The optic angle decreases with rising temperature, becoming $0^{\circ}$ for Li light at $42^{\circ}$, for Na at $48^{\circ}$ and for F light at $58^{\circ}$. At higher temperatures the optic plane is (010). Colorless. PD 3.12, 3.00, 2.98; 8-51. Made from water solution.
$\mathbf{A g}_{2} \mathbf{S O}_{4}$ is orthorhombic with ${ }^{23 a} a: b: c=0.461: 1: 0.808$. Crystals pyramidal with distinct $\{010\}$ and poor $\{111\}$ cleavages. G. 5.363 . $(+) 2 \mathrm{~V}=$ $73^{\circ}$ calc.; $n_{\mathrm{X}}=1.7583, n_{\mathrm{Y}}=1.7748, n_{\mathrm{Z}}=1.7842, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0269$. $n_{\mathrm{X}}=1.7524 \mathrm{Li}, 1.7627$ (for $\lambda=546$ ). PD 2.87, 2.64, 3.17; 7-203.
$\mathbf{C s}_{2} \mathbf{S O}_{4}$ is orthorhombic with ${ }^{21} a: b: c=0.571: 1: 0.753$. Crystals $\{001\}$ or $\{010\}$ tablets with all three pinacoids prominent. Distinct $\{010\}$ and poor $\{001\}$ cleavages. G. 4.24. $\mathrm{Y}=b ; \mathrm{X}=c$. $(-) 2 \mathrm{~V}=65^{\circ} 20^{\prime} \mathrm{D}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{X}}=1.5573 \mathrm{C}, 1.5598 \mathrm{D}, 1.5660 \mathrm{~F}, n_{\mathrm{Y}}=1.5619 \mathrm{C}, 1.5644 \mathrm{D}$, $1.5706 \mathrm{~F}, n_{\mathrm{Z}}=1.5637 \mathrm{C}, 1.5662 \mathrm{D}, 1.5725 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0064$. PD 3.29, 3.15, 3.13; 8-462. Made from aqueous solution. Probably miscible in all proportions with $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SO}_{4}, \mathrm{~K}_{2} \mathrm{SO}_{4}, \mathrm{Rb}_{2} \mathrm{SO}_{4}$ and $\mathrm{Tl}_{2} \mathrm{SO}_{4}$.
$\mathbf{T l}_{2} \mathbf{S O}_{4}$ is orthorhombic with ${ }^{21} a: b: c=0.555: 1: 0.733$. Crystals $\{010\}$ tablets often long parallel to $a$. Perfect $\{010\}$ and very good $\{001\}$ cleavages. G. 6.765. $\mathrm{Y}=b ; \mathrm{Z}=a$. $(+) 2 \mathrm{~V}=68^{\circ} 4^{\prime} \mathrm{Na}, \mathrm{r}>\mathrm{v}$ very weak. $n_{\mathrm{X}}=1.8509 \mathrm{C}, 1.8600 \mathrm{D}, 1.8859 \mathrm{~F}, n_{\mathrm{Y}}=1.8579 \mathrm{C}, 1.8671 \mathrm{D}, 1.8935 \mathrm{~F}$, $n_{\mathrm{z}}=1.8753 \mathrm{C}, 1.8853 \mathrm{D}, 1.9126 \mathrm{~F}, n_{\mathrm{z}}-n_{\mathrm{X}}=0.0253 \mathrm{D}$. Colorless. PD 3.12, 3.05, 3.53; 7-188.
$\mathrm{K}_{2} \mathrm{CrO}_{4}$ (Tarapacaite) is orthorhombic with $a=5.92, b=10.40, c=$ 7.61 kX . U.C. 4. Crystals often $\{001\}$ tablets. Common pseudo-hexagonal forms from twinning on $\{110\}$. Distinct $\{010\}$ and $\{001\}$ cleavages. G. 2.74. $\mathrm{X}=b ; \mathrm{Y}=a .(-) 2 \mathrm{~V}=52^{\circ}, \mathrm{r}>\mathrm{v}$ weak. ${ }^{24} n_{\mathrm{X}}=1.687, n_{\mathrm{Y}}=1.722, n_{\mathrm{Z}}=$ $1.731, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.044$. Color bright yellow. PD 2.96, 4.28, 3.07; 1-0892. Made from aqueous solution. It has a reversible inversion at $636^{\circ} \mathrm{C}$. Miscible in all proportions with $\mathrm{K}_{2} \mathrm{SO}_{4}$. With 19 per cent $\mathrm{K}_{2} \mathrm{SO}_{4}, n_{\mathrm{X}}=$ ?, $n_{\mathrm{Y}}=$ $1.6688, n_{\mathrm{Z}}=1.6727$. With 79.4 per cent $\mathrm{K}_{2} \mathrm{SO}_{4}, n_{\mathrm{X}}=1.5316, n_{\mathrm{Y}}=1.5378$, $n_{\mathrm{Z}}=1.5432, n_{\mathrm{z}}-n_{\mathrm{X}}=0.0115$.
${ }^{21}$ Tutton: Zeit. Krist. XXXVIII, p. 602 (1904). Trans. Chem. Soc. London LXXXIII, p. 1049 (1903).
${ }^{22}$ Wyrouboff: Bull. Soc. Fr. Min. III, p. 198 (1880).
${ }^{23} a b c$ changed to $b a c$ to make $b>a>c$.
${ }^{23 a}$ Herman and Ilge: Zeit. Krist. LXXX, p. 402 (1931).
${ }^{24}$ Larsen and Berman: U. S. Geol. Surv. Bull. 848, 1934.
$\mathbf{R b}_{2} \mathbf{C r O}_{4}$ is orthorhombic with $a: b: c=0.566: 1: 0.749$. Crystals long parallel with $a$. Good $\{001\}$ cleavage. G. $3.52 . \mathrm{X}=c ; \mathrm{Y}=b$. (-) $2 \mathrm{H}=$ $74^{\circ}, \mathrm{r}<\mathrm{v}$. Bolland ${ }^{25}$ gives for "rubidium chromate" (hydrated?): $n_{1}=$ $1.71, n_{2}=1.72$; these are probably $n_{\mathrm{Y}}$ and $n_{\mathrm{z}}$. Color yellow. Made from aqueous solution.
$\mathbf{K}_{2} \mathbf{S e O}_{4}$ is orthorhombic with ${ }^{26} a: b: c=0.573: 1: 0.732$. Crystals $\{010\}$ tablets or prismatic needles vertically striated. Common three-part twins. Perfect $\{010\}$ and distinct $\{001\}$ cleavages. G. 3.067. Deliquescent. $\mathrm{Y}=a$; $\mathrm{Z}=c$. (+) $2 \mathrm{~V}=76^{\circ} 47^{\prime} \mathrm{C}, 76^{\circ} 53^{\prime} \mathrm{D}, 76^{\circ} 57^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.5325 \mathrm{C}$, $1.5352 \mathrm{D}, 1.5421 \mathrm{~F}, n_{\mathrm{Y}}=1.5362 \mathrm{C}, 1.5390 \mathrm{D}, 1.5460 \mathrm{~F}, n_{\mathrm{Z}}=1.5418 \mathrm{C}$, $1.5446 \mathrm{D}, 1.5518 \mathrm{~F}, n_{\mathrm{z}}-n_{\mathrm{X}}=0.0094 \mathrm{D}$. Colorless. PD 3.00, 4.30, 3.08; 1-0857. Made from aqueous solution.
$\mathbf{R b}_{2} \mathbf{S e O}_{4}$ is orthorhombic with $^{26} a: b: c=0.571: 1: 0.739$. Crystals brachydomatic columnar. Perfect $\{010\}$ and distinct $\{001\}$ cleavages. G. 3.902. Deliquescent. $\mathrm{Y}=a ; \mathrm{Z}=c$. $(+) 2 \mathrm{~V}=68^{\circ} 53^{\prime} \mathrm{D}, \mathrm{r}>\mathrm{v}$ very weak. $n_{\mathrm{X}}=1.5487 \mathrm{C}, 1.5515 \mathrm{D}, 1.5586 \mathrm{~F}, n_{\mathrm{Y}}=1.5509 \mathrm{C}, 1.5537 \mathrm{D}$, $1.5609 \mathrm{~F}, n_{\mathrm{Z}}=1.5554 \mathrm{C}, 1.5582 \mathrm{D}, 1.5655 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0067 \mathrm{D}$. Colorless. Made from aqueous solution.
$\mathbf{C s}_{2} \mathbf{S e O}_{4}$ is orthorhombic with ${ }^{26} a: b: c=0.570: 1: 0.742$. Crystals thick basal tablets. Perfect $\{010\}$ and distinct $\{001\}$ cleavages. G. 4.456. Very deliquescent. $\mathrm{X}=b ; \mathrm{Y}=c$. $(-) 2 \mathrm{~V}=73^{\circ} 7^{\prime} \mathrm{C}, 71^{\circ} 49^{\prime} \mathrm{Na}, 68^{\circ} 58^{\prime} \mathrm{F}, \mathrm{r}>\mathrm{v}$ distinct. $n_{\mathrm{X}}=1.5955 \mathrm{C}, 1.5989 \mathrm{D}, 1.6070 \mathrm{~F}, n_{\mathrm{Y}}=1.5965 \mathrm{C}, 1.5999 \mathrm{D}$, $1.6080 \mathrm{~F}, n_{\mathrm{Z}}=1.5969 \mathrm{C}, 1.6003 \mathrm{D}, 1.6084 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0014 \mathrm{D}$. The optic angle increases rapidly with heat becoming positive at about $60^{\circ} \mathrm{C}$. and uniaxial at about $95^{\circ} \mathrm{C}$.; at $150^{\circ} \mathrm{C}$. it is again decidedly biaxial (positive) with $\mathrm{Y}=b$; at $280^{\circ} \mathrm{C}$. the optic angle about ( $\mathrm{Z}=b$ ) is much more than $90^{\circ}$ and the sign is again negative ( $\mathrm{X}=c$ ). Made from aqueous solution.
$\mathbf{T l}_{2} \mathbf{S e O}_{4}$ is orthorhombic ${ }^{26}$ with $a: b: c=0.555: 1: 0.724$. Crystals columnar brachydomatic or $\{010\},\{001\}$ or $\{011\}$ tablets. $\{010\}$ and $\{001\}$ cleavages. G. $6.875 . \mathrm{X}=b ; \mathrm{Y}=c$. $(-) 2 \mathrm{~V}=72^{\circ} 58^{\prime}, \mathrm{r}>\mathrm{v}$ weak. $n_{\mathrm{X}}=$ $1.9355 \mathrm{C}, 1.9493 \mathrm{D}, 1.9840 \mathrm{~F}, n_{\mathrm{Y}}=1.9450 \mathrm{C}, 1.9592 \mathrm{D}, 1.9942 \mathrm{~F}, n_{\mathrm{Z}}=$ $1.9500 \mathrm{C}, 1.9640 \mathrm{D}, 1.9987 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{x}}=0.0147 \mathrm{D}$. Made from a dilute acid solution.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{S e O}_{4}$ is monoclinic ${ }^{27}$ with $a: b: c=1.890: 1: 1.199, \beta=115^{\circ} 29^{\prime}$. Crystals $\{100\}$ or $\{001\}$ tablets or columnar parallel to $b$. Twinning on $\{001\}$ common. Perfect $\{100\}$ and $\{001\}$ and distinct $\{010\}$ cleavages. G. 2.194. $\mathrm{X}=b ; \mathrm{Z} \wedge c=+113^{\circ} 11^{\prime} .(+) 2 \mathrm{~V}=37^{\circ} 19^{\prime} \mathrm{C}, 37^{\circ} 54^{\prime} \mathrm{D}$, $38^{\circ} 44^{\prime} \mathrm{F}, \mathrm{r}<$ v weak. $n_{\mathrm{X}}=1.5571 \mathrm{C}, 1.5607 \mathrm{D}, 1.5687 \mathrm{~F}, n_{\mathrm{Y}}=1.5594 \mathrm{C}$,

[^81]$1.5630 \mathrm{D}, 1.5713 \mathrm{~F}, n_{\mathrm{Z}}=1.5806 \mathrm{C}, 1.5846 \mathrm{D}, 1.5935 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.0239 D . Becomes uniaxial at $114^{\circ} \mathrm{C}$. for D and at $119^{\circ} \mathrm{C}$. for F . $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SeO}_{4}$ is also orthorhombic in isomorphous mix-crystals (and also alone?); it is then said to have $a: b: c=0.534: 1: 0.75$, and G. 2.077. Crystals $\{010\}$ tablets. $\mathrm{X}=c ; \mathrm{Y}=b$. ( -$) 2 \mathrm{~V}=55^{\circ} 36^{\prime}$ red, $58^{\circ} 54^{\prime}$ blue. $n_{\mathrm{Y}}=1.56$. Colorless. Made from aqueous solution.
$\mathbf{L i}_{2} \mathbf{S O}_{4}$ is monoclinic with $a: b: c=1.004: 1: 1.380, \beta=92^{\circ} 8^{\prime}$. Crystals pseudo-octahedral and pyramidal. Perfect $\{101\},\{10 \overline{1}\}$ and $\{011\}$ cleavages. G. 2.23. Unstable in air. $\mathrm{X} \wedge c=-31^{\circ} ; \mathrm{Z}=b$. ( $-2 \mathrm{~V}=72^{\circ} 58^{\prime}$, $\mathrm{r}>\mathrm{v}$ weak, $n_{\mathrm{Y}}=1.465, n_{\mathrm{z}}-n_{\mathrm{X}}=$ rather weak. Colorless. Made from fusion. Two other phases are known; one is hexagonal and inverts at $500^{\circ} \mathrm{C}$.; the other is isometric. PD 4.01, 3.16, 2.47; 1-0443 (which phase?).

## 2. Formula Type $\mathbf{A X O}_{4}$

$\mathrm{CaSO}_{4}$ (Anhydrite) is orthorhombic with $a=6.94, b=6.97, c=$ 6.20 kX . U.C. 4. Crystals varied in habit; equant or $\{010\},\{100\}$ or $\{001\}$ tablets; or elongated parallel to $a$ or $c$. Perfect $\{010\}$, very good $\{100\}$ and distinct $\{001\}$ cleavages. H. 3-3.5. G. 2.98. Soluble in HCl. M.P. $1450^{\circ} \mathrm{C} . \mathrm{X}=b ; \mathrm{Z}=c .(+) 2 \mathrm{~V}=43^{\circ}, \mathrm{r}<\mathrm{v}$ weak. ${ }^{28} n_{\mathrm{X}}=1.5698, n_{\mathrm{Y}}=$ $1.5754, n_{\mathrm{Z}}=1.6136 \mathrm{Na}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0438$. Colorless in transmitted light; thick crystals may be bluish or violet with X colorless to pale yellow or rose, Y pale violet or rose, Z violet. $\mathrm{PD} 3.50,2.85,2.33 ; 6-0226^{*}$. Made in several ways: for example by cooling a fusion of $\mathrm{CaSO}_{4}$ with $\mathrm{CaCl}_{2}$ or $\mathrm{NaCl} \mathrm{CaSO}_{4}$ inverts at $1195^{\circ} \mathrm{C}$. to the $\alpha$-phase which is monoclinic ${ }^{29}$ with lamellar twinning like plagioclase; it has ${ }^{30} n_{\mathrm{X}}=1.50, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.56$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.06$. Another phase ( $\beta-\mathrm{CaSO}_{4}$ ) is obtained by heating anhydrite above $170^{\circ} \mathrm{C}$. It is stable to at least $500^{\circ} \mathrm{C}$. It is probably orthorhombic and is pseudo-hexagonal. G. 2.85. $\mathrm{Z}=c .(+) 2 \mathrm{E}=45^{\circ} \pm, n_{\mathrm{X}}=1.562 \pm$ $0.003, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.595, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.013$. A third phase $\left(\gamma-\mathrm{CaSO}_{4}\right)$ has been called "soluble anhydrite" since it is much more soluble in water than ordinary anhydrite. It is made by dehydrating $\mathrm{CaSO}_{4} \cdot 0.5 \mathrm{H}_{2} \mathrm{O}$ at about $30^{\circ}$ C. Crystals are hexagonal basal plates. G. 2.61 (Gaubert ${ }^{31}$ ), 2.55 (Gaudefroy ${ }^{30}$ ). Uniaxial positive ${ }^{31}$ with $n_{\mathrm{O}}=1.505, n_{\mathrm{E}}=1.548 \pm$ $.003, n_{\mathrm{E}}-n_{\mathrm{O}}=0.043$. Again: $:^{30} n_{\mathrm{O}}=1.56, n_{\mathrm{E}}=1.50, n_{\mathrm{E}}-n_{\mathrm{O}}=0.06$. This phase takes up $0.5 \mathrm{H}_{2} \mathrm{O}$ readily in contact with moist air. It varies markedly in properties with variation of temperature: for example ${ }^{32}$ at

[^82]$100^{\circ} \mathrm{C}$. it has $n_{\mathrm{X}}=1.547, n_{\mathrm{Z}}=1.570$; at $150^{\circ} \mathrm{C}$. it has $n_{\mathrm{X}}=1.499$, $n_{\mathrm{z}}=1.544$; and at $450^{\circ}-550^{\circ} \mathrm{C}$. it is isotropic with $n=1.500$. PD 6.05, 3.01, 2.80; 2-0134.
$\mathbf{Z n S O}_{4}$ (Zinkosite?) is orthorhombic ${ }^{33}$ with $a=6.74, b=8.58, c=$ 4.76 kX . Crystals rectangular or rhombic $\{001\}$ plates. G. 3.7. Alters on exposure to air. $\mathrm{X}=b ; \mathrm{Z}=c .(-) 2 \mathrm{~V}=$ small, $n_{\mathrm{X}}=1.658, n_{\mathrm{Y}}=1.669$, $n_{\mathrm{Z}}=1.670, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.012$. Colorless or white. PD 3.54, 4.17, 2.65; $8-491$. Made by dissolving zinc in $\mathrm{H}_{2} \mathrm{SO}_{4}$ and drying. A natural substance called zinkosite is perhaps the same.


Fig. 7-3. A crystal habit of $\mathrm{BaSO}_{4}$, barite.
$\mathrm{CuSO}_{4}$ (Chalcocyanite) is orthorhombic with $a: b: c=0.797: 1: 1.130$. Crystals tabular, pseudo-hexagonal. ${ }^{34}$ Effloresces slowly in air, altering to chalcanthite. H. 3.5. G. 3.65. $\mathrm{X}=\mathrm{b} ; \mathrm{Z}=c$. $(-) 2 \mathrm{~V}=$ large, $\mathrm{r}>\mathrm{v}$ extreme. $n_{\mathrm{X}}=1.724, n_{\mathrm{Y}}=1.733, n_{\mathrm{Z}}=1.739, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.015$. Pure $\mathrm{CuSO}_{4}$ crystals are colorless, but natural crystals are pale green, brownish, yellowish, sky-blue or violet with Z darkest. PD 2.62, 4.20, 3.55; 1-1081.


Fig. 7-4. A crystal habit of $\mathrm{BaSO}_{4}$, barite.
$\mathrm{BaSO}_{4}$ (Barite) is orthorhombic with $a=8.85, b=5.43, c=7.13 \mathrm{kX}$. U.C. 4. Crystals $\{001\}$ tablets often bounded by $\{210\}$, or equant or columnar parallel to $a$ or to $b$. Perfect $\{001\}$ and $\{210\}$ and poor $\{010\}$ cleavages. H. 3-3.5. G. 4.50. M.P. $1580^{\circ}$ C. Insoluble. $\mathrm{Y}=b, \mathrm{Z}=a .{ }^{28}(+) 2 \mathrm{~V}=$
${ }^{33}$ Schiff: Zeit. Krist. LXXXVII, p. 379 (1934). $a$ and $b$ interchanged to make $b>a>c$.
${ }^{34}$ Posnjak and Tunell: Am. J. Sci. CCXVIII, p. 1 (1929).
$36^{\circ} 37^{\prime} \mathrm{C}, 37^{\circ} 2^{\prime} \mathrm{D}, 37^{\circ} 45^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v}$ distinct. $n_{\mathrm{X}}=1.6336 \mathrm{C}, 1.6363 \mathrm{D}$, $1.6427 \mathrm{~F}, n_{\mathrm{Y}}=1.6346 \mathrm{C}, 1.6373 \mathrm{D}, 1.6440 \mathrm{~F}, n_{\mathrm{Z}}=1.6456 \mathrm{C}, 1.6484 \mathrm{D}$, $1.6551 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0121 \mathrm{D} . \mathrm{PD} 3.44,3.10,2.12 ; 5-0448$. Colorless to white or (stained?) yellow, reddish brown, gray. Inverts to a monoclinic (?) phase at $1149^{\circ} \mathrm{C}$. Made by fusion of $\mathrm{BaSO}_{4}$ with $\mathrm{BaCl}_{2}$ and in other ways. Forms a (probably) continuous series with $\mathrm{SrSO}_{4}$; may contain Pb up to about $\mathrm{Pb}: \mathrm{Ba}=1: 4$.
$\mathrm{SrSO}_{4}$ (Celestite) is orthorhombic with $a=8.36, b=5.36, c=6.84 \mathrm{kX}$. U.C. 4. Crystals resemble barite in form. Perfect $\{001\}$, good $\{210\}$ and poor $\{010\}$ cleavages. H. 3-3.5. G. 3.97. M.P. about $1605^{\circ}$ C. $\mathrm{X}=c$; $\mathrm{Y}=b .{ }^{28}(+) 2 \mathrm{~V}=49^{\circ} 50^{\prime} \mathrm{C}, 50^{\circ} 25^{\prime} \mathrm{D}, 51^{\circ} 36^{\prime} \mathrm{F} ; \mathrm{r}<\mathrm{v}$ distinct. $n_{\mathrm{X}}=$ $1.6189 \mathrm{C}, 1.6215 \mathrm{D}, 1.6273 \mathrm{~F}, n_{\mathrm{Y}}=1.6207 \mathrm{C}, 1.6232 \mathrm{D}, 1.6292 \mathrm{~F}, n_{\mathrm{Z}}=$ $1.6279 \mathrm{C}, 1.6305 \mathrm{D}, 1.6367 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0092 \mathrm{D}$. Colorless to pale blue; also white, reddish, greenish or brownish. PD 2.97, 3.30, 2.73; 5-0593. Inverts to a hexagonal phase at about $1152^{\circ}$ C. Forms a series (probably complete) with $\mathrm{BaSO}_{4}$.
$\mathbf{P b S O}_{4}$ (Anglesite) is orthorhombic with $a=8.45, b=5.38, c=$ $6.93 k X$. U.C. 4. Crystals of varied habit-thick $\{001\}$ tablets, pyramidal, prismatic along $a$, equant, etc. Good $\{001\}$, distinct $\{210\}$ and poor $\{010\}$ cleavages. H. 2.5-3. G. 6.38. Decomposes at $900^{\circ}-1000^{\circ} \mathrm{C} . \mathrm{X}=c ; \mathrm{Y}=b .{ }^{28}$ $(+) 2 \mathrm{~V}=68^{\circ} 7^{\prime} \mathrm{B}, 68^{\circ} 28^{\prime} \mathrm{D}, 68^{\circ} 42^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{x}}=1.8707 \mathrm{C}$, $1.8781 \mathrm{D}, 1.8965 \mathrm{~F}, n_{\mathrm{Y}}=1.8761 \mathrm{C}, 1.8832 \mathrm{D}, 1.9020 \mathrm{~F}, n_{\mathrm{Z}}=1.8869 \mathrm{C}$, $1.8947 \mathrm{D}, 1.9137 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0166 \mathrm{D} . \mathrm{PD} 3.00,4.26,3.33 ; 5-0577$. Colorless to white or tinted gray, yellow, green or blue. Streak colorless. Made by slow precipitation of lead chloride dissolved in $\mathrm{H}_{2} \mathrm{SO}_{4}$ (with HCl ). Inverts to a monoclinic phase at about $864^{\circ} \mathrm{C}$.
$\mathrm{PbCrO}_{4}$ (Crocoite) is monoclinic with $a=7.10, b=7.40, c=6.80 \mathrm{kX}$, $\beta=102^{\circ} 27^{\prime}$. U.C. 4. Crystals prismatic, equant, etc. Distinct $\{110\}$ and poor $\{001\}$ and $\{100\}$ cleavages. H. 2.5-3. G. 6.1. $\mathrm{Y}=b ; \mathrm{Z} \wedge c^{35}=+5.5^{\circ}$. $(+) 2 \mathrm{~V}=57^{\circ} \mathrm{Li}, 54^{\circ} 3^{\prime} \mathrm{Na}, \mathrm{r}>\mathrm{v}$ very strong. $n_{\mathrm{X}}=2.29 \pm 0.02 \mathrm{Li},{ }^{11} n_{\mathrm{Y}}=$ $2.36 \pm 0.02, n_{\mathrm{Z}}=2.66 \pm 0.02 \mathrm{Li}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.37 \pm$. Inclined dispersion. Color hyacinth-red or orange or yellow. Pleochroic with X and Y orangered, Z blood-red. PD 3.28, 3.03, 3.48; 8-209/10. Made by cooling a solution of $\mathrm{PbCrO}_{4}$ in HCl or $\mathrm{KNO}_{3}$. It can dissolve considerable $\mathrm{PbSO}_{4}$ or $\mathrm{PbMoO}_{4}$. Two other phases are known. One is tetragonal; it is stable only at high temperature or as mix-crystals with $\mathrm{PbMoO}_{4}$. An unstable orthorhombic phase can form mix-crystals with $\mathrm{PbSO}_{4}$; it is more orange in color.

## 3. Formula Type $\mathbf{A}_{2}\left(\mathrm{XO}_{4}\right)_{3}$

$\mathbf{F e}_{2}\left(\mathbf{S O}_{4}\right)_{3}$ has at least two phases. One is hexagonal ${ }^{24}$ with $c / a=1.35$. Crystals flattened rhombohedrons with rhombohedral cleavage. Uniaxial

[^83]negative with $n_{\mathrm{O}}=1.756 \mathrm{C}, 1.770 \mathrm{D}, 1.809 \mathrm{~F}, n_{\mathrm{E}}=1.746 \mathrm{C}, 1.760 \mathrm{D}$, $1.798 \mathrm{~F}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.010 \mathrm{D}$. Colorless or grayish yellow. Made in a steel bomb at moderate temperature. A second phase is orthorhombic with ${ }^{36}$ $a: b: c=0.957: 1: 1.357$. Crystals basal tablets bounded by $\{010\},\{110\}$, $\{111\},\{101\}$ and $\{100\} .(-) 2 \mathrm{~V}=60^{\circ}, n_{\mathrm{x}}=1.787 \mathrm{C}, 1.802 \mathrm{D}, 1.844 \mathrm{~F}$, $n_{\mathrm{Y}}=1.799 \mathrm{C}, 1.814 \mathrm{D}, 1.857 \mathrm{~F}, n_{\mathrm{Z}}=1.803 \mathrm{C}, 1.818 \mathrm{D}, 1.861 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.016 D. Color grayish yellow. PD 3.59, 6.08, 4.40; 9-5. Made in a steel bomb at moderate temperature.

## 4. Formula Type $\mathrm{A}_{\boldsymbol{m}} \mathrm{B}_{n}\left(\mathrm{XO}_{4}\right)_{p}$

$\mathrm{K}_{2} \mathbf{M g}_{2}\left(\mathrm{SO}_{4}\right)_{3}$ (Langbeinite) is isometric with $a=9.96 k X$. U.C. 4. Crystals rare; usually massive or granular. No cleavage. H. 3.5-4. G. 2.83. M.P. $930^{\circ}$ C. Isotropic ${ }^{37}$ with $n=1.5323 \mathrm{Li}, 1.5347 \mathrm{Na}, 1.5370 \mathrm{Tl}$. Again: $1.5281 \mathrm{Li}, 1.5329 \mathrm{Na}, 1.5344 \mathrm{Tl} . \mathrm{PD} 3.14,2.67,4.06$; 3-0532. Colorless; rarely tinted (with stain?). Made by heating the mixed anhydrous sulfates ${ }^{36}$ to $80^{\circ} \mathrm{C}$.
$\mathbf{K}_{2} \mathbf{M n}_{2}\left(\mathbf{S O}_{4}\right)_{3}$ (Manganolangbeinite) is isometric with ${ }^{38} a=10.014 \AA$. U.C. 4. Crystals small tetrahedrons. G. 3.02. Isotropic with $n=1.572$. Color rose-red. Made from fusion.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{C a}_{2}\left(\mathbf{S O}_{4}\right)_{3}$ is isometric and pyritohedral. Isotropic with $n=1.532$. Colorless.
$\mathbf{K}_{2} \mathbf{A l}_{2}\left(\mathbf{S O}_{4}\right)_{4}$ is hexagonal. Crystals rhombohedral with prisms and base. Micaceous basal cleavage. Uniaxial negative with $n_{\mathrm{O}}=1.545 \pm, n_{\mathrm{E}}=$ $1.533 \pm, n_{\mathrm{O}}-n_{\mathrm{E}}=0.012 \pm$. Colorless. PD 3.63, 2.86, 2.36; 3-0337.
$\mathrm{K}_{2} \mathbf{P b}\left(\mathrm{SO}_{4}\right)_{2}$ (Palmierite) is hexagonal with $a=5.58, c=20.67 \mathrm{kX}$. Crystals basal plates. G. 4.5. Uniaxial negative ${ }^{39}$ with $n_{0}=1.712$, $n_{\mathrm{o}}-n_{\mathrm{E}}=$ strong. Colorless. Made from fusion of components.
$\mathbf{N a}_{2} \mathbf{C a}\left(\mathbf{S O}_{4}\right)_{2}$ (Glauberite) is monoclinic with $a=9.99, b=8.19, c=$ $8.41 k X, \beta=112^{\circ} 11^{\prime}$. U.C. 4. Crystals basal tablets, prismatic, or pyramidal. Perfect $\{001\}$ and poor $\{110\}$ cleavages. H. 2.5-3. G. 2.8. Y $\wedge c=$ $12^{\circ}, \mathrm{Z}=b .{ }^{24}(-) 2 \mathrm{~V}=7^{\circ}, \mathrm{r}>\mathrm{v}$ strong; also inclined dispersion. $n_{\mathrm{X}}=$ $1.515, n_{\mathrm{Y}}=1.535, n_{\mathrm{Z}}=1.536, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.021$. The optic properties vary markedly with change of temperature. ${ }^{40}$ Color gray, yellowish or colorless or stained red with iron oxide. PD 3.13, 6.22, 2.66; 2-0556. Made from aqueous solutions of $\mathrm{Na}_{2} \mathrm{SO}_{4}$ and $\mathrm{CaSO}_{4}$ at about $35^{\circ} \mathrm{C}$.
$\mathbf{N a} \mathbf{6} \mathbf{M g}\left(\mathbf{S O}_{4}\right)_{4}$ (Vanthoffite) is biaxial (probably monoclinic). Known ${ }^{36}$ Posnjak and Merwin: J. Am. Chem. Soc. XLIV, p. 1965 (1922). Also Scharizer: Zeit. Krist. LXV, p. 335 (1927).
${ }^{37}$ Görgey: Tsch. Min. Pet. Mitt. XXVIII, p. 334 (1909).
${ }^{38}$ Bellanca: Acc. Linc. Att. Cl. Sci. II, p. 451 (1947).
${ }^{39}$ Zambonini: N. Jahrb. Min. Monatshefte, 1955, p. 209.
${ }^{40}$ Kraus: Zeit. Krist. LII, p. 321 (1913); Kraus and Peck: Mich. Acad. Sci. Ann. Rept. XIX, p. 95 (1917).
only in grains or masses. H. 3.5-4. G. 2.69. ( - ) $2 \mathrm{~V}=84^{\circ}, \mathrm{r}<\mathrm{v}$ weak. ${ }^{37}$ $n_{\mathrm{X}}=1.4855, n_{\mathrm{Y}}=1.4876, n_{\mathrm{Z}}=1.4893, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0038$. Colorless. Made from a mixture of the two sulfates under pressure at $80^{\circ} \mathrm{C}$.

## D. HYDRATED SULFITES, SELENITES, THIOSULFATES, THIONATES, ETC.

$\mathrm{CaS}_{2} \mathbf{O}_{\mathbf{6}} \cdot \mathbf{4 \mathrm { H } _ { 2 } \mathrm { O }}$ is hexagonal rhombohedral with $c / a=1.50$. Crystals sixsided basal plates. Poor $\{0001\}$ cleavage. G. 2.18. Uniaxial negative with ${ }^{40 \mathrm{a}}$ $n_{\mathrm{O}}=1.5456 \mathrm{~B}, 1.5516 \mathrm{D}, 1.5580 \mathrm{~F}, n_{\mathrm{E}}=1.5369 \mathrm{~B}, 1.5414 \mathrm{D}, 1.5467 \mathrm{~F}$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.0102 \mathrm{D}$. Colorless.
$\mathrm{SrS}_{2} \mathrm{O}_{6} \cdot \mathbf{4 \mathbf { H } _ { 2 } \mathrm { O }}$ is hexagonal rhombohedral with $c / a=1.502$. Crystals sixsided basal plates. Poor $\{0001\}$ cleavage. G. 2.37. Uniaxial negative with ${ }^{40 \mathrm{a}}$ $n_{\mathrm{o}}=1.5260$ (672), 1.5297 (579), 1.5357 (492), $n_{\mathrm{E}}=1.5232$ (672), 1.5262 (579), 1.5310 (492), $n_{\mathrm{O}}-n_{\mathrm{E}}=0.0035$ D. Colorless.
$\mathbf{P b S}_{2} \mathrm{O}_{6} \cdot \mathbf{4 \mathrm { H } _ { 2 } \mathbf { O }}$ is hexagonal rhombohedral with $c / a=1.516$. Crystals sixsided basal plates. No cleavage. G. 3.25. Uniaxial positive with ${ }^{40 a} n_{\mathrm{O}}=$ 1.6303 (672), 1.6366 (579), 1.6480 (492), $n_{\mathrm{E}}=1.6500$ (672), 1.6557 (579), 1.6672 (492), $n_{\mathrm{E}}-n_{\mathrm{O}}=0.0191$ (579). May be slightly biaxial. Made from cold water solution. It forms a continuous series of mix-crystals with $\mathrm{SrS}_{2} \mathrm{O}_{6} \cdot 4 \mathrm{H}_{2} \mathrm{O}$, with linear variation of the refractive indices.
$\mathbf{N a}_{3} \operatorname{Ir}\left(\mathrm{SO}_{3}\right)_{3}\left(\mathrm{NH}_{3}\right)_{3} \cdot 6 \mathrm{H}_{2} \mathbf{O}$ is hexagonal ${ }^{40 \mathrm{~b}}$ with $c / a=3.169$. Uniaxial negative with $n_{\mathrm{O}}=1.570, n_{\mathrm{E}}=1.546, n_{\mathrm{O}}-n_{\mathrm{E}}=0.024$.
$\mathrm{K}_{3} \mathrm{Rh}\left(\mathrm{SO}_{3}\right)_{3}\left(\mathbf{N H}_{3}\right)_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is hexagonal ${ }^{40 \mathrm{~b}}$ with $c / a=3.184$. Uniaxial negative with $n_{\mathrm{O}}=1.597, n_{\mathrm{E}}=1.563, n_{\mathrm{O}}-n_{\mathrm{E}}=0.034$.
$\mathbf{M g S O}_{3} \cdot \mathbf{6 H}_{2} \mathrm{O}$ is hexagonal (trigonal hemimorphic) with $a=8.82, c=$ 9.04 kX . Crystals trigonal pyramids above a basal pedion. G. 1.725. Star-shaped twinning. Colorless. Uniaxial negative with ${ }^{41} n_{0}=1.511$, $n_{\mathrm{E}}=1.464, n_{\mathrm{O}}-n_{\mathrm{E}}=0.047$ for yellow Hg light and $n_{\mathrm{O}}=1.524, n_{\mathrm{E}}=$ $1.474, n_{\mathrm{O}}-n_{\mathrm{E}}=0.050$ for blue Hg light. No rotary polarization. PD 3.87, 2.74, 4.10; 1-0473.
$\mathrm{CoSO}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is trigonal hemimorphic ${ }^{41}$ with $c / a=1.004$. G. 2.01. Uniaxial negative with $n_{\mathrm{O}}=1.553, n_{\mathrm{E}}=1.506, n_{\mathrm{O}}-n_{\mathrm{E}}=0.047$. Color ruby-red.
$\mathrm{NiSO}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is trigonal hemimorphic ${ }^{41}$ with $c / a=1.012$. G. 2.027. Starlike twins common. Uniaxial negative with $n_{\mathrm{O}}=1.552, n_{\mathrm{E}}=1.509$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.043$ (Hg-green). Color emerald-green.

[^84]$\mathrm{CuSeO}_{3} \cdot \mathbf{2 H}_{2} \mathbf{O}$ (Chalcomenite) is orthorhombic with $a=6.56, b=$ $9.10, c=7.36 k X$. U.C. 4. Crystals acicular. No cleavage. H. 2-2.5. G. 3.35. $\mathrm{X}=a ; \mathrm{Y}=c .(-) 2 \mathrm{~V}=34^{\circ} \mathrm{Li}, \mathrm{r}>\mathrm{v}$ strong. ${ }^{11} n_{\mathrm{X}}=1.710, n_{\mathrm{Y}}=1.731$, $n_{\mathrm{Z}}=1.732$ all $\pm 0.003, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.022$. Color blue. Made by heating the precipitated salt with water in a closed tube.
$\mathbf{C a}\left(\mathrm{NH}_{2} \mathrm{SO}_{3}\right)_{2} \cdot \mathbf{3 H}_{2} \mathrm{O}$ is biaxial; ${ }^{7}$ micro- to cryptocrystalline. ( - ) $2 \mathrm{~V}=$ $48^{\circ}, \mathrm{r}>\mathrm{v} . n_{\mathrm{X}}=1.488, n_{\mathrm{Y}}=1.508$ calc., $n_{\mathrm{Z}}=1.512, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.029$.
$\mathbf{L i}_{2} \mathbf{S}_{2} \mathbf{O}_{6} \cdot \mathbf{2 H}_{2} \mathrm{O}$ is orthorhombic with $a: b: c=0.966: 1: 0.578$. Crystals macrodomatic. Perfect $\{100\}$ cleavage. G. 2.16.42 $\mathrm{Y}=c ; \mathrm{Z}=a$. $(+) 2 \mathrm{~V}^{42 \mathrm{a}}=78^{\circ} 16^{\prime}, n_{\mathrm{X}}=1.5462 \mathrm{C}, 1.5487 \mathrm{D}, 1.5548 \mathrm{~F}, n_{\mathrm{Y}}=1.5565 \mathrm{C}$, $1.5602 \mathrm{D}, 1.5680 \mathrm{~F}, n_{\mathrm{Z}}=1.5763 \mathrm{C}, 1.5788 \mathrm{D}, 1.5887 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.0301 D. Colorless.
$\mathrm{Na}_{2} \mathrm{~S}_{2} \mathrm{O}_{6} \cdot 2 \mathrm{H}_{2} \mathbf{O}$ is orthorhombic with $a: b: c=0.992: 1: 0.598$. Crystals prismatic. Perfect $\{110\}$ cleavage. G. 2.19. ${ }^{42} \mathrm{Y}=b ; \mathrm{Z}=a$. (+) $2 \mathrm{~V}=$ $73^{\circ} 26^{\prime} \mathrm{Li}, 75^{\circ} 14^{\prime} \mathrm{Na}, 76^{\circ} 28^{\prime}$ green, $\mathrm{r}<$ v strong. $n_{\mathrm{X}}=1.4803 \mathrm{Li}, 1.4820 \mathrm{Na}$, 1.4838 green, $n_{\mathrm{Y}}=1.4927 \mathrm{Li}, 1.4953 \mathrm{Na}, 1.4978$ green, $n_{\mathrm{Z}}=1.5158 \mathrm{Li}$, $1.5185 \mathrm{Na}, 1.5212$ green, $n_{\mathrm{z}}-n_{\mathrm{x}}=0.0365 \mathrm{Na}$. Colorless. PD 3.82, 5.35, 4.87; 5-0357*.
$\mathrm{Ag}_{2} \mathrm{~S}_{2} \mathrm{O}_{6} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ is orthorhombic with $a: b: c=0.988: 1: 0.581$. Crystals prismatic. Perfect $\{110\}$ cleavage. G. $3.61 .{ }^{42} \mathrm{X}=b ; \mathrm{Y}=c$. (-) $2 \mathrm{~V}^{42 \mathrm{a}}=$ $33^{\circ} 21^{\prime} \mathrm{C}, 28^{\circ} 6^{\prime} \mathrm{F}, \mathrm{r}>$ v strong. $n_{\mathrm{X}}=1.6272 \mathrm{C}, 1.6404 \mathrm{~F}, n_{\mathrm{Y}}=1.6573 \mathrm{C}$, $1.6748 \mathrm{~F}, n_{\mathrm{Z}}=1.6601 \mathrm{C}, 1.6770 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0329 \mathrm{C}, 0.0366 \mathrm{~F}$. Isomorphous with $\mathrm{Na}_{2} \mathrm{~S}_{2} \mathrm{O}_{6} \cdot 2 \mathrm{H}_{2} \mathrm{O}$. PD 3.82, 5.35, 4.87; 5-0357*.
$\mathbf{3} \mathrm{K}_{2} \mathbf{S}_{5} \mathbf{O}_{6} \cdot \mathbf{2} \mathbf{H}_{2} \mathbf{O}$ is orthorhombic with $a: b: c=0.456: 1: 0.305$. Crystals prismatic with $\{110\},\{010\},\{011\}$, etc., or thick $\{010\}$ tablets terminated by $\{221\}$. No distinct cleavage. $\mathrm{X}=a ; \mathrm{Y}=b .{ }^{42 \mathrm{~b}}$ Positive elongation. $(-) 2 \mathrm{~V}=65^{\circ} \pm, \mathrm{r}>\mathrm{v} .{ }^{\prime} n_{\mathrm{X}}=1.570, n_{\mathrm{Y}}=1.63 \pm, n_{\mathrm{Z}}=1.658, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.088. Again: ${ }^{1} n_{\mathrm{X}}=1.565, n_{\mathrm{Y}}=1.63, n_{\mathrm{Z}}=1.655 \pm, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.090$. Colorless. Made from water solution.
$\mathbf{7 B a S}_{5} \mathrm{O}_{6} \cdot \mathbf{2} \mathrm{H}_{2} \mathbf{O}$ ? is orthorhombic in rectangular tablets flattened parallel with the optic plane. (+)2V fairly large. ${ }^{4 \mathrm{~b}} n_{\mathrm{X}}=1.620-, n_{\mathrm{Y}}=1.640-$, $n_{\mathrm{Z}}=1.670, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.050+$. Colorless. Made from water solution by addition of alcohol.
$\mathrm{K}_{2} \mathrm{Cr}_{2} \mathrm{O}_{7} \cdot \mathbf{H g}(\mathrm{CN})_{2} \cdot \mathbf{2} \mathbf{H}_{2} \mathrm{O}$ is orthorhombic with $a: b: c=0.794: 1: 1.495$. Crystals short prismatic with $\{110\}$ cleavage. $\mathrm{Y}=a ; \mathrm{Z}=c$. ( + ) $2 \mathrm{~V}=$ $57^{\circ} 18^{\prime}$ red, $\mathrm{r}>$ v strong. $n_{\mathrm{Y}}=1.591$ red. Made from solution.
$\mathrm{NaAgS}_{2} \mathrm{O}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ is monoclinic domatic ${ }^{42 \mathrm{c}}$ with $a: b: c=0.853: 1: 0.868$, $\beta=97^{\circ} 32^{\prime}$. Crystals $\{010\}$ tablets or prismatic. Strongly piezoelectric.

[^85]$\mathrm{X} \wedge c=+12^{\circ} ; \mathrm{Z}=b .2 \mathrm{~V}=$ about $90^{\circ} ; n_{\mathrm{X}}=1.69, n_{\mathrm{Y}}=$ about 1.715 calc., $n_{\mathrm{Z}}=1.74, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.05$.
$\mathrm{BaS}_{2} \mathbf{O}_{6} \cdot 2 \mathrm{H}_{2} \mathbf{O}$ is monoclinic with $a: b: c=0.94: 1: 1.38, \beta=111^{\circ} 21^{\prime}$. Crystals varied; perfect $\{001\}$ cleavage. Twinning on $\{001\}$. G. 3.12. $\mathrm{Y}=b ;^{42 \mathrm{~d}} \mathrm{Z} \wedge c=-13^{\circ}$ 。 ( + ) $2 \mathrm{~V}=83^{\circ} 6^{\prime}-83^{\circ} 31^{\prime} \mathrm{Li}, 84^{\circ} 28^{\prime}-84^{\circ} 38^{\prime} \mathrm{Na}$, $87^{\circ} 18^{\prime}-87^{\circ} 38^{\prime}$ green, $\mathrm{r}<\mathrm{v}$ strong. $n_{\mathrm{X}}=1.5848 \mathrm{Li}, 1.5860 \mathrm{Na}, 1.5881$ green, $n_{\mathrm{Y}}=1.5935 \mathrm{Li}, 1.5951 \mathrm{Na}, 1.5976$ green, $n_{\mathrm{Z}}=1.6055 \mathrm{Li}, 1.6072 \mathrm{Na}$, 1.6090 green, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0212 \mathrm{Na}$. Colorless.
$\mathbf{B a S}_{2} \mathbf{O}_{6} \cdot \mathbf{4 H}_{2} \mathbf{O}$ is monoclinic with $a: b: c=1.222: 1: 1.127, \beta=94^{\circ} 16^{\prime}$. $\{110\}$ cleavage. Pseudo-hexagonal by twinning on $\{110\}$. G. 3.1. $\mathrm{X} \wedge c=$ $-45^{\circ} ; \mathrm{Z}=b .(+) 2 \mathrm{~V}=87^{\circ} 20^{\prime}$ red, $89^{\circ} 42^{\prime}$ green, $\mathrm{r}<$ v strong. $n_{\mathrm{Y}}=1.532$ red, ${ }^{42 \mathrm{e}} n_{\mathrm{Z}}-n_{\mathrm{X}}=$ strong. Colorless.
$\mathrm{CaS}_{2} \mathrm{O}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ forms biaxial crystals ${ }^{1}$ with oblique extinction. ( + ) $2 \mathrm{~V}=$ $60^{\circ} \pm$ calc., $n_{\mathrm{X}}=1.545 \pm, n_{\mathrm{Y}}=1.560 \pm, \quad n_{\mathrm{Z}}=1.605 \pm, \quad n_{\mathrm{Z}}-n_{\mathrm{X}}=$ $0.060 \pm$. Colorless.
$\mathrm{Na}_{2} \mathrm{~S}_{2} \mathbf{O}_{3} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=0.351: 1: 0.275, \beta=103^{\circ} 58^{\prime}$. Crystals prismatic or $\{010\}$ laths. G. $1.7 \pm . \mathrm{X} \wedge c=-41.5^{\circ} \mathrm{Na}$, $-42^{\circ} 18^{\prime} \mathrm{F} ; \mathrm{Z}=b .(+) 2 \mathrm{~V}=80^{\circ} 40^{\prime} \mathrm{Na}, \mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.4849 \mathrm{Li}, 1.4886$ $\mathrm{Na}, 1.4919 \mathrm{Tl}, n_{\mathrm{Y}}=1.5038 \mathrm{Li}, 1.5079 \mathrm{Na}, 1.5117 \mathrm{Tl}, n_{\mathrm{Z}}=1.5311 \mathrm{Li}$, $1.5360 \mathrm{Na}, 1.5405 \mathrm{Tl}, n_{\mathrm{z}}-n_{\mathrm{x}}=0.0474 \mathrm{Na}$. Colorless. PD 2.93, 5.4, 2.84; 1-0914. Made from water solution.
$\mathrm{Na}_{2} \mathrm{Cr}_{2} \mathrm{O}_{7} \cdot \mathbf{2 H}_{2} \mathrm{O}$ is monoclinic with ${ }^{42 \mathrm{f}} a: b: c=0.57: 1: 1.182, \beta=94^{\circ} 55^{\prime}$. Crystals basal plates. No cleavage. Deliquescent. G. 2.53. $\mathrm{X}=\mathrm{b} ; \mathrm{Z} \wedge c=$ $+13^{\circ}$. $(+) 2 \mathrm{~V}=83^{\circ} 42^{\prime}, \mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.6610, n_{\mathrm{Y}}=1.6994, n_{\mathrm{Z}}=1.7510$, $n_{\mathrm{z}}-n_{\mathrm{X}}=0.090$. PD 3.93, 5.4, 3.04; 1-0460. Made from solution.
$\mathbf{S r C r}_{2} \mathbf{O}_{7} \cdot 3 \mathbf{H}_{2} \mathbf{O}$ is monoclinic with $a: b: c=0.602: 1: 0.546, \beta=92^{\circ} 32^{\prime}$. Crystals $\{100\}$ plates. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=+78^{\circ}$. ( + ) $2 \mathrm{~V}=20^{\circ} 28^{\prime}, \mathrm{r}<\mathrm{v}$. $n_{\mathrm{X}}=1.7146, n_{\mathrm{Y}}=1.7174, n_{\mathrm{Z}}=1.812$ calc., $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0954$. Made from solution.
$\mathrm{Ce}_{2}\left(\mathbf{S}_{2} \mathrm{O}_{6}\right) \cdot 15 \mathrm{H}_{2} \mathrm{O}$ is triclinic pinacoidal with $a: b: c=0.592: 1: 1.191$, $\alpha=81^{\circ} 26^{\prime}, \beta=105^{\circ} 21^{\prime}, \gamma=86^{\circ} 38^{\prime}$. Crystals thick $\{001\}$ tablets. Perfect $\{100\}$ cleavage. G. 2.29. Both optic axes visible through $\{001\}$ with the acute bisectrix inclined to the left and with unsymmetrical dispersion; the optic plane cuts the $a$ axis at about $20^{\circ}$. (-) $2 \mathrm{~V}=88^{\circ} 52^{\prime}, \mathrm{r}>\mathrm{v}$ weak. $n_{\mathrm{Y}}=1.507, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ ? Made from solution below $15^{\circ} \mathrm{C}$.
${ }^{42 \mathrm{~d}}$ Brio: Sitzb. Akad. Wiss. Wien, LV (II), p. 145 (1867).
${ }^{42 \mathrm{e}}$ Wyrouboff: Bull. Soc. Fr. Min. VIII, p. 78 (1885).
${ }^{42 f}$ Wyrouboff: Bull. Soc. Fr. Min. XIV, p. 77 (1891).

## E. HYDRATED ACID SULFATES

$\left(\mathbf{U O}_{2}\right)_{2} \mathbf{H}_{2}\left(\mathbf{S O}_{4}\right)_{3} \cdot 5 \mathrm{H}_{2} \mathbf{O}$ is orthorhombic with ${ }^{42 g} a=12.86, b=12.99, c=$ $11.57 \AA$ A. G. 3.16. $\mathrm{Z}=c$. (-) 2 V near $0^{\circ}$. $n_{\mathrm{X}}=1.555, n_{\mathrm{Y}}=1.586, n_{\mathrm{Z}}=$ 1.586, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.031$. Pleochroic with X colorless, Y and Z pale yellow. PD 6.32, 3.19, 2.76; 8-152. Made from solution.
$\mathrm{FeH}\left(\mathrm{SO}_{4}\right)_{2} \cdot \mathbf{4 \mathbf { H } _ { 2 } \mathrm { O }}$ (Rhomboclase) is orthorhombic with $a: b: c=$ $0.5577: 1: 0.9370$. Crystals basal plates. Perfect $\{001\}$ and good $\{110\}$ cleavages. H. 2. G. 2.23. $\mathrm{X}=c ;{ }^{43} \mathrm{Y}=a$. ( $+2 \mathrm{~V}=27^{\circ}$. $n_{\mathrm{X}}=1.533$, $n_{\mathrm{Y}}=1.550, n_{\mathrm{Z}}=1.635, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.102$. Colorless to white, gray or yellow. It is a stable phase in the system $\mathrm{Fe}_{2} \mathrm{O}_{3}-\mathrm{SO}_{3}-\mathrm{H}_{2} \mathrm{O}$ at temperatures up to $140^{\circ} \mathrm{C}$.
$\mathrm{NaHSO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=0.997: 1: 1.048, \beta=119^{\circ} 35^{\prime}$. Crystals prismatic, often platy parallel (110) or (110). Bolland ${ }^{25}$ measured on "sodium bisulfate" (hydrated?): $n_{\mathrm{X}}=1.43, n_{\mathrm{Y}}=1.46, n_{\mathrm{Z}}=1.47$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.04 \therefore(-) 2 \mathrm{~V}=$ moderate. Colorless. PD 3.40, 2.98, 2.77; 1-0624. Made from a solution of $\mathrm{Na}_{2} \mathrm{SO}_{4}$ containing an excess of $\mathrm{H}_{2} \mathrm{SO}_{4}$.

## F. HYDRATED NORMAL SULFATES, CHROMATES, AND SELENATES

## 1. Formula Type $\mathrm{A}_{2} \mathrm{XO}_{4} \cdot \mathbf{q H}_{2} \mathrm{O}$

$\mathbf{N a}\left(\mathbf{N H}_{4}, \mathrm{~K}_{\text {) }} \mathrm{SO}_{4} \cdot \mathbf{2 H}_{2} \mathrm{O}\right.$ (Lecontite) is orthorhombic with $a: b: c=$ $0.785: 1: 1.532$. Crystals prismatic. ${ }^{11} \mathrm{H} .2-2.5$. ( - ) $2 \mathrm{~V}=40^{\circ} \pm 1^{\circ}, n_{\mathrm{X}}=$ $1.440, n_{\mathrm{Y}}=1.452, n_{\mathrm{Z}}=1.453$ all $\pm 0.003, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.013-0.006$. Colorless. PD 5.07, 4.64, 3.85; 2-0161*. $\mathrm{NaNH}_{4} \mathrm{SO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ crystallizes from a water solution of $\mathrm{Na}_{2} \mathrm{SO}_{4}$ with excess of $\left(\mathrm{NH}_{4}\right)_{2} \cdot \mathrm{SO}_{4}$.
$\mathbf{L i}_{2} \mathbf{S O}_{4} \cdot \mathbf{H}_{2} \mathbf{O}$ is monoclinic ${ }^{44}$ with $a: b: c=1.607: 1: 0.563, \beta=92^{\circ} 5^{\prime}$. Crystals $\{\overline{1} 01\}$ plates long parallel with $b$. Twinning on $\{\overline{1} 01\}$ common. Perfect $\{101\}$ distinct $\{100\}$ and poor $\{110\}$ cleavages. G. 2.06. $\mathrm{X} \wedge c=$ $-36^{\circ} 32^{\prime} ; \mathrm{Z}=b$. (-) $2 \mathrm{~V}=78^{\circ} 24^{\prime}, \mathrm{r}<\mathrm{v}$ very weak. $n_{\mathrm{X}}=1.459, n_{\mathrm{Y}}=$ 1.477, $n_{\mathrm{Z}}=1.488, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.029$. Colorless. PD 4.12, 5.10, 3.54; 1-0425.
$\mathbf{N a}_{2} \mathbf{S O}_{4} \cdot \mathbf{1 0 H}_{2} \mathbf{O}$ (Mirabilite) is monoclinic with $a: b: c=1.110: 1: 1.239$, $\beta=107^{\circ} 45^{\prime}$. Crystals columnar parallel to $b,\{001\}$ tablets long parallel to $b$, or short prismatic. Perfect $\{100\}$ and poor $\{001\},\{010\}$ and $\{011\}$ cleavages. Loses some water easily. H. 1.5-2. G. 1.49; also reported as

[^86]1.46-1.48. $\mathrm{X}=b ; \mathrm{Z} \wedge c=+31^{\circ} \mathrm{Li}, 26.5^{\circ}$ blue. ( - ) $2 \mathrm{~V}=76^{\circ}, \mathrm{r}>\mathrm{v}$ weak with strong crossed dispersion. ${ }^{11} n_{\mathrm{X}}=1.394, n_{\mathrm{Y}}=1.396, n_{\mathrm{Z}}=1.398$ all $\pm 0.003, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.004$. Again: ${ }^{45} n_{\mathrm{X}}=1.396 \mathrm{Na}, n_{\mathrm{Y}}=1.4103, n_{\mathrm{Z}}=$ 1.419 calc., $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.023$. Sections or grains normal to X give abnormal interference colors; other sections give sharp extinction. Colorless. PD 5.50, 3.22, 3.10; 1-0207.


Fig. 7-5. A crystal habit of $\mathrm{Na}_{2} \mathrm{SO}_{4} \cdot 10 \mathrm{H}_{2} \mathrm{O}$.
$\mathrm{Na}_{2} \mathrm{CrO}_{4} \cdot \mathbf{4 H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=1.112: 1: 1.062, \beta=105^{\circ} 4^{\prime}$. Crystals often elongated along $a$. No distinct cleavage. Twinning on $\{001\}$. Deliquescent. The optic plane is $\{010\}$ for light of wave-length less than $645 \mathrm{~m} \mu$ and normal to $\{010\}$ for $\lambda=$ more than $645 \mathrm{~m} \mu$; it is uniaxial positive at $\lambda=645 \mathrm{~m} \mu$. ( + ) $2 \mathrm{~V}=31^{\circ}$ to $12^{\circ}$ for $\lambda=450-600 \mathrm{~m} \mu$. $\mathrm{Z} \wedge c=$ $5^{\circ}$ for $\lambda=589 \mathrm{~m} \mu$.

| $\lambda$ | 472 | 535 | 573 | 589 | 625 | 645 | 650 | 670 |
| :--- | :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $n_{\mathrm{X}}$ |  | 1.342 |  | 1.321 | 1.308 |  | 1.291 | 1.221 |
| $n_{\mathrm{Y}}$ |  | 1.471 |  | 1.447 | 1.383 |  | 1.297 | 1.285 |
| $n_{\mathrm{Z}}$ |  | 1.576 |  | 1.561 | 1.551 |  | 1.545 | 1.536 |
| $n_{\mathrm{Z}}-n_{\mathrm{X}}$ |  | 0.234 |  | 0.240 | 0.243 |  | 0.254 | 0.315 |
| $\mathrm{Z} \wedge c$ | $17^{\circ}$ |  | $5.5^{\circ}$ |  |  |  | $2.5^{\circ}$ |  |
| 2 V | $35^{\circ} \mathrm{ca}$. |  |  |  |  | $0^{\circ}$ | $12^{\circ}$ |  |

PD 4.50, 3.58, 3.20; 1-0334. Made from solution at $25^{\circ}-29^{\circ} \mathrm{C}$.

## 2. Formula Type $\mathbf{A}_{2} \mathbf{B}\left(\mathrm{XO}_{4}\right)_{2} \cdot \mathbf{q} \mathbf{H}_{2} \mathrm{O}$

$\mathbf{N a}_{4} \mathbf{M g}_{2}\left(\mathrm{SO}_{4}\right)_{4} \cdot \mathbf{5 H _ { 2 }} \mathbf{O}$ (Loeweite) is tetragonal ${ }^{46}(?)$. Poor basal cleavage. H. 2.5-3. G. 2.37. F. 1.5. Soluble in water. Uniaxial negative with ${ }^{47} n_{\mathrm{O}}=$ $1.490, n_{\mathrm{E}}=1.471, n_{\mathrm{O}}-n_{\mathrm{E}}=0.019$. Colorless. Made from water solution. Also said to be trigonal ${ }^{47}$ with $c / a 0.702$.

[^87]$\mathrm{K}_{2} \mathrm{Ca}\left(\mathrm{SO}_{4}\right)_{2} \cdot \mathbf{H}_{2} \mathrm{O}$ (Syngenite) is monoclinic with $a=9.70, b=7.15$, $c=6.20 k X . \beta=104^{\circ} 5^{\prime}$. U.C. 2. Crystals $\{100\}$ tablets or prismatic. Common twinning on $\{100\}$. Perfect $\{110\}$ and $\{100\}$ and distinct $\{010\}$ cleavages. H. 2.5. G. 2.6. $\mathrm{X} \wedge c^{48}=-2^{\circ} 17^{\prime} ; \mathrm{Z}=b$. $(-) 2 \mathrm{~V}=28^{\circ} 18^{\prime} \mathrm{Na}$, $\mathrm{r}<\mathrm{v}$ very strong. $n_{\mathrm{X}}=1.5010 \mathrm{Na}, n_{\mathrm{Y}}=1.5166, n_{\mathrm{Z}}=1.5176, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.0166 . When heated the optic angle becomes zero in yellow light at $158^{\circ}$ and then opens out in the $\{010\}$ plane. 2 V is $0^{\circ}$ at $127^{\circ}$ in red light, at $172^{\circ}$ in green light and at $177.5^{\circ}$ in blue light. Colorless or white. Made from solutions rich in $\mathrm{H}_{2} \mathrm{SO}_{4}$ between $0^{\circ}$ and $100^{\circ} \mathrm{C}$.
$\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Ca}\left(\mathrm{SO}_{4}\right)_{2} \cdot \mathbf{H}_{2} \mathbf{O}$ (Koktaite) is monoclinic. ${ }^{49}$ Crystals acicular. No cleavage. Soluble in water. G. 2.09. $\mathrm{Y}=b ; \mathrm{Z} \wedge c$ on (110) is $2^{\circ}$. (-) $2 \mathrm{~V}=$ $72^{\circ}, \mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.524, n_{\mathrm{Y}}=1.532, n_{\mathrm{Z}}=1.536, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.012$. Again: ${ }^{50}$ $(-) 2 \mathrm{~V}=50^{\circ}, n_{\mathrm{X}}=1.521, n_{\mathrm{Y}}=1.527, n_{\mathrm{Z}}=1.529, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.007$. Colorless. PD 3.04, 3.19, 5.70; 2-0615.
$\mathrm{K}_{4} \mathrm{Cd}_{2}\left(\mathbf{S O}_{4}\right)_{4} \cdot \mathbf{3} \mathrm{H}_{2} \mathbf{O}$ is monoclinic with $a: b: c=0.987: 1: 2.025, \beta=$ $104^{\circ} 42^{\prime}$. Crystals prismatic with $\{010\}$ cleavage. $\mathrm{X} \wedge c=-69^{\circ} 15^{\prime} ; \mathrm{Z}=$ b. $(-) 2 \mathrm{~V}=63^{\circ} 33^{\prime} \mathrm{Li}, 64^{\circ} 16^{\prime} \mathrm{Tl} . n_{\mathrm{Y}}=1.509 \mathrm{Li}, 1.511 \mathrm{Tl}, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ ? Made from solution at room temperature.
$\mathbf{K}_{4} \mathbf{M n}_{2}\left(\mathbf{S O}_{4}\right)_{4} \cdot 3 \mathbf{H}_{2} \mathbf{O}$ is monoclinic with $a: b: c=0.974: 1: 1.058, \beta=$ $104^{\circ}$. Crystals prismatic with distinct basal cleavage. $\mathrm{X} \wedge c=+100^{\circ}$; $\mathrm{Z}=b$. $(+) 2 \mathrm{~V}=61^{\circ} 48^{\prime}, \mathrm{r}<\mathrm{v} . n_{\mathrm{Y}}=1.512 \mathrm{D}, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ ? Made from water solution above $55^{\circ} \mathrm{C}$.
$\mathrm{Na}_{2} \mathrm{Cu}\left(\mathrm{SO}_{4}\right)_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ (Kröhnkite) is monoclinic with $a=5.78, b=$ $12.58, c=5.48 k X, \beta=108^{\circ} 30^{\prime}$. U.C. 2. Crystals short prismatic, octahedral, etc. Twinning on $\{101\}$ common. Perfect $\{010\}$ and poor $\{\overline{1} 01\}$ cleavages. H. 2.5-3. G. 2.90. $\mathrm{X} \wedge c=+48^{\circ}, \mathrm{Y}=b .^{51}(-) 2 \mathrm{~V}=78^{\circ} 36^{\prime}$, $\mathrm{r}<\mathrm{v}$ weak; also inclined dispersion. $n_{\mathrm{X}}=1.544, n_{\mathrm{Y}}=1.578, n_{\mathrm{Z}}=1.601$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.057 \mathrm{Na}$. Color sky-blue. Made from water solution above $17^{\circ} \mathrm{C}$.
$\mathbf{N a} \mathbf{2}_{2} \mathbf{M g}\left(\mathrm{SO}_{4}\right)_{2} \cdot \mathbf{4 H _ { 2 }} \mathbf{O}$ (Bloedite) is monoclinic with $a=11.04, b=8.15$, $c=5.49 k X, \beta=100^{\circ} 41^{\prime}$. U.C. 4. Crystals equant, short prismatic, often highly modified. H. 3. G. 2.25. $\mathrm{X} \wedge c=37^{\circ} ; \mathrm{Y}=b . .^{52}(-) 2 \mathrm{~V}=70^{\circ} 5^{\prime}$ red, $72^{\circ} 34^{\prime}$ blue, $n_{\mathrm{X}}=1.4826, n_{\mathrm{Y}}=1.4855, n_{\mathrm{Z}}=1.4869, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0041$ Na. Colorless or stained bluish green or reddish. PD 3.25, 4.53, 2.71; $4-0549$. Made from a solution at $21^{\circ}-71^{\circ} \mathrm{C}$.
$\mathbf{N a} \mathbf{2} \mathbf{F e}\left(\mathbf{S O}_{4}\right)_{2} \cdot \mathbf{4 H _ { 2 }} \mathbf{O}$ is monoclinic with ${ }^{53} a: b: c=1.356: 1: 0.671, \beta=$
${ }^{48}$ Schreiber: N. Jahrb. Min. Bl. Bd. XXXVII, p. 247 (1914).
${ }^{49}$ Sekanina: Acta Ac. Sci. Nat. Moravo Siles. XX, No. 1 (1948).
${ }^{50}$ Merz, Hardesty, and Hendricks: J. Am. Chem. Soc. LV, p. 3571 (1933).
${ }^{51}$ Merwin in Palache and Warren: Am. J. Sci. XXVI, p. 342 (1908).
${ }^{52}$ Laszkiewicz: Arch. Min. Soc. Warsaw V, p. 79 (1929); Schaller: Am. Min. XVII, p. 530 (1932).
${ }^{53}$ Boky: N. Jahrb. Min. I, p. 94 (1936).
$100^{\circ} 34^{\prime}$. Crystals show $\{001\},\{110\}$ and $\{210\} .(-) 2 \mathrm{~V}=60^{\circ}, n_{\mathrm{X}}=1.493$, $n_{\mathrm{Y}}=1.500$ calc., $n_{\mathrm{Z}}=1.503, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.010$. Color green. Made from water solution.
$\mathrm{K}_{2} \mathbf{M g}\left(\mathbf{S O}_{4}\right)_{2} \cdot \mathbf{4 H _ { 2 }} \mathbf{O}$ (Leonite) is monoclinic with $a: b: c=1.232: 1: 1.038$, $\beta=95^{\circ} 9^{\prime}$. Crystals $\{100\}$ tablets long parallel to $c$. May show lamellar twinning. H. 2.5-3. G. 2.20. $\mathrm{Y}=b ; \mathrm{Z} \wedge a$ small. (+)2V large. ${ }^{54} n_{\mathrm{X}}=$ 1.479, $n_{\mathrm{Y}}=1.482, n_{\mathrm{Z}}=1.487, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.008$. Colorless or yellowish. Made from solution at $41^{\circ}-89^{\circ} \mathrm{C}$.

## $\mathrm{A}_{2} \mathrm{~B}\left(\mathrm{XO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$-Tutton's Salts

Nearly 80 monoclinic salts with this formula (in which $\mathrm{A}=\mathrm{K}, \mathrm{NH}_{4}$, $\mathrm{Rb}, \mathrm{Cs}$, or $\mathrm{Ti}, \mathrm{B}=\mathrm{Mg}, \mathrm{Zn}, \mathrm{Cd}, \mathrm{Mn}, \mathrm{Fe}, \mathrm{Co}, \mathrm{Ni}$, or Cu , and $\mathrm{X}=\mathrm{S}, \mathrm{Se}$, or Cr ) have been studied by Tutton. Another isostructural crystal is $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Ni}\left(\mathrm{BeF}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$, and no doubt still others will be found.

Crystals of these salts are generally prismatic parallel to $c$ or to $a$, or tabular parallel to $\{001\}$, or intermediate combinations. All show good cleavage parallel to $\{20 \overline{1}\}$. A few have cleavage parallel to $\{010\}$, this being the better cleavage in $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Cu}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$. The sulfates tend to be less strongly colored than the selenates; they are blue or greenish blue in the Cu salts, green or bluish green in the Ni and Fe salts, rose or pink in the Mn salts, ruby-red in the Co salts, and colorless or white in the Mg , Zn , and Cd salts. The chromates are yellow. All these colors are pale enough to be invisible in small microscopic grains. Solid solutions intermediate between these salts have not been studied, but presumably could be made.

The following tables show selected data for the known compositions; they are useful for comparisons and preliminary identification. Complete data are given in the descriptions of the individual compounds. The tables indicate the degree to which refringence and birefringence tend to increase as the element A ranges through the series $\mathrm{K}, \mathrm{Rb}, \mathrm{NH}_{4}, \mathrm{Cs}, \mathrm{Tl}$, and as the element B ranges through the series $\mathrm{Mg}, \mathrm{Mn}, \mathrm{Cd}, \mathrm{Fe}, \mathrm{Zn}, \mathrm{Cu}, \mathrm{Co}$, and Ni . Most of the exceptions to these rules are compounds containing Cu . The crystallographic ratios $a: b: c$, and $\beta$ are remarkably constant, as would be expected in an isostructural group of substances. The optic orientation $\mathrm{X} \wedge c$ varies from $0^{\circ}$ to $93^{\circ}$ as shown in Fig. 7-6; extinction angles $\mathrm{X} \wedge\{20 \overline{1}\}$ cleavage correspondingly range from about $-40^{\circ}$ through zero to $+52^{\circ}$. However, the sign is rarely determinable without special techniques. Measurements of $2 \mathrm{~V}_{\mathrm{z}}$ are useful in distinguishing various members of this family because that angle varies from about zero to somewhat over $90^{\circ}$. The optic sign is mostly ( + ) but in about 20 instances it is ( - ). The

[^88]

Fig. 7-6. Optic orientation of Tutton's salts $\mathrm{A}_{2} \mathrm{~B}\left(\mathrm{XO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$.
three chromates of Mg and $\mathrm{NH}_{4}, \mathrm{Rb}$, or Cs fit the patterns indicated in the table, but have distinctly higher refringences.

Refractive index $n_{\mathrm{X}}$ in Tutton's salts, $\mathrm{A}_{2} \mathrm{~B}\left(\mathrm{XO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$
a. Sulfates, $X=S$

| Element | $\mathrm{B}=\mathrm{Mg}$ | Zn | Cd | Mn | Fe | Co | Ni | Cu |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{A}=\mathrm{K}$ | 1.4607 | 1.4775 |  |  | 1.4759 | 1.4807 | 1.4836 | 1.4836 |
| NH | 1.4716 | 1.4888 | 1.4847 | 1.4801 | 1.4870 | 1.4902 | 1.4949 | 1.4910 |
| Rb | 1.4672 | 1.4833 | 1.4798 | 1.4767 | 1.4815 | 1.4859 | 1.4895 | 1.4886 |
| Cs | 1.4857 | 1.5022 | 1.4975 | 1.4946 | 1.5003 | 1.5057 | 1.5087 | 1.5048 |
| Tl | 1.5705 | 1.5931 |  | 1.5861 | 1.5929 | 1.6009 | 1.6024 | 1.5996 |
| b. Selenates, $\mathrm{X}=\mathrm{Se}$ |  |  |  |  |  |  |  |  |
| $\mathrm{A}=\mathrm{K}$ | 1.4969 | 1.5121 |  |  |  |  |  |  |
| $\mathrm{NH}_{4}$ | 1.5070 | 1.5240 | 1.5206 | 1.5160 | 1.5216 | 1.5361 | 1.5285 | 1.5201 |
| Rb | 1.5011 | 1.5162 |  | 1.5094 | 1.5133 | 1.5199 | 1.5198 | 1.5153 |
| Cs | 1.5178 | 1.5326 |  | 1.5250 | 1.5306 | 1.5354 | 1.5395 | 1.5282 |
| Tl | 1.6250 | 1.6414 |  | 1.6276 | 1.6352 | 1.6442 | 1.6378 |  |

Birefringence $n_{\mathrm{Z}}-n_{\mathrm{X}}$ in Tutton's salts
a. Sulfates, $X=S$

| $\mathrm{A}=\mathrm{K}$ | . 0148 | . 0194 |  |  | . 0210 | . 0197 | . 0215 | . 0184 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{NH}_{4}$ | . 0070 | . 0106 | . 0112 | . 0112 | . 0119 | . 0130 | . 0132 | . 0144 |
| Rb | . 0107 | . 0124 | . 0150 | . 0140 | . 0162 | . 0155 | . 0157 | . 0150 |
| Cs | . 0059 | . 0071 | . 0087 | . 0079 | . 0091 | . 0075 | . 0075 | . 0105 |
| Tl | . 0244 | . 0237 |  | . 0223 | . 0233 | . 0229 | . 0200 | . 0194 |
| b. Selenates, $\mathrm{X}=\mathrm{Se}$ |  |  |  |  |  |  |  |  |
| $\mathrm{A}=\mathrm{K}$ | . 0170 | . 0214 |  |  | . 0250 | . 0222 | . 0246 | . 0248 |
| $\mathrm{NH}_{4}$ | . 0099 | . 0145 | . 0146 | . 0128 | . 0165 | . 0156 | . 0185 | . 0186 |
| Rb | . 0124 | . 0169 |  | . 0164 | . 0195 | . 0170 | . 0192 | . 0165 |
| Cs | . 0058 | . 0086 |  | . 0088 | . 0108 | . 0099 | . 0094 | . 0112 |
| Tl | . 0154 | . 0201 |  | . 0255 | . 0237 | . 0148 | . 0182 | . 0324 |

Optic axial angle, $2 \mathrm{~V}_{\mathrm{z}}$ ( $>90^{\circ}$ if optically negative)

| a. Sulfates, $\mathrm{X}=\mathrm{S}$ |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{A}=\mathrm{K}$ | $47^{\circ} 54^{\prime}$ | $68^{\circ} 14^{\prime}$ |  |  | $67^{\circ} 07^{\prime}$ | $68^{\circ} 41^{\prime}$ | $75^{\circ} 16^{\prime}$ | $46^{\circ} 32^{\prime}$ |
| $\mathrm{NH}_{4}$ | 5111 | 7900 | $72^{\circ} 51^{\prime}$ | $69^{\circ} 46^{\prime}$ | 7625 | 8209 | 8633 | 11157 |
| Rb | 4846 | 7333 | 7226 | 6705 | 7321 | 7511 | 8200 | 4442 |
| Cs | 1625 | 7411 | 6753 | 5957 | 7451 | 8134 | 9239 | 4324 |
| Tl | 10503 | 11036 |  | 10834 | 11100 | 11321 | 11823 | 9444 |
| b. Selenates, $\mathrm{X}=\mathrm{Se}$ |  |  |  |  |  |  |  |  |
| $\mathrm{A}=\mathrm{K}$ | $39^{\circ} 38^{\prime}$ | $66^{\circ} 15^{\prime}$ |  |  | $64^{\circ} 18^{\prime}$ | $62^{\circ} 19^{\prime}$ | $72^{\circ} 48^{\prime}$ | $91^{\circ} 33^{\prime}$ |
| $\mathrm{NH}_{4}$ | 5447 | 8207 | $76^{\circ} 31^{\prime}$ | $70^{\circ} 23^{\prime}$ | 7744 | 8214 | 8621 | 12453 |
| Rb | 4703 | 7508 |  | 6602 | 7332 | 7337 | 8213 | 12649 |
| Cs | 1835 | 8306 |  | 6849 | 8247 | 8648 | 9652 | 13134 |
| Tl | 10227 | 11126 |  | 10733 | 11024 | 11318 | 12101 |  |

## $\mathrm{A}_{2} \mathrm{~B}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ Salts (Sulfates) of Tutton

$\mathrm{K}_{2} \mathrm{Mg}\left(\mathrm{SO}_{4}\right)_{2} \cdot \mathbf{6 H} \mathbf{H} \mathbf{O}$ (Picromerite) is monoclinic with $a=9.04, b=$ $12.24, c=6.095 k X, \beta=104^{\circ} 48^{\prime}$. Crystals nearly equant and short prismatic. Perfect $\{20 \overline{1}\}$ cleavage. H. 2.5. G. 2.03. $\mathrm{X} \wedge c^{55}=+13^{\circ} 38^{\prime}$; $\mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=27^{\circ} 50^{\prime} \mathrm{D} ; \mathrm{Y}=b .(+) 2 \mathrm{~V}=47^{\circ} 54^{\prime} \mathrm{D}, \mathrm{r}>\mathrm{v}$ very


Fig. 7-7. A crystal habit of $\mathrm{K}_{2} \mathrm{Mg}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$.
weak. ${ }^{56} n_{\mathrm{X}}=1.4585 \mathrm{C}, 1.4607 \mathrm{D}, 1.4658 \mathrm{~F}, n_{\mathrm{Y}}=1.4607 \mathrm{C}, 1.4629 \mathrm{D}$, $1.4678 \mathrm{~F}, n_{\mathrm{Z}}=1.4731 \mathrm{C}, 1.4755 \mathrm{D}, 1.4810 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0148 \mathrm{D}$. Colorless, white or stained. Made from water solution between $-5^{\circ}$ and $47.5^{\circ} \mathrm{C}$.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{M g}\left(\mathrm{SO}_{4}\right)_{2} \cdot \mathbf{6 H} \mathbf{2} \mathbf{O}$ (Boussingaultite) is monoclinic with $a=9.28$, $b=12.57, c=6.20 k X, \beta=107^{\circ} 6^{\prime}$. Crystals short prismatic. Perfect $\{20 \overline{1}\}$ and distinct $\{010\}$ cleavages. H. 2. G. 1.72. $\mathrm{X} \wedge c=4^{\circ} 58^{\prime} ; \mathrm{X} \wedge$ $\{20 \overline{1}\}=37^{\circ} 53^{\prime} ; \mathrm{Y}=b .^{56}(+) 2 \mathrm{~V}=51^{\circ} 11^{\prime}, \mathrm{r}>$ v very weak. $n_{\mathrm{X}}=1.4689 \mathrm{C}$, $1.4716 \mathrm{D}, 1.4771 \mathrm{~F}, n_{\mathrm{Y}}=1.4705 \mathrm{C}, 1.4730 \mathrm{D}, 1.4786 \mathrm{~F}, n_{\mathrm{Z}}=1.4760 \mathrm{C}$, $1.4786 \mathrm{D}, 1.4842 \mathrm{~F}, n_{\mathrm{z}}-n_{\mathrm{X}}=0.007 \mathrm{D}$. Colorless. Made from water solution between $0^{\circ}$ and $100^{\circ} \mathrm{C}$. (or more?).
$\mathbf{R} b_{2} \mathbf{M g}\left(\mathbf{S O}_{4}\right)_{2} \cdot 6 \mathbf{H}_{2} \mathbf{O}$ is monoclinic with ${ }^{57} a: b: c=0.740: 1: 0.498, \beta=$ $105^{\circ} 59^{\prime}$. Crystals thick basal tablets to short prismatic. Distinct $\{20 \overline{1}\}$ cleavage. G. 2.38. $\mathrm{X} \wedge c=+21^{\circ} 14^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\} \quad$ cleavage $=20^{\circ} 31^{\prime}$; $\mathrm{Y}=b$. (+) $2 \mathrm{~V}=49^{\circ} 2^{\prime} \mathrm{C}, 48^{\circ} 46^{\prime} \mathrm{D}, 48^{\circ} 10^{\prime} \mathrm{F}, \mathrm{r}>\mathrm{v}$ distinct. $n_{\mathrm{X}}=1.4650$ $\mathrm{C}, 1.4672 \mathrm{Na}, 1.4724 \mathrm{~F}, n_{\mathrm{Y}}=1.4668 \mathrm{C}, 1.4689 \mathrm{D}, 1.4743 \mathrm{~F}, n_{\mathrm{Z}}=1.4759 \mathrm{C}$, 1.4779 D, 1.4835 F, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0107 \mathrm{Na}$. Colorless. Made from water solution.

[^89]$\mathrm{Cs}_{2} \mathbf{M g}\left(\mathbf{S O}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathbf{O}$ is monoclinic with ${ }^{57} a: b: c=0.728: 1: 0.495, \beta=$ $107^{\circ} 6^{\prime}$. Crystals short prismatic parallel to $a$. Perfect $\{20 \overline{1}\}$ cleavage. G. 2.67. $\mathrm{X} \wedge c=+46^{\circ} 43^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}=4^{\circ} 47^{\prime} ;$ the optic plane is (010) for wave-lengths greater than $450 \mathrm{~m} \mu$ (including daylight) and normal to (010) for shorter wave-lengths (blue and violet). ( + ) $2 \mathrm{~V}=18^{\circ} 0^{\prime} \mathrm{C}, 16^{\circ} 25^{\prime}$ $\mathrm{D}, 11^{\circ} 15^{\prime} \mathrm{F}, 8^{\circ}(450 \mathrm{~m} \mu), 7^{\circ} 0^{\prime}$ G. $n_{\mathrm{X}}=1.4832 \mathrm{C}, 1.4857 \mathrm{D}, 1.4912 \mathrm{~F}$, $n_{\mathrm{Y}}=1.4834 \mathrm{C}, 1.4858 \mathrm{D}, 1.4912 \mathrm{~F}, n_{\mathrm{Z}}=1.4892 \mathrm{C}, 1.4916 \mathrm{D}, 1.4970 \mathrm{~F}$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0059 \mathrm{D}$. Colorless. Made from water solution.


Fig. 7-8. A common crystal habit of $\mathrm{Cs}_{2} \mathrm{Mg}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$.
$\mathbf{T l}_{2} \mathbf{M g}\left(\mathbf{S O}_{4}\right)_{2} \cdot \mathbf{6} \mathbf{H}_{2} \mathbf{O}$ is monoclinic with $^{58} \quad a: b: c=0.744: 1: 0.500 ; \beta=$ $106^{\circ} 30^{\prime}$. Crystals nearly equant with $\{110\},\{011\},\{010\},\{20 \overline{\}}\}$, etc. Distinct $\{20 \overline{1}\}$ cleavage. G. 3.57. $\mathrm{X} \wedge c=+80^{\circ} 56^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=38^{\circ} 49^{\prime} ; \mathrm{Y}=b .(-) 2 \mathrm{~V}=74^{\circ} 42^{\prime} \mathrm{C}, 74^{\circ} 57^{\prime} \mathrm{D}, 75^{\circ} 34^{\prime} \mathrm{F} . n_{\mathrm{x}}=1.5665 \mathrm{C}$, $1.5705 \mathrm{D}, 1.5808 \mathrm{~F}, n_{\mathrm{Y}}=1.5841 \mathrm{C}, 1.5884 \mathrm{D}, 1.5993 \mathrm{~F}, n_{\mathrm{Z}}=1.5905 \mathrm{C}$, $1.5949 \mathrm{D}, 1.6063 \mathrm{~F}, n_{\mathrm{z}}-n_{\mathrm{x}}=0.0244 \mathrm{D}$. Colorless. Made from water solution.
$\mathrm{K}_{2} \mathbf{Z n}\left(\mathbf{S O}_{4}\right)_{2} \cdot 6 \mathbf{H}_{2} \mathbf{O}$ is monoclinic with $^{57} a: b: c=0.741: 1: 0.504, \beta=$ $104^{\circ} 48^{\prime}$. Crystals nearly equant, with $\{001\}$, $\{110\}$, etc. Perfect $\{20 \overline{1}\}$ cleavage. G. 2.24. $\mathrm{X} \wedge c=+10^{\circ} 18^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=30^{\circ} 52^{\prime}$; $\mathrm{Y}=b .{ }^{56}(+) 2 \mathrm{~V}=68^{\circ} 16^{\prime} \mathrm{C}, 68^{\circ} 14^{\prime} \mathrm{Na}, 68^{\circ} 9^{\prime} \mathrm{F}, \mathrm{r}>\mathrm{v}$ very weak. $n_{\mathrm{X}}=$ $1.4752 \mathrm{C}, 1.4775 \mathrm{D}, 1.4826 \mathrm{~F}, n_{\mathrm{Y}}=1.4809 \mathrm{C}, 1.4833 \mathrm{D}, 1.4889 \mathrm{~F}, n_{\mathrm{Z}}=$ 1.4942 C , 1.4969 D, 1.5027 F, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0194$ D. Colorless. PD 4.14, 3.68, 2.37; 1-0421.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{Z n}\left(\mathbf{S O}_{4}\right)_{2} \cdot 6 \mathbf{H}_{2} \mathbf{O}$ is monoclinic ${ }^{56}$ with $a: b: c=0.737: 1: 0.4997$, $\beta=106^{\circ} 52^{\prime}$. Crystals short prismatic to thick basal tablets. Good $\{20 \overline{1}\}$ cleavage. H. 2. G. 1.93. $\mathrm{X} \wedge c=+7^{\circ} ; \mathrm{X} \wedge\{20 \overline{\mathrm{Y}}\}$ cleavage $=34^{\circ} 56^{\prime}$; $\mathrm{Y}=b$. (+) $2 \mathrm{~V}=78^{\circ} 58^{\prime} \mathrm{C}, 79^{\circ} \mathrm{D}, 79^{\circ} 3^{\prime} \mathrm{F}, \mathrm{r}>\mathrm{v}$ very weak. $n_{\mathrm{x}}=1.4862$ $\mathrm{C}, 1.4888 \mathrm{D}, 1.4947 \mathrm{~F}, n_{\mathrm{Y}}=1.4904 \mathrm{C}, 1.4930 \mathrm{D}, 1.4990 \mathrm{~F}, n_{\mathrm{Z}}=1.4967 \mathrm{C}$,

[^90]$1.4836 \mathrm{D}, 1.4889 \mathrm{~F}, n_{\mathrm{Y}}=1.4893 \mathrm{C}, 1.4916 \mathrm{D}, 1.4972 \mathrm{~F}, n_{\mathrm{Z}}=1.5026 \mathrm{C}$, $1.5051 \mathrm{D}, 1.5109 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0215$. Color bright green.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{N i}\left(\mathbf{S O}_{4}\right)_{2} \cdot \mathbf{6 H}_{2} \mathbf{O}$ is monoclinic with ${ }^{61} a: b: c=0.737: 1: 0.500, \beta=$ $106^{\circ} 57^{\prime}$. Crystals short prisms or basal tablets. Distinct $\{20 \overline{1}\}$ and $\{010\}$ cleavages. G. 1.92. $\mathrm{X} \wedge c=+5^{\circ} 12^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=36^{\circ} 40^{\prime}$; $\mathrm{Y}=b .(+) 2 \mathrm{~V}=86^{\circ} 33^{\prime}, \mathrm{r}<\mathrm{v}$ very weak. $n_{\mathrm{X}}=1.4921 \mathrm{C}, 1.4949 \mathrm{D}$, $1.5007 \mathrm{~F}, n_{\mathrm{Y}}=1.4980 \mathrm{C}, 1.5007 \mathrm{D}, 1.5069 \mathrm{~F}, n_{\mathrm{Z}}=1.5051 \mathrm{C}, 1.5081 \mathrm{D}$, $1.5142 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0132 \mathrm{D}$. Color deep bluish green. PD 4.16, 3.76, 5.4; 1-0419.
$\mathbf{R b}_{2} \mathrm{Ni}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is monoclinic with ${ }^{57} a: b: c=0.735: 1: 0.502, \beta=$ $106^{\circ} 3^{\prime}$. Crystals short prismatic to basal tablets. Good $\{20 \overline{1}\}$ cleavage. G. 2.58. $\mathrm{X} \wedge c=+12^{\circ} 38^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=28^{\circ} 49^{\prime} ; \mathrm{Y}=b .(+) 2 \mathrm{~V}$ $=82^{\circ} 4^{\prime} \mathrm{C}, 82^{\circ} 0^{\prime} \mathrm{D}, 81^{\circ} 48^{\prime} \mathrm{F}, \mathrm{r}>\mathrm{v}$ very weak. $n_{\mathrm{x}}=1.4872 \mathrm{C}, 1.4895 \mathrm{D}$, $1.4949 \mathrm{~F}, n_{\mathrm{Y}}=1.4937 \mathrm{C}, 1.4961 \mathrm{D}, 1.5017 \mathrm{~F}, n_{\mathrm{Z}}=1.5027 \mathrm{C}, 1.5052 \mathrm{D}$, $1.5110 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0157 \mathrm{D}$. Color deep green.
$\mathrm{Cs}_{2} \mathbf{N i}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is monoclinic with ${ }^{57} a: b: c=0.727: 1: 0.498, \beta=$ $107^{\circ} 2^{\prime}$. Crystals clinodomatic. Distinct $\{20 \overline{1}\}$ cleavage. G. 2.87. $X \wedge$ $c=+24^{\circ} 7^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=17^{\circ} 27^{\prime} ; \mathrm{Y}=b .{ }^{56}(-) 2 \mathrm{~V}=87^{\circ} 17^{\prime} \mathrm{C}$, $87^{\circ} 21^{\prime} \mathrm{D}, 87^{\circ} 40^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v}$ very weak. $n_{\mathrm{X}}=1.5065 \mathrm{C}, 1.5087 \mathrm{D}, 1.5146 \mathrm{~F}$, $n_{\mathrm{Y}}=1.5104 \mathrm{C}, 1.5129 \mathrm{D}, 1.5187 \mathrm{~F}, n_{\mathrm{Z}}=1.5137 \mathrm{C}, 1.5162 \mathrm{D}, 1.5221 \mathrm{~F}$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0075 \mathrm{D}$. Color bright green.
$\mathbf{T l}_{2} \mathrm{Ni}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is monoclinic with ${ }^{64} a: b: c=0.740: 1: 0.4997, \beta=$ $106^{\circ} 23^{\prime}$. Crystals short clinodomatic. Distinct $\{20 \overline{1}\}$ cleavage. G. 3.77. $\mathrm{X} \wedge c=+75^{\circ} 20^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=33^{\circ} 23^{\prime} ; \mathrm{Y}=b$. (-) $2 \mathrm{~V}=60^{\circ} 58^{\prime}$ $\mathrm{C}, 61^{\circ} 37^{\prime} \mathrm{D}, 63^{\circ} 11^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v}$ strong. $n_{\mathrm{X}}=1.5990 \mathrm{C}, 1.6024 \mathrm{D}, 1.6115 \mathrm{~F}$, $n_{\mathrm{Y}}=1.6150 \mathrm{C}, 1.6183 \mathrm{D}, 1.6280 \mathrm{~F}, n_{\mathrm{Z}}=1.6190 \mathrm{C}, 1.6224 \mathrm{D}, 1.6324 \mathrm{~F}$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0200 \mathrm{D}$. Again: ${ }^{65} n_{\mathrm{X}}=1.6025 \mathrm{D}, n_{\mathrm{Y}}=1.6184, n_{\mathrm{Z}}=1.6252$, $n_{\mathrm{z}}-n_{\mathrm{x}}=0.0227 \mathrm{D}$. Color green. Difficultly made from water solution.
$\mathrm{K}_{2} \mathrm{Cu}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ (Cyanochroite) is monoclinic with ${ }^{61} a: b: c=$ $0.749: 1: 0.5088, \beta=104^{\circ} 28^{\prime}$. Crystals thick basal tablets. Perfect $\{20 \overline{1}\}$ cleavage. G. 2.23. $\mathrm{X} \wedge c=+18^{\circ} 33^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\} \quad$ cleavage $=22^{\circ} 36^{\prime}$; $\mathrm{Y}=b$. (+) $2 \mathrm{~V}=46^{\circ} 6^{\prime} \mathrm{C}, 46^{\circ} 32^{\prime} \mathrm{D}, 47^{\circ} 33^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v}$ distinct. $n_{\mathrm{X}}=$ $1.4811 \mathrm{C}, 1.4836 \mathrm{D}, 1.4893 \mathrm{~F}, n_{\mathrm{Y}}=1.4838 \mathrm{C}, 1.4864 \mathrm{D}, 1.4922 \mathrm{~F}, n_{\mathrm{Z}}=$ $1.4994 \mathrm{C}, 1.5020 \mathrm{D}, 1.5081 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0184 \mathrm{D}$. Color greenish blue. PD 3.68, 4.21, 2.37; 1-0507.
$\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Cu}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is monoclinic with ${ }^{61} a: b: c=0.746: 1: 0.507, \beta=$ $106^{\circ} 9^{\prime}$. Crystals short prisms or thick basal tablets. Perfect $\{010\}$ and distinct $\{20 \overline{1}\}$ cleavages. G. 1.93. $\mathrm{X} \wedge c=+18^{\circ} 47^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=22^{\circ} 49^{\prime} ; ~ Y=b .(-) 2 V=68^{\circ} 57^{\prime} \mathrm{C}, 68^{\circ} 31^{\prime} \mathrm{D}, 66^{\circ} 55^{\prime} \mathrm{F}, \mathrm{r}>\mathrm{v}$ distinct. $n_{\mathrm{X}}=1.4883 \mathrm{C}, 1.4910 \mathrm{D}, 1.4971 \mathrm{~F}, n_{\mathrm{Y}}=1.4977 \mathrm{C}, 1.5007 \mathrm{D}$,

[^91]$1.5067 \mathrm{~F}, n_{\mathrm{Z}}=1.5025 \mathrm{C}, 1.5054 \mathrm{D}, 1.5116 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0144 \mathrm{D}$. Color pale blue. PD 4.19, 3.74, 5.4; 1-0410.
$\mathbf{R b}_{2} \mathbf{C u}\left(\mathbf{S O}_{4}\right)_{2} \cdot 6 \mathbf{H}_{2} \mathbf{O}$ is monoclinic with ${ }^{62} a: b: c=0.749: 1: 0.503, \beta=$ $105^{\circ} 18^{\prime}$. Crystals basal tablets or short prisms. Good $\{20 \overline{1}\}$ cleavage. G. 2.57. $\mathrm{X} \wedge c=+26^{\circ} 28^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=15^{\circ} 20^{\prime} ; \mathrm{Y}=b$. $(+) 2 \mathrm{~V}$ $=44^{\circ} 29^{\prime} \mathrm{C}, 44^{\circ} 42^{\prime} \mathrm{D}, 45^{\circ} 15^{\prime} \mathrm{F}, \mathrm{r}>$ v very weak. $n_{\mathrm{X}}=1.4862 \mathrm{C}, 1.4886 \mathrm{D}$, $1.4943 \mathrm{~F}, n_{\mathrm{Y}}=1.4882 \mathrm{C}, 1.4906 \mathrm{D}, 1.4966 \mathrm{~F}, n_{\mathrm{Z}}=1.5011 \mathrm{C}, 1.5036 \mathrm{D}$, $1.5098 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0150 \mathrm{D}$. Color pale greenish blue.
$\mathbf{C s}_{2} \mathbf{C u}\left(\mathbf{S O}_{4}\right)_{2} \cdot 6 \mathbf{H}_{2} \mathbf{O}$ is monoclinic with ${ }^{65} a: b: c=0.743: 1: 0.495, \beta=$ $106^{\circ} 10^{\prime}$. Crystals clinodomatic to short prismatic. Distinct $\{20 \overline{1}\}$ cleavage. G. 2.86. $\mathrm{X} \wedge c=+42^{\circ} 47^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=0^{\circ} 37^{\prime} .(+) 2 \mathrm{~V}=43^{\circ} 9^{\prime}$ $\mathrm{C}, 43^{\circ} 24^{\prime} \mathrm{D}, 44^{\circ} 3^{\prime} \mathrm{F}, \mathrm{r}<$ v weak. $n_{\mathrm{X}}=1.5021 \mathrm{C}, 1.5048 \mathrm{D}, 1.5108 \mathrm{~F}$, $n_{\mathrm{Y}}=1.5036 \mathrm{C}, 1.5061 \mathrm{D}, 1.5123 \mathrm{~F}, n_{\mathrm{Z}}=1.5126 \mathrm{C}, 1.5153 \mathrm{D}, 1.5216 \mathrm{~F}$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0105 \mathrm{D}$. Color pale greenish blue.
$\mathbf{T l}_{2} \mathbf{C u}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathbf{O}$ is monoclinic with ${ }^{58} a: b: c=0.750: 1: 0.503, \beta=$ $105^{\circ} 33^{\prime}$. Crystals equant to basal tablets with $\{110\},\{011\}$, and $\{20 \overline{1}\}$ prominent. Distinct $\{20 \overline{1}\}$ cleavage. G. 3.73. $\mathrm{X} \wedge c=-72^{\circ} 40^{\prime} ; \mathrm{X} \wedge$ $\{20 \overline{1}\}$ cleavage $=30^{\circ} 29^{\prime} ; \mathrm{Y}=b .(-) 2 \mathrm{~V}=85^{\circ} 21^{\prime} \mathrm{C}, 85^{\circ} 16^{\prime} \mathrm{D}, 85^{\circ} 2^{\prime} \mathrm{F}$, $\mathrm{r}>\mathrm{v}$ very weak. $n_{\mathrm{X}}=1.5950 \mathrm{C}, 1.5996 \mathrm{D}, 1.6120 \mathrm{~F}, n_{\mathrm{Y}}=1.6050 \mathrm{C}$, $1.6096 \mathrm{D}, 1.6222 \mathrm{~F}, n_{\mathrm{Z}}=1.6144 \mathrm{C}, 1.6190 \mathrm{D}, 1.6318 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0194$ D. Color bright blue.

## $\mathrm{A}_{2} \mathrm{~B}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ Salts (Selenates) of Tutton

$\mathrm{K}_{2} \mathbf{M g}\left(\mathrm{SeO}_{4}\right)_{2} \cdot \mathbf{6 H} \mathbf{H} \mathbf{O}$ is monoclinic with $^{66} a: b: c=0.749: 1: 0.503, \beta=$ $104^{\circ} 18^{\prime}$. Crystals short prismatic to basal tablets. Distinct $\{20 \overline{1}\}$ cleavage. G. 2.36. $\mathrm{X} \wedge c=+11^{\circ} 18^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=30^{\circ} 7^{\prime} ; \mathrm{Y}=b$. $(+) 2 \mathrm{~V}$ $=39^{\circ} 42^{\prime} \mathrm{C}, 39^{\circ} 38^{\prime} \mathrm{D}, 39^{\circ} 25^{\prime} \mathrm{F}, \mathrm{r}>\mathrm{v}$ very weak. $n_{\mathrm{X}}=1.4941 \mathrm{C}, 1.4969$ $\mathrm{D}, 1.5035 \mathrm{~F}, n_{\mathrm{Y}}=1.4963 \mathrm{C}, 1.4991 \mathrm{D}, 1.5058 \mathrm{~F}, n_{\mathrm{Z}}=1.5108 \mathrm{C}, 1.5139 \mathrm{D}$, $1.5210 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0170 \mathrm{D}$. Colorless.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{M g}\left(\mathrm{SeO}_{4}\right)_{2} \cdot \mathbf{6 H} \mathbf{2} \mathbf{O}$ is monoclinic ${ }^{61}$ with $a: b: c=0.742: 1: 0.497$. $\beta=106^{\circ} 27^{\prime}$. Crystals short prisms or thick basal tablets. Perfect $\{20 \overline{1}\}$ cleavage. G. 2.06. $\mathrm{X} \wedge c=+0^{\circ} 13^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=31^{\circ} 59^{\prime} ; \mathrm{Y}=b$. $(+) 2 \mathrm{~V}=54^{\circ} 55^{\prime} \mathrm{C}, 54^{\circ} 47^{\prime} \mathrm{D}, 54^{\circ} 4^{\prime} \mathrm{F}, \mathrm{r}>\mathrm{v}$ very weak. $n_{\mathrm{X}}=1.5038 \mathrm{C}$, $1.5070 \mathrm{D}, 1.5144 \mathrm{~F}, n_{\mathrm{Y}}=1.5060 \mathrm{C}, 1.5093 \mathrm{D}, 1.5166 \mathrm{~F}, n_{\mathrm{Z}}=1.5136 \mathrm{C}$, $1.5169 \mathrm{D}, 1.5242 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0099 \mathrm{D}$. Colorless.
$\mathbf{R b}_{2} \mathbf{M g}\left(\mathbf{S e O}_{4}\right)_{2} \cdot 6 \mathbf{H}_{2} \mathbf{O}$ is monoclinic with ${ }^{66} a: b: c=0.742: 1: 0.501, \beta=$ $105^{\circ} 14^{\prime}$. Crystals thick basal tablets to short prisms. Distinct $\{20 \overline{1}\}$ cleavage. G. 2.68. $\mathrm{X} \wedge c=+16^{\circ} 24^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=25^{\circ} 13^{\prime} ; \mathrm{Y}=b$. $(+) 2 \mathrm{~V}=47^{\circ} 24^{\prime} \mathrm{C}, 47^{\circ} 3^{\prime} \mathrm{D}, 46^{\circ} 6^{\prime} \mathrm{F}, \mathrm{r}>$ v weak. $n_{\mathrm{X}}=1.4983 \mathrm{C}, 1.5011 \mathrm{D}$, $1.5077 \mathrm{~F}, n_{\mathrm{Y}}=1.5002 \mathrm{C}, 1.5031 \mathrm{D}, 1.5098 \mathrm{~F}, n_{\mathrm{Z}}=1.5105 \mathrm{C}, 1.5135 \mathrm{D}$, $1.5205 \mathrm{~F}, n_{\mathrm{z}}-n_{\mathrm{X}}=0.0124 \mathrm{D}$. Colorless.
${ }^{66}$ Tutton: Trans. Roy. Soc. London A CXCVII, p. 255 (1901).
$\mathbf{C s}_{2} \mathbf{M g}\left(\mathbf{S e O}_{4}\right)_{2} \cdot 6 \mathbf{H}_{2} \mathbf{O}$ is monoclinic with ${ }^{66} a: b: c=0.731: 1: 0.496, \beta=$ $106^{\circ} 17^{\prime}$. Crystals prismatic parallel to $a$. Distinct $\{20 \overline{1}\}$ cleavage. G. 2.94. $\mathrm{X} \wedge c=+36^{\circ} 47^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=4^{\circ} 59^{\prime}$. The optic plane is (010) for wave-lengths greater than $466 \mathrm{~m} \mu$ and normal thereto for shorter wavelengths (blue). (+) $2 \mathrm{~V}=20^{\circ} 34^{\prime} \mathrm{C}, 18^{\circ} 35^{\prime} \mathrm{D}, 10^{\circ} 30^{\prime} \mathrm{F}, 0^{\circ}(466 \mathrm{~m} \mu$ ), $12^{\circ} 49^{\prime} \mathrm{G}$. At $78^{\circ} \mathrm{C}$. it is uniaxial for Na light. $n_{\mathrm{x}}=1.5148 \mathrm{C}, 1.5178 \mathrm{D}$, $1.5248 \mathrm{~F}, n_{\mathrm{Y}}=1.5150 \mathrm{C}, 1.5179 \mathrm{D}, 1.5248 \mathrm{~F}, n_{\mathrm{Z}}=1.5206 \mathrm{C}, 1.5236 \mathrm{D}$, $1.5308 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0058 \mathrm{D}$. Colorless.
$\mathbf{T l}_{2} \mathbf{M g}\left(\mathrm{SeO}_{4}\right)_{2} \cdot \mathbf{6} \mathrm{H}_{2} \mathrm{O}$ is monoclinic with ${ }^{58} a: b: c=0.749: 1: 0.499, \beta=$ $105^{\circ} 36^{\prime}$. Crystals basal tablets with $\{001\},\{110\},\{011\}$, etc. Distinct $\{20 \overline{1}\}$ cleavage. G. 3.72. $\mathrm{X} \wedge c=+85^{\circ} 33^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=43^{\circ} 27^{\prime}$; $\mathrm{Y}=b .(-) 2 \mathrm{~V}=77^{\circ} 20^{\prime} \mathrm{C}, 77^{\circ} 33^{\prime} \mathrm{D}, 78^{\circ} 10^{\prime} \mathrm{F}, \mathrm{r}<$ v weak. $n_{\mathrm{X}}=1.6210 \mathrm{C}$, $1.6250 \mathrm{D}, 1.6363 \mathrm{~F}, n_{\mathrm{Y}}=1.6297 \mathrm{C}, 1.6337 \mathrm{D}, 1.6452 \mathrm{~F}, n_{\mathrm{Z}}=1.6364 \mathrm{C}$, $1.6404 \mathrm{D}, 1.6521 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0154 \mathrm{D}$. Colorless. Made from water solution containing an excess of magnesium selenate.
$\mathrm{K}_{2} \mathbf{Z n}\left(\mathrm{SeO}_{4}\right)_{2} \cdot \mathbf{6 H _ { 2 }} \mathbf{O}$ is monoclinic with $^{67} a: b: c=0.746: 1: 0.507 . \beta=$ $104^{\circ} 12^{\prime}$. Crystals short prisms to thick basal tablets. Distinct $\{20 \overline{1}\}$ cleavage. G. 2.55. $\mathrm{X} \wedge c=+9^{\circ} 9^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=31^{\circ} 51^{\prime} ; \mathrm{Y}=b$. $(+) 2 \mathrm{~V}=66^{\circ} 13^{\prime} \mathrm{C}, 66^{\circ} 15^{\prime} \mathrm{D}, 66^{\circ} 20^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v}$ very weak. $n_{\mathrm{x}}=1.5092 \mathrm{C}$, $1.5121 \mathrm{D}, 1.5189 \mathrm{~F}, n_{\mathrm{Y}}=1.5151 \mathrm{C}, 1.5181 \mathrm{D}, 1.5252 \mathrm{~F}, n_{\mathrm{Z}}=1.5302 \mathrm{C}$, $1.5335 \mathrm{D}, 1.5410 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0214 \mathrm{D}$. Colorless.
$\left(\mathrm{NH}_{4}\right)_{2} \mathbf{Z n}\left(\mathbf{S e O}_{4}\right)_{2} \cdot \mathbf{6 H} \mathbf{H} \mathbf{O}$ is monoclinic with ${ }^{61} a: b: c=0.741: 1: 0.504$, $\beta=106^{\circ} 14^{\prime}$. Crystals short prisms or thick $\{001\}$ tablets. Perfect $\{20 \overline{1}\}$ cleavage. G. 2.26. $\mathrm{X} \wedge c=+3^{\circ} 24^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=38^{\circ} 14^{\prime}$; $\mathrm{Y}=b$. (+) $2 \mathrm{~V}=82^{\circ} 5^{\prime} \mathrm{C}, 82^{\circ} 7^{\prime} \mathrm{D}, 82^{\circ} 10^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v}$ very weak. $n_{\mathrm{X}}=$ $1.5206 \mathrm{C}, 1.5240 \mathrm{D}, 1.5316 \mathrm{~F}, n_{\mathrm{Y}}=1.5265 \mathrm{C}, 1.5300 \mathrm{D}, 1.5378 \mathrm{~F}, n_{\mathrm{Z}}=$ $1.5349 \mathrm{C}, 1.5385 \mathrm{D}, 1.5463 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0145 \mathrm{D}$. Colorless.
$\mathbf{R b}_{2} \mathbf{Z n}\left(\mathbf{S e O}_{4}\right)_{2} \cdot \mathbf{6 H}_{2} \mathbf{O}$ is monoclinic with ${ }^{67} a: b: c=0.743: 1: 0.502, \beta=$ $105^{\circ} 16^{\prime}$. Crystals thick basal tablets or short prisms. Perfect $\{20 \overline{1}\}$ cleavage. G. 2.86. $\mathrm{X} \wedge c=+13^{\circ} 13^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=28^{\circ} 21^{\prime} ; \mathrm{Y}=b$. $(+) 2 \mathrm{~V}=75^{\circ} 14^{\prime} \mathrm{C}, 75^{\circ} 8^{\prime} \mathrm{D}, 74^{\circ} 55^{\prime} \mathrm{F}, \mathrm{r}>\mathrm{v}$ very weak. $n_{\mathrm{x}}=1.5134 \mathrm{C}$, $1.5162 \mathrm{D}, 1.5233 \mathrm{~F}, n_{\mathrm{Y}}=1.5193 \mathrm{C}, 1.5222 \mathrm{D}, 1.5293 \mathrm{~F}, n_{\mathrm{Z}}=1.5299 \mathrm{C}$, $1.5331 \mathrm{D}, 1.5405 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0169 \mathrm{D}$. Colorless.
$\mathbf{C s}_{2} \mathbf{Z n}\left(\mathbf{S e O}_{4}\right)_{2} \cdot 6 \mathbf{H}_{2} \mathbf{O}$ is monoclinic with ${ }^{67} a: b: c=0.731: 1: 0.497, \beta=$ $106^{\circ} 11^{\prime}$. Crystals prismatic parallel to $a$. Perfect $\{20 \overline{1}\}$ cleavage. G. 3.12. $\mathrm{X} \wedge c=+21^{\circ} 57^{\prime} ; \mathrm{X} \wedge\{20 \overline{\overline{1}}\}$ cleavage $=19^{\circ} 48^{\prime} ; \mathrm{Y}=b .(+) 2 \mathrm{~V}=83^{\circ} 30^{\prime}$ $\mathrm{C}, 83^{\circ} 6^{\prime} \mathrm{D}, 82^{\circ} 14^{\prime} \mathrm{F}, \mathrm{r}>$ v weak. $n_{\mathrm{x}}=1.5295 \mathrm{C}, 1.5326 \mathrm{D}, 1.5399 \mathrm{~F}$, $n_{\mathrm{Y}}=1.5331 \mathrm{C}, 1.5362 \mathrm{D}, 1.5435 \mathrm{~F}, n_{\mathrm{Z}}=1.5380 \mathrm{C}, 1.5412 \mathrm{D}, 1.5488 \mathrm{~F}$, $n_{\mathrm{z}}-n_{\mathrm{X}}=0.0086$. Colorless.
$\mathbf{T l}_{2} \mathbf{Z n}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is monoclinic with ${ }^{58} a: b: c=0.748: 1: 0.502, \beta=$
${ }^{67}$ Tutton: Proc. Roy. Soc. London A LXVII, p. 58 (1900); Zeit. Krist. XXXIII, p. 1 (1900).
$105^{\circ} 54^{\prime}$. Crystals basal tablets with $\{110\},\{100\}$ and $\{010\}$ or $\{20 \overline{1}\}$, $\{110\}$ and $\{011\}$. Distinct $\{20 \overline{1}\}$ cleavage. G. 3.96. $\mathrm{X} \wedge c=+83^{\circ}{ }^{1} 4^{\prime}$; $\mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=41^{\circ} 14^{\prime} ; \mathrm{Y}=b .(-) 2 \mathrm{~V}=68^{\circ} 15^{\prime} \mathrm{C}, 68^{\circ} 34^{\prime} \mathrm{D}$, $69^{\circ} 30^{\prime} \mathrm{F}, \mathrm{r}<$ v weak. $n_{\mathrm{X}}=1.6358 \mathrm{C}, 1.6414 \mathrm{D}, 1.6576 \mathrm{~F}, n_{\mathrm{Y}}=1.6481 \mathrm{C}$, $1.6539 \mathrm{D}, 1.6706 \mathrm{~F}, n_{\mathrm{Z}}=1.6555 \mathrm{C}, 1.6615 \mathrm{D}, 1.6793 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{x}}=0.0201$ D. Colorless.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{C d}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathbf{O}$ is monoclinic with ${ }^{68} a: b: c=0.742: 1: 0.503$, $\beta=106^{\circ} 1^{\prime}$. Crystals $\{001\}$ or $\{20 \overline{1}\}$ tablets or varied. Distinct $\{20 \overline{1}\}$ cleavage. G. 2.45. $\mathrm{X} \wedge c=6^{\circ} 0^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=35^{\circ} 44^{\prime} ; \mathrm{Y}=b$. $(+) 2 \mathrm{~V}=76^{\circ} 11^{\prime} \mathrm{C}, 76^{\circ} 31^{\prime} \mathrm{D}, 77^{\circ} 13^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{x}}=1.5172 \mathrm{C}$, $1.5206 \mathrm{D}, 1.5283 \mathrm{~F}, n_{\mathrm{Y}}=1.5227 \mathrm{C}, 1.5260 \mathrm{D}, 1.5338 \mathrm{~F}, n_{\mathrm{Z}}=1.5317 \mathrm{C}$, $1.5352 \mathrm{D}, 1.5427 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0146 \mathrm{D}$. Colorless. Made from water solution at about $0^{\circ} \mathrm{C}$.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{M n}\left(\mathbf{S e O}_{4}\right)_{2} \cdot \mathbf{6} \mathbf{H}_{2} \mathbf{O}$ is monoclinic with ${ }^{69} a: b: c=0.743: 1: 0.499$, $\beta=106^{\circ} 16^{\prime}$. Crystals basal tablets, prisms or varied. Perfect $\{010\}$ and distinct $\{20 \overline{1}\}$ cleavages. G. 2.16. $\mathrm{X} \wedge c=+3^{\circ} 22^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=38^{\circ} 42^{\prime} ; \mathrm{Y}=b .(+) 2 \mathrm{~V}=70^{\circ} 18^{\prime} \mathrm{C}, 70^{\circ} 23^{\prime} \mathrm{D}, 70^{\circ} 34^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v}$ very weak. $n_{\mathrm{X}}=1.5129 \mathrm{C}, 1.5160 \mathrm{D}, 1.5235 \mathrm{~F}, n_{\mathrm{Y}}=1.5169 \mathrm{C}, 1.5202 \mathrm{D}$, $1.5276 \mathrm{~F}, n_{\mathrm{Z}}=1.5255 \mathrm{C}, 1.5288 \mathrm{D}, 1.5364 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0128 \mathrm{D}$. Color pink.
$\mathrm{Rb}_{2} \mathbf{M n}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathbf{O}$ is monoclinic with ${ }^{69} a: b: c=0.742: 1: 0.501, \beta=$ $105^{\circ} 9^{\prime}$. Crystals basal tablets or short prisms. Good $\{20 \overline{1}\}$ cleavage. G. 2.76. $\mathrm{X} \wedge c=+13^{\circ} 7^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=28^{\circ}{ }^{\circ} 7^{\prime} ; \mathrm{Y}=b .(+) 2 \mathrm{~V}$ $=66^{\circ} 5^{\prime} \mathrm{C}, 66^{\circ} 2^{\prime} \mathrm{D}, 65^{\circ} 52^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v}$ very weak. $n_{\mathrm{x}}=1.5064 \mathrm{C}, 1.5094 \mathrm{D}$, $1.5163 \mathrm{~F}, n_{\mathrm{Y}}=1.5110 \mathrm{C}, 1.5140 \mathrm{D}, 1.5210 \mathrm{~F}, n_{\mathrm{Z}}=1.5226 \mathrm{C}, 1.5258 \mathrm{D}$, $1.5332 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0164 \mathrm{D}$. Color pale pink.
$\mathrm{Cs}_{2} \mathbf{M n}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is monoclinic with ${ }^{69} a: b: c=0.732: 1: 0.496, \beta=$ $106^{\circ} 22^{\prime}$. Crystals short prismatic parallel to $a$ or to $c$. Perfect $\{20 \overline{1}\}$ cleavage. G. 3.01. $\mathrm{X} \wedge c=+22^{\circ} 11^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=19^{\circ} 36^{\prime} ; \mathrm{Y}=b$. $(+) 2 \mathrm{~V}=69^{\circ} 1^{\prime} \mathrm{C}, 68^{\circ} 49^{\prime} \mathrm{D}, 68^{\circ} 5^{\prime} \mathrm{F}, \mathrm{r}>\mathrm{v}$ weak. $n_{\mathrm{X}}=1.5220 \mathrm{C}, 1.5250 \mathrm{D}$, $1.5323 \mathrm{~F}, n_{\mathrm{Y}}=1.5248 \mathrm{C}, 1.5279 \mathrm{D}, 1.5350 \mathrm{~F}, n_{\mathrm{Z}}=1.5306 \mathrm{C}, 1.5338 \mathrm{D}$, $1.5415 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{x}}=0.0088$ D. Color pink.
$\mathbf{T l}_{2} \mathbf{M n}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is monoclinic with ${ }^{58} a: b: c=0.746: 1: 0.499, \beta=$ $105^{\circ} 29^{\prime}$. Crystals $\{001\}$ tablets with $\{110\}$. Distinct $\{20 \overline{1}\}$ cleavage. G. 3.83. $\mathrm{X} \wedge c=+81^{\circ} 39^{\prime} ; \mathrm{X} \wedge\{20 \overline{\mathrm{l}}\}$ cleavage $=39^{\circ} 43^{\prime} ; \mathrm{Y}=b$. $(-) 2 \mathrm{~V}$ $=72^{\circ} 4^{\prime} \mathrm{C}, 72^{\circ} 27^{\prime} \mathrm{D}, 73^{\circ} 32^{\prime} \mathrm{F}, n_{\mathrm{x}}=1.6219 \mathrm{C}, 1.6276 \mathrm{D}, 1.6422 \mathrm{~F}, n_{\mathrm{Y}}=$ $1.6370 \mathrm{C}, 1.6429 \mathrm{D}, 1.6579 \mathrm{~F}, n_{\mathrm{Z}}=1.6470 \mathrm{C}, 1.6531 \mathrm{D}, 1.6685 \mathrm{~F}, n_{\mathrm{o}}-$ $n_{\mathrm{X}}=0.0255 \mathrm{D}$. Color pink. Made from water solution with an excess of manganese selenate.

[^92]$\mathrm{K}_{2} \mathrm{Fe}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is monoclinic with $^{70} a: b: c=0.749: 1: 0.504, \beta=$ $103^{\circ} 50^{\prime}$. Crystals thick basal tablets or short prisms. Good $\{20 \overline{1}\}$ cleavage. G. 2.49. $\mathrm{X} \wedge c=+10^{\circ} 27^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=30^{\circ} 45^{\prime} ; \mathrm{Y}=b$. $(+) 2 \mathrm{~V}$ $=64^{\circ} 12^{\prime} \mathrm{C}, 64^{\circ} 18^{\prime} \mathrm{D}, 64^{\circ} 36^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v}$ very weak. $n_{\mathrm{X}}=1.5064 \mathrm{C}, 1.5095 \mathrm{D}$, $1.5164 \mathrm{~F}, n_{\mathrm{Y}}=1.5149 \mathrm{C}, 1.5182 \mathrm{D}, 1.5253 \mathrm{~F}, n_{\mathrm{Z}}=1.5311 \mathrm{C}, 1.5345 \mathrm{D}$, $1.5421 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0250 \mathrm{D}$. Color pale green. Made from water solution at $0^{\circ} \mathrm{C}$. Dehydrates quickly at ordinary temperature.
$\left(\mathrm{NH}_{4}\right)_{2} \mathbf{F e}\left(\mathrm{SeO}_{4}\right)_{2} \cdot \mathbf{6 H}_{2} \mathrm{O}$ is monoclinic with ${ }^{70} a: b: c=0.743: 1: 0.502, \beta=$ $106^{\circ} 9^{\prime}$. Crystals thick basal tablets or short prisms. Good $\{20 \overline{1}\}$ cleavage. G. 2.19. $\mathrm{X} \wedge c=+5^{\circ} 24^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=36^{\circ} 28^{\prime} ; \mathrm{Y}=b$. (+)2V $=77^{\circ} 37^{\prime} \mathrm{C}, 77^{\circ} 44^{\prime} \mathrm{D}, 77^{\circ} 54^{\prime} \mathrm{F}, \mathrm{r}<$ v very weak. $n_{\mathrm{X}}=1.5182 \mathrm{C}, 1.5216 \mathrm{D}$, $1.5291 \mathrm{~F}, n_{\mathrm{Y}}=1.5246 \mathrm{C}, 1.5280 \mathrm{D}, 1.5354 \mathrm{~F}, n_{\mathrm{Z}}=1.5348 \mathrm{C}, 1.5381 \mathrm{D}$, $1.5457 \mathrm{~F}, n_{\mathrm{z}}-n_{\mathrm{X}}=0.0165 \mathrm{D}$. Color very pale yellowish green. Made from water solution at $0^{\circ} \mathrm{C}$.
$\mathbf{R b _ { 2 }} \mathbf{F e}\left(\mathbf{S e O}_{4}\right)_{2} \cdot 6 \mathbf{H}_{2} \mathbf{O}$ is monoclinic with $^{70} a: b: c=0.742: 1: 0.500, \beta=$ $104^{\circ} 57^{\prime}$. Crystals clinodomatic to basal tablets. Distinct $\{20 \overline{1}\}$ cleavage. G.2.80. $\mathrm{X} \wedge c=+13^{\circ} 37^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=27^{\circ} 56^{\prime} ; \mathrm{Y}=b$. ( + ) $2 \mathrm{~V}=$ $73^{\circ} 34^{\prime} \mathrm{C}, 73^{\circ} 32^{\prime} \mathrm{D}, 73^{\circ} 26 \mathrm{~F}, \mathrm{r}>\mathrm{v}$ very weak. $n_{\mathrm{x}}=1.5104 \mathrm{C}, 1.5133 \mathrm{D}$, $1.5202 \mathrm{~F}, n_{\mathrm{Y}}=1.5170 \mathrm{C}, 1.5200 \mathrm{D}, 1.5272 \mathrm{~F}, n_{\mathrm{Z}}=1.5295 \mathrm{C}, 1.5328 \mathrm{D}$, 1.5404 F. $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0195 \mathrm{D}$. Color pale bluish green. Made from water solution at about $0^{\circ} \mathrm{C}$.
$\mathbf{C s}_{2} \mathbf{F e}\left(\mathbf{S e O}_{4}\right)_{2} \cdot \mathbf{6 H}_{2} \mathbf{O}$ is monoclinic with $^{70} a: b: c=0.731: 1: 0.498, \beta=$ $106^{\circ} 2^{\prime}$. Crystals clinodomatic. Perfect $\{20 \overline{1}\}$ cleavage. G. 3.05. $\mathrm{X} \wedge c=$ $+21^{\circ} 4^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=20^{\circ} 27^{\prime} ; \mathrm{Y}=b .(+) 2 \mathrm{~V}=82^{\circ} 56^{\prime} \mathrm{C}, 82^{\circ} 47^{\prime}$ $\mathrm{D}, 82^{\circ} 20^{\prime} \mathrm{F}, \mathrm{r}>$ v very weak. $n_{\mathrm{X}}=1.5274 \mathrm{C}, 1.5306 \mathrm{D}, 1.5379 \mathrm{~F}, n_{\mathrm{Y}}=$ $1.5322 \mathrm{C}, 1.5352 \mathrm{D}, 1.5425 \mathrm{~F}, n_{\mathrm{Z}}=1.5384 \mathrm{C}, 1.5414 \mathrm{D}, 1.5491 \mathrm{~F}, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.0108 \mathrm{D}$. Color very pale bluish green. Made from water solution at $0^{\circ} \mathrm{C}$.
$\mathbf{T l}_{2} \mathbf{F e}\left(\mathrm{SeO}_{4}\right)_{2} \cdot \mathbf{6 H} \mathbf{2} \mathbf{O}$ is monoclinic with $^{58} a: b: c=0.745: 1: 0.501, \beta=$ $105^{\circ} 27^{\prime}$. Crystals thick $\{001\}$ tablets with $\{110\},\{011\},\{100\},\{20 \overline{1}\}$, etc. Distinct $\{20 \overline{1}\}$ cleavage. G. 3.94. $\mathrm{X} \wedge c=+80^{\circ} 51^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=39^{\circ} 2^{\prime} ; \mathrm{Y}=b$. (-)2V $=69^{\circ} 5^{\prime} \mathrm{C}, 69^{\circ} 36^{\prime} \mathrm{D}, 70^{\circ} 45^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{X}}=1.6297 \mathrm{C}, 1.6352 \mathrm{D}, 1.6496 \mathrm{~F}, n_{\mathrm{Y}}=1.6459 \mathrm{C}, 1.6514 \mathrm{D}, 1.6662 \mathrm{~F}$, $n_{\mathrm{Z}}=1.6533 \mathrm{C}, 1.6589 \mathrm{D}, 1.6743 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0237 \mathrm{D}$. Color of fresh crystals very pale green, slowly becoming yellowish green. Made from water solution with an excess of iron selenate.
$\mathrm{K}_{2} \mathbf{C o}\left(\mathrm{SeO}_{4}\right)_{2} \cdot \mathbf{6 H} \mathbf{2}$ is monoclinic ${ }^{71}$ with $a: b: c=0.752: 1: 0.506, \beta=$ $104^{\circ} 17^{\prime}$. Crystals short prismatic to basal tablets. Perfect $\{20 \overline{1}\}$ cleavage. G. 2.53. $\mathrm{X} \wedge c=+8^{\circ} 54^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=32^{\circ} 25^{\prime} ; \mathrm{Y}=b$. $(+) 2 \mathrm{~V}$

[^93]$=62^{\circ} 13^{\prime} \mathrm{C}, 62^{\circ} 19^{\prime} \mathrm{D}, 62^{\circ} 27^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v}$ very weak. $n_{\mathrm{X}}=1.5127 \mathrm{C}, 1.5158 \mathrm{D}$, $1.5231 \mathrm{~F}, n_{\mathrm{Y}}=1.5186 \mathrm{C}, 1.5218 \mathrm{D}, 1.5291 \mathrm{~F}, n_{\mathrm{Z}}=1.5347 \mathrm{C}, 1.5380 \mathrm{D}$, $1.5456 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0222 \mathrm{D}$. Color ruby-red.
$\left(\mathrm{NH}_{4}\right)_{2} \mathbf{C o}\left(\mathbf{S e O}_{4}\right)_{2} \cdot \mathbf{6 H} \mathbf{2} \mathbf{O}$ is monoclinic with ${ }^{71} a: b: c=0.745: 1: 0.503, \beta=$ $106^{\circ} 23^{\prime}$. Crystals $\{001\}$ tablets with $\{110\}$ and $\{011\}$. Perfect $\{20 \overline{1}\}$ and poor $\{010\}$ cleavages. G. 2.23. $\mathrm{X} \wedge c=+2^{\circ} 23^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=$ $39^{\circ} 30^{\prime} ; \mathrm{Y}=b .(+) 2 \mathrm{~V}=82^{\circ} 6^{\prime} \mathrm{C}, 82^{\circ} 14^{\prime} \mathrm{D}, 82^{\circ} 28^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v}$ very weak. $n_{\mathrm{X}}=1.5228 \mathrm{C}, 1.5261 \mathrm{D}, 1.5335 \mathrm{~F}, n_{\mathrm{Y}}=1.5292 \mathrm{C}, 1.5327 \mathrm{D}, 1.5401 \mathrm{~F}$, $n_{\mathrm{Z}}=1.5382 \mathrm{C}, 1.5417 \mathrm{D}, 1.5496 \mathrm{~F}, n_{\mathrm{z}}-n_{\mathrm{X}}=0.0156 \mathrm{D}$. Color ruby-red.
$\mathbf{R b _ { 2 }} \mathbf{C o}\left(\mathbf{S e O}_{4}\right)_{2} \cdot 6 \mathbf{H}_{2} \mathbf{O}$ is monoclinic with ${ }^{71} a: b: c=0.743: 1: 0.502, \beta=$ $105^{\circ} 14^{\prime}$. Crystals basal tablets to short prisms. Perfect $\{20 \overline{1}\}$ cleavage. G. 2.84. $\mathrm{X} \wedge c=+12^{\circ} 50^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=28^{\circ} 41^{\prime} ; \mathrm{Y}=b$. $(+) 2 \mathrm{~V}$ $=73^{\circ} 41^{\prime} \mathrm{C}, 73^{\circ} 37^{\prime} \mathrm{D}, 73^{\circ} 33^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v}$ very weak. $n_{\mathrm{x}}=1.5163 \mathrm{C}, 1.5199 \mathrm{D}$, $1.5273 \mathrm{~F}, n_{\mathrm{Y}}=1.5225 \mathrm{C}, 1.5256 \mathrm{D}, 1.5332 \mathrm{~F}, n_{\mathrm{Z}}=1.5334 \mathrm{C}, 1.5369 \mathrm{D}$, $1.5446 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{x}}=0.0170 \mathrm{D}$. Color ruby-red.
$\mathbf{C s}_{2} \mathbf{C o}\left(\mathbf{S e O}_{4}\right)_{2} \cdot \mathbf{6} \mathbf{H}_{2} \mathbf{O}$ is monoclinic with ${ }^{71} a: b: c=0.731: 1: 0.499, \beta=$ $106^{\circ} 18^{\prime}$. Crystals clinodomatic. Perfect $\{20 \overline{1}\}$ cleavage. G. 3.09. $\mathrm{X} \wedge$ $c=+19^{\circ} 23^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=22^{\circ} 9^{\prime} ; \mathrm{Y}=b . \quad(+) 2 \mathrm{~V}=87^{\circ} 8^{\prime} \mathrm{C}$, $86^{\circ} 48^{\prime} \mathrm{D}, 86^{\circ} 32^{\prime} \mathrm{F}, \mathrm{r}>$ v very weak. $n_{\mathrm{X}}=1.5321 \mathrm{C}, 1.5354 \mathrm{D}, 1.5430 \mathrm{~F}$, $n_{\mathrm{Y}}=1.5365 \mathrm{C}, 1.5399 \mathrm{D}, 1.5475 \mathrm{~F}, n_{\mathrm{Z}}=1.5418 \mathrm{C}, 1.5453 \mathrm{D}, 1.5531 \mathrm{~F}$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0099 \mathrm{D}$. Color ruby-red.
$\mathbf{T l}_{2} \mathbf{C o}\left(\mathrm{SeO}_{4}\right)_{2} \cdot \mathbf{6 H}_{2} \mathrm{O}$ is monoclinic with ${ }^{58} a: b: c=0.746: 1: 0.502, \beta=$ $105^{\circ} 40^{\prime}$. Crystals thick $\{001\}$ tablets with $\{110\}$ prominent. Distinct $\{20 \overline{1}\}$ cleavage. G. 4.00. $\mathrm{X} \wedge c=+81^{\circ} 38^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\} \quad$ cleavage $=39^{\circ} 45^{\prime}$; $\mathrm{Y}=b$. (-) $2 \mathrm{~V}=66^{\circ} 15^{\prime} \mathrm{C}, 66^{\circ} 42^{\prime} \mathrm{D}, 67^{\circ} 36^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v}$ very weak. $n_{\mathrm{X}}=$ $1.6402 \mathrm{C}, 1.6442 \mathrm{D}, 1.6552 \mathrm{~F}, n_{\mathrm{Y}}=1.6495 \mathrm{C}, 1.6535 \mathrm{D}, 1.6646 \mathrm{~F}, n_{\mathrm{Z}}=$ $1.6550 \mathrm{C}, 1.6590 \mathrm{D}, 1.6706 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0148 \mathrm{D}$. Color ruby-red. Made from water solution with excess of cobalt selenate.
$\mathrm{K}_{2} \mathrm{Ni}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is monoclinic with ${ }^{72} a: b: c=0.747: 1: 0.506, \beta=$ $104^{\circ} 27^{\prime}$. Crystals basal tablets to short prisms. Distinct $\{20 \overline{1}\}$ cleavage. G. 2.56. $\mathrm{X} \wedge c=+6^{\circ} 59^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=34^{\circ} 15^{\prime} ; \mathrm{Y}=b$. $(+) 2 \mathrm{~V}$ $=72^{\circ} 45^{\prime} \mathrm{C}, 72^{\circ} 48^{\prime} \mathrm{D}, 72^{\circ} 56^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v}$ very weak. $n_{\mathrm{X}}=1.5147 \mathrm{C}, 1.5181 \mathrm{D}$, $1.5251 \mathrm{~F}, n_{\mathrm{Y}}=1.5237 \mathrm{C}, 1.5272 \mathrm{D}, 1.5344 \mathrm{~F}, n_{\mathrm{Z}}=1.5392 \mathrm{C}, 1.5427 \mathrm{D}$, $1.5507 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0246 \mathrm{D}$. Color bright green.
$\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Ni}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is monoclinic with ${ }^{72} a: b: c=0.740: 1: 0.505, \beta=$ $106^{\circ} 17^{\prime}$. Crystals thick basal tablets. Perfect $\{20 \overline{1}\}$ and poor $\{010\}$ cleavages. G. 2.24. $\mathrm{X} \wedge c=+2^{\circ} 0^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=39^{\circ} 31^{\prime} ; \mathrm{Y}=b$. $(+) 2 \mathrm{~V}=86^{\circ} 19^{\prime} \mathrm{C}, 86^{\circ} 21^{\prime} \mathrm{D}, 86^{\circ} 29^{\prime} \mathrm{F} . \mathrm{r}<\mathrm{v}$ very weak. $n_{\mathrm{X}}=1.5251 \mathrm{C}$, $1.5285 \mathrm{D}, 1.5360 \mathrm{~F}, n_{\mathrm{Y}}=1.5337 \mathrm{C}, 1.5370 \mathrm{D}, 1.5447 \mathrm{~F}, n_{\mathrm{Z}}=1.5424 \mathrm{C}$, $1.5460 \mathrm{D}, 1.5539 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0185 \mathrm{D}$. Color bright green.
$\mathbf{R b}_{2} \mathrm{Ni}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathbf{O}$ is monoclinic with ${ }^{72} a: b: c=0.740: 1: 0.503, \beta=$ ${ }^{72}$ Tutton: Trans. Roy. Soc. London A CCXVII, p. 199 (1918).
$105^{\circ} 20^{\prime}$. Crystals basal tablets to short prisms. Distinct $\{20 \overline{1}\}$ cleavage. G. 2.86. $\mathrm{X} \wedge c=+9^{\circ} 59^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=31^{\circ} 23^{\prime} ; \mathrm{Y}=b$. $(+) 2 \mathrm{~V}$ $=82^{\circ} 22^{\prime} \mathrm{C}, 82^{\circ} 13^{\prime} \mathrm{D}, 81^{\circ} 58^{\prime} \mathrm{F}, \mathrm{r}>\mathrm{v}$ very weak. $n_{\mathrm{X}}=1.5166 \mathrm{C}, 1.5189 \mathrm{D}$, $1.5268 \mathrm{~F}, n_{\mathrm{Y}}=1.5258 \mathrm{C}, 1.5291 \mathrm{D}, 1.5362 \mathrm{~F}, n_{\mathrm{Z}}=1.5356 \mathrm{C}, 1.5390 \mathrm{D}$, $1.5466 \mathrm{~F}, n_{\mathrm{z}}-n_{\mathrm{X}}=0.0192 \mathrm{D}$. Color bright green.
$\mathrm{Cs}_{2} \mathbf{N i}\left(\mathbf{S e O}_{4}\right)_{2} \cdot \mathbf{6 H} \mathbf{2} \mathbf{O}$ is monoclinic with $^{72} a: b: c=0.729: 1: 0.499, \beta=$ $106^{\circ} 11^{\prime}$. Crystals prismatic parallel to $a$ or basal tablets. Distinct $\{20 \overline{1}\}$ cleavage. G. 3.11. $\mathrm{X} \wedge c=+16^{\circ} 51^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\} \quad$ cleavage $=24^{\circ} 26^{\prime}$; $\mathrm{Y}=b$. (-) $2 \mathrm{~V}=82^{\circ} 43^{\prime} \mathrm{C}, 83^{\circ} 8^{\prime} \mathrm{D}, 83^{\circ} 43^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{x}}=1.5363 \mathrm{C}$, $1.5395 \mathrm{D}, 1.5467 \mathrm{~F}, n_{\mathrm{Y}}=1.5417 \mathrm{C}, 1.5450 \mathrm{D}, 1.5525 \mathrm{~F}, n_{\mathrm{Z}}=1.5456 \mathrm{C}$, $1.5489 \mathrm{D}, 1.5568 \mathrm{~F}, n_{\mathrm{z}}-n_{\mathrm{X}}=0.0094 \mathrm{D}$. Color deep green.
$\mathrm{Tl}_{2} \mathrm{Ni}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is monoclinic with $^{58} a: b: c=0.746: 1: 0.502, \beta=$ $105^{\circ} 36^{\prime}$. Crystals nearly equant with $\{110\},\{001\}$ and $\{011\}$ prominent. Distinct $\{20 \overline{1}\}$ cleavage. G. 3.99. $\mathrm{X} \wedge c=+79^{\circ} 41^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=38^{\circ} 0^{\prime} ; ~ \mathrm{Y}=b$. (-) $2 \mathrm{~V}=58^{\circ} 10^{\prime} \mathrm{C}, 58^{\circ} 59^{\prime} \mathrm{D}, 60^{\circ} 53^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v}$. $n_{\mathrm{X}}=1.6339 \mathrm{C}, 1.6378 \mathrm{D}, 1.6523 \mathrm{~F}, n_{\mathrm{Y}}=1.6459 \mathrm{C}, 1.6498 \mathrm{D}, 1.6643 \mathrm{~F}$, $n_{\mathrm{Z}}=1.6517 \mathrm{C}, 1.6560 \mathrm{D}, 1.6709 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0182 \mathrm{D}$. Color bright green. Made from water solution with an excess of nickel selenate.
$\mathrm{K}_{2} \mathrm{Cu}\left(\mathrm{SeO}_{4}\right)_{2} \cdot \mathbf{6 H}_{2} \mathrm{O}$ is monoclinic with $^{73} a: b: c=0.751: 1: 0.514, \beta=$ $103^{\circ} 25^{\prime}$. Crystals short prismatic or basal tablets. Perfect $\{20 \overline{1}\}$ and distinct $\{010\}$ cleavages. G. 2.54. $\mathrm{X} \wedge c=+13^{\circ} 34^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=$ $26^{\circ} 56^{\prime} ; \mathrm{Y}=b$. (-) $2 \mathrm{~V}=88^{\circ} 46^{\prime} \mathrm{C}, 88^{\circ} 27^{\prime} \mathrm{D}, 87^{\circ} 36^{\prime} \mathrm{F}, \mathrm{r}>\mathrm{v}$ weak. $n_{\mathrm{X}}=1.5068 \mathrm{C}, 1.5101 \mathrm{D}, 1.5171 \mathrm{~F}, n_{\mathrm{Y}}=1.5195 \mathrm{C}, 1.5228 \mathrm{D}, 1.5308 \mathrm{~F}$, $n_{\mathrm{Z}}=1.5317 \mathrm{C}, 1.5349 \mathrm{D}, 1.5428 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0248 \mathrm{D}$. Color pale blue.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{C u}\left(\mathbf{S e O}_{4}\right)_{2} \cdot \mathbf{6} \mathbf{H}_{2} \mathbf{O}$ is monoclinic with ${ }^{73} a: b: c=0.748: 1: 0.515, \beta=$ $105^{\circ} 30^{\prime}$. Crystals short prismatic. Perfect $\{20 \overline{1}\}$ and $\{010\}$ cleavages. G. 2.22. $\mathrm{X} \wedge c=+12^{\circ} 42^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=28^{\circ} 42^{\prime} ; \mathrm{Y}=b$. $(-) 2 \mathrm{~V}$ $=55^{\circ} 42^{\prime} \mathrm{C}, 55^{\circ} 7^{\prime} \mathrm{D}, 53^{\circ} 48^{\prime} \mathrm{F}, \mathrm{r}>$ v weak. $n_{\mathrm{X}}=1.5166 \mathrm{C}, 1.5201 \mathrm{D}$, $1.5278 \mathrm{~F}, n_{\mathrm{Y}}=1.5309 \mathrm{C}, 1.5344 \mathrm{D}, 1.5424 \mathrm{~F}, n_{\mathrm{Z}}=1.5352 \mathrm{C}, 1.5387 \mathrm{D}$, $1.5469 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0186 \mathrm{D}$. Color pale blue.
$\mathbf{R b}_{2} \mathbf{C u}\left(\mathbf{S e O}_{4}\right)_{2} \cdot 6 \mathbf{H}_{2} \mathrm{O}$ is monoclinic with ${ }^{73} a: b: c=0.750: 1: 0.507, \beta=$ $104^{\circ} 44^{\prime}$. Crystals basal tablets. Perfect $\{20 \overline{1}\}$ and distinct $\{010\}$ cleavages. G. 2.84. $\mathrm{X} \wedge c=+23^{\circ} 5^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=18^{\circ} 14^{\prime} ; \mathrm{Y}=b$. $(+) 2 \mathrm{~V}$ $=52^{\circ} 58^{\prime} \mathrm{C}, 53^{\circ} 11^{\prime} \mathrm{D}, 53^{\circ} 43^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{x}}=1.5122 \mathrm{C}, 1.5153 \mathrm{D}$, $1.5225 \mathrm{~F}, n_{\mathrm{Y}}=1.5152 \mathrm{C}, 1.5183 \mathrm{D}, 1.5257 \mathrm{~F}, n_{\mathrm{Z}}=1.5286 \mathrm{C}, 1.5318 \mathrm{D}$, $1.5396 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0165 \mathrm{D}$. Color pale blue.
$\mathbf{C s}_{2} \mathbf{C u}\left(\mathbf{S e O}_{4}\right)_{2} \cdot 6 \mathbf{H}_{2} \mathbf{O}$ is monoclinic with ${ }^{73} a: b: c=0.740: 1: 0.498, \beta=$ $105^{\circ} 42^{\prime}$. Crystals clinodomatic. Perfect $\{20 \overline{1}\}$ and distinct $\{010\}$ cleavages. G. 3.07. $\mathrm{X} \wedge c=+38^{\circ} 12^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=40^{\circ} 53^{\prime} ; \mathrm{Y}=b$. $(+) 2 \mathrm{~V}=48^{\circ} 20^{\prime} \mathrm{C}, 48^{\circ} 26^{\prime} \mathrm{D}, 48^{\circ} 42^{\prime} \mathrm{F}, \mathrm{r}<\mathrm{v}$ very weak. $n_{\mathrm{X}}=1.5248 \mathrm{C}$,

[^94]$1.5282 \mathrm{D}, 1.5355 \mathrm{~F}, n_{\mathrm{Y}}=1.5264 \mathrm{C}, 1.5298 \mathrm{D}, 1.5372 \mathrm{~F}, n_{\mathrm{Z}}=1.5360 \mathrm{C}$, $1.5394 \mathrm{D}, 1.5467 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0112 \mathrm{D}$. Color pale blue.
$\mathbf{T l}_{2} \mathbf{C u}\left(\mathbf{S e O}_{4}\right)_{2} \cdot 6 \mathbf{H}_{2} \mathbf{O}$ is monoclinic with ${ }^{58} a: b: c=0.753: 1: 0.505, \beta=$ $104^{\circ} 59^{\prime}$. Crystals short prismatic to basal tablets. Perfect $\{20 \overline{1}\}$ cleavage. G. 3.94. $\mathrm{X} \wedge c=+75^{\circ} 35^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=33^{\circ} 53^{\prime} ; \mathrm{Y}=b$. ( -2 V $=85^{\circ} 13^{\prime} \mathrm{C}, 85^{\circ} 9^{\prime} \mathrm{D}, 84^{\circ} 56^{\prime} \mathrm{F}, \mathrm{r}>\mathrm{v}$ very weak. $n_{\mathrm{x}}=1.6345 \mathrm{C}, 1.6396 \mathrm{D}$, $1.6537 \mathrm{~F}, n_{\mathrm{Y}}=1.6511 \mathrm{C}, 1.6565 \mathrm{D}, 1.6709 \mathrm{~F}, n_{\mathrm{Z}}=1.6662 \mathrm{C}, 1.6720 \mathrm{D}$, $1.6867 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0324 \mathrm{D}$. Color bright blue. Made from water solution with an excess of copper selenate.

## $\mathrm{A}_{2} \mathrm{~B}\left(\mathrm{CrO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ Salts (Chromates) of Tutton

$\left(\mathrm{NH}_{4}\right)_{2} \mathbf{M g}\left(\mathrm{CrO}_{4}\right)_{2} \cdot \mathbf{6 H} \mathbf{2} \mathbf{O}$ is monoclinic with ${ }^{74} a: b: c=0.752: 1: 0.492$, $\beta=106^{\circ} 7^{\prime}$. Crystals short prismatic parallel to $c$ and also to $a$ as in Fig. $7-11$, or basal tablets. Perfect $\{20 \overline{1}\}$ cleavage. G. 1.83. The optic plane


Fig. 7-11. A crystal habit of $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Mg}\left(\mathrm{CrO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$.
is $\{010\}$ for wave-lengths less than $664 \mathrm{~m} \mu$ and normal to $\{010\}$ for wavelengths greater than $664 \mathrm{~m} \mu$ (red). $\mathrm{X} \wedge c=+93^{\circ} 27^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=52^{\circ} 31^{\prime} .(+) 2 \mathrm{~V}=10^{\circ} 47^{\prime}(684 \mathrm{~m} \mu), 0^{\circ}(664 \mathrm{~m} \mu), 26^{\circ} 53^{\prime}(589 \mathrm{~m} \mu=$ Na ), $38^{\circ} 57^{\prime} \mathrm{Tl}, 44^{\circ} 37^{\prime} \mathrm{Cd} . n_{\mathrm{x}}=1.6248 \mathrm{Li}, 1.6363 \mathrm{Na}, 1.6489 \mathrm{Tl}, 1.6571$ $\mathrm{Cd}, n_{\mathrm{Y}}=1.6250 \mathrm{Li}, 1.6371 \mathrm{Na}, 1.6509 \mathrm{Tl}, 1.6602 \mathrm{Cd}, n_{\mathrm{Z}}=1.6390 \mathrm{Li}$, 1.6531 Na, 1.6687 Tl, 1.6799 Cd, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0168 \mathrm{Na}$. Color yellow. $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Mg}\left(\mathrm{CrO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is said to be miscible in all proportions with ${ }^{75}$ $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Mg}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$, but crystals are not homogeneous (suggesting imperfect miscibility) and very accurate measures are impossible; with 11.6 molecular per cent of the sulfate $n_{\mathrm{X}}=1.627, n_{\mathrm{Y}}=1.627, n_{\mathrm{Z}}=1.641$;

[^95]with 37.2 per cent: $n_{\mathrm{X}}=1.589, n_{\mathrm{Y}}=1.590, n_{\mathrm{Z}}=1.598$; with 56.2 per cent: $n_{\mathrm{X}}=1.554, n_{\mathrm{Y}}=1.557, n_{\mathrm{Z}}=1.560$; with 73.8 per cent: $n_{\mathrm{X}}=1.520$, $n_{\mathrm{Y}}=1.525, n_{\mathrm{Z}}=1.528$; with 90.0 per cent: $n_{\mathrm{X}}=1.491, n_{\mathrm{Y}}=1.493$, $n_{\mathrm{Z}}=1.495 .\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Mg}\left(\mathrm{CrO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is miscible in all proportions with ${ }^{75}$ $\mathrm{Rb}_{2} \mathrm{Mg}\left(\mathrm{CrO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$. In such mix-crystals the refractive index for light vibrating along $b$ is directly proportional to the volume (sensibly $=$ the molecular) composition, while the other indices are curvilinear functions of the composition. These variations are shown in Fig. 7-12.


Volume Percent
Fig. 7-12. Variations in composition and in optic properties in the $\mathrm{Rb}_{2} \mathrm{Mg}\left(\mathrm{CrO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ - $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Mg}\left(\mathrm{CrO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ series.
$\mathbf{R b}_{2} \mathbf{M g}\left(\mathbf{C r O}_{4}\right)_{2} \cdot \mathbf{6} \mathbf{H}_{2} \mathbf{O}$ is monoclinic with ${ }^{74} a: b: c=0.753: 1: 0.495, \beta=$ $104^{\circ} 49^{\prime}$. Crystals short prismatic or basal tablets. Good $\{20 \overline{1}\}$ cleavage. G. 2.47. $\mathrm{X} \wedge c=+41^{\circ} 50^{\prime}\left(5^{\circ}\right.$ less for green than for red light). $\mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=0^{\circ} 35^{\prime}$ and Z is nearly normal to the cleavage. $(-) 2 \mathrm{~V}=88^{\circ} 4^{\prime}$ $\mathrm{C}, 86^{\circ} 32^{\prime} \mathrm{D}, 84^{\circ} 31^{\prime} \mathrm{Tl}, 83^{\circ} 15^{\prime} \mathrm{Cd}, \mathrm{r}>$ v strong. $n_{\mathrm{x}}=1.6105 \mathrm{Li}, 1.6217$ $\mathrm{Na}, 1.6342 \mathrm{Tl}, 1.6426 \mathrm{Cd}, n_{\mathrm{Y}}=1.6208 \mathrm{Li}, 1.6330 \mathrm{Na}, 1.6466 \mathrm{Tl}, 1.6561 \mathrm{Cd}$, $n_{\mathrm{Z}}=1.6310 \mathrm{Li}, 1.6435 \mathrm{Na}, 1.6577 \mathrm{Tl}, 1.6672 \mathrm{Cd}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0218 \mathrm{Na}$. Color yellow. Miscible in all proportions with $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Mg}\left(\mathrm{CrO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ as described above.
$\mathbf{C s}_{2} \mathbf{M g}\left(\mathrm{CrO}_{4}\right)_{2} \cdot \mathbf{6 H}_{2} \mathbf{O}$ is monoclinic with ${ }^{74} a: b: c=0.743: 1: 0.489, \beta=$ $106^{\circ} 4^{\prime}$. Crystals prismatic parallel to $a$ or to $c$. Good $\{20 \overline{1}\}$ cleavage. G. 2.75. $\mathrm{X} \wedge c=+80^{\circ} 38^{\prime} ; \mathrm{X} \wedge\{20 \overline{1}\}$ cleavage $=37^{\circ} 44^{\prime} ; \mathrm{Y}=b$. $(+) 2 \mathrm{~V}$ $=67^{\circ} 7^{\prime} \mathrm{C}, 67^{\circ} 3^{\prime} \mathrm{D}, 66^{\circ} 33^{\prime} \mathrm{Tl}, 65^{\circ} 57^{\prime} \mathrm{Cd}, \mathrm{r}>\mathrm{v}$ distinct. $n_{\mathrm{x}}=1.6257 \mathrm{Li}$, $1.6369 \mathrm{Na}, 1.6493 \mathrm{Tl}, 1.6578 \mathrm{Cd}, n_{\mathrm{Y}}=1.6310 \mathrm{Li}, 1.6425 \mathrm{Na}, 1.6552 \mathrm{Tl}$,
$1.6640 \mathrm{Cd}, n_{\mathrm{Z}}=1.6424 \mathrm{Li}, 1.6547 \mathrm{Na}, 1.6683 \mathrm{Tl}, 1.6778 \mathrm{Cd}, n_{\mathrm{z}}-n_{\mathrm{X}}=$ 0.0178 Na . Color bright yellow.
3. Formula Type $A_{m} \mathbf{B}_{n}\left(\mathrm{XO}_{4}\right)_{p} \cdot \mathbf{q} \mathrm{H}_{2} \mathrm{O}$ with $(m+n): p<3: 2$ and $>1: 1$
$\mathbf{N a}_{3} \mathbf{F e}\left(\mathbf{S O}_{4}\right)_{3} \cdot \mathbf{3 H} \mathbf{H} \mathbf{O}$ (Ferrinatrite) is hexagonal with ${ }^{76} \quad c / a=0.556$. Crystals short prismatic; also stellate groups of fibrous masses. Perfect $\{10 \overline{1} 0\}$ and good $\{11 \overline{2} 0\}$ cleavages. H. 2.5. G. 2.6 ca. Uniaxial positive with $n_{\mathrm{O}}=1.558, n_{\mathrm{E}}=1.614, n_{\mathrm{E}}-n_{\mathrm{O}}=0.055$. Colorless. Made by the action of $\mathrm{H}_{2} \mathrm{SO}_{4}$ on $\mathrm{Na}_{2} \mathrm{Fe}\left(\mathrm{SO}_{4}\right)_{2}(\mathrm{OH}) \cdot 3 \mathrm{H}_{2} \mathrm{O}$.
$\mathbf{N a} \mathbf{4} \mathbf{C a}\left(\mathbf{S O}_{4}\right)_{2} \cdot 2 \mathbf{H}_{2} \mathbf{O}$ forms long needles ${ }^{77}$ which are labile. In the long direction $n_{\mathrm{z}}=1.510 \pm 0.003$. Colorless.
$\mathrm{K}_{2} \mathrm{Ca}_{5}\left(\mathrm{SO}_{4}\right)_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ (Görgeyite) is monoclinic. Crystals prismatic. ${ }^{78}$ No cleavage. G. 2.897. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=11^{\circ}$. ( + ) $2 \mathrm{~V}=85^{\circ} \pm, n_{\mathrm{X}}=1.550$, $n_{\mathrm{Y}}=1.565, n_{\mathrm{Z}}=1.583, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.033$. Again $:^{78 \mathrm{a}} n_{\mathrm{X}}=1.560, n_{\mathrm{Y}}=$ $1.569, n_{\mathrm{Z}}=1.584, \mathrm{Z} \wedge c=+17^{\circ}$. Colorless. PD 3.14, 2.98, 2.83; 2-0551.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{C a}_{5}\left(\mathrm{SO}_{4}\right)_{6} \cdot \mathbf{H}_{2} \mathrm{O}$ is monoclinic. $\beta=122^{\circ}$. Crystals prismatic with base and pyramids. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=8^{\circ} .(+) 2 \mathrm{~V}=86^{\circ}, \mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.567$, $n_{\mathrm{Y}}=1.580, n_{\mathrm{Z}}=1.595$, all $\pm 0.003, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.028$. Colorless.
$\mathrm{Na}_{2} \mathrm{Ca}_{5}\left(\mathrm{SO}_{4}\right)_{6} \cdot \mathbf{3 H}_{2} \mathrm{O}$ is probably monoclinic. ${ }^{77}$ Crystals acicular ended by pyramid faces. $\mathrm{Z} \wedge c=11^{\circ} \pm 2^{\circ} . n_{\mathrm{X}}=1.5557 \pm 0.003, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{z}}=1.567, n_{\mathrm{z}}-n_{\mathrm{X}}=0.0113$. Colorless. Made from water solution at $60^{\circ}-70^{\circ} \mathrm{C}$.
$\mathrm{K}_{2} \mathrm{Ca}_{2} \mathbf{M g}\left(\mathrm{SO}_{4}\right)_{4} \cdot \mathbf{2} \mathrm{H}_{2} \mathrm{O}$ (Polyhalite) is triclinic with $a: b: c=$ $0.7176: 1: 0.4657, \alpha=91^{\circ} 39^{\prime}, \beta=89^{\circ} 50.5^{\prime}, \gamma=88^{\circ} 6.5^{\prime}$. Crystals rare; tabular on $\{010\}$ or vertically elongated. Twinning common and often complicated. Perfect $\{10 \overline{1}\}$ cleavage. H. 3.5. G. 2.78. $(-) 2 \mathrm{~V}=62^{\circ}$. $n_{\mathrm{X}}{ }^{24}=1.547, n_{\mathrm{Y}}=1.560, n_{\mathrm{Z}}=1.567, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.020$. Colorless or stained pink to red by iron oxide inclusions. The easy cleavage lamellæ show one optic axis just outside the field of view. PD 2.90, 3.17, 3.39; 10-355.

## 4. Formula Type $A_{m} \mathbf{B}_{n}\left(\mathrm{XO}_{4}\right)_{p} \cdot \mathbf{q} \mathrm{H}_{2} \mathrm{O}$ with $(\mathrm{m}+\mathrm{n}): \mathrm{p} \approx 1: 1$

$\mathrm{KFe}^{\prime \prime} \mathbf{F e}^{\prime \prime \prime}\left(\mathbf{S O}_{4}\right)_{3} \cdot \mathbf{4 H _ { 2 }} \mathbf{O}(?)$ (Voltaite) is isometric with $a=27.33 \mathrm{kX}$. Crystals cubic, octahedral, or, rarely, dodecahedral. No cleavage. H. 3. G. $2.7 \pm 0.1$. Isotropic with ${ }^{11} n=1.593^{79}-1.608,,^{80}$ the variation being probably due to variation in composition ( Mg may replace some $\mathrm{Fe}^{\prime \prime}$ and

[^96]Al may replace some $\mathrm{Fe}^{\prime \prime \prime}$ ). Often weakly birefringent in sectors, due probably to strain from variations in composition or pressure. Color greenish black or oil-green; translucent on edges or splinters and greenish. Made from water solution. Similar salts have been synthesized, including $\mathrm{KMgFe}^{\prime \prime \prime}, \mathrm{KMnFe}^{\prime \prime \prime}$, $\mathrm{KCoFe}^{\prime \prime \prime}$, $\mathrm{TlFe}^{\prime \prime} \mathrm{Fe}^{\prime \prime \prime}$, $\mathrm{TlMgFe}^{\prime \prime \prime}$, TlCdFe"', RbCdFe"'", $\mathrm{NH}_{4} \mathrm{MgFe}^{\prime \prime \prime}, \mathrm{KZnFe}^{\prime \prime \prime}$ and others, but indices are not known.
$\mathrm{NaAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot \mathbf{1 2 H}_{\mathbf{2}} \mathrm{O}$ (Soda alum) is isometric diploidal with $a=$ 12.19 kX . U.C. 4. Crystals octahedral. H. $3 \pm$. G. 1.67. Isotropic ${ }^{81}$ with $n=1.4365 \mathrm{C}, 1.4388 \mathrm{D}, 1.4441 \mathrm{~F}$. Colorless. Made (not easily) from water solution. Not isostructural with potash alum. $\mathrm{NaAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ (or only $11 \mathrm{H}_{2} \mathrm{O}$ ?) has also a monoclinic phase (known in nature as mendozite) with $a: b: c=2.506: 1: 0.9125 . \beta=109^{\circ} 1^{\prime}$. Crystals prismatic or pseudo-rhombohedral. Good $\{100\}$ and poor $\{001\}$ and $\{010\}$ cleavages. H. 3土. G. 1.76. $\mathrm{X}=b ; \mathrm{Y} \wedge c=30^{\circ}$. (-) $2 \mathrm{~V}=56^{\circ}$ with distinct crossed dispersion. $n_{\mathrm{X}}=1.449,{ }^{11} n_{\mathrm{Y}}=1.461, n_{\mathrm{Z}}=1.463, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.014$. Colorless. PD 4.23, 3.65, 3.98; $1-0397$. Made from water solution above $20^{\circ} \mathrm{C}$.
$\mathrm{KAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot \mathbf{1 2} \mathrm{H}_{2} \mathrm{O}$ (Potash alum) is isometric diploidal with $a=$ 12.133 kX . U.C. 4. Crystals octahedral or cubic. H. 2. G. 1.757. No cleavage. Isotropic with ${ }^{81} n=1.4540 \mathrm{C}, 1.4565 \mathrm{D}, 1.4600 \mathrm{~F}$. Colorless. PD 4.30, $3.25,4.05 ; 7-17 . \mathrm{KAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ is alum in the narrowest sense. It intercrystallizes freely with $\mathrm{NH}_{4} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ and rather freely also with $\mathrm{NH}_{4} \mathrm{Cr}, \mathrm{NH}_{4} \mathrm{Fe}, \mathrm{KFe}, \mathrm{KCr}$-alums. Such intergrowths are often birefringent, perhaps due to lamellar intercrystallization, and can be either positive or negative. $\mathrm{KAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ seems to have another phase, known as kalinite, which is probably hexagonal; it is uniaxial negative ${ }^{11}$ with $n_{\mathrm{O}}=1.456, n_{\mathrm{E}}=1.429, n_{\mathrm{O}}-n_{\mathrm{E}}=0.027$. Colorless. A third phase is probably monoclinic; it is platy and fibrous. Z is normal to the plates ${ }^{11}$ and $\mathrm{Y} \wedge c(=$ elongation $)=13^{\circ}$. ( $-2 \mathrm{~V}=52^{\circ}$ with slight dispersion, $n_{\mathrm{X}}=1.430, n_{\mathrm{Y}}=1.452, n_{\mathrm{Z}}=1.458, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.028$. Colorless.
$\mathbf{N H}_{4} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot \mathbf{1 2} \mathrm{H}_{2} \mathbf{O}$ (Ammonia alum) is isometric diploidal with $a=$ 12.215 kX . U.C. 4. Isostructural with potash alum but not with soda alum. Crystals octahedral. H. 1.5. G. 1.645. Isotropic with ${ }^{82} n=1.4569$ C, $1.4594 \mathrm{D}, 1.4648 \mathrm{~F}$. Optic anomalies (birefringence, etc.) easily produced in it by pressure; they are not rare in nature. PD 4.33, 4.08, 3.27; 7-22. There is a complete series of artificial mix-crystals with $\mathrm{KAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$. Similar (complete?) mix-crystals are known with $\mathrm{KCr}, \mathrm{NH}_{4} \mathrm{Cr}, \mathrm{NH}_{4} \mathrm{Fe}$ alums. These often show anomalous birefringence, either positive or negative.
The following salts also belong to the alum group. ${ }^{82}$

[^97]| Sulfates |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Salt | G | $n$ (C) | $n$ (D) | $n$ (F) | Notes |  |  | D |  |
| $\mathrm{RbAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.89 | 1.4542 | 1.4566 | 1.4619 | $\begin{array}{r} a=12.220 \\ \text { Colorless } \end{array}$ | 4.33 | 2.81 | 3.27; | 7-16 |
| $\mathrm{CsAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.97 | 1.4562 | 1.4586 | 1.4639 | $\begin{array}{r} a=12.333 \\ \text { Colorless } \end{array}$ | 4.37 | 2.84 | 2.76 | 7-4 |
| $\operatorname{TlAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 2.33 | 1.4944 | 1.4975 | 1.5046 | $a=12.206$ <br> Also biref. | 4.32 | 2.81 | 7.06; | 7-20 |
| $\mathrm{NH}_{4} \mathrm{~V}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.69 |  | 1.475 |  | violet |  |  |  |  |
| $\mathrm{RbV}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.915 |  | 1.469 |  | violet |  |  |  |  |
| $\mathrm{CsV}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 2.03 |  | 1.478 |  | violet |  |  |  |  |
| $\mathrm{TlV}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 2.34 |  | 1.514 |  | violet |  |  |  |  |
| $\mathrm{KCr}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.85 | 1.4787 | 1.4814 | 1.4875 | $\begin{aligned} & a=12.175 \\ & \text { No cleavage } \end{aligned}$ | 4.31 | 3.26 | 4.06; | 7-14 |
| $\mathrm{NH}_{4} \mathrm{Cr}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.73 | 1.4813 | 1.4842 | 1.4904 | $\begin{aligned} & a=12.251 \\ & \text { No cleavage } \end{aligned}$ | 4.34 | 3.28 | 7.08; | 7-3 |
| $\mathrm{RbCr}\left(\mathrm{SO}_{4}\right)_{2} \cdot \mathbf{1 2 H} \mathrm{H}_{2} \mathrm{O}$ | 1.97 | 1.4787 | 1.4815 | 1.4878 | $\begin{array}{r} a=12.256 \\ \text { Dark red } \end{array}$ | 4.34 | 3.28 | 2.82; | 7-21 |
| $\mathrm{CsCr}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 2.04 | 1.4784 | 1.4810 | 1.4872 | $\begin{array}{r} a=12.378 \\ \text { Dark red } \end{array}$ | 4.39 | 2.84 | 2.77; | 8-59 |
| $\mathrm{TlCr}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 2.39 | 1.5192 | 1.5228 | 1.5308 | $a=12.238$ <br> Octahedrons | 4.34 | 2.81 | 2.74; | 7-15 |
| $\mathrm{CsMn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ |  | 1.483 Li |  |  | No cleavage |  |  |  |  |
| $\mathrm{KFe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.83 | 1.4783 | 1.4817 | 1.4893 | Darkens slowly |  |  |  |  |
| $\mathrm{NH}_{4} \mathrm{Fe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.72 | 1.4815 | 1.4848 | 1.4929 | $\begin{aligned} & a=12.14 \\ & \text { Opt. anom. } \end{aligned}$ | 4.34 | 3.29 | 4.10; | 7-5 |
| $\mathrm{RbFe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.92 | 1.4789 | 1.4825 | 1.4900 | Octahedrons |  |  |  |  |
| $\mathrm{CsFe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 2.06 | 1.4804 | 1.4838 | 1.4914 | Colorless or violet | 4.39 | 2.85 | 2.78; | 7-1 |
| $\mathrm{TlFe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 2.38 | 1.5194 | 1.5237 | 1.5328 | Octahedrons |  |  |  |  |
| $\mathrm{RbTi}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ |  | 1.465 Li |  |  | Color red |  |  |  |  |
| $\mathrm{CsTi}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ |  | 1.472 Li | 1.4736 | 1.476 | Violet-red |  |  |  |  |
| $\mathrm{KGa}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.90 | 1.4630 | 1.4653 | 1.4709 | $\begin{array}{r} a=12.223 \\ \text { Colorless } \end{array}$ |  |  |  |  |
| $\mathrm{NH}_{4} \mathrm{Ga}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.78 | 1.4658 | 1.4684 | 1.4741 | $\begin{array}{r} a=12.268 \\ \text { Colorless } \end{array}$ | 4.34 | 7.08 | 3.70; | 7-18 |
| $\mathrm{RbGa}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.96 | 1.4633 | 1.4658 | 1.4713 | $\begin{array}{r} a=12.270 \\ \text { Colorless } \end{array}$ |  |  |  |  |
| $\mathrm{CsGa}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 2.11 | 1.4624 | 1.4650 | 1.4703 | $\begin{array}{r} a=12.402 \\ \text { Colorless } \end{array}$ | 4.39 | 2.77 | 6.21; | 8-58 |
| $\mathrm{TlGa}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 2.48 | 1.5035 | 1.5067 | 1.5139 | $\begin{array}{r} a=12.258 \\ \text { Colorless } \end{array}$ | 4.34 | 6.12 | 2.74; | 7-19 |
| $\mathrm{NH}_{4} \mathrm{In}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 2.01 | 1.4635 | 1.4664 | 1.4723 | Unstable Colorless |  |  |  |  |
| $\mathrm{RbIn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 2.06 | 1.4613 | 1.4638 | 1.4696 | Unstable Colorless |  |  |  |  |
| $\mathrm{CsIn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 2.24 | 1.4628 | 1.4652 | 1.4711 | Colorless |  |  |  |  |
| $\mathrm{NH}_{4} \mathrm{Rh}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ |  | 1.5073 Li | 1.5103 | 1.5150 g | r. Orange yellow |  |  |  |  |
| $\mathrm{RbRh}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ |  | $1.498 \pm \mathrm{Li}$ | $1.501 \pm$ | $1.504 \pm$ | gr. Yellow Octah. |  |  |  |  |
| $\mathrm{CsRh}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ |  | 1.5063 Li | 1.5077 | 1.5112 g | r. Honey-yellow |  |  |  |  |
| $\mathrm{TlRh}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ |  | 1.546 Li | 1.548 | $1.549 \pm$ | gr. Honey-yellow |  |  |  |  |
| $\mathrm{NH}_{3} \mathrm{CH}_{3} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.595 | 1.4506 | 1.4531 | 1.4584 | $\begin{array}{r} a=12.479 \\ \text { Colorless } \end{array}$ |  |  |  |  |
| $\mathrm{NH}_{2}(\mathrm{OH}) \mathrm{HAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.672 | 1.4617 | 1.4642 | 1.4698 | Colorless |  |  |  |  |
| $\mathrm{NH}_{2}\left(\mathrm{CH}_{3}\right)_{2} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.591 | 1.4500 | 1.4525 | 1.4578 | Colorless |  |  |  |  |
| $\mathrm{N}\left(\mathrm{CH}_{3}\right)_{4} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.66 | 1.4559 | 1.4592 | 1.4651 | Colorless |  |  |  |  |
| $\mathrm{NH}_{3} \mathrm{C}_{2} \mathrm{H}_{5} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.64 |  | 1.459 |  | Colorless |  |  |  |  |
| $\mathrm{NH}_{2}\left(\mathrm{C}_{2} \mathrm{H}_{5}\right)_{2} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.648 | 1.4562 | 1.4592 | 1.4654 | Colorless |  |  |  |  |
| $\mathrm{NH}\left(\mathrm{C}_{2} \mathrm{H}_{5}\right)_{3} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.655 |  | 1.4594 |  | Colorless |  |  |  |  |
| $\mathrm{N}\left(\mathrm{C}_{2} \mathrm{H}_{5}\right)_{4} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.650 |  | 1.4595 |  | Colorless |  |  |  |  |
| $\mathrm{NH}_{3} \mathrm{C}_{3} \mathrm{H}_{7} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.650 | 1.4568 | 1.4602 | 1.4652 | Colorless |  |  |  |  |
| $\mathrm{NH}_{3} \mathrm{C}_{4} \mathrm{H}_{9} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ |  | 1.4567 | 1.4598 | 1.4660 | Colorless |  |  |  |  |
| $\mathrm{NH}_{3} \mathrm{C}_{5} \mathrm{H}_{11} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ |  | 1.4578 | 1.4602 | 1.4672 | Colorless |  |  |  |  |


| Salt | G | $n$ (C) | $n$ (D) | $n$ (F) | Notes |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{NH}_{3}(\mathrm{OH}) \mathrm{Cr}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.750 |  | 1.4863 |  | Violet-red |
| $\mathrm{NH}_{3} \mathrm{CH}_{3} \mathrm{Cr}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.662 |  | 1.4745 |  | Violet-red |
|  | Selenates |  |  |  |  |
| $\mathrm{NH}_{3} \mathrm{CH}_{3} \mathrm{Al}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.833 |  | 1.4780 |  | Very dark |
| $\mathrm{KAl}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.991 | 1.4773 | 1.4801 | 1.4868 | Opt. anom. |
| $\mathrm{NH}_{4} \mathrm{Al}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.891 |  | 1.4856 |  | Very dark |
| $\mathrm{RbAl}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 2.123 |  | 1.4810 |  | Very dark |
| $\mathrm{CsAl}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 2.232 |  | 1.4865 |  | Very dark |
| $\mathrm{TlAl}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 2.531 |  | 1.522 |  | Very dark |
| $\mathrm{RbFe}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 2.13 | 1.5047 Li | 1.5070 | 1.5119 g | Very dark |
| $\mathrm{CsFe}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 3.62 | 1.5088 Li | 1.5116 | 1.5162 g | r. Very dark |

The color of the alum salts seems to depend chiefly upon the trivalent base; thus, the aluminum salts are all colorless (unless stained by impurities); vanadium alums are all violet; chromium alums are violet to dark red; the manganese alum is garnet red; the iron alums are colorless when pure and freshly prepared, but usually violet; gallium and indium alums are all colorless; titanium alums are reddish violet; rhodium alums are yellow to orange; the selenate alums are nearly black, but not opaque in thin splinters.
$\mathrm{NaAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ (Tamarugite) is monoclinic prismatic with $a: b: c=$ $0.292: 1: 0.242, \beta=94^{\circ} 49.5^{\prime}$. Crystals $\{010\}$ tablets or short prisms. Perfect $\{010\}$ cleavage. Multiple twinning may occur. H. 3 ca. G. 2.07. Soluble in water. $\mathrm{X} \wedge c=+4^{\circ}$ to $5^{\circ} ; \mathrm{Y}=b .(+) 2 \mathrm{~V}^{83}=60^{\circ} c a . n_{\mathrm{X}}=$ 1.488, $n_{\mathrm{Y}}=1.491, n_{\mathrm{Z}}=1.500$, all $\pm 0.001, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.013$. Again: $:^{80}$ $n_{\mathrm{X}}=1.490, n_{\mathrm{Y}}=1.492, n_{\mathrm{Z}}=1.504, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.014$. Colorless. Made by partial dehydration of soda alum or mendozite.

## 5. Formula Type $\mathrm{AXO}_{4} \cdot \mathbf{q H}_{2} \mathrm{O}$

$\mathrm{BeSO}_{4} \cdot \mathbf{4 \mathrm { H } _ { 2 } \mathrm { O }}$ is tetragonal with $c / a=0.946$. Crystals pyramidal. No distinct cleavage. Cruciform or lamellar twinning on $\{101\}$ common. G. 1.73. Uniaxial negative with $n_{\mathrm{O}}=1.4691 \mathrm{C}, 1.4720 \mathrm{D}, 1.4779 \mathrm{~F}$, $n_{\mathrm{E}}=1.4374 \mathrm{C}, 1.4395 \mathrm{D}, 1.4450 \mathrm{~F}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0325 \mathrm{D}$. Again $^{84} n_{\mathrm{O}}-$ $n_{\mathrm{E}}=0.0392$ Na. Colorless. PD 3.91, 2.53, 3.21; 1-0469. May take $\mathrm{BeSeO} \mathrm{O}_{4} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ in crystal solution with little effect on the optic properties.
$\mathrm{NiSO}_{\mathbf{4}} \cdot \mathbf{6 H}_{\mathbf{2}} \mathbf{O}$ (Retgersite) is tetragonal with $a=6.776, c=18.249 \mathrm{kX}$. U.C. 4. Crystals thick $\{001\}$ tablets to short prismatic. Perfect $\{001\}$ cleavage. H. 2.5. G. 2.07. Uniaxial negative with ${ }^{85} n_{0}=1.5078$ C, 1.5109 D, $1.5173 \mathrm{~F}, n_{\mathrm{E}}=1.4844 \mathrm{C}, 1.4873 \mathrm{D}, 1.4930 \mathrm{~F}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0236 \mathrm{D}$. Color emerald green (bluish). Made from water solution at about $35^{\circ} \mathrm{C}$. Crystallizing from solution at about $60^{\circ} \mathrm{C}$. the crystals are monoclinic with

[^98]$a: b: c=1.372: 1: 1.676, \beta=98^{\circ} 17^{\prime}$. Crystals basal tablets with no cleavage. $\mathrm{X} \wedge c=26^{\circ} 17^{\prime} ; \mathrm{Y}=b$. (-) $2 \mathrm{H}=19^{\circ} 25^{\prime}, \mathrm{r}>\mathrm{v}$. Color emerald green. PD 4.25, 4.57, 2.96; 8-470.
$\mathbf{N i S e O} \mathbf{H}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is tetragonal with $c / a=1.836$. Crystals from cold solutions are basal tablets and from hot solutions are acute pyramidal. Perfect basal cleavage. G. 2.31. Uniaxial negative with $n_{\mathrm{O}}=1.5357 \mathrm{C}, 1.5393 \mathrm{D}$, $1.5473 \mathrm{~F}, n_{\mathrm{E}}=1.5089 \mathrm{C}, 1.5125 \mathrm{D}, 1.5196 \mathrm{~F}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0268 \mathrm{D}$. Made from water solution.
$\mathrm{CoSO}_{4} \cdot \mathbf{6 H}_{2} \mathrm{O}$ is probably tetragonal being uniaxial ${ }^{86}$ negative with $n_{\mathrm{O}}=$ $1.495, n_{\mathrm{E}}=1.460, n_{\mathrm{O}}-n_{\mathrm{E}}=0.035$. Blue in mass; faintly pleochroic in pink. Also monoclinic when crystallized at about $45^{\circ} \mathrm{C}$. Crystals prismatic with $\{001\}$. G. 2.0. X nearly normal to $\{\overline{1} 02\} ; \mathrm{Y}=b$. (-) $2 \mathrm{H}=8^{\circ}, \mathrm{r}>\mathrm{v}$ with weak inclined dispersion.
$\mathbf{Z n S e O} \cdot \mathbf{6} \cdot \mathbf{H}_{2} \mathbf{O}$ is tetragonal with $c / a=1.895$. Crystals basal tablets or pyramidal. Perfect basal cleavage. G. 2.33. Uniaxial negative with $n_{\mathrm{O}}=$ $1.5255 \mathrm{C}, 1.5291 \mathrm{D}, 1.5367 \mathrm{~F}, n_{\mathrm{E}}=1.5004 \mathrm{C}, 1.5039 \mathrm{D}, 1.5108 \mathrm{~F}, n_{\mathrm{O}}-$ $n_{\mathrm{E}}=0.0183 \mathrm{D}$. Colorless. Made from water solution at about $15^{\circ} \mathrm{C}$.
$\mathbf{2 C a S O}_{4} \cdot \mathbf{H}_{2} \mathbf{O}$ (Bassanite?) is hexagonal with ${ }^{87} a=6.82, c=6.24 \mathrm{kX}$. Crystals six-sided prisms. G. 2.7. Uniaxial positive with $n_{0}=1.558$, $n_{\mathrm{E}}=1.586, n_{\mathrm{E}}-n_{\mathrm{O}}=0.028$. The water is zeolitic and is held in channels in the crystal structure; it is nearly or entirely lost at about $130^{\circ} \mathrm{C}$. Colorless. PD 2.98, 2.78, 5.98; 2-0675. Made by partial dehydration of gypsum at about $120^{\circ} \mathrm{C}$.; it is then acicular with a silken luster. Commercially it is plaster of Paris. $2 \mathrm{CaSO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ (another phase?) is also reported to be monoclinic with ${ }^{88} a: b: c=1.744: 1: 1.852, \beta=90^{\circ} 36^{\prime}$. Crystals pseudo-hexagonal with common twinning on $\{100\}$. ( $+2 \mathrm{~V}=14^{\circ}, n_{\mathrm{X}}=1.559, n_{\mathrm{Y}}=1.5595$, $n_{\mathrm{Z}}=1.5836, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0246$. Again $:^{89}$ fibers have parallel extinction and positive elongation. $n_{\mathrm{X}}=1.55, n_{\mathrm{Z}}=1.57, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.02$. Also : $:^{90}$ $n_{\mathrm{X}}=1.550, n_{\mathrm{Z}}=1.556, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.006$. Once more ${ }^{91} 2 \mathrm{CaSO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ is said to be rhombohedral above $45^{\circ} \mathrm{C}$., and orthorhombic below $45^{\circ} \mathrm{C}$. with $2 \mathrm{~V}=10^{\circ}-15^{\circ}$ and $n_{\mathrm{Z}}=1.584$.
$\mathrm{BeSeO}_{4} \cdot \mathbf{4 H}_{2} \mathrm{O}$ is orthorhombic with $a: b: c=0.960: 1: 0.903$. Crystals macrodomatic columnar. No good cleavage. Cruciform twinning on $\{110\}$. G. 2.03. $\mathrm{X}=c ; ~ \mathrm{Y}=a$. $(-) 2 \mathrm{~V}=26^{\circ} 43^{\prime}, n_{\mathrm{X}}=1.4637 \mathrm{C}, 1.4664 \mathrm{D}$, $1.4725 \mathrm{~F}, n_{\mathrm{Y}}=1.4973 \mathrm{C}, 1.5007 \mathrm{D}, 1.5084 \mathrm{~F}, n_{\mathrm{Z}}=1.4992 \mathrm{C}, 1.5027 \mathrm{D}$, $1.5101 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0363 \mathrm{D}$. Colorless. Made from water solution. May

[^99]take $\mathrm{BeSO}_{4} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ in crystal solution to at least 60 per cent with little change in the optic properties.
$\mathbf{M g S O}_{4} \cdot \mathbf{7 H _ { 2 }} \mathbf{O}$ (Epsomite) is orthorhombic with $a=11.94, b=12.03$, $c=6.865 k X$. U.C. 4. Crystals usually prismatic terminated by one (or


Fig. 7-13. Crystal habit of $\mathrm{MgSO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$.
more) sphenoids; often fibrous. See Figs. 7-13, 7-14. H. 2.5. G. 1.677. Distinct $\{010\}$ and poor $\{101\}$ cleavages. Soluble in water. $\mathrm{X}=b ; \mathrm{Y}=c$. $(-) 2 \mathrm{~V}=51^{\circ} 25^{\prime} \mathrm{D}, \mathrm{r}>\mathrm{v}$ weak. $n_{\mathrm{X}}=1.4305 \mathrm{C}, 1.4325 \mathrm{D}, 1.4374 \mathrm{~F}$, $n_{\mathrm{Y}}=1.4530 \mathrm{C}, 1.4554 \mathrm{D}, 1.4607 \mathrm{~F}, n_{\mathrm{Z}}=1.4583 \mathrm{C}, 1.4608 \mathrm{D}, 1.4657 \mathrm{~F}$,


Fig. 7-14. Crystal habit of $\mathrm{MgSO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$.
$n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0283$ D. Colorless. PD 4.21, 5.35, 2.68; 8-467. Made from water solution at temperatures below about $50^{\circ} \mathrm{C}$. It rotates the plane of polarization $1.98^{\circ}$ per mm . (of thickness) for $\lambda=579$. Epsomite is miscible in all proportions with ${ }^{92} \mathrm{NiSO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ or $\mathrm{ZnSO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ with linear variation

[^100]of the refractive indices. Also miscible to some extent with $\mathrm{Mn}, \mathrm{Fe}, \mathrm{Cu}$ or Co sulfates. A second phase of $\mathrm{MgSO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=$ 1.22:1:1.58, $\beta=104^{\circ} 24^{\prime}$. Crystals pseudo-rhombohedral and isomorphous with $\mathrm{FeSO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ with which it is miscible to at least 40 per cent; likewise miscible with $\mathrm{CuSO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$, but optic data are lacking.
$\mathbf{N i S O}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ (Morenosite) is orthorhombic with $a=11.8, b=12.0$, $c=6.80 k X$. U.C. 4. Crystals short prismatic or fibrous. Perfect $\{010\}$ cleavage. H. $2-2.5$. G. 1.95. F. 7. $\mathrm{X}=b ; \mathrm{Y}=c$. $(-) 2 \mathrm{~V}=41^{\circ} 45^{\prime}, \mathrm{r}>\mathrm{v}$ weak. ${ }^{93} \quad n_{\mathrm{X}}=1.4693, n_{\mathrm{Y}}=1.4893, n_{\mathrm{Z}}=1.4923, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.023 \mathrm{D}$. Color apple-green. PD 4.20, 5.30, 2.85; 1-0403. Miscible in all proportions with $\mathrm{MgSO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$.
$\mathbf{Z n S O}_{4} \cdot \mathbf{7 \mathrm { H } _ { 2 } \mathbf { O }}$ (Goslarite) is orthorhombic with $a=11.85, b=12.00$, $c=6.83 k X$. U.C. 4. Crystals stout prismatic to acicular. Perfect $\{010\}$ cleavage. H. 2-2.5. G. 1.98. Dehydrates in dry air. $\mathrm{X}=b ; \mathrm{Y}=c .^{92}$ $(-) 2 \mathrm{~V}=46^{\circ} 14^{\prime} \mathrm{r}>$ v weak. $n_{\mathrm{X}}=1.4544 \mathrm{C}, 1.4568 \mathrm{D}, 1.4620 \mathrm{~F}, n_{\mathrm{Y}}=$ $1.4776 \mathrm{C}, 1.4801 \mathrm{D}, 1.4860 \mathrm{~F}, n_{\mathrm{z}}=1.4812 \mathrm{C}, 1.4836 \mathrm{D}, 1.4897 \mathrm{~F}, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.0268$. Colorless. PD 4.21, 5.36, 4.18; $9-395$. Made from water solution. Miscible in all proportions with $\mathrm{MgSO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ and at least to some extent with $\mathrm{Cu}, \mathrm{Fe}$ or Mn sulfates. With $\mathrm{Fe}: \mathrm{Zn}=1: 2$ it has ${ }^{94}$ $(+) 2 \mathrm{~V}=78^{\circ} 48^{\prime}, \quad n_{\mathrm{X}}=1.4709, n_{\mathrm{Y}}=1.4785, n_{\mathrm{Z}}=1.4867, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.0158 . Color green to brown.
 Crystals columnar prismatic. Perfect $\{010\}$ cleavage. G. 1.69. $\mathrm{X}=b$; $\mathrm{Y}=c .(-) 2 \mathrm{~V}=75^{\circ} 28^{\prime}, \mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.5131 \mathrm{C}, 1.5211 \mathrm{D}, n_{\mathrm{Y}}=1.5415 \mathrm{C}$, $1.5500 \mathrm{D}, n_{\mathrm{Z}}=1.5633 \mathrm{C}, 1.5680 \mathrm{D}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0469 \mathrm{D}$. PD 5.00 , 3.77, $6.00 ; 1-0243$. Made from water solution.
$\mathrm{MgSO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ (Kieserite) is monoclinic prismatic with $a=6.89, b=$ 7.69, $c=7.52 k X, \beta=116^{\circ} 5^{\prime}$. U.C. 4. Crystals bipyramidal. Perfect $\{110\}$ and $\{111\}$ and poor $\{\overline{1} 11\},\{\overline{1} 01\}$ and $\{011\}$ cleavages. H. 3.5. G. 2.57. Slowly soluble in water. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=-76.5^{\circ} .(+) 2 \mathrm{~V}=57^{\circ}, \mathrm{r}>\mathrm{v}$ distinct. ${ }^{95} n_{\mathrm{X}}=1.523, n_{\mathrm{Y}}=1.525, n_{\mathrm{Z}}=1.596, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.063$. Colorless. PD 3.38, 4.82, 2.55; 1-0638. Made from water solution above $67^{\circ} \mathrm{C}$.
$\mathrm{FeSO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ (Szomolnokite) is monoclinic with $a: b: c=0.934: 1: 1.008$, $\beta=116^{\circ} 14^{\prime}$. Crystals bipyramidal. Common twinning. H. 2.5. G. 3.05. $\mathrm{X} \wedge c=-26^{\circ} ; \mathrm{Y}=b .^{80}(+) 2 \mathrm{~V}=80^{\circ}, \mathrm{r}>\mathrm{v}$ strong. $n_{\mathrm{X}}=1.591, n_{\mathrm{Y}}=$ $1.623, n_{\mathrm{Z}}=1.663, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.072$. Color yellow to brown; also blue or colorless. PD 3.42, 4.85, 3.13; 1-0612. Made by dehydrating $\mathrm{FeSO}_{4} \cdot ? \mathrm{H}_{2} \mathrm{O}$ at $100^{\circ} \mathrm{C}$.
$\mathbf{M n S O}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ (Szmikite) is probably monoclinic. H. 1.5. G. 3.15. F. 7.

[^101]One perfect cleavage. $\mathrm{Y} \wedge c=$ large; $\mathrm{Z}=b .(+) 2 \mathrm{~V}^{86}=$ nearly $90^{\circ} . n_{\mathrm{X}}=$ $1.562, n_{\mathrm{Y}}=1.595, n_{\mathrm{Z}}=1.632, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.070$. Color dirty white to rose-red. PD 3.51, 3.15, 2.59; 1-0565. Made by dehydration of any higher hydrate at $100^{\circ} \mathrm{C}$.
$\mathrm{CoSO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ is probably monoclinic since it has inclined extinction. $(-) 2 \mathrm{~V}=$ nearly $^{96} 90^{\circ}, n_{\mathrm{X}}=1.603, n_{\mathrm{Y}}=1.639, n_{\mathrm{Z}}=1.683, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.080 as formed in a desiccator from $\mathrm{CoSO}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$. The monohydrate formed by evaporation on a steam bath has $n_{\mathrm{X}}=1.600, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=$ $1.645, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.045$, and negative elongation. $\mathrm{PD} 3.40,4.82,3.08$; 1-0619.
$\mathrm{CuSO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ is biaxial, ${ }^{34}$ but of unknown symmetry. (-) $2 \mathrm{~V}=75^{\circ}$ calc., $\mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.626, n_{\mathrm{Y}}=1.671, n_{\mathrm{Z}}=1.699, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.073$. Bluish white in mass; colorless in section. PD 3.40, 4.81, 2.47; 1-0620.
$\mathbf{4} \mathbf{M g S O}_{4} \cdot \mathbf{5 H}_{2} \mathrm{O}$ is probably monoclinic ${ }^{97}$ in twinned diamond-shaped crystals with $n_{\mathrm{X}}=1.512, n_{\mathrm{Y}}=1.530, n_{\mathrm{Z}}=$ ? Colorless.
$\mathbf{M g S O}_{4} \cdot \mathbf{2} \mathrm{H}_{2} \mathbf{O}$ forms fine radiated masses ${ }^{97}$ with $n_{\mathrm{Y}}=1.493$. A substance given as $\mathrm{MgSO}_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ (?) is perhaps the same. It is biaxial negative with ${ }^{98}$ $n_{\mathrm{Y}}=1.490 \pm$. Colorless.


Fig. 7-15. A crystal habit of $\mathrm{CaSO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$.
$\mathrm{CaSO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ (Gypsum) is monoclinic with $a=5.67, b=15.15, c=$ $6.28 k X, \beta=113^{\circ} 50^{\prime}$. Crystals usually simple in habit, often tabular parallel to $\{010\}$ as in Fig. $7-15$, or prismatic to acicular along $c$. Perfect $\{010\}$ and poor $\{100\}$ and $\{\overline{1} 11\}$ cleavages. Twinning on $\{100\}$ common in

[^102]arrow-head forms, as in Fig. 7-16. H. 2. G. 2.32. F. 2.5-3. Soluble in HCl . $\mathrm{Y}=b ; \mathrm{Z} \wedge c=+52^{\circ}$. At room temperature $(+) 2 \mathrm{~V}=58^{\circ} \mathrm{Na}, \mathrm{r}>\mathrm{v}$ with strong inclined dispersion, $n_{\mathrm{X}}=1.5205 \mathrm{Na}, n_{\mathrm{Y}}=1.5226, n_{\mathrm{Z}}=1.5296$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0091$. At $105^{\circ} \mathrm{C} .{ }^{99} n_{\mathrm{X}}=1.5184, n_{\mathrm{Y}}=1.5188, n_{\mathrm{Z}}=1.5274$,


Fig. 7-16. Gypsum crystal twinned on (100).
$n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0090 \mathrm{Na}$. The optic angle varies rapidly with change of temperature from $2 \mathrm{E}=$ about $95^{\circ}$ at $20^{\circ} \mathrm{C}$. to $0^{\circ}$ at about $91^{\circ} \mathrm{C}$. The optic angle then opens in a plane normal to (010) ( X and Y changing places) at temperatures above $91^{\circ} \mathrm{C}$. At the same time the dispersion becomes $\mathrm{r}<\mathrm{v}$ and horizontal (for example, at $120^{\circ} \mathrm{C}$.). PD 7.56, 3.06, 4.27; 6-0046/7. Gypsum loses three-fourths of its water at about $120^{\circ} \mathrm{C}$. (becoming plaster of Paris) and the rest of the water at $163^{\circ} \mathrm{C} . ;$ when heated above this temperature it is "dead burned" and has $n_{\mathrm{O}}=1.50$ and $n_{\mathrm{E}}=1.56$. Made by reaction of soluble calcium salts with sulfates.
$\mathbf{3 C d S O}_{4} \cdot \mathbf{8 H _ { 2 }} \mathbf{O}(?)$ is monoclinic with $a: b: c=0.799: 1: 0.690, \beta=$ $117^{\circ} 58^{\prime}$. Crystals basal plates. Perfect $\{010\}$ cleavage. G. 3.05. $\mathrm{X}=b$; $\mathrm{Z} \wedge c=+76^{\circ} 14^{\prime}$ red, $77^{\circ} 3^{\prime}$ blue. ( - ) $2 \mathrm{~V}=87^{\circ} 57^{\prime}$ red, $88^{\circ} 9^{\prime} \mathrm{Na}, 88^{\circ} 23^{\prime}$ blue, $\mathrm{r}>\mathrm{v}$ weak. $n_{\mathrm{Y}}=1.563$ red, $1.565 \mathrm{Na}, 1.576$ blue, $n_{\mathrm{Z}}-n_{\mathrm{X}}=$ ?. Made from water solution.

[^103]$\mathrm{CuSO}_{4} \cdot \mathbf{3 H}_{2} \mathrm{O}$ is monoclinic with ${ }^{99 \mathrm{a}} a: b: c=0.432: 1: 0.552, \beta=96^{\circ} 25^{\prime}$. Crystals short prismatic; twinning common on $\{100\}$. Distinct $\{010\}$ cleavage. $(+) 2 \mathrm{~V}=75^{\circ}$ calc. $n_{\mathrm{X}}=1.554, n_{\mathrm{Y}}=1.577, n_{\mathrm{Z}}=1.618, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.064$. Blue; colorless in section. PD 4.45, 3.65, 5.15; 3-0194.
$\mathbf{M g S O}_{4} \cdot \mathbf{4 H}_{2} \mathbf{O}$ is monoclinic with $a: b: c=0.45: 1: ?, \beta=90^{\circ} 11^{\prime}$. Crystals short prismatic. Good $\{100\}$ and $\{010\}$ cleavages. ${ }^{97} \mathrm{X} \wedge c=+81^{\circ}, \mathbf{Z}=b$. $(+) 2 \mathrm{~V}=50^{\circ}, \mathrm{r}>\mathrm{v}$ with strong horizontal dispersion. $n_{\mathrm{X}}=1.490, n_{\mathrm{Y}}=$ 1.491, $n_{\mathrm{Z}}=1.497, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.007$. The prism angle, (110) $\wedge$ ( $1 \overline{1} 0$ ), $\left(=48^{\circ} 40^{\prime}\right)$ is often seen. Colorless. PD 4.48, 2.95, 5.50; 1-0341.
$\mathrm{FeSO}_{4} \cdot \mathbf{4 H}_{2} \mathrm{O}$ is monoclinic ${ }^{100}$ with $a: b: c=0.438: 1: 0.587, \beta=90^{\circ} 31^{\prime}$. Crystals short prismatic. Good $\{010\}$ cleavage. Striations on $\{001\}$ and $\{011\}$. G. 2.28. $\mathrm{Z}=b$. ( -$) 2 \mathrm{~V}=$ very large. Horizontal dispersion. $n_{\mathrm{X}}=1.533, n_{\mathrm{Y}}=1.535, n_{\mathrm{Z}}=1.537$ (from $n_{\mathrm{X}}, n_{\mathrm{Y}}$ and 2 V ), $n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.004 . Color pale green. PD 5.50, 4.49, 3.99; 1-0201. Made from water solution at about $80^{\circ} \mathrm{C}$.
$\mathrm{MnSO}_{4} \cdot \mathbf{4 H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=0.432: 1: 0.582, \beta=90^{\circ} 53^{\prime}$. Crystals short prismatic or basal plates along parallel to $a$. Perfect $\{010\}$ cleavage. G. 2.26. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=85^{\circ} 48^{\prime} \mathrm{Li}, 84^{\circ} 8^{\prime}$ blue. ( - ) $2 \mathrm{~V}=63^{\circ}$, $\mathrm{r}>\mathrm{v}$ weak. ${ }^{24} n_{\mathrm{X}}=1.508, n_{\mathrm{Y}}=1.518, n_{\mathrm{Z}}=1.522, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.014$. Color pink. PD 4.48, 5.56, 3.96; 3-0185. Made from water solution at about $45^{\circ} \mathrm{C}$.
$\mathrm{MgSO}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ (Hexahydrite) is monoclinic with $a=10.04, b=7.15$, $c=24.34 k X, \beta=98^{\circ} 14^{\prime}$. Crystals thick basal tablets or prismatic. Perfect $\{100\}$ cleavage. H. 2. G. 1.75. F. 7, but exfoliates. $\mathrm{X} \wedge c=-25^{\circ}$; X is nearly normal ${ }^{101}$ to $\{\overline{1} 02\} ; \mathrm{Y}=b .(-) 2 \mathrm{~V}=38^{\circ}, \mathrm{r}>\mathrm{v} . n_{\mathrm{X}}=1.426$, $n_{\mathrm{Y}}=1.453, n_{\mathrm{Z}}=1.456, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.030$. Colorless, white or rarely pale green. PD 4.40, 2.92, 4.04; 1-0354. Made from water solution between $48^{\circ}$ and $69^{\circ}$.
$\mathrm{ZnSO}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ (Bianchite) is monoclinic with $a: b: c=1.385: 1: 3.352$, $\beta=98^{\circ} 12^{\prime}$. Crystals basal tablets with $\{110\}$ and $\{112\}$, etc. H. 2.5 ca . G. 2.03. Often contains some Fe in place of Zn . With $\mathrm{Zn}: \mathrm{Fe}=2: 1$ it has ${ }^{102} \mathrm{X} \wedge c=-26^{\circ} ; \mathrm{Y}=b .(-) 2 \mathrm{~V}=10^{\circ} . n_{\mathrm{X}}=1.465, n_{\mathrm{Y}}=1.494$, $n_{\mathrm{Z}}=1.495, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.030$. With no Fe: $(-) 2 \mathrm{~V}=15^{\circ}-16^{\circ}, n_{\mathrm{X}}=1.462$, $n_{\mathrm{Y}}=1.4895, n_{\mathrm{Z}}=1.490, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.028$. Color white, becoming yellowish as iron oxidizes. PD 4.40, 4.05, 2.92; 1-0352.
$\mathbf{M g S e O}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=1.385: 1: 1.685, \beta=98^{\circ} 32^{\prime}$. Crystals thick basal tablets with perfect $\{10 \overline{1}\}$ cleavage. G. 1.93. $\mathrm{X} \wedge$ $c=-27^{\circ} ; \mathrm{Y}=b$. (-) $2 \mathrm{~V}=28^{\circ} 12^{\prime}, \mathrm{r}>\mathrm{v}$ strong. $n_{\mathrm{X}}=1.4856 \mathrm{D}, n_{\mathrm{Y}}=$

[^104]$1.4864 \mathrm{C}, 1.4892 \mathrm{D}, 1.4965 \mathrm{~F}, n_{\mathrm{Z}}=1.4911 \mathrm{D}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0055$. Colorless. Made from water solution at ordinary temperature.
$\mathrm{CoSeO}_{4} \cdot \mathbf{6 H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=1.371: 1: 1.682, \beta=98^{\circ} 14^{\prime}$. Crystals thick basal tablets or short prismatic with perfect $\{10 \overline{1}\}$ cleavage. G. 2.18. $\mathrm{X} \wedge c=-34^{\circ} 42^{\prime} ; \mathrm{Y}=b$. ( $-2 \mathrm{~V}=7^{\circ} 13^{\prime}, \mathrm{r}>\mathrm{v}$. $n_{\mathrm{X}}=1.47$ calc., $n_{\mathrm{Y}}=1.5183 \mathrm{Li}, 1.5225 \mathrm{Na}, n_{\mathrm{Z}}=1.5227 \mathrm{Na}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.05$ calc. Made from water solution above $15^{\circ} \mathrm{C}$.
$\mathrm{FeSO}_{4} \cdot \mathbf{7 H}_{2} \mathrm{O}$ (Melanterite) is monoclinic with $a=15.34, b=12.98$, $c=20.02 k X, \beta=104^{\circ} 16^{\prime}$. U.C. 16. Crystals nearly equant as in Fig. 7-17


Fig. 7-17. A crystal habit of $\mathrm{FeSO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$.
or varied. Perfect $\{001\}$ and distinct $\{110\}$ cleavages. H. 2. G. 1.90. F. easy. Dehydrates in dry air. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=-62^{\circ} .(+) 2 \mathrm{~V}=85^{\circ} 27^{\prime}$, $\mathrm{r}>\mathrm{v}$ weak with weak inclined dispersion. ${ }^{103} n_{\mathrm{X}}=1.4681 \mathrm{Li}, 1.4713 \mathrm{Na}$, $n_{\mathrm{Y}}=1.4748 \mathrm{Li}, 1.4782 \mathrm{Na}, 1.4861 \mathrm{blue}, n_{\mathrm{Z}}=1.4824 \mathrm{Li}, 1.4856 \mathrm{Na}$, $n_{\mathrm{z}}-n_{\mathrm{X}}=0.0143 \mathrm{Na}$. Color green to nearly white; becomes yellow by alteration. PD 4.90, 3.78, 3.23; 1-0255. Made from water solution at temperatures up to $56^{\circ} \mathrm{C}$. When dehydrated to about $5 \mathrm{H}_{2} \mathrm{O}$ (as found in some drugs) it has: ${ }^{104} n_{\mathrm{X}}=1.525, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.539, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.014$. The iron of melanterite may be replaced in part (or even wholly in some cases) by $\mathrm{Mg}, \mathrm{Cu}, \mathrm{Zn}, \mathrm{Co}, \mathrm{Ni}$, or Mn (or 2 or more of these). With some Cu (in nature called pisanite) the optic properties remain nearly the same, with $\mathrm{Y}=b, \mathrm{Z} \wedge c=-68^{\circ},(+) 2 \mathrm{~V}=$ very large. $n_{\mathrm{X}}=1.472, n_{\mathrm{Y}}=1.479$, $n_{\mathrm{Z}}=1.487, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.015$. Color pale blue. PD 4.86, 3.77, 5.37; 7-392. With some Zn (and Cu )-called calingastite-it has (+)2V = large, $n_{\mathrm{X}}=1.479, n_{\mathrm{Y}}=1.483, n_{\mathrm{Z}}=1.488, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.009$. Color blue-green.
$\mathrm{CuSO}_{4} \cdot \mathbf{7 H}_{2} \mathbf{O}$ (Boothite) is monoclinic with $a: b: c=1.162: 1: 1.500$,

[^105]$\beta=105^{\circ} 36^{\prime}$. Crystals fibrous. Poor basal cleavage. H. 2-2.5. G. about 2. X near $c ; \mathrm{Y}=b .(-?) 2 \mathrm{~V}=$ large, ${ }^{24} n_{\mathrm{X}}=1.47, n_{\mathrm{Y}}=1.48, n_{\mathrm{Z}}=1.49$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.02$. Color pale blue. Made from water solution by seeding with $\mathrm{FeSO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$.
$\mathrm{CoSO}_{4} \cdot \mathbf{7 H}_{2} \mathrm{O}$ (Bieberite) is monoclinic with $a=15.45, b=13.08, c=$ $20.04 k X, \beta=104^{\circ} 40^{\prime}$. U.C. 16. Crystals complex $\{10 \overline{1}\}$ tablets. Perfect $\{001\}$ and distinct $\{110\}$ cleavages. H. 2. G. 1.96. F. easy. Dehydrates in dry air. The optic plane is (010); ( - ) $2 \mathrm{~V}=88^{\circ}, \mathrm{r}<\mathrm{v}$ weak. ${ }^{105} n_{\mathrm{X}}=1.4748$, $n_{\mathrm{Y}}=1.4820, n_{\mathrm{Z}}=1.4885, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0137$. Color carmine; slightly pleochroic in pink tints. Made from water solution at $23^{\circ} \mathrm{C}$.
$\mathbf{M g S O}_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ (Pentahydrite) is triclinic with ${ }^{106} a: b: c=0.602: 1: 0.560$, $\alpha=81^{\circ} 30^{\prime}, \beta=109^{\circ} 0^{\prime}, \gamma=104^{\circ} 55^{\prime}$. Crystals vertically elongated with $\{100\}$ and $\{11 \overline{1}\}$ prominent. No cleavage. G. 1.718. Unstable in air.


Fig. 7-18. A crystal habit of $\mathrm{CuSO}_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$.

X nearly normal to ${ }^{97}$ (010). ( - ) $2 \mathrm{~V}=45^{\circ} 8^{\prime}, \mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.482, n_{\mathrm{Y}}=$ 1.492, $n_{\mathrm{Z}}=1.493, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.011$. Colorless. Made from water solution.
$\mathrm{FeSO}_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ (Siderotil) is triclinic ${ }^{106 a}$ with $a: b: c=0.596: 1: 0.577, \alpha=$ $81^{\circ} 23^{\prime}, \beta=110^{\circ} 28^{\prime}, \gamma=105^{\circ} 33^{\prime}$. Crystals short prismatic to acicular. H. 2-3. G. 2.2. F. 3. ( -$) 2 \mathrm{~V}=$ moderate, $\mathrm{r}>\mathrm{v}$ weak. $n_{\mathrm{X}}=1.526, n_{\mathrm{Y}}=$ 1.536, $n_{\mathrm{Z}}=1.542, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.016$. Again: ${ }^{11} n_{\mathrm{X}}=1.528, n_{\mathrm{Y}}=1.537$, $n_{\mathrm{Z}}=1.545, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.017$. Color white to yellowish or pale green. Not certainly produced artificially.

[^106]$\mathrm{CuSO}_{4} \cdot \mathbf{5 H}_{2} \mathrm{O}$ (Chalcanthite) is triclinic ${ }^{107}$ with $a=6.104, b=10.72$, $c=5.949 \AA, \alpha=97^{\circ} 34^{\prime}, \beta=107^{\circ} 17^{\prime}, \gamma=77^{\circ} 26^{\prime}$, U.C. 2. Crystals short prismatic, almost equant. Poor $\{110\}$ and $\{1 \overline{1} 0\}$ cleavages. H. 2.5. G. 2.28. F. 3. $\mathrm{X} \wedge c=76^{\circ}$ in a plane ${ }^{107}$ at $79^{\circ}$ with (010); $Z \wedge c=18^{\circ}$ in a plane


Fig. 7-19. Stereogram showing common forms and optic orientation of $\mathrm{CuSO}_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$.
at $35^{\circ}$ with (010). Angular coordinates of common faces and of optical directions and crystal axes follow: ${ }^{107}$

| Form | $\varphi$ | $\rho$ | Form | $\varphi$ | $\rho$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $c(001)$ | $76^{\circ} 22^{\prime}$ | $17^{\circ} 45 \frac{1}{2}^{\prime}$ | $p$ (1111) | $-112^{\circ} 38^{\prime}$ | $37^{\circ} 44^{\prime}$ |
| $b(010)$ | 000 | 9000 | $z(\overline{1} 21)$ | -140 33 | 4820 |
| $a(100)$ | 10052 | 9000 | X* | 16847 | 7553 |
| $m(110)$ | 7000 | 9000 | Y* | 7525 | 7651 |
| $M(110)$ | 12648 | 9000 | Z* | -55 03 | 1929 |
| $q(011)$ | 2544 | 3537 | [c] $\dagger$ | - | 000 |
| $Q(0111)$ | 14750 | 3018 | $[-b] \dagger$ | -169 08 | 8226 |
| $W(0 \overline{2} 1)$ | 16343 | 4759 | $[-a] \dagger$ | -90 00 | 7243 |

Crystals formed on a glass slide by evaporation of an aqueous solution all lie on the face $M(1 \overline{1} 0)$ or $-M(\overline{1} 10)$, which is only $15^{\circ}$ from normal to ${ }^{107}$ Fisher: Am. Min. XXXVII, p. 95 (1952); also Barth and Tunell: ibid. XVIII 187 (1933).
the optic symmetry plane containing X and Y . Such a face is usually an almost equilateral parallelogram with angles of $57^{\circ}$ and $123^{\circ}$, and the optic symmetry plane XY intersects one of these sides at about $75^{\circ}$ in the obtuse angle of the parallelogram. (-) $2 \mathrm{~V}=56^{\circ} 02^{\prime}, \mathrm{r}<\mathrm{v}$ weak ${ }^{108}$ with components of crossed and strongly inclined dispersion. $n_{\mathrm{X}}=1.5141 \mathrm{Na}, n_{\mathrm{Y}}=$ $1.5368, n_{\mathrm{Z}}=1.5435, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0294$. Color blue; nearly colorless in section. PD 4.70, 5.45, 3.97; 8-89. Made from water solution. It may contain $\mathrm{Mg}, \mathrm{Fe}, \mathrm{Mn}$, or Zn replacing some Cu .
$(\mathbf{Z n}, \mathbf{C u}) \mathrm{SO}_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ is similar. ${ }^{106 a}$ G. 2.1. ( - ) $2 \mathrm{~V}=$ moderate. $n_{\mathrm{X}}=$ $1.513, n_{\mathrm{Y}}=1.533, n_{\mathrm{Z}}=1.540, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.027$. Color pale blue; nearly colorless in section.
$\mathrm{CoSO}_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ is similar. ${ }^{106 a}$ H. 2-3. G. 2.2. F. 3. ( -$) 2 \mathrm{~V}=$ moderate, dispersion not strong. $n_{\mathrm{X}}=1.530, n_{\mathrm{Y}}=1.548, n_{\mathrm{Z}}=1.550 . n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.020. Color rose-pink. Made from water solution.
$\mathrm{MnSO}_{4} \cdot \mathbf{5 H}_{2} \mathrm{O}$ is triclinic ${ }^{106 a}$ with $a: b: c=0.589: 1: 0.569, \alpha=81^{\circ} 37^{\prime}$, $\beta=100^{\circ} 5^{\prime}, \gamma=104^{\circ} 59^{\prime}$. Crystals nearly equant, acicular parallel to $c$, or lamellar parallel to (100). Poor $\{011\}$ cleavage. H. 2-3. G. 2.1. F. 3. Y nearly normal to plates in which extinction is at $15^{\circ}$ to length. ( -$) 2 \mathrm{~V}=$ rather large, with $\mathrm{r}>\mathrm{v} . n_{\mathrm{X}}=1.495, n_{\mathrm{Y}}=1.508, n_{\mathrm{Z}}=1.514, n_{\mathrm{Z}}-$ $n_{\mathrm{x}}=0.019$. Color pale pink. Made from water solution in a desiccator under reduced pressure.
$\mathrm{CuSeO}_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ is triclinic with $a: b: c=0.568: 1: 0.555, a=98^{\circ} 2^{\prime}, \beta=$ $106^{\circ} 54^{\prime}, \gamma=103^{\circ} 11^{\prime}$. Crystals short prismatic, vertically striated like $\mathrm{CuSO}_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$. G. 2.56. Bolland ${ }^{25}$ measured on "copper selenate" of unknown formula: $n_{1}=1.565, n_{2}=1.56$; sign - , and extinction angle of $34^{\circ}$. Color red. Made from water solution.

## 6. Formula Type $\mathrm{AB}_{2}\left(\mathrm{XO}_{4}\right)_{4} \cdot \mathbf{q} \mathrm{H}_{2} \mathrm{O}$

$\mathbf{M g A l}_{2}\left(\mathrm{SO}_{4}\right)_{4} \cdot \mathbf{2 2 \mathrm { H } _ { 2 } \mathrm { O }}$ (Pickeringite) is monoclinic with $a=20.8, b=$ $24.2, c=6.17 k X, \beta=95^{\circ} \mathrm{ca}$. U.C. 4. Crystals acicular. Poor $\{010\}$ cleavage. H. 1.5. G. 1.73-1.79. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=36^{\circ} .(-) 2 \mathrm{~V}^{11}=60^{\circ} ; n_{\mathrm{X}}=1.476$, $n_{\mathrm{Y}}=1.480, n_{\mathrm{Z}}=1.483, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.008$. Colorless or tinted yellowish or reddish probably due to some Fe in place of Mg . A complete replacement is possible leading to halotrichite. It may also have some Mn in place of Mg . Seems to have been made from a dilute $\mathrm{H}_{2} \mathrm{SO}_{4}$ solution of Mg and Al sulfates.
$\mathrm{FeAl}_{2}\left(\mathrm{SO}_{4}\right)_{4} \cdot \mathbf{2 2 \mathrm { H } _ { 2 } \mathrm { O }}$ (Halotrichite) is monoclinic with $a=20.47, b=$ $24.2, c=6.17 k X, \beta=101^{\circ} c a$. U.C. 4. Crystals acicular. Poor $\{010\}$ cleavage. H. 1.5. G. 1.89. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=38^{\circ}$. (-) $2 \mathrm{~V}=35^{\circ} ; n_{\mathrm{X}}=1.480$, $n_{\mathrm{Y}}=1.486, n_{\mathrm{Z}}=1.490, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.010 \mathrm{Na}$. Colorless or pale yellow or green. Made from water solution.

[^107]( $\mathrm{Zn}, \mathrm{Fe}, \mathrm{Mn}) \mathrm{Al}_{2}\left(\mathrm{SO}_{4}\right)_{4} \cdot \mathbf{2 2 \mathrm { H } _ { 2 } \mathrm { O }}$ (Dietrichite) is monoclinic. Fibrous aggregates. H. 2. $\mathrm{X}=b ; \mathrm{Z} \wedge c=29^{\circ} c a .(+) 2 \mathrm{~V}=$ large. ${ }^{11} n_{\mathrm{X}}=1.475$, $n_{\mathrm{Y}}=1.480, n_{\mathrm{Z}}=1.488$, all $\pm 0.003, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.013$. Color dirty white to brownish yellow. Said to have been made from water solution.

## 7. Formula Type $\boldsymbol{A}_{2}\left(\mathrm{XO}_{4}\right)_{3} \cdot \mathbf{q} \mathbf{H}_{2} \mathbf{O}$

$\mathbf{C r}_{2}\left(\mathbf{S O}_{4}\right)_{3} \cdot \mathbf{1 8 H}_{\mathbf{2}} \mathbf{O}$ as obtained commercially is granular and amorphous with $^{109} n=1.564 \pm .003 \mathrm{Na}$. Color dark green. No crystals form; no X -ray pattern is obtained; it is isotropic.
$\mathbf{L a}_{2}\left(\mathbf{S O}_{4}\right)_{3} \cdot \mathbf{9 H}_{2} \mathbf{O}$ is hexagonal with $c / a=0.736$. Crystals long prismatic; no cleavage. G. 2.82. Uniaxial positive with $n_{\mathrm{O}}=1.564, n_{\mathrm{E}}=1.569$, $n_{\mathrm{E}}-n_{\mathrm{O}}=0.005$. Made from water solution.
$\mathrm{Fe}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot \mathbf{9 \mathrm { H } _ { 2 } \mathrm { O }}$ (Coquimbite) is hexagonal with $a=10.85, c=$ $17.03 k X$. U.C. 4. Crystals short prismatic or pyramidal. Poor $\{10 \overline{1} 1\}$ cleavage. H. 2.5. G. 2.11. Uniaxial positive with ${ }^{110} n_{\mathrm{O}}=1.536, n_{\mathrm{E}}=1.572$, $n_{\mathrm{E}}-n_{\mathrm{O}}=0.036$. Color pale violet to amethystine; also yellowish or greenish. PD 8.26, 2.76, 5.45; 6-0040. Made from water solution containing an excess of $\mathrm{H}_{2} \mathrm{SO}_{4}$.
$\mathrm{Fe}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot \mathbf{6 H}_{2} \mathrm{O}$ (Lausenite) is monoclinic. ${ }^{36}$ Crystals $\{010\}$ laths long parallel to $c . \mathrm{X} \wedge c=22^{\circ}$ red, $26^{\circ}$ blue; $\mathrm{Y}=b$. ( $-2 \mathrm{~V}=$ large, $n_{\mathrm{X}}=$ $1.598 \mathrm{C}, 1.605 \mathrm{D}, 1.624 \mathrm{~F}, n_{\mathrm{Y}}=1.627 \mathrm{C}, 1.635 \mathrm{D}, 1.656 \mathrm{~F}, n_{\mathrm{Z}}=1.648 \mathrm{C}$, $1.657 \mathrm{D}, 1.681 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.052 \mathrm{D}$. Again: $\mathrm{X} \wedge c=27^{\circ}, n_{\mathrm{X}}=1.598$, $n_{\mathrm{Y}}=1.628, n_{\mathrm{Z}}=1.654, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.056$. Colorless. Made from water solution; stable from $50^{\circ}$ to about $150^{\circ} \mathrm{C}$.
$\mathbf{F e}_{2}\left(\mathbf{S O}_{4}\right)_{3} \cdot \mathbf{7 H} \mathbf{H} \mathbf{O}$ (Kornelite) is monoclinic ${ }^{36}$ with $a: b: c=0.707: 1: 0.542$, $\beta=97^{\circ} 5^{\prime}$. Crystals laths or needles or fibers with $\{010\}$ cleavage. G. 2.31. $\mathrm{X} \wedge c=20^{\circ} \pm 2^{\circ} ; \mathrm{Z}=b .(+) 2 \mathrm{~V}=49^{\circ}-62^{\circ}, \mathrm{r}>\mathrm{v} . n_{\mathrm{X}}=1.572, n_{\mathrm{Y}}=$ 1.586, $n_{\mathrm{Z}}=1.640$, all $\pm 0.003, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.068 \mathrm{Na}$. Color pale rose-pink to violet. Made from $\mathrm{Fe}_{2} \mathrm{O}_{3} \cdot \mathrm{SO}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ below $80^{\circ} \mathrm{C}$.
$\mathbf{Y}_{2}\left(\mathbf{S O}_{4}\right)_{3} \cdot \mathbf{8 H} \mathbf{H} \mathbf{O}$ is monoclinic with $a: b: c=3.028: 1: 2.009, \beta=118^{\circ} 25^{\prime}$. Crystals equant to columnar by elongation parallel to $\{11 \overline{1}\}$. Twinning on $\{100\}$. Perfect $\{001\}$ and distinct $\{101\}$ cleavages. G. 2.56. X nearly normal to $\{001\} ; \mathrm{Y}=b .{ }^{111}(+) 2 \mathrm{~V}=50^{\circ} 43^{\prime}, \mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.5433, n_{\mathrm{Y}}=$ $1.549, n_{\mathrm{Z}}=1.5755, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0322$. Made from solution.
$\mathbf{P r}_{2}\left(\mathbf{S O}_{4}\right)_{3} \cdot \mathbf{8 H} \mathbf{2} \mathbf{O}$ is monoclinic with $a: b: c=2.986: 1: 2.00, \beta=118^{\circ}$. Crystals basal tablets or nearly equant with $\{001\},\{11 \overline{1}\},\{100\}$, etc. Perfect $\{001\}$ and distinct $\{10 \overline{1}\}$ cleavages. G. 2.82. X nearly normal to ( 001 ) ; $\mathrm{Z}=b .{ }^{111}(+) 2 \mathrm{~V}=84^{\circ} 51^{\prime} \mathrm{Li}, 85^{\circ} 27^{\prime} \mathrm{Na}, 84^{\circ} 52^{\prime} \mathrm{Tl}$; (abnormal

[^108]variations in 2 V between $\lambda=580$ and 600 (an absorption band). $n_{\mathrm{x}}=$ $1.5366 \mathrm{Li}, 1.5399 \mathrm{Na}, 1.5430 \mathrm{Tl}, n_{\mathrm{Y}}=1.5459 \mathrm{Li}, 1.5494 \mathrm{Na}, 1.5525 \mathrm{Tl}$, $n_{\mathrm{Z}}=1.5573 \mathrm{Li}, 1.5607 \mathrm{Na}, 1.5641 \mathrm{Tl}, n_{\mathrm{z}}-n_{\mathrm{X}}=0.0208 \mathrm{Na}$. Color dark green. Made from solution.
$\mathrm{Nd}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot \mathbf{8} \mathrm{H}_{2} \mathbf{O}$ is monoclinic with $a: b: c=2.984: 1: 1.997, \beta=118^{\circ} c a$. Crystals of varied habit. Perfect basal cleavage. G. 2.85. X nearly normal to $\{001\} ;^{111} \mathrm{Z}=b$. (+) $2 \mathrm{~V}=83^{\circ} 49^{\prime} \mathrm{Li}, 83^{\circ} 57^{\prime} \mathrm{Na}, 83^{\circ} 48^{\prime} \mathrm{Tl}$. $n_{\mathrm{x}}=1.5379$ $\mathrm{Li}, 1.5413 \mathrm{Na}, 1.5441 \mathrm{Tl}, n_{\mathrm{Y}}=1.5469 \mathrm{Li}, 1.5505 \mathrm{Na}, 1.5534 \mathrm{Tl}, n_{\mathrm{Z}}=1.5583$ $\mathrm{Li}, 1.5621 \mathrm{Na}, 1.5652 \mathrm{Tl}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0092 \mathrm{Na}$. Color light red with weak pleochroism and X and $\mathrm{Y}>\mathrm{Z}$. Made from solution. The same compound with $\operatorname{Pr}$ replacing some Nd has $\mathrm{G} .2 .83, \mathrm{X} \wedge c=26^{\circ} c a ., \mathrm{Z}=b$. (+) $2 \mathrm{~V}=$ $84^{\circ} 10^{\prime} . n_{\mathrm{X}}=1.5392, n_{\mathrm{Y}}=1.5479, n_{\mathrm{Z}}=1.5592, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.020$. Color light red (to green).
$\mathbf{S m}_{2}\left(\mathbf{S O}_{4}\right)_{3} \cdot \mathbf{8 H _ { 2 }} \mathbf{O}$ is monoclinic with $a: b: c=3.003: 1: 2.002, \beta=118^{\circ} 16^{\prime}$. Crystals basal tablets, etc. Perfect $\{001\}$ cleavage. Twinning common on $\{001\}$. X nearly normal to $\{001\} ; ;^{111} \mathrm{Z}=b .(+) 2 \mathrm{~V}=$ large. $n_{\mathrm{X}}=1.5395$ $\mathrm{Li}, 1.5427 \mathrm{Na}, 1.5458 \mathrm{Tl}, n_{\mathrm{Y}}=1.5486 \mathrm{Li}, 1.5519 \mathrm{Na}, 1.5551 \mathrm{Tl}, n_{\mathrm{Z}}=$ $1.5594 \mathrm{Li}, 1.5629 \mathrm{Na}, 1.5663 \mathrm{Tl}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0202 \mathrm{Na}$. Made from solution.
$\mathrm{Al}_{2}\left(\mathbf{S O}_{4}\right)_{3} \cdot \mathbf{1 8 H} \mathbf{H} \mathbf{O}$ (Alunogen) is triclinic with ${ }^{112} a: b: c=0.836: 1: 0.675$, $\alpha=89^{\circ} 58^{\prime}, \beta=97^{\circ} 26^{\prime}, \gamma=91^{\circ} 52^{\prime}$. Crystals rare, prismatic; usually fibrous. Perfect $\{010\}$ cleavage; also (?) $\{100\}$ and ( $\overline{3} 13\}$. H. 1.5-2. G. 1.78. X nearly $=b ; \mathrm{Z} \wedge c=41^{\circ} .(+) 2 \mathrm{~V}=31^{\circ}, n_{\mathrm{X}}=1.460, n_{\mathrm{Y}}=1.461, n_{\mathrm{Z}}=$ $1.470, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.010$. Colorless. PD 4.42, 3.95, 2.48; 1-0348. The water content of alunogen varies easily; the indices depend on the water content. Indices given are for a sample with $15.5 \mathrm{H}_{2} \mathrm{O}$. On heating to $75^{\circ} \mathrm{C}$. the content was about 12.5 and the indices were $n_{\mathrm{X}}=1.483, n_{\mathrm{Y}}=1.484$, $n_{\mathrm{Z}}=1.496$. Over about $90^{\circ} \mathrm{C}$. the material becomes isotropic with $n$ about 1.50 ; at $290^{\circ} \mathrm{C}$. the index is 1.54 . The substance does not rehydrate easily on exposure. Made from solution in HCl .

## 8. Formula Type $\mathbf{A}\left(\mathrm{XO}_{4}\right)_{2} \cdot \mathbf{q} \mathbf{H}_{2} \mathrm{O}$

$\mathbf{T h}\left(\mathbf{S O}_{4}\right)_{2} \cdot \mathbf{8 H _ { 2 }} \mathbf{O}$ is monoclinic with $a: b: c=0.754: 1: 0.557, \beta=93^{\circ}$. Crystals prismatic, striated parallel with $\{001\}$. Y $=b ; \mathrm{Z} \wedge c=+65^{\circ}$. $(+) 2 \mathrm{~V}=76^{\circ} 20^{\prime}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{Y}}=1.5168, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ very weak. Made from solution at about $30^{\circ} \mathrm{C}$.

## G. SULFITES, ETC., CONTAINING HALOGEN OR HYDROXYL

$\mathbf{C s S O}_{3} \mathbf{F}$ is tetragonal ${ }^{113}$ with $a=5.61, c=14.13 \AA$. U.C. 4. Crystals basal plates. G. $>3.38$. Good basal cleavage. Uniaxial negative with $n_{0}=$

[^109]$1.4755, n_{\mathrm{E}}=1.4645, n_{\mathrm{O}}-n_{\mathrm{E}}=0.011$. Also slightly biaxial. Colorless. PD 3.48, 2.21, 1.73; 3-0371.
$\left(\mathbf{N H}_{4}\right)_{3} \mathbf{P d S O}_{3} \mathbf{C l}_{3} \cdot \mathbf{H}_{2} \mathbf{O}$ is hexagonal rhombohedral with $c / a=0.892$. Distinct prismatic cleavage. Uniaxial positive with $n_{\mathrm{O}}=1.643, n_{\mathrm{E}}-n_{\mathrm{O}}=$ strong. Color deep red with O carmine and E reddish yellow. Made from water solution.

## H. SULFATES, ETC., CONTAINING HALOGEN, HYDROXYL, OR EXTRA OXYGEN

## 1. Formula Type $A_{m}\left(\mathrm{XO}_{4}\right)_{p} \mathbf{Z}_{q}$ with m:p $>\mathbf{2 : 1}$

$\mathbf{N a}_{3} \mathbf{S O}_{4}(\mathbf{F}, \mathbf{C l})$ (Schairerite) is hexagonal with $a=12.12, c=19.19 \mathrm{kX}$. Crystals basal tablets or rhombohedral. Distinct $\{0001\}$ cleavage. H. 3.5. G. 2.612. Uniaxial positive with ${ }^{114} n_{\mathrm{O}}=1.436, n_{\mathrm{E}}=1.439, n_{\mathrm{E}}-n_{\mathrm{O}}=$ 0.003 Na for the pure artificial F salt. With $\mathrm{F}: \mathrm{Cl}=4: 1 n_{\mathrm{O}}=1.440, n_{\mathrm{E}}=$ $1.445, n_{\mathrm{E}}-n_{\mathrm{O}}=0.005$; no cleavage. With $\mathrm{F}: \mathrm{Cl}=1: 1$ the compound is isometric. Colorless. PD 2.99, 2.69, 1.74; 2-0668. Made from water solution.
$\mathrm{Cu}_{3} \mathbf{S O}_{4}(\mathrm{OH})_{4}$ (Antlerite) is orthorhombic dipyramidal with $a=8.22$, $b=11.97, c=6.02 k X$. U.C. 4. Crystals often $\{010\}$ tablets or equant or short prismatic. Perfect $\{010\}$ and poor $\{100\}$ cleavages. H. 3.5. G. 3.88. $\mathrm{X}=b ; \quad \mathrm{Y}=a .{ }^{34}(+) 2 \mathrm{~V}=53^{\circ}, \quad n_{\mathrm{X}}=1.726, n_{\mathrm{Y}}=1.738, n_{\mathrm{Z}}=1.789$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.051$. Color green; pleochroic with X yellow-green, Y bluegreen, Z green. PD 4.86, 2.57, 3.60; 7-407/8. Made from water solution.
$\mathrm{Cu}_{4} \mathrm{SO}_{4}(\mathbf{O H})_{6}$ (Brochantite) is monoclinic ${ }^{114 a}$ with $a=13.05, b=9.83$, $c=5.85 \mathrm{kX}, \beta=103^{\circ} 22^{\prime}$. Crystals prismatic; twinning on $\{100\}$ common. Perfect $\{100\}$ cleavage. H. 3.5-4. G. 3.97. $\mathrm{X} \wedge a=13^{\circ} ; \mathrm{Y}=b$; Z very near $c .(-) 2 \mathrm{~V}=77^{\circ} \pm 2^{\circ}, \mathrm{r}<\mathrm{v}$ medium. ${ }^{34} n_{\mathrm{X}}=1.728, n_{\mathrm{Y}}=1.771$, $n_{\mathrm{z}}=1.800, n_{\mathrm{z}}-n_{\mathrm{x}}=0.072$. Color emerald green. PD 3.91, 6.5, 2.53; $3-0282$. Made from water solution.

## 2. Formula Type $A_{m}\left(\mathrm{XO}_{4}\right)_{p} \mathrm{Z}_{q}$ with $\mathrm{m}: \mathrm{p} \approx 2: 1$

$\mathbf{P b}_{2} \mathbf{S O}_{4}(\mathbf{O H})_{2}$ is isometric ${ }^{115}$ and isotropic with $n=1.93$.
$\left.\mathrm{KAl}_{3}\left(\mathbf{S O}_{4}\right)_{2} \mathbf{( O H}\right)_{6}$ (Alunite) is hexagonal with $a=6.96, c=17.35 \mathrm{kX}$. Crystals rare, may be pseudo-cubic. Distinct $\{0001\}$ cleavage. H. 3.5-4. G. 2.75. F. 7. Uniaxial positive with ${ }^{116} n_{\mathrm{O}}=1.572, n_{\mathrm{E}}=1.592, n_{\mathrm{E}}-n_{\mathrm{O}}=$ 0.020 . Colorless. PD 1.90, 1.75, 3.00; 4-0865*. Made by heating a solution of alum and aluminum sulfate in a sealed tube at $230^{\circ} \mathrm{C}$.

[^110]$\mathrm{KFe}_{3}\left(\mathbf{S O}_{4}\right)_{2} \mathbf{( \mathbf { O H } ) _ { 6 } \text { (Jarosite) is hexagonal, ditrigonal-pyramidal, with }}$ $a=7.20, c=17.00 \mathrm{kX}$. Crystals pseudo-cubic rhombohedrons. Distinct $\{0001\}$ cleavage. H. 2.5-3.5. G. 2.9-3.2. Uniaxial negative ${ }^{11}$ with $n_{\mathrm{O}}=$ $1.820, n_{\mathrm{E}}=1.715, n_{\mathrm{O}}-n_{\mathrm{E}}=0.105$. Also anomalously biaxial ${ }^{117}$ with $(-) 2 \mathrm{~V}$ very small. $n_{\mathrm{X}}=1.715 \pm .003, n_{\mathrm{Y}}=1.817, n_{\mathrm{Z}}=1.820, n_{\mathrm{Z}}-n_{\mathrm{X}}$ $=0.105$. Color brown with O brown, E colorless. PD 3.08, 3.11, 2.29; 10-443. Made at $110^{\circ} \mathrm{C}$. from a water solution.
$\mathbf{N H}_{4} \mathbf{F e}_{3}\left(\mathbf{S O}_{4}\right)_{2}(\mathbf{O H})_{6}$ (Ammoniojarosite) is hexagonal, ditrigonalpyramidal with $a=7.20, c=17.00 \mathrm{kX}$. Small grains may have hexagonal outline. G. 3.1 calc. Uniaxial negative with ${ }^{118} n_{\mathrm{O}}=1.800 \pm 0.005, n_{\mathrm{E}}=$ $1.750 \pm 0.005, n_{\mathrm{O}}-n_{\mathrm{E}}=0.05$. Again: ${ }^{119} n_{\mathrm{O}}=1.83, n_{\mathrm{E}}=1.745, n_{\mathrm{O}}-$ $n_{\mathrm{E}}=0.085$. Colorless.
$\mathbf{R b F e}_{3}\left(\mathbf{S O}_{4}\right)_{2}(\mathbf{O H})_{6}$ is hexagonal rhombohedral. Basal cleavage. Uniaxial negative. $n_{\mathrm{O}}=1.805, n_{\mathrm{E}}=1.720, n_{\mathrm{O}}-n_{\mathrm{E}}=0.085$. Color brown. Easily formed in a pyrex tube at $110^{\circ} \mathrm{C}$.
$\left.\mathrm{AgFe}_{3}\left(\mathbf{S O}_{4}\right)_{2} \mathbf{( O H}\right)_{6}$ (Argentojarosite) is hexagonal rhombohedral, with $a=7.22, c=16.40 k X$. Crystals $\{0001\}$ scales. Basal cleavage. G. 3.66. Uniaxial negative with ${ }^{24} n_{\mathrm{O}}=1.882, n_{\mathrm{E}}=1.785, n_{\mathrm{O}}-n_{\mathrm{E}}=0.097$. Color yellow to brown; pleochroic with O yellow, E pale yellow. Made from an acid solution at $110^{\circ} \mathrm{C}$.
$\mathbf{P b F e}_{6}\left(\mathrm{SO}_{4}\right)_{4}(\mathbf{O H})_{12}$ (Plumbojarosite) is hexagonal scalenohedral with $a=7.20, c=33.60 k X$. Fair $\{10 \overline{1} 4\}$ cleavage. H. $1 c a$. G. 3.665. Uniaxial negative ${ }^{120}$ with $n_{\mathrm{O}}=1.870, n_{\mathrm{E}}=1.783, n_{\mathrm{O}}-n_{\mathrm{E}}=0.087$. Again: ${ }^{11}$ $n_{\mathrm{O}}=1.875, n_{\mathrm{E}}=1.786, n_{\mathrm{O}}-n_{\mathrm{E}}=0.089$ (with a little $\mathrm{Na}, \mathrm{K}, \mathrm{Cu}, \mathrm{Ca}$ ). Color brown; pleochroic with O yellow-brown, E nearly colorless. PD 2.78, 1.72, 3.57; 5-0635.
$\left(\mathrm{H}_{2} \mathrm{O}\right) \mathrm{Fe}_{3}\left(\mathrm{SO}_{4}\right)_{2}\left[(\mathrm{OH})_{5} \mathrm{H}_{2} \mathrm{O}\right]$ (Carphosiderite) is hexagonal, ditrigonal pyramidal with $a=7.16, c=16.70 k X$. Crystals hexagonal plates or rhombohedrons. H. 4-4.5. G. 2.9(?). Uniaxial negative with ${ }^{36} n_{\mathrm{O}}=1.816$, $n_{\mathrm{E}}=1.728, n_{\mathrm{O}}-n_{\mathrm{E}}=0.088$. Color yellow with O deep yellow, E pale yellow. PD 3.06, 4.9, 1.97; 2-0597. Made from acid solutions ${ }^{36}$ of ferric sulfate up to $170^{\circ} \mathrm{C}$.
$\mathbf{P b}_{2} \mathbf{S O}_{4} \mathbf{O}$ (Lanarkite) is monoclinic prismatic with $a=13.73, b=5.68$, $c=7.07 k X, \beta=116^{\circ} 13^{\prime}$. Crystals long parallel to $b$. Perfect $\{\overline{2} 01\}$ and poor $\{\overline{4} 01\}$ and $\{201\}$ cleavages. H. 2-2.5. G. 6.92. Y $=b ;^{121} \mathrm{Z} \wedge c=30^{\circ}$. $(-) 2 \mathrm{~V}=60^{\circ} \pm 2^{\circ}, \mathrm{r}>\mathrm{v}$ strong, with inclined dispersion. $n_{\mathrm{X}}=1.928$,

[^111]$n_{\mathrm{Y}}=2.007, n_{\mathrm{Z}}=2.036$, all $\pm 0.003, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.108$. Colorless or nearly so. PD 3.33, 2.95, 3.67; 6-0276. Made by fusing PbO with $\mathrm{PbSO}_{4}$.
$\mathrm{Cu}_{2} \mathrm{SO}_{4} \mathrm{O}$ (Dolerophanite) is monoclinic prismatic with $a=9.39, b=$ $6.30, c=7.62 k X, \beta=127^{\circ} 41^{\prime}$. Crystals long parallel to $b$. Perfect $\{\overline{1} 01\}$ cleavage. H. 3. G. 4.17. $\mathrm{Y}=b^{121 \mathrm{a}} ; \mathrm{Z} \wedge c=+10^{\circ}$. $(+) 2 \mathrm{~V}=85^{\circ}, \mathrm{r}>\mathrm{v}$ strong with crossed dispersion. $n_{\mathrm{X}}=1.715, n_{\mathrm{Y}}=1.820, n_{\mathrm{Z}}=1.880$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.165$. Color brown; pleochroic with X deep brown, Y brownish yellow, Z lemon yellow. Made by ignition of $\mathrm{CuSO}_{4}$ at $650^{\circ} \mathrm{C}$.
$\mathbf{C u P b}\left(\mathbf{S O}_{4}\right)(\mathbf{O H})_{2}($ Linarite $)$ is monoclinic with $a: b: c=1.716: 1: 0.8296$, $\beta=102^{\circ} 37^{\prime}$. Crystals prismatic along $b$. Distinct $\{100\}$ and poor $\{001\}$ cleavages. G. 5.3-5.4. $\mathrm{X} \wedge c=-14^{\circ}, \mathrm{Z}=b .^{122}(-) 2 \mathrm{~V}=79^{\circ} 59^{\prime}, \mathrm{r}<\mathrm{v}$. $n_{\mathrm{X}}=1.8090, n_{\mathrm{Y}}=1.8380, n_{\mathrm{Z}}=1.8593, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0503$. Color blue with weak pleochroism. PD 3.12, 3.53, 1.79; 4-0598. Found in many old furnace slags.

## 3. Formula Type $A_{m}\left(\mathrm{XO}_{4}\right)_{p} \mathbf{Z}_{q} \cdot \mathbf{x H} \mathbf{H}$

$\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{SO}_{4}(\mathbf{O H})_{12} \cdot \mathbf{6} \mathrm{H}_{2} \mathrm{O}$ is hexagonal. ${ }^{123}$ Crystals basal plates. G. 1.95. Positive elongation. Uniaxial negative with ${ }^{11} n_{\mathrm{O}}=1.504, n_{\mathrm{E}}=1.488$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.016$. Again: $n_{\mathrm{O}}=1.517, n_{\mathrm{E}}=1.499, n_{\mathrm{O}}-n_{\mathrm{E}}=0.018$. Partial dehydration (to $4 \mathrm{H}_{2} \mathrm{O}$ ?) leads to ${ }^{124} n_{\mathrm{O}}=1.519, n_{\mathrm{E}}=1.506, n_{\mathrm{O}}-n_{\mathrm{E}}=$ 0.013 . Dehydration at $110^{\circ} \mathrm{C}$. to about $3 \mathrm{H}_{2} \mathrm{O}$ leads to variable results, as $n_{\mathrm{O}}=1.529-1.535, \quad n_{\mathrm{E}}=1.519-1.527, \quad n_{\mathrm{O}}-n_{\mathrm{E}}=0.010-0.008$. Not as stable as $\mathrm{Ca}_{6} \mathrm{Al}_{2}\left(\mathrm{SO}_{4}\right)_{3}(\mathrm{OH})_{12} \cdot 26 \mathrm{H}_{2} \mathrm{O}$. Colorless. Produced by reaction of sulfate water on Portland cement; also from water solution at high temperature.
$\mathrm{Cu}_{4} \mathrm{SO}_{4}(\mathrm{OH})_{6} \cdot \mathrm{H}_{2} \mathrm{O}(?)$ (Langite) is orthorhombic with $a: b: c=$ $0.5347: 1: 0.6346$. Crystals equant or lamellar. $\{001\}$ and $\{010\}$ cleavages. H. 2.5-3. G. $3.48-3.50 . \mathrm{X}=c ; \mathrm{Y}=b .^{125}(-) 2 \mathrm{~V}=37^{\circ}-66^{\circ}, n_{\mathrm{X}}=1.654$, $n_{\mathrm{Y}}=1.713, n_{\mathrm{Z}}=1.722, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.068 \mathrm{Na}$. Color blue or greenish. Pleochroic with X light yellow-green, Y blue-green, Z sky-blue. Made by treating $\mathrm{Cu}_{2} \mathrm{SO}_{5}$ with cold water. PD 3.91, 6.50, 2.53; 3-0282(?).
$\mathrm{Al}_{4} \mathrm{SO}_{4}(\mathbf{O H})_{10} \cdot \mathbf{1 0 H}_{2} \mathrm{O}$ (Paraluminite) is orthorhombic(?). X parallel with elongation. ${ }^{125 \mathrm{a}}(-) 2 \mathrm{~V}=$ small, $n_{\mathrm{X}}=1.463 \pm .003, \quad n_{\mathrm{Y}}=1.471$, $n_{\mathrm{Z}}=1.471, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.008$. Color white to pale yellow. Found in concrete.
${ }^{121 a}$ Richmond and Wolfe: Am. Min. XXV, p. 606 (1940); the usual meaning of "crossed dispersion" cannot apply if $\mathrm{Y}=b$.
${ }^{122}$ Brugnatelli: Zeit. Krist. XXVIII, p. 307 (1897).
${ }^{123}$ Lerch, Ashton and Bogue: J. Res. Nat. Bur. Stand. II, p. 715 (1929).
${ }^{124}$ Mylius: Acta Acad. Abo Math. Phys. VII, No. 3 (1933).
${ }^{125}$ Meixner: Zent. Min. p. 11 (1941); Koritnig: Zent. Min. p. 154 (1941).
${ }^{125 a}$ Hutton: New Zealand J. Sci. Tech. XXVI, 242 (1945).
$\mathrm{Ca}_{6} \mathrm{Fe}_{2}\left(\mathrm{SO}_{4}\right)_{3}(\mathbf{O H})_{12} \cdot \mathbf{2 6} \mathrm{H}_{2} \mathrm{O}$ is hexagonal. Crystals prismatic with positive elongation. Uniaxial positive ${ }^{126}$ with $n_{\mathrm{O}}=1.486, n_{\mathrm{E}}=1.492, n_{\mathrm{O}}-$ $n_{\mathrm{E}}=0.006$.
$\mathrm{Ca}_{6} \mathrm{Al}_{2}\left(\mathrm{SO}_{4}\right)_{3}(\mathbf{O H})_{12} \cdot \mathbf{2 6 H}_{2} \mathrm{O}$ (Ettringite) is hexagonal with $a=11.24$, $c=21.45 k X$. U.C. 2. Crystals small prismatic. Perfect $\{10 \overline{1} 0\}$ cleavage. H. 2-2.5. G. 1.77. Uniaxial negative with $n_{\mathrm{O}}=1.464, n_{\mathrm{E}}=1.458, n_{\mathrm{O}}-$ $n_{\mathrm{E}}=0.006$. During dehydration the indices increase, $n_{\mathrm{E}}$ more rapidly than $n_{\mathrm{O}}$, and the sign becomes positive. ${ }^{127}$ Colorless. PD 9.73, 5.61, 3.88; 9-414. Made from solution at moderate temperature.
$\mathbf{K M g S O} 4 \mathbf{C l} \cdot \mathbf{3 H} \mathbf{2} \mathbf{O}$ (Kainite) is monoclinic with ${ }^{127} a=19.05, b=16.24$, $c=9.86 \AA, \beta=94^{\circ} 55^{\prime}$. Crystals nearly equant often with many faces. Perfect $\{001\}$ cleavage. H. 2.5-3. G. 2.15. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=13^{\circ}$. (-) $2 \mathrm{~V}=$ $85^{\circ} c a ., \mathrm{r}>$ v very weak. $n_{\mathrm{X}}=1.494, n_{\mathrm{Y}}=1.505, n_{\mathrm{Z}}=1.516, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.022 . Colorless or may be stained blue, violet, gray, yellowish or reddish; blue or violet samples may be pleochroic with X violet, Y blue and Z yellowish. Made from water solutions ${ }^{12^{-a}}$ (rich in $\mathrm{MgCl}_{2}$ ) between $13^{\circ} \mathrm{C}$. and $95^{\circ} \mathrm{C}$.
$\mathrm{Na}_{4} \mathrm{Fe}_{2}\left(\mathrm{SO}_{4}\right)_{4}(\mathbf{O H})_{2} \cdot \mathbf{3} \mathrm{H}_{2} \mathrm{O}$ (Metasideronatrite) is orthorhombic with $a: b: c=0.4571: 1: 0.1187$. Crystals prismatic, rare. Perfect $\{100\}$ and $\{010\}$, and good $\{001\}$ cleavages. H. 2.5. G. 2.46. $\mathrm{X}=a ; \mathrm{Y}=b .(+) 2 \mathrm{~V}=$ $60^{\circ}, \mathrm{r}>\mathrm{v}$ strong. ${ }^{80} n_{\mathrm{X}}=1.543, n_{\mathrm{Y}}=1.575, n_{\mathrm{Z}}=1.634, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.091 . Color yellow; pleochroic with X colorless, Y light yellow, Z brownish yellow. Made by dehydration of sideronatrite over sulfuric acid.
$\mathrm{Na}_{2} \mathrm{Fe}\left(\mathrm{SO}_{4}\right)_{2}(\mathbf{O H}) \cdot \mathbf{3 H} \mathbf{H}_{2} \mathrm{O}$ (Sideronatrite) is orthorhombic(?). Crystals acicular along $c$. Perfect $\{100\}$ cleavage. H. 1.5-2.5. G. 2.15-2.35. $\mathrm{X}=a$; $\mathrm{Y}=b .{ }^{11}(+) 2 \mathrm{~V}=58^{\circ} \pm 5^{\circ}$ calc., $\mathrm{r}>\mathrm{v}$ strong. $n_{\mathrm{X}}=1.508, n_{\mathrm{Y}}=1.525$, $n_{\mathrm{Z}}=1.586$, all $\pm 0.003, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.078$. Color yellow of various shades. Pleochroic with X nearly colorless, Y very pale amber yellow, Z pale amber yellow. Made from water solution.
$\mathrm{K}_{2}\left(\mathbf{U O}_{2}\right)\left(\mathbf{S O}_{4}\right)_{2} \cdot \mathbf{2 H} \mathbf{H} \mathbf{O}$ is orthorhombic with ${ }^{128} a=11.55, b=13.78, c=$ $7.28 \AA$. U.C. 4. Crystals basal tablets or pyramidal. Distinct $\{001\}$ cleavage. G. 3.33. $\mathrm{X}=c ; \mathrm{Y}=a$. ( + ) $2 \mathrm{~V}=60^{\circ}$ calc.; for ${ }^{128} \lambda=720 \mathrm{~m} \mu$ : $n_{\mathrm{X}}=$ $1.510, n_{\mathrm{Y}}=1.522, n_{\mathrm{Z}}=1.563, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.054$; for $\lambda=580 \mathrm{~m} \mu: n_{\mathrm{X}}=$ $1.5144, n_{\mathrm{Y}}=1.5266, n_{\mathrm{Z}}=1.5705, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0561$; for $\lambda=500 \mathrm{~m} \mu$ : $n_{\mathrm{X}}=1.520, n_{\mathrm{Y}}=1.535, n_{\mathrm{Z}}=1.585, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.065$. Again: ${ }^{129} n_{\mathrm{X}}=$ ?, $n_{\mathrm{Y}}=1.529, n_{\mathrm{Z}}=1.575$. Not pleochroic. PD 6.81, $5.54,3.65 ; 8-128$. Made from water solution with $\mathrm{NH}_{4} \mathrm{OH}$ added at $25^{\circ} \mathrm{C}$.

[^112]$\mathbf{H}_{2}\left(\mathbf{U O}_{2}\right)\left(\mathbf{S O}_{4}\right)_{2} \cdot 5 \mathbf{H}_{2} \mathbf{O}$ is orthorhombic ${ }^{129}$ with $a=12.86, b=12.99, c=$ 11.57 Å. U.C. 4. G. 3.16. $\mathrm{Z}=c .(-) 2 \mathrm{~V}=$ very small, $n_{\mathrm{X}}=1.555, n_{\mathrm{Y}}=$ $1.586, n_{\mathrm{Z}}=1.586, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.031$. Pleochroic with X colorless, Y and Z pale yellow. Made from water solution.
$\left(\mathbf{U O}_{2}\right)_{3}\left(\mathrm{SO}_{4}\right)_{2}(\mathbf{O H})_{2} \cdot \mathbf{8} \mathrm{H}_{\mathbf{2}} \mathrm{O}$ (Zippeite) is monoclinic with ${ }^{129} a=8.81$, $b=14.13, c=8.85 \AA, \beta=104^{\circ} 15^{\prime}$. U.C. 2. Crystals tiny $\{010\}$ plates. Twinning on $\{001\}$ very common. H. 3. G. 3.66. $\mathrm{X}=b ; \mathrm{Z} \wedge c=3^{\circ}$. $(-) 2 \mathrm{~V}=83^{\circ}$ calc. $n_{\mathrm{X}}=1.655, n_{\mathrm{Y}}=1.717, n_{\mathrm{Z}}=1.765, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.110$. Again: ${ }^{11} n_{\mathrm{X}}=1.64, n_{\mathrm{Y}}=1.718, n_{\mathrm{Z}}=1.766, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.126$. Color orange yellow with X colorless, Y pale yellow, Z yellow. PD 7.31, 3.66, 3.15; 8-402*. Made from water solution.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{U O}_{2}\left(\mathbf{S O}_{4}\right)_{2} \cdot 2 \mathbf{H}_{2} \mathbf{O}$ is monoclinic with ${ }^{129} a=20.53, b=7.30, c=$ $7.74, \beta=99^{\circ} 25^{\prime}$. U.C. 4. G. 3.07. $n_{\mathrm{X}}=$ ?, $n_{\mathrm{Y}}=1.555, n_{\mathrm{Z}}=1.600$. Pleochroic with X and Y colorless, Z pale green. PD 6.7, 3.38, $5.38 ; 8-182$.
$\left(\mathrm{UO}_{2}\right)_{6}(\mathbf{O H})_{10} \mathbf{S O}_{4} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ (Uranopilite) ${ }^{129 \mathrm{a}}$ is probably monoclinic. ${ }^{129}$ Crystals needles or laths. Perfect $\{010\}$ cleavage. G. 3.7-4.0. Loses $\mathrm{H}_{2} \mathrm{O}$ easily down to $5 \mathrm{H}_{2} \mathrm{O} . \mathrm{X}=b ; \mathrm{Y} \wedge c=16^{\circ}-18^{\circ}$. (+) $2 \mathrm{~V}=$ moderate, $\mathrm{r}<\mathrm{v}$ extreme. $n_{\mathrm{X}}=1.620, n_{\mathrm{Y}}=1.624, n_{\mathrm{Z}}=1.630, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.010$. Color yellow, not pleochroic. PD 7.12, 9.18, 4.28; 8-443.
$\mathrm{Be}_{2}\left(\mathrm{C}_{2} \mathbf{H}_{5}\right)_{2}\left(\mathbf{S O}_{4}\right)_{2} \mathbf{O} \cdot \mathbf{4 \mathbf { H } _ { 2 } \mathbf { O }}$ is tetragonal with ${ }^{130} \quad c / a=0.671$. Crystals show $\{001\},\{111\},\{100\}$. No good cleavage. G. 1.857. Uniaxial negative with $n_{\mathrm{O}}=1.473, n_{\mathrm{E}}=1.435, n_{\mathrm{O}}-n_{\mathrm{E}}=0.038$.
$(\mathrm{K}, \mathrm{Na})_{5} \mathrm{Fe}^{\prime \prime \prime}{ }_{3}\left(\mathrm{SO}_{4}\right)_{6}(\mathbf{O H}) \cdot \mathbf{9} \mathrm{H}_{2} \mathrm{O}$ (?) (Metavoltine) is hexagonal with $a=19.43, c=18.60 k X$. U.C. 8. (It may contain some $\mathrm{Fe}^{\prime \prime}$.) Crystals basal tablets. Perfect $\{0001\}$ cleavage. H. 2.5. G. 2.396. Uniaxial negative with $^{80} n_{\mathrm{O}}=1.589-1.590, n_{\mathrm{E}}=1.572-1.574, n_{\mathrm{O}}-n_{\mathrm{E}}=0.017-0.016$. Color yellowish to greenish brown with O dark yellow to lemon, E light yellow (greenish).
$\left(\mathbf{U O}_{2}\right)\left(\mathbf{S O}_{4}\right) \cdot 3 \mathrm{H}_{2} \mathbf{O}$ is orthorhombic with ${ }^{129} a=12.58, b=17.00, c=$ 6.73 $k X$. U.C. 8. G. 3.84. $\mathrm{Z}=c .(-) 2 \mathrm{~V}=54^{\circ}$ calc. $n_{\mathrm{X}}=1.574, n_{\mathrm{Y}}=$ $1.589, n_{\mathrm{Z}}=1.593, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.019$. Pleochroic with X colorless, Y pale green, Z grayish green. PD 5.0, 3.99, 2.50; 8-191. Made from water solution.
$\mathrm{Fe}\left(\mathrm{SO}_{4}\right)(\mathbf{O H}) \cdot 2 \mathrm{H}_{2} \mathrm{O}$ (Butlerite) is monoclinic(?) with $a: b: c=$ $0.8752: 1: 0.7897, \beta=108^{\circ} 35^{\prime}$. Crystals $\{001\}$ or $\{100\}$ tablets or octahedral. Perfect $\{100\}$ cleavage. H. 2.5. G. 2.55. $\mathrm{X} \wedge c=19^{\circ} ; \mathrm{Z}=b .{ }^{36}$ $(-) 2 \mathrm{~V}=$ large, $n_{\mathrm{X}}=1.588, n_{\mathrm{Y}}=1.678, n_{\mathrm{Z}}=1.749, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.161$. Color deep orange; pleochroic with X colorless, Y faint yellow, Z light yellow. Made from water solution.
$\mathrm{Fe}\left(\mathrm{SO}_{4}\right)(\mathbf{O H}) \cdot \mathbf{3 \mathrm { H } _ { 2 } \mathrm { O }}$ (Amarantite) is triclinic pinacoidal with $a: b: c=$

[^113]
## VIII. Molybdates and Tungstates

The molybdates and tungstates are classified as A. anhydrous, B. hydrated, C. compound. The anhydrous have three types of formula: $\mathrm{AXO}_{4}, \mathrm{~A}_{2}\left(\mathrm{XO}_{4}\right)_{3}$ and $\mathrm{AB}\left(\mathrm{XO}_{4}\right)_{2}$.
A. Anhydrous . . . . . . . . . . . . . . . . . . . . . . . . . . . . 180

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B. Hydrated . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 183
C. Compound Molybdates and Tungstates . . . . . . . . . . . . . . . 183

## A. ANHYDROUS

## 1. Formula Type $\mathbf{A X O}_{4}$

$\mathrm{CaWO}_{4}$ (Scheelite) is tetragonal dipyramidal with $a=5.246, c=$ $11.349 k X$. U.C. 4. Crystals pyramidal or tabular with distinct $\{101\}$ cleavage. H. 4.5-5. G. 6.10. M.P. $1570^{\circ}$ C. Decomposed by HCl. Uniaxial positive with ${ }^{1} n_{\mathrm{O}}=1.9124 \mathrm{C}, 1.9200 \mathrm{D}, 1.9298 \mathrm{E}, 1.9344$ (475), $n_{\mathrm{E}}=$ $1.9281 \mathrm{C}, 1.9365 \mathrm{D}, 1.9468 \mathrm{E}, 1.9525$ (475), $n_{\mathrm{E}}-n_{\mathrm{O}}=0.0165 \mathrm{D}$. Color white. Made from fusion and in other ways. $\mathrm{CaWO}_{4}$ with 10.3 per cent of $\mathrm{Ce}_{2}\left(\mathrm{WO}_{4}\right)_{3}$ is nearly the same, with $n_{\mathrm{O}}=1.9197 \mathrm{C}, 1.9266 \mathrm{D}, 1.9365 \mathrm{E}$, $n_{\mathrm{E}}=1.9331 \mathrm{C}, 1.9412 \mathrm{D}, 1.9517 \mathrm{E}, n_{\mathrm{E}}-n_{\mathrm{O}}=0.0146 \mathrm{D}$. Color yellow. PD 3.11, 1.60, 1.94; 8-145*.
$\mathrm{CaMoO}_{4}$ (Powellite) is tetragonal dipyramidal with $a=5.23, c=$ $11.44 k X$. U.C. 4. Crystals pyramidal; rarely thin basal plates. Poor $\{101\}$ cleavage; also $\{112\}$ and $\{001\}$. H. 3.5-4. G. 4.2. F. 4. Decomposed by HCl . Uniaxial positive with $^{2} n_{\mathrm{O}}=1.959, n_{\mathrm{E}}=1.967$ for $667 \mathrm{~m} \mu ; n_{\mathrm{O}}=$ $1.974, n_{\mathrm{E}}=1.984, n_{\mathrm{E}}-n_{\mathrm{O}}=0.010$ for $570 m \mu ; n_{\mathrm{O}}=1.982, n_{\mathrm{E}}=1.993$ for $533 m \mu$. Color yellow, brown, greenish blue, etc. Made from fusion. $\mathrm{CaMoO}_{4}$ with 10.28 per cent of $\mathrm{WO}_{3}$ has $^{3} n_{\mathrm{O}}=1.967 \pm 0.005, n_{\mathrm{E}}=1.978$ $\pm 0.005, n_{\mathrm{E}}-n_{\mathrm{O}}=0.013 . \mathrm{CaMoO}_{4}$ with $^{1} 39$ per cent of $(\mathrm{Nd}, \operatorname{Pr})_{2}\left(\mathrm{MoO}_{4}\right)_{3}$ is uniaxial positive ${ }^{4}$ with $n_{\mathrm{O}}=2.007, n_{\mathrm{E}}=2.001, n_{\mathrm{O}}-n_{\mathrm{E}}=0.006$. Color violet. $\mathrm{CaMoO}_{4}$ with ${ }^{1} 4.7$ per cent of $\mathrm{Y}_{2}\left(\mathrm{MoO}_{4}\right)_{3}$ has $n_{\mathrm{O}}=1.978, n_{\mathrm{E}}=1.986$ for $667 m \mu ; n_{\mathrm{O}}=1.993, n_{\mathrm{E}}=2.002, n_{\mathrm{E}}-n_{\mathrm{O}}=0.009$ for $570 m \mu ; n_{\mathrm{O}}=$ $2.003, n_{\mathrm{E}}=2.012$ for $533 m \mu$. Color white. $\mathrm{CaMoO}_{4}$ with ${ }^{1} 21$ per cent of

[^114]$\mathrm{Ce}_{2}\left(\mathrm{MoO}_{4}\right)_{3}$ and 24.3 per cent of $\mathrm{Y}_{2}\left(\mathrm{MoO}_{4}\right)_{3}$ has $n_{\mathrm{O}}=1.9905 \mathrm{C}, 2.0004 \mathrm{D}$, $2.0163 \mathrm{E}, n_{\mathrm{E}}=1.9939 \mathrm{C}, 2.0049 \mathrm{D}, 2.0208 \mathrm{E}, n_{\mathrm{E}}-n_{\mathrm{O}}=0.0045 \mathrm{D}$. Color orange red. PD 3.10, 1.93, 4.76; 7-212*.
$\mathrm{SrMoO}_{4}$ is tetragonal ${ }^{1}$ with $c / a=1.574$. Crystals pyramidal. G. 4.15. Uniaxial positive. With 2.4 per cent of $\mathrm{Ce}_{2}\left(\mathrm{MoO}_{4}\right)_{3}: n_{\mathrm{O}}=1.9088, n_{\mathrm{E}}=$ 1.9127 for $667 m \mu$; $n_{\mathrm{O}}=1.9210, n_{\mathrm{E}}=1.9258, n_{\mathrm{E}}-n_{\mathrm{O}}=0.0048$ for 570 $m \mu ; n_{\mathrm{O}}=1.9290, n_{\mathrm{E}}=1.9350$ for $533 m \mu$. With 39.7 per cent of $\mathrm{Ce}_{2}\left(\mathrm{MoO}_{4}^{\prime}\right)_{3}$ : $n_{\mathrm{O}}=1.937, n_{\mathrm{E}}=1.940$ for $667 m \mu ; n_{\mathrm{O}}=1.952, n_{\mathrm{E}}=1.956, n_{\mathrm{E}}-n_{\mathrm{O}}=$ 0.004 for $570 m \mu$; $n_{\mathrm{O}}=1.958, n_{\mathrm{E}}=1.963$ for $533 m \mu$. Color yellow. Made from fusion with NaCl at $1200^{\circ} \mathrm{C}$. PD 3.22, 2.01, 1.64; 8-482.
$\mathbf{P b M o O}_{4}$ (Wulfenite) is tetragonal with $a=5.401, c=12.079 k X$. U.C. 4. Crystals basal tablets or, rarely, pyramidal. Distinct $\{011\}$ cleavage. H. 3. G. $6.5-7.0$. M.P. $1065^{\circ}$ C. Uniaxial negative with ${ }^{5} n_{\mathrm{O}}=2.3620, n_{\mathrm{E}}=$ 2.2558 for $687 m \mu, n_{\mathrm{O}}=2.4053, n_{\mathrm{E}}=2.2826, n_{\mathrm{O}}-n_{\mathrm{E}}=0.1227$ for $589 m \mu$; $n_{\mathrm{O}}=2.4542, n_{\mathrm{E}}=2.3131$ for $527 m \mu$. Color yellow; also gray, green, brown, red. Made by fusion. May contain some W for Mo and (or) Ca for Pb . $\mathrm{PD} 3.24,2.02,1.65 ; 8-475^{*}$.
$\mathrm{PbWO}_{4}$ (Stolzite) is tetragonal with $a=5.452, c=12.031 k X$. U.C. 4 . Crystals often pyramidal. Poor $\{001\}$ cleavage. H. 2.5-3. G. 7.9-8.3. M.P. $1123^{\circ}$ C. Uniaxial negative with $^{3} n_{\mathrm{O}}=2.27 \pm 0.01, n_{\mathrm{E}}=2.19 \pm 0.01$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.08$. Color brown or yellow; rarely green or red. Made by sublimation or fusion. PD 3.24, 1.66, 2.02; 8-108*.
$\mathrm{MnWO}_{4}$ (Huebnerite) is monoclinic prismatic with $a=4.84, b=5.76$, $c=4.97 k X, \beta=90^{\circ} 53^{\prime}$. Crystals usually prismatic. Perfect $\{010\}$ cleavage. H. 4. G. 7.1. $\mathrm{X}=b ; \mathrm{Z} \wedge c=17^{\circ}$ in acute $\beta$. $(+) 2 \mathrm{~V}=75^{\circ}$. $n_{\mathrm{X}}=$ $2.150, n_{\mathrm{Y}}=2.195, n_{\mathrm{Z}}=2.283, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.133$. Color yellowish to reddish brown with varying pleochroism, for example: X green or yellow or red, Y yellowish brown or greenish yellow or red, Z olive green or red. Made by fusion. ${ }^{6} \mathrm{PD} 3.00,2.96,3.78 ; 10-477 . \mathrm{MnWO}_{4}$ forms a complete series of mix-crystals (wolframite) with $\mathrm{FeWO}_{4}$ (ferberite).
$\mathrm{FeWO}_{4}$ (Ferberite) is monoclinic with $a=4.70, b=5.69, c=4.93 \mathrm{kX}$, $\beta=90^{\circ} 0^{\prime}$. Crystals often long parallel with $b$; rarely prismatic. Perfect $\{010\}$ cleavage. H. 4.5. G. 7.5. $\mathrm{X}=b ; \mathrm{Z} \wedge c=30^{\circ} c a$. (less with some Mn ) in acute $\beta$. ( + ) $2 \mathrm{~V}=68^{\circ}, n_{\mathrm{X}}=2.255, n_{\mathrm{Y}}=2.305, n_{\mathrm{Z}}=2.414, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.159. Color black. Opaque even in thin flakes. Optic properties determined in infrared light. ${ }^{7}$ Made by fusion. ${ }^{6}$ PD 2.94, 1.71, 2.47; 10-449. $\mathrm{FeWO}_{4}$ forms a complete series of mix-crystals (wolframite) with $\mathrm{MnWO}_{4}$ (huebnerite).

[^115]$\mathbf{M g W O}_{4}$ is monoclinic ${ }^{8}$ and isomorphous with wolframite with $a=4.67$, $b=5.66, c=4.92 \AA ., \beta=90^{\circ} 25^{\prime}$. G. 5.66 . $\mathrm{Y}=b$ and extinction on $\{010\}$ is at $4.5^{\circ} .2 \mathrm{~V}=$ large. Refringence very high and birefringence extreme. PD 2.93, 3.70, 4.68; 7-190.
$\mathbf{P b W O}_{4}$ (Raspite) is monoclinic prismatic with $a: b: c=1.345: 1: 1.115$, $\beta=107^{\circ} 37^{\prime}$. Crystals usually $\{100\}$ tablets with $\{001\},\{011\},\{010\}$, etc. Perfect $\{100\}$ cleavage. H. 2.5-3. G. 8.46. Y $=b,{ }^{3} \mathrm{Z} \wedge c \approx 30^{\circ}$. (+)2V $=$ very small. $n_{\mathrm{X}}$ and $n_{\mathrm{Y}}=2.27 \pm 0.02, n_{\mathrm{Z}}=2.30 \pm 0.02, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.03$. Color brown, yellow, gray. Two phases of $\mathrm{PbWO}_{4}$ have been made; they are probably stolzite and raspite. PD $3.25,2.02,1.66 ; 8-476$ (raspite?); $3.24,1.66,2.02 ; 8-108$ (stolzite).

## 2. Formula Type $\mathbf{A B}\left(\mathrm{XO}_{4}\right)_{2}$

$\mathrm{NaAl}\left(\mathrm{WO}_{4}\right)_{2}$ is orthorhombic. ${ }^{8 \mathrm{a}}$ Crystals acicular. $n_{\mathrm{X}}=1.658, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.702, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.044$. Color white. Made from fusion.

## 3. Formula Type $\mathbf{A}_{2}\left(\mathrm{XO}_{4}\right)_{3}$

$\mathbf{Y}_{2}\left(\mathbf{M o O}_{4}\right)_{3}$ is tetragonal with $c / a=1.542$. Crystals pyramidal with $\{001\}$. Distinct basal cleavage. G. 4.79. M.P. $1347^{\circ}$ C. Uniaxial positive with $n_{\mathrm{E}}=2.013$ for $667 m \mu, 2.031$ for $570 m \mu$, and 2.043 for $533 m \mu$. $n_{\mathrm{E}}-$ $n_{0}=$ very weak. Also slightly biaxial with $2 \mathrm{E}=10^{\circ}$ or less. Also orthorhombic with perfect $\{001\}$ and distinct $\{110\}$ cleavages. Color white or yellowish. Made from fusion.
$\mathbf{C e}_{2}\left(\mathbf{M o O}_{4}\right)_{3}$ is tetragonal ${ }^{1}$ (above $900^{\circ}$ C.) with $c / a=1.562$. Uniaxial negative with $n_{\mathrm{O}}=2.0185, n_{\mathrm{E}}=2.0067$ for $667 \mathrm{~m} \mathrm{\mu}$; $n_{\mathrm{O}}=2.0403, n_{\mathrm{E}}=$ 2.0277, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.0126$ for $570 m \mu$; $n_{\mathrm{O}}=2.0512, n_{\mathrm{E}}=2.0375$ for 533 $m \mu$. Color orange to red; yellow in powder. Made by heating to about $900^{\circ} \mathrm{C}$. Metastable at $0^{\circ} \mathrm{C}$., the stable form being orthorhombic and dark green, not measured optically.
$\mathbf{P r}_{2}\left(\mathbf{M o O}_{4}\right)_{3}$ is tetragonal ${ }^{1}$ with $c / a=1.544$. Crystals pyramidal. G. 4.84. M.P. $1030^{\circ}$ C. Uniaxial negative with $n_{\mathrm{E}}=1.990$ for $667 m \mu, 2.007$ for $570 m \mu$ and 2.016 for $533 m \mu$. $n_{\mathrm{O}}-n_{\mathrm{E}}=$ weak: Color grass-green. Made from fusion.
$(\mathbf{N d}, \mathbf{P r})_{2}\left(\mathbf{M o O}_{4}\right)_{3}$ is tetragonal ${ }^{1}$ with $c / a=1.549$. Crystals pyramidal or $\{001\}$ tablets. G. 4.96. M.P. 1125-1144 ${ }^{\circ}$ C. Uniaxial negative with $n=$ $2.012 \mathrm{C}, 2.026 \mathrm{D}, 2.054 \mathrm{~F}, n_{\mathrm{O}}-n_{\mathrm{E}}=$ weak. Made from fusion.
$\mathbf{N d}_{2}\left(\mathbf{M o O}_{4}\right)_{3}$ is tetragonal ${ }^{1}$ with $c / a=1.548$. Crystals pyramidal. G. 5.14. M.P. $1176^{\circ}$ C. Uniaxial negative with $n_{\mathrm{O}}=2.0052, n_{\mathrm{E}}=2.0038$ for $667 m \mu ; n_{\mathrm{O}}=2.0239, n_{\mathrm{E}}=2.0218, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0021$ for $570 m \mu ; n_{\mathrm{O}}=$ $2.0313, n_{\mathrm{E}}=2.0293$ for $533 \mathrm{~m} \mu$. Color violet. Made from fusion.
${ }^{8}$ Machatschki: Zeit. Krist. LXVII, p. 163 (1928).
${ }^{8 a}$ Saalfeld: N. Jahrb. Min. Monatshefte, 1955, p. 207.

## B. HYDRATED

$\mathrm{Na}_{2} \mathbf{W O}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ is orthorhombic with $a: b: c=0.800: 1: 0.647$. Crystals basal tablets with good basal cleavage. G. 3.25. $\mathrm{X}=b ; \mathrm{Y}=a,{ }^{9}(+) 2 \mathrm{~V}=$ $25^{\circ} \mathrm{D}, 2 \mathrm{~V}_{\mathrm{F}}-2 \mathrm{~V}_{\mathrm{C}}=9^{\circ} . n_{\mathrm{X}}=1.5526, n_{\mathrm{Y}}=1.5533, n_{\mathrm{Z}}=1.5695, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.0169$. Dispersion ( $\mathrm{F}-\mathrm{C}$ ) for $n_{\mathrm{X}}, 0.0123$; for $n_{\mathrm{Y}}, 0.0130$; for $n_{\mathrm{Z}}$, 0.0138. PD 6.9, 4.22, 3.17; 1-0107.
$\left(\mathrm{NH}_{4}\right)_{3} \mathrm{H}_{6} \mathrm{Al}\left(\mathrm{MoO}_{4}\right)_{6} \cdot \mathbf{7 H}_{2} \mathrm{O}$ is probably orthorhombic ${ }^{10}$ in rhombs (assumed to be basal plates) with (110) $\wedge(1 \overline{1} 0)=86^{\circ}$ and symmetrical extinction with the fast ray parallel to $b$. Parallel extinction when placed on edge. $n_{1}\left(=n_{\mathrm{X}}\right.$ or $\left.n_{\mathrm{Y}}\right)=1.700, n_{2}\left(=n_{\mathrm{Y}}\right.$ or $\left.n_{\mathrm{Z}}\right)=1.741, n_{2}-n_{1}=0.041$. Colorless. Made from water solution.
$\mathrm{Fe}_{2}\left(\mathrm{MoO}_{4}\right)_{3} \cdot \mathbf{8 H _ { 2 }} \mathbf{O}$ ? (Ferrimolybdite) is probably orthorhombic. Massive or fibrous. Soft. G. 2.99. Z parallel fibers. ${ }^{11}(+) 2 \mathrm{~V}=$ small to $28^{\circ}, \mathrm{r}<\mathrm{v}$ marked. $n_{\mathrm{X}}=1.78, n_{\mathrm{Y}}=1.79, n_{\mathrm{Z}}=2.04, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.26$. Again: $n_{\mathrm{X}}=$ $1.74, n_{\mathrm{Y}}=1.75, n_{\mathrm{Z}}=1.95, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.21$. Also: $n_{\mathrm{X}}=1.720, n_{\mathrm{Y}}=$ $1.733, n_{\mathrm{Z}}=1.935, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.215$. This variation in indices seems probably due to variation in water content, which occurs easily. Color yellow; pleochroic with X and Y clear and nearly colorless, Z dirty gray to canary yellow.
$\mathbf{H}_{6} \mathbf{M g}\left(\mathrm{WO}_{4}\right)_{4} \cdot 5 \mathbf{H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=0.676: 1: 0.779, \beta=$ $106^{\circ} 43^{\prime}$. Crystals basal plates. $\mathrm{X} \wedge c=-66^{\circ} ; \mathrm{Z}=b$. (+) $2 \mathrm{~V}=77^{\circ} 50^{\prime}$, $\mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{Y}}=1.74, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ ?. Made from barium metatungstate and magnesium sulfate.
$\mathrm{H}_{8} \mathrm{Na}_{6}\left(\mathrm{MoO}_{4}\right)_{7} \cdot \mathbf{1 8 H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=2.092: 1: 2.024, \beta=$ $103^{\circ} 25^{\prime}$. Crystals short columnar $\{100\}$ and $\{010\}$, twinned on $\{100\}$, with poor $\{100\}$ cleavage. $\mathrm{X}=b ; \mathrm{Z} \wedge c=-85^{\circ}$ red, $-84^{\circ} 30^{\prime} \mathrm{Na},-83^{\circ}$ blue. $(+) 2 \mathrm{~V}=84^{\circ} 16^{\prime}$ red, $84^{\circ} 6^{\prime} \mathrm{Na}, 83^{\circ}$ blue, $\mathrm{r}>\mathrm{v}$ weak. $n_{\mathrm{Y}}=1.627, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=$ strong. Made from $\mathrm{HNO}_{3}$ solution of sodium molybdate.

## C. COMPOUND MOLYBDATES AND TUNGSTATES

$\mathbf{L i}_{6} \mathbf{T e}\left(\mathbf{M o O}_{4}\right)_{6} \cdot \mathbf{1 3 H}_{2} \mathbf{O}$ is hexagonal with ${ }^{9} c / a=1.915$. Crystals often flattened on a rhombohedral face. Doubtful basal cleavage. H. 2.5. G. 2.2. Uniaxial negative with $n_{\mathrm{O}}=1.703, n_{\mathrm{E}}=1.612, n_{\mathrm{O}}-n_{\mathrm{E}}=0.091$. Colorless to very pale pink. Made from water solution.
$\mathrm{K}_{6} \mathbf{T e}\left(\mathbf{M o O}_{4}\right)_{6} \cdot \mathbf{8 H _ { 2 }} \mathbf{O}$ is orthorhombic and pseudo-tetragonal ${ }^{11 \mathrm{a}}$ with

[^116]$a: b: c=1: 1: 1.052$. Crystals equant or tabular on $\{010\}$ or $\{100\}$. H. 2.5. G. 3.25. $\mathrm{Y}=a ; \mathrm{Z}=b$. $(+) 2 \mathrm{~V}=81^{\circ}, n_{\mathrm{X}}=1.66, n_{\mathrm{Y}}=1.70, n_{\mathrm{Z}}=1.76$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.10$. Colorless.
$\mathbf{N a}_{6} \mathbf{P}_{2} \mathbf{M o}_{5} \mathbf{O}_{23} \cdot \mathbf{1 4 H}_{2} \mathbf{O}$ is orthorhombic with $a: b: c=0.797: 1: 1.073$. Crystals prismatic. Perfect $\{102\}$ cleavage. $\mathrm{X}=b ; \mathrm{Y}=a$. ( $-2 \mathrm{~V}=$ $51^{\circ} 18^{\prime} \mathrm{Na}, \mathrm{r}<$ v weak. $n_{\mathrm{X}}=1.5906 \mathrm{Li}, 1.5962 \mathrm{Na}, 1.6017 \mathrm{Tl}, n_{\mathrm{Y}}=1.6328$ $\mathrm{Li}, 1.6411 \mathrm{Na}, 1.6494 \mathrm{Tl}, n_{\mathrm{Z}}=1.6430 \mathrm{Li}, 1.6520 \mathrm{Na}, 1.6610 \mathrm{Tl}, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.0558 Na . Colorless.
$\mathrm{Sr}_{2} \mathrm{SiW}_{12} \mathrm{O}_{40} \cdot \mathbf{1 6} \mathrm{H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=1.845: 1: 1.570, \beta=$ $104^{\circ} 36^{\prime}$. Crystals prismatic with $\{110\},\{100\},\{10 \overline{1}\},\{001\},\{011\}$, etc. $\mathrm{X}=b ; \mathrm{Z} \wedge c=-17^{\circ} .(+) 2 \mathrm{~V}=86^{\circ} 50^{\prime} \mathrm{Na}, \mathrm{r}<\mathrm{v}$ strong. $n_{\mathrm{Y}}=1.749$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=$ rather strong. Made from water solution above $50^{\circ} \mathrm{C}$.
$\mathrm{Be}_{2} \mathbf{S i W}_{12} \mathbf{O}_{40} \cdot \mathbf{1 6 H}_{2} \mathbf{O}$ is monoclinic with $a: b: c=1.799: 1: 1.544, \beta=$ $103^{\circ} 53^{\prime}$. Crystals short prismatic with $\{110\},\{100\},\{10 \overline{1}\}$ and $\{011\}$. $\mathrm{X}=b ; \mathrm{Z} \wedge c=-14^{\circ}$. (-) $2 \mathrm{~V}=78^{\circ} 44^{\prime} \mathrm{Na}, \mathrm{r}>\mathrm{v}$ very strong. $n_{\mathrm{Y}}=$ $1.816, n_{\mathrm{Z}}-n_{\mathrm{Y}}=$ rather strong. Made from solution above $30^{\circ} \mathrm{C}$.
$\left(\mathrm{NH}_{4}\right)_{6} \mathbf{T e}_{2}(\mathbf{O H})_{6}\left(\mathrm{MoO}_{4}\right)_{6} \cdot \mathbf{7 H}_{2} \mathrm{O}$ is monoclinic with ${ }^{\mathbf{1 2}} \quad a: b: c=$ 1.891:1:1.073, $\beta=115^{\circ} 38^{\prime}$. Crystals basal tablets with distinct $\{100\}$ cleavage. H. 2.5. G. 2.22. $\mathrm{X}=b ; \mathrm{Z} \wedge c=-58.5^{\circ}$. ( - ) $2 \mathrm{~V}=58^{\circ}$ calc. $n_{\mathrm{X}}=1.684, n_{\mathrm{Y}}=1.727, n_{\mathrm{Z}}=1.741, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.057$. Made from water solution.
$\mathrm{Cs}_{6} \mathbf{T e}\left(\mathrm{MoO}_{4}\right)_{6} \cdot \mathbf{7 H}_{2} \mathrm{O}$ is triclinic with ${ }^{13} a: b: c=0.950: 1: 0.606, \alpha=$ $96^{\circ} 41^{\prime}, \beta=102^{\circ} 1^{\prime}, \gamma=101^{\circ} 31^{\prime}$. Crystals of varied habit. No cleavage or twinning seen. $(+) 2 \mathrm{~V}=34^{\circ}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{X}}=1.709, n_{\mathrm{Y}}=1.716, n_{\mathrm{Z}}=$ 1.797, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.088$. Colorless. Another caesium telluro-molybdate is also triclinic with ${ }^{13} a: b: c=0.937: 1: 0.799, \alpha=93^{\circ} 45^{\prime}, \beta=94^{\circ} 8^{\prime}, \gamma=$ $88^{\circ} 21^{\prime}$. Crystals $\{1 \overline{1} 0\}$ tablets. No cleavage or twinning seen. (-) $2 \mathrm{~V}=30^{\circ}$, $\mathrm{r}>\mathrm{v}$ strong. $n_{\mathrm{X}}=1.669, n_{\mathrm{Y}}=1.734, n_{\mathrm{Z}}=1.738, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.069$. Colorless. Made from water solution. Unstable in air.
$\mathbf{N a}_{6} \mathbf{T e}\left(\mathrm{MoO}_{4}\right)_{6} \cdot \mathbf{2 2 H}_{2} \mathrm{O}$ is triclinic with ${ }^{14} a: b: c=0.955: 1: 0.934, \alpha=$ $115^{\circ} 22^{\prime}, \beta=105^{\circ} 14^{\prime}, \gamma=89^{\circ} 54^{\prime}$. Crystals often $\{100\}$ or $\{010\}$ tablets. No cleavage or twinning seen. H. 2.5. G. 2.58. X makes angles of $102.5^{\circ}$, $58.5^{\circ}$, and $29.5^{\circ}$ with the normals to (100), (010), and (001); Y makes angles of $42^{\circ}, 110^{\circ}$, and $63^{\circ}$, and Z makes angles of $129^{\circ}, 140^{\circ}$, and $102.5^{\circ}$ with the same normals. The extinction angle to the edge (100):(010) is $34^{\circ}$ on (100) and $17^{\circ}$ on (010). (-) $2 \mathrm{~V}=51^{\circ}, \mathrm{r}>\mathrm{v} . n_{\mathrm{X}}=1.577, n_{\mathrm{Y}}=1.662$, $n_{\mathrm{Z}}=1.683$, all $\pm 0.003, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.106$. Colorless. Alters slowly in dry air.

[^117]$\mathbf{4 N a} \mathbf{N a}_{2} \cdot \mathbf{P}_{2} \mathrm{O}_{5} \cdot 24 \mathrm{WO}_{3} \cdot \mathbf{n H}_{2} \mathrm{O}$ is triclinic with ${ }^{15} a: b: c=1.112: 1: 1.065$, $\alpha=91^{\circ} 2^{\prime}, \beta=94^{\circ} 13^{\prime}, \gamma=83^{\circ} 46^{\prime}$. Crystals equant. ( + ) $2 \mathrm{~V}=69^{\circ}, n_{\mathrm{X}}=$ $1.766, n_{\mathrm{Y}}=1.776, n_{\mathrm{Z}}=1.789, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.023$. Readily attacked in the air.
${ }^{15}$ Bokii: Trudy Inst. Krist. Nauk. U.S.S.R. 1947, No. 3. [Chem. Abstr. XLII, p. 3764 (1950)].

## IX. Phosphates, etc.

The phosphates, vanadates, arsenates and antimonates are included in this division. The arrangement begins with anhydrous salts which are followed by hydrated salts, and then salts containing halogen, hydroxyl or extra oxygen. Phosphites, metaphosphates, hypophosphates and pyrophosphates are then considered, and finally come some compound phosphates. An outline follows:
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## A. ANHYDROUS ACID PHOSPHATES, ETC.

## 1. Formula Type $\mathrm{AH}_{2} \mathrm{XO}_{4}$ (or $\mathrm{A}_{2} \mathrm{HXO}_{4}$ )

$\mathbf{K H}_{2}\left(\mathbf{P O}_{4}\right)$ is tetragonal scalenohedral with $c / a=0.939$. Crystals simple prisms terminated by a simple pyramid. No distinct cleavage. G. 2.34.

Uniaxial negative ${ }^{1}$ with $n_{\mathrm{O}}=1.5064 \mathrm{C}, 1.5095 \mathrm{D}, 1.5154 \mathrm{~F}, n_{\mathrm{E}}=1.4664 \mathrm{C}$, $1.4684 \mathrm{D}, 1.4734 \mathrm{~F}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0411 \mathrm{D}$. Colorless. Made from cold solution.
$\mathbf{K H}_{2}\left(\mathbf{A s O}_{4}\right)$ is tetragonal scalenohedral with $c / a=0.938$. Crystals simple prisms terminated by a simple pyramid. G. 2.88. Uniaxial negative with ${ }^{1,2}$ $n_{\mathrm{O}}=1.5632 \mathrm{C}, 1.5674 \mathrm{D}, 1.5762 \mathrm{~F}, n_{\mathrm{E}}=1.5146 \mathrm{C}, 1.5179 \mathrm{D}, 1.5252 \mathrm{~F}$, $n_{\mathrm{o}}-n_{\mathrm{E}}=0.0495 \mathrm{D}$. Colorless.
$\mathbf{N H}_{4} \mathbf{H}_{2}\left(\mathbf{P O}_{4}\right)$ is tetragonal scalenohedral with $c / a=1.0076$. Crystals prismatic terminated by a pyramid. G. 1.80. Uniaxial negative ${ }^{1}$ with $n_{0}=$ $1.5212 \mathrm{C}, 1.5246 \mathrm{D}, 1.5314 \mathrm{~F}, n_{\mathrm{E}}=1.4768 \mathrm{C}, 1.4792 \mathrm{D}, 1.4847 \mathrm{~F}, n_{\mathrm{O}}-$ $n_{\mathrm{E}}=0.0454$ D. Colorless. PD 5.32, 3.08, 3.07; 6-0125.
$\mathbf{N H}_{4} \mathbf{H}_{2}\left(\mathbf{A s O}_{4}\right)$ is tetragonal scalenohedral with $c / a=1.0035$. Crystals prismatic or pyramidal. No distinct cleavage. G. 2.32. Uniaxial negative ${ }^{1}$ with $n_{\mathrm{O}}=1.5721 \mathrm{C}, 1.5766 \mathrm{D}, 1.5859 \mathrm{~F}, n_{\mathrm{E}}=1.5186 \mathrm{C}, 1.5217 \mathrm{D}, 1.5296$ $\mathrm{F}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0549 \mathrm{D}$. Colorless.
$\mathbf{A g}_{2} \mathbf{H}\left(\mathbf{P O}_{4}\right)$ is hexagonal (trigonal) with $c / a=0.7297$. Crystals prisms or basal tablets. Very unstable in light or moisture. Uniaxial negative with ${ }^{3}$ $n_{\mathrm{O}}=1.8036 \mathrm{Na}, n_{\mathrm{E}}=1.7983, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0053$.
$\mathbf{N a H}_{2}\left(\mathbf{P O}_{4}\right)$ is biaxial with ${ }^{4}(-) 2 \mathrm{~V}=64^{\circ}, n_{\mathrm{X}}=1.481, n_{\mathrm{Y}}=1.507, n_{\mathrm{Z}}=$ $1.517, n_{\mathrm{z}}-n_{\mathrm{X}}=0.036$. Colorless.
$\mathbf{N a}_{2} \mathbf{H}\left(\mathbf{P O}_{4}\right)$ is biaxial with ${ }^{4}(+) 2 \mathrm{~V}=78^{\circ}, n_{\mathrm{X}}=1.483, n_{\mathrm{Y}}=1.499, n_{\mathrm{Z}}=$ $1.525, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.042$. Formed by evaporation at $105^{\circ} \mathrm{C}$.
$\left(\mathbf{N H}_{4}\right)_{2} \mathbf{H}\left(\mathbf{P O}_{4}\right)$ is monoclinic prismatic with $a: b: c=1.198: 1: 1.655, \beta=$ $113^{\circ} 14^{\prime}$. Crystals equant with ${ }^{5}\{110\},\{001\},\{10 \overline{1}\}$, etc., or long parallel with $b$. ( -$) 2 \mathrm{~V}=28^{\circ}, n_{\mathrm{X}}=1.468, n_{\mathrm{Y}}=1.570, n_{\mathrm{Z}}=1.582, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.114. PD 5.05, 3.24, 3.21; 8-33.

## 2. Formula Type $\mathrm{AHXO}_{4}$

$\mathbf{S r H}\left(\mathbf{P O}_{4}\right)$ is orthorhombic with $a: b: c=0.648: 1: 0.858$. Crystals thin $\{100\}$ plates. G. 3.54. $\mathrm{Y}=a .{ }^{6} n_{\mathrm{X}}=1.608, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.625, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.017 . Colorless. Made from solution above $150^{\circ} \mathrm{C}$.
$\mathbf{B a H}\left(\mathbf{P O}_{4}\right)$ is orthorhombic with $a: b: c=0.713: 1: 0.812$. Crystals short prisms. G. 4.16. $\mathrm{Y}=a .^{6} n_{\mathrm{X}}=1.617, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.635, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.018. Colorless. Made from solution. PD 3.59, 2.52, 3.53; 9-113.
$\mathbf{P b H}\left(\mathrm{AsO}_{4}\right.$ ) (Schultenite) is monoclinic with $a: b: c=0.865: 1: 0.720$, $\beta=95^{\circ} 24^{\prime}$. Crystals $\{010\}$ plates. Distinct $\{010\}$ cleavage. H. 2.5. G. 5.94.

[^118]$\mathrm{X}=b ; \mathrm{Y} \wedge c^{7}=-24^{\circ}, \mathrm{Z} \wedge c=+66^{\circ} ;(+) 2 \mathrm{~V}=58^{\circ}, n_{\mathrm{X}}=1.8903$ (calc.), $n_{\mathrm{Y}}=1.9097, n_{\mathrm{Z}}=1.9765 \mathrm{Na}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0862$. Colorless. Made by cooling a boiling solution of the salt in dilute $\mathrm{HNO}_{3}$. Used as an insecticide. PD 3.39, 3.17, 2.93; 1-0635.
$\mathbf{C a H}\left(\mathbf{P O}_{4}\right)$ (Monetite) is triclinic pinacoidal ${ }^{7 a}$ with $a=6.91, b=6.66$, $c=7.02 \AA, \alpha=96^{\circ} 7^{\prime}, \beta=103^{\circ} 53^{\prime}, \gamma=89^{\circ} 11^{\prime}$. Crystals thin $\{010\}$ plates; often in crusts or stalactites. H. 3.5. G. 2.93. F. 3. Soluble in acid. X nearly normal to $\{11 \overline{1}\}$ and at $52^{\circ}$ to the normal to $\{010\}$. On (010) an extinction is at $15^{\circ}$ with (101) and at $38^{\circ}$ with ( $01 \overline{1}$ ); on (001) an extinction is at $30^{\circ}$ with (010). (-) $2 \mathrm{~V}=$ large, ${ }^{8} \mathrm{r}>\mathrm{v}$ weak. $n_{\mathrm{X}}=1.587, n_{\mathrm{Y}} \approx 1.615$, $n_{\mathrm{Z}}=1.640, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.053$. Colorless. Made from solution above $50^{\circ} \mathrm{C}$. PD 2.96, 3.35, 3.37; 9-80.
$\mathbf{S r H}\left(\mathbf{A s O}_{4}\right)$ is triclinic with $a: b: c=0.647: 1: 0.835, \alpha=86^{\circ} 32^{\prime}, \beta=$ $90^{\circ} 46^{\prime}, \gamma=92^{\circ} 4^{\prime}$. Crystals long parallel b. G. 4.03. On (100) an extinction at $14^{\circ}$ to $b^{6}$ in obtuse angle $\alpha$. $n_{\mathrm{X}}=1.65, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.67, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.02. Colorless. Made from solution.
$\mathbf{C a H}\left(\mathbf{A s O}_{4}\right)$ is triclinic(?). G. 3.47. Crystals long plates with inclined extinction ${ }^{9}$ and two "true" indices-1.625 and 1.655. Again: ${ }^{10} n_{\mathrm{X}}=1.635$, $n_{\mathrm{Y}}=1.650, n_{\mathrm{Z}}=1.653, n_{\mathrm{Z}}-n_{\mathrm{Y}}=0.018 . \therefore(-) 2 \mathrm{~V}=50^{\circ} c a$.

## 3. Formula Type $\mathrm{AH}_{4}\left(\mathrm{XO}_{4}\right)_{2}$ or $\mathrm{ABH}_{2}\left(\mathrm{XO}_{4}\right)_{2}$

$\mathbf{C a H}_{4}\left(\mathbf{P O}_{4}\right)_{2}{ }^{11}$ is triclinic with ${ }^{7 a} a=5.55, b=7.60, c=9.07 \AA . \alpha=$ $121^{\circ} 54^{\prime}, \beta=108^{\circ} 48^{\prime}, \gamma=87^{\circ} 28^{\prime}$. Crystals rods parallel with $a$, or $\{010\}$ or $\{01 \overline{1}\}$ tablets. No cleavage seen. G. 2.546. It decomposes at $268^{\circ} \mathrm{C}$. The XY plane is normal to $\{010\}$ and nearly parallel with $a, \mathrm{Y}$ inclined $15^{\circ}$ to $\{010\}$ in obtuse angle $\gamma .(+) 2 \mathrm{~V}=85^{\circ} 14^{\prime}$ calc., $\mathrm{r}<\mathrm{v}$ very weak. For $\lambda=$ $425 m \mu n_{\mathrm{X}}=1.543, n_{\mathrm{Y}}=1.567, n_{\mathrm{Z}}=1.596, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.053$. For $\lambda=$ $610 m_{\mu} n_{\mathrm{X}}=1.548, n_{\mathrm{Y}}=1.572, n_{\mathrm{Z}}=1.602, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.054$. Colorless. Made from water solution at $130^{\circ} \mathrm{C}$. PD 3.63, 3.61, 3.49; 9-390.
$\mathbf{P b H}_{4}\left(\mathbf{A s O}_{4}\right)_{2}$ is triclinic. ${ }^{12}$ Crystals rhomboidal plates with an angle of $68^{\circ}$. G. 4.46. (-? $) 2 \mathrm{~V}=$ ?, $n_{\mathrm{X}}=1.74, n_{\mathrm{Y}}=1.82, n_{\mathrm{Z}}=$ ?, $n_{\mathrm{Z}}-n_{\mathrm{X}}>0.08$. Extinction at $8^{\circ}$ to a long edge.
$\mathbf{K F e H}_{2}\left(\mathbf{P O}_{4}\right)_{2}$ is triclinic ${ }^{13}$ with $\alpha=106^{\circ}, \beta=109^{\circ}, \gamma=99^{\circ}$. Crystals $\{010\}$ tablets. Twinning common on $\{110\}$. G. 2.90. Optic plane nearly

[^119]normal to $\{010\}$. X nearly normal to $\{001\},(-) 2 \mathrm{~V}=66^{\circ}, \mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=$ $1.631, n_{\mathrm{Y}}=1.665, n_{\mathrm{Z}}=1.680, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.049$. Color lavender.
$\mathbf{N H}_{4} \mathbf{F e H}_{2}\left(\mathbf{P O}_{4}\right)_{2}$ is columnar ${ }^{14}$ in spherulites. $n_{1}$ (parallel width) $=c a$. 1.67; $n_{2}$ (parallel length) $=c a$. 1.66, $n_{2}-n_{1}=0.01$.

## B. ANHYDROUS NORMAL PHOSPHATES, ETC.

## 1. Formula Type $\mathbf{A}_{3} \mathrm{XO}_{4}$

$\mathbf{H}_{3} \mathbf{P O}_{4}$ is monoclinic with ${ }^{14 \mathrm{a}} a=5.80, b=4.85, c=11.62 \AA, \beta=95^{\circ} 30^{\prime}$. Crystals prismatic parallel $b$. No cleavage seen. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=28^{\circ}$ in acute $\beta$. ( - ) $2 \mathrm{~V}=12^{\circ} 16^{\prime}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{X}}=1.455, n_{\mathrm{Y}}=1.504, n_{\mathrm{Z}}=$ $1.505, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.050$ for $\lambda=425 m \mu$. Colorless.
$\mathbf{N a}_{3} \mathbf{P O}_{4}$ is monoclinic. ${ }^{15}$ Crystals equant with $\{100\},\{110\},\{001\}$, etc. Common twinning on $\{100\}$. $\mathrm{Y} \wedge c=10^{\circ} c a . ; \mathrm{Z}=b .(+) 2 \mathrm{~V}=76^{\circ}$ calc., $\mathrm{r}>\mathrm{v}$ distinct. $n_{\mathrm{X}}=1.493, n_{\mathrm{Y}}=1.499, n_{\mathrm{Z}}=1.508, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.015$. Colorless. PD 2.55, 4.25, 2.70; 1-1103.

## 2. Formula Type $\mathrm{A}_{3}\left(\mathrm{XO}_{4}\right)_{2}$

$\mathbf{C a}_{3}\left(\mathbf{P O}_{4}\right)_{2}$ (Whitlockite) is hexagonal with $a=10.32, c=36.9 \mathrm{kX}$. Crystals rhombohedral; rarely basal tablets. No cleavage. H. 5. G. 3.12. Inverts at $1350^{\circ} \mathrm{C}$. Uniaxial negative with ${ }^{16} n_{\mathrm{O}}=1.629, n_{\mathrm{E}}=1.626$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.003$. Again: $:^{11} n_{\mathrm{O}}=1.622, n_{\mathrm{E}}=1.620, n_{\mathrm{O}}-n_{\mathrm{E}}=0.002$. With some $\mathrm{CO}_{3}$ (in place of $\mathrm{PO}_{4}$ ) the indices are notably lower- $n_{0}=1.607$, $n_{\mathrm{E}}=1.604 . \mathrm{Mg}, \mathrm{Fe}$ and Mn may replace some Ca . Colorless, gray or yellowish. Found in some slags. Another phase of $\mathrm{Ca}_{3}\left(\mathrm{PO}_{4}\right)_{2}$ (stable above about $1200^{\circ} \mathrm{C}$.) is monoclinic ${ }^{17}$ with $a=12.86, b=9.11, c=15.23 \AA$. $\beta=125^{\circ} 20^{\prime}$. U.C. 8. G. 2.814 . M.P. $1720^{\circ} \mathrm{C}$. It has two sets of polysynthetic twinning nearly at right angles with extinction nearly parallel to the twinning. $(+) 2 \mathrm{~V}=75^{\circ},{ }^{18} n_{\mathrm{X}}=1.588, n_{\mathrm{Y}}=1.5891$ calc., $n_{\mathrm{Z}}=1.591$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.003$. Colorless. Found in some slags. PD 2.91, 2.62, 3.88; 9-348 ( $\alpha$-) ; 2.88, 2.61, 3.21; 9-169 ( $\beta$-).
$\mathbf{P b}_{3}\left(\mathbf{P O}_{4}\right)_{2}$ is hexagonal. ${ }^{19}$ Crystals prismatic. M.P. $1015^{\circ}$ C. Uniaxial negative with $n_{\mathrm{O}}=1.9588 \mathrm{C}, 1.9702 \mathrm{D}, 1.9994 \mathrm{~F}, n_{\mathrm{Z}}=1.9261 \mathrm{C}, 1.9364 \mathrm{D}$, $1.9618 \mathrm{~F}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0338 \mathrm{D}$. Colorless. Made from fusion. It may take some Ce in place of Pb . With 3 per cent of $\mathrm{CePO}_{4}$ crystals are golden yellow

[^120]with O canary yellow and E colorless; then $n_{\mathrm{O}}=1.9586 \mathrm{C}, 1.9697 \mathrm{D}$, $1.9995 \mathrm{~F}, n_{\mathrm{E}}=1.9221 \mathrm{C}, 1.9326 \mathrm{D}, 1.9591 \mathrm{~F}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0371 \mathrm{D}$. PD 2.88, 2.79, 3.99; 6-0431*.

## 3. Formula Type $\mathrm{AXO}_{4}$

$\mathbf{B P O}_{4}$ is tetragonal ${ }^{20}$ pyramidal with $a=4.332, c=6.640 k X$. Crystals sphenoidal with a structure related to that of cristobalite. G. 2.76. Uniaxial positive with ${ }^{20} n_{\mathrm{O}}=1.5947, n_{\mathrm{E}}=1.6013, n_{\mathrm{E}}-n_{\mathrm{O}}=0.0066 \mathrm{D}$. Colorless. PD 3.62, 2.25, 1.87; 1-0519.
$\mathbf{B A s O}_{4}$ is tetragonal ${ }^{20}$ pyramidal with $a=4.458, c=6.796 k X$. Crystals pyramidal with a structure related to that of cristobalite. G. 3.64. Uniaxial positive with ${ }^{20} n_{\mathrm{O}}=1.681, n_{\mathrm{E}}=1.690, n_{\mathrm{E}}-n_{\mathrm{O}}=0.009$ D. Colorless. PD 3.74, 2.32, 1.50; 3-0314.
$\mathrm{YPO}_{4}$ (Xenotime) is tetragonal with $a=6.88, c=6.03 k X$. U.C. 4. Isostructural with zircon $\left(\mathrm{ZrSiO}_{4}\right)$. Crystals prismatic or pyramidal. Good $\{100\}$ cleavage. H. 4-5. G. 4.4 ca. Uniaxial positive with $n_{0}=1.7207$, $n_{\mathrm{E}}=1.8155, n_{\mathrm{E}}-n_{\mathrm{O}}=0.0948$. Again: ${ }^{21} n_{\mathrm{O}}=1.720, n_{\mathrm{E}}=1.827, n_{\mathrm{E}}-$ $n_{\mathrm{O}}=0.107$. Color brown, red, yellow, gray; it may also show O pink, yellow or brownish, E brownish yellow, grayish brown or greenish. Made by fusion of yttrium oxide with potassium pyrophosphate. PD 3.44, 2.56, 1.76; 9-377.
$\mathrm{AlPO}_{4}$ (Berlinite) is hexagonal with $a=4.93, c=10.94 k X$. U.C. 3. Crystals structurally like quartz, and forms are similar. No cleavage. H. 6.5 ca . G. 2.6. M.P. $1460^{\circ}$ C. Uniaxial positive ${ }^{22}$ with $n_{\mathrm{O}}=1.5235, n_{\mathrm{E}}=$ 1.529, $n_{\mathrm{E}}-n_{\mathrm{O}}=0.0055$. Again: ${ }^{13} n_{\mathrm{O}}=1.523, n_{\mathrm{E}}=1.530, n_{\mathrm{E}}-n_{\mathrm{O}}=$ 0.007 . Colorless or nearly so. Made from solution in phosphoric acid. $\mathrm{AlPO}_{4}$ is also orthorhombic in plates with $(+) 2 \mathrm{~V}=50^{\circ}$ calc., $n_{\mathrm{X}}=1.546$, $n_{\mathrm{Y}}=1.556, n_{\mathrm{Z}}=1.578, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.032$. PD 3.37, 4.28, 1.84; 10-423.
$\mathrm{BiVO}_{4}$ (Pucherite) is orthorhombic with ${ }^{23} a=5.38, b=11.98, c=$ $5.04 k X$. U.C. 4. Crystals $\{010\}$ tablets or acicular. Perfect basal cleavage. H. 4. G. 6.57 calc. $\mathrm{X}=b ; \mathrm{Y}=a$. ( $-2 \mathrm{~V}=19^{\circ} \pm 5^{\circ}, \mathrm{r}<\mathrm{v}$ extreme. ${ }^{24}$ $n_{\mathrm{X}}=2.41, n_{\mathrm{Y}}=2.50, n_{\mathrm{Z}}=2.51$, all $\pm .02, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.10$. Color reddish to yellowish brown. Made from a solution of bismuth nitrate and vanadium chloride.
$\mathrm{FeAsO}_{4}$ is monoclinic with $a: b: c=0.616: 1: 0.322, \beta=102^{\circ} 52^{\prime}$. Crystals prismatic, vertically striated, with distinct $\{001\}$ cleavage. H. 5. G. 4.32. F. easy. Slowly soluble in acid. Extinction on (010) at $+53^{\circ}$ to $c . n=1.78$.

[^121]Color black to brown; strongly pleochroic with $a$ greenish yellow, $b$ dark brownish yellow as seen in (001) and olive brown to clear yellowish brown as seen in (010).
(Ce,La) $\mathrm{PO}_{4}$ (Monazite) is monoclinic prismatic with $a=6.782, b=$ 6.993, $c=6.445 k X, \beta=103^{\circ} 38^{\prime}$. U.C. 4. Crystals varied with $\{100\}$, $\{110\},\{010\},\{\overline{1} 11\}$, etc. Twinning common on $\{100\}$. Distinct $\{100\}$ cleavage. H. 5-5.5. G. $5.1 \mathrm{ca} . \mathrm{X}=b ; \mathrm{Z} \wedge c=2^{\circ}-6^{\circ}$. (+) $2 \mathrm{~V} \approx 11^{\circ}-15^{\circ}$, usually $\mathrm{r}<\mathrm{v}$ with weak horizontal dispersion. ${ }^{21} n_{\mathrm{X}}=1.787-1.800, n_{\mathrm{Y}}=$ $1.788-1.801, n_{\mathrm{Z}}=1.837-1.849, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.045-0.055$. Notable variation of indices undoubtedly due to variation in composition; not only can the $\mathrm{Ce}-\mathrm{La}$ ratio vary, but Th can replace them up to about 30 per cent of $\mathrm{ThO}_{2}$ and Y earths and less $\mathrm{Ca}, \mathrm{Mg}, \mathrm{Fe}$, etc., may be present. With no $\mathrm{ThO}_{2}{ }^{25} n_{\mathrm{X}}=1.785, n_{\mathrm{Y}}=1.787, n_{\mathrm{Z}}=1.840, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.055$. Color yellow to brown with little or no pleochroism. Made by fusion of phosphate and chloride of cerium. PD 3.09, 3.31, 2.88; 4-0612.
$\mathrm{BiAsO}_{4}$ (Rooseveltite) is monoclinic and isostructural with monazite. H. $4-4.5$. G. 6.68 . $(+) 2 \mathrm{~V}=50^{\circ}$ calc. ${ }^{26} n_{\mathrm{X}}=2.14, n_{\mathrm{Y}}=2.15, n_{\mathrm{Z}}=2.18$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.04$. PD 3.28, 3.20, 3.11; 7-387*. On cooling it slowly inverts to a tetragonal phase with ${ }^{27} a=5.08, c=11.70 \AA$. ( $\pm .02$ ). Indices not known. PD 3.05, 1.91, 2.53; 5-0573.

## 4. Formula Type $\mathrm{ABXO}_{4}$

$\mathrm{LiMnPO}_{4}$ (Lithiophilite) is orthorhombic dipyramidal with $a: b: c=$ $0.5823: 1: 0.4541$. U.C. 4. Crystals rare; usually massive. Good $\{100\}$ and poor $\{010\}$ cleavages. H. $4-5$. G. 3.34. $\mathrm{X}=c ; \mathrm{Y}=a$. $(+) 2 \mathrm{~V}=65^{\circ} c a$. $\mathrm{r}<\mathrm{v}$ strong. $n_{\mathrm{X}}=1.663, n_{\mathrm{Y}}=1.666, n_{\mathrm{Z}}=1.673, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.010$. Color brown to yellow or salmon; colorless or pleochroic in section with X deep pink, Y pale greenish yellow, $Z$ pale pink. Made by fusion of LiCl , $\mathrm{Li}_{3} \mathrm{PO}_{4}$ and $\mathrm{Mn}_{3}\left(\mathrm{PO}_{4}\right)_{2}$. There is a complete series of mix-crystals from $\mathrm{LiMnPO}_{4}$ to $\mathrm{LiFePO}_{4}$. In this series the index of refraction for light vibrating along $a$ is least ( $n_{\mathrm{X}}$ ) at the Mn end and greatest $\left(n_{\mathrm{Z}}\right)$ at the Fe end, the optic angle passing through zero twice, and the optic sign being negative at the Fe end with $n_{\mathrm{X}}=1.696, n_{\mathrm{Y}}=1.700, n_{\mathrm{Z}}=1.702, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.006$ for about 81 per cent $\mathrm{LiFePO}_{4}$ (called triphylite). Some Mg is often present ${ }^{28}$ in this series, lowering the indices.
$\mathrm{NaBePO}_{4}$ (Beryllonite) is monoclinic ${ }^{29}$ with $a=8.13, b=7.76, c=$ $14.17 k X, \beta=90^{\circ} 0^{\prime}$. U.C. 12. Very nearly orthorhombic. Perfect $\{010\}$,

[^122]and good $\{100\}$ cleavages. H. 5.5-6. G. 2.81. $\mathrm{X}=b ; \mathrm{Y}=a$. (-) $2 \mathrm{~V}=$ $67^{\circ} 51^{\prime} \mathrm{Li}, 67^{\circ} 56^{\prime} \mathrm{Na}, 67^{\circ} 57^{\prime} \mathrm{Tl}, \mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.5492 \mathrm{Li}, 1.5520 \mathrm{Na}, 1.5544$ $\mathrm{Tl}, n_{\mathrm{Y}}=1.5550 \mathrm{Li}, 1.5579 \mathrm{Na}, 1.5604 \mathrm{Tl}, n_{\mathrm{Z}}=1.560 \mathrm{Li}, 1.561 \mathrm{Na}$, $1.564 \mathrm{Tl}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.009$. Colorless, white or pale yellow. Made from a fusion of BeO in sodium metaphosphate. PD 2.84, 3.65, 2.28; 6-0443.

## C. HYDRATED ACID PHOSPHATES, ETC.

## 1. Formula Type $\mathrm{A}_{2} \mathrm{HXO}_{4} \cdot \mathbf{x H}_{2} \mathrm{O}$

$\mathbf{N a}_{2} \mathbf{H P O}_{4} \cdot \mathbf{2 H}_{2} \mathrm{O}$ is orthorhombic disphenoidal with G. 2.066. ( + ) $2 \mathrm{~V}=$ $80^{\circ} c a .,^{4} n_{\mathrm{X}}=1.450, n_{\mathrm{Y}}=1.461, n_{\mathrm{Z}}=1.477, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.027$. Colorless. Made by evaporating a solution at $60^{\circ}$. PD 3.36, 4.64, 5.28; 10-190.
$\mathrm{Na}_{2} \mathbf{H P O}_{4} \cdot \mathbf{7 H}_{2} \mathbf{O}$ is monoclinic prismatic with $a: b: c=1.205: 1: 1.327$, $\beta=96^{\circ} 57^{\prime}$. Crystals thick prismatic basal tablets. G. 1.68. $\mathrm{X}=b$; $\mathrm{Z} \wedge c^{30}=-72^{\circ} .(+) 2 \mathrm{~V}=39^{\circ} 33^{\prime} \mathrm{Li}, 38^{\circ} 50^{\prime} \mathrm{Na}, 37^{\circ} 59^{\prime} \mathrm{Tl}, \mathrm{r}>\mathrm{v} . n_{\mathrm{x}}=$ $1.4382 \mathrm{Li}, 1.4412 \mathrm{Na}, 1.4437 \mathrm{Tl}, n_{\mathrm{Y}}=1.4395 \mathrm{Li}, 1.4424 \mathrm{Na}, 1.4449 \mathrm{Tl}$, $n_{\mathrm{Z}}=1.4497 \mathrm{Li}, 1.4526 \mathrm{Na}, 1.4552 \mathrm{Tl}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0114 \mathrm{Na}$. Colorless. Made from water solution above $30^{\circ} \mathrm{C}$. PD 2.82, 4.25, 2.92; 10-191*.
$\mathrm{Na}_{2} \mathbf{H A s O}_{4} \cdot \mathbf{7 H}_{2} \mathbf{O}$ is monoclinic with $a: b: c=1.229: 1: 1.353, \beta=97^{\circ} 14^{\prime}$. Crystals thick basal plates or prismatic. Good $\{100\}$ cleavage. G. 1.88. $\mathrm{X}=b ; \mathrm{Z} \wedge c=-65^{\circ} .(+) 2 \mathrm{~V}=57^{\circ} 32^{\prime} \mathrm{Li}, 57^{\circ} 7^{\prime} \mathrm{Na}, 56^{\circ} 43^{\prime} \mathrm{Tl}, \mathrm{r}>\mathrm{v}$ weak. ${ }^{30} n_{\mathrm{X}}=1.4587 \mathrm{Li}, 1.4622 \mathrm{Na}, 1.4654 \mathrm{Tl}, n_{\mathrm{Y}}=1.4623 \mathrm{Li}, 1.4658 \mathrm{Na}$, $1.4689 \mathrm{Tl}, n_{\mathrm{Z}}=1.4746 \mathrm{Li}, 1.4782 \mathrm{Na}, 1.4814 \mathrm{Tl}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.016 \mathrm{Na}$. Colorless. Made from water solution above $20^{\circ}$ C. PD 5.26, 3.93, 2.98; 3-0118.
$\mathbf{N a}_{2} \mathbf{H P O}_{4} \cdot \mathbf{1 2} \mathrm{H}_{2} \mathbf{O}$ is monoclinic with $a: b: c=1.732: 1: 1.416, \beta=121^{\circ} 24^{\prime}$. Crystals prismatic, with $\{110\},\{001\},\{\overline{1} 11\},\{100\},\{\overline{1} 01\},\{010\}$. G. 1.53. $\mathrm{X} \wedge c=-31^{\circ}$, distinct dispersion; ${ }^{30} \mathrm{Y}=b$. ( - ) $2 \mathrm{~V}=54^{\circ} 38^{\prime} \mathrm{Li}, 56^{\circ} 43^{\prime}$ $\mathrm{Na}, 58^{\circ} 9^{\prime} \mathrm{Tl}, \mathrm{r}<$ v marked. $n_{\mathrm{X}}=1.4290 \mathrm{Li}, 1.4321 \mathrm{Na}, 1.4348 \mathrm{Tl}, n_{\mathrm{Y}}=$ $1.4330 \mathrm{Li}, 1.4361 \mathrm{Na}, 1.4389 \mathrm{Tl}, n_{\mathrm{z}}=1.4341 \mathrm{Li}, 1.4373 \mathrm{Na}, 1.4402 \mathrm{Tl}$, $n_{\mathrm{z}}-n_{\mathrm{X}}=0.0052 \mathrm{Na}$. Colorless. Another phase is orthorhombic. PD 5.40, 2.94, 2.71; 1-0223.
$\mathrm{Na}_{2} \mathrm{HAsO}_{4} \cdot \mathbf{1 2 H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=1.75: 1: 1.412, \beta=131^{\circ} 49^{\prime}$. Crystals prismatic. G. 1.67. $\mathrm{X} \wedge c^{4}=1^{\circ} ; \mathrm{Z}=b$. (-)2V $=65^{\circ} 13^{\prime} . n_{\mathrm{X}}=$ $1.4420 \mathrm{Li}, 1.4453 \mathrm{Na}, 1.4482 \mathrm{Tl}, n_{\mathrm{Y}}=1.4462 \mathrm{Li}, 1.4496 \mathrm{Na}, 1.4527 \mathrm{Tl}$. $n_{\mathrm{Z}}=1.4480 \mathrm{Li}, 1.4513 \mathrm{Na}, 1.4545 \mathrm{Tl} . n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0060 \mathrm{Na}$. Colorless.

## 2. Formula Type $\mathrm{ABHXO}_{4} \cdot \mathbf{x H}_{2} \mathrm{O}$

$\left(\mathbf{N H}_{4}\right) \mathbf{N a H}\left(\mathbf{A s O}_{4}\right) \cdot \mathbf{4 H _ { 2 }} \mathbf{O}$ is monoclinic with ${ }^{31} a: b: c=2.8723: 1: 1.8589$, $\beta=98^{\circ} 59^{\prime}$. Crystals short prismatic. No cleavage. H. 2. G. 1.845. Y $=b$;
${ }^{30}$ Dufet: Bull. Soc. Fr. Min. X, p. 77 (1887).
${ }^{31}$ Schaschek: Tsch. Min. Pet. Mitt. XXXII, p. 402 (1914).
$\mathrm{Z} \wedge c=+18^{\circ} .(+) 2 \mathrm{~V}=38^{\circ}, n_{\mathrm{X}}=1.4649, n_{\mathrm{Y}}=1.4663, n_{\mathrm{Z}}=1.4791$ $\mathrm{Na}, n_{\mathrm{Z}}-n_{\mathrm{x}}=0.0142$. Colorless.
$\left(\mathrm{NH}_{4}\right) \mathbf{N a H}\left(\mathrm{PO}_{4}\right) \cdot \mathbf{4 H _ { 2 }} \mathbf{O}$ (Stercorite) is triclinic and pseudo-monoclinic with $a: b: c=2.908: 1: 1.859, \beta=98^{\circ} 30^{\prime}$. Crystals short prismatic with $\{110\}$ modified by $\{001\},\{100\},\{\overline{1} 01\}$, and other $\{h 0 l\}$. Apparently monoclinic due to multiple twinning on $\{010\}$. No cleavage. H. 2. G. 1.57. M.P. $79^{\circ}$ C. The optic plane is (nearly) normal ${ }^{31}$ to $\{010\}$; on (001), $\mathrm{X}^{\prime} \wedge(100)=9^{\circ} 35^{\prime}$; on (100), $\mathrm{X}^{\prime} \wedge(001)=1^{\circ} 20^{\prime}$ with strong dispersion; Z is nearly normal to $\{001\} .(+) 2 \mathrm{~V}=35^{\circ} 34^{\prime} ; \mathrm{r}>\mathrm{v}$ rather strong. $n_{\mathrm{X}}=$ $1.439, n_{\mathrm{Y}}=1.442, n_{\mathrm{Z}}=1.469, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.030$. A section parallel to (010) shows two sets of lamellar twinning at about $90^{\circ}$. Colorless. Made from water solution. It is often called microcosmic salt. It loses $\mathrm{NH}_{3}$ and $\mathrm{H}_{2} \mathrm{O}$ between $96^{\circ}$ and $200^{\circ}$ C., changing to $\mathrm{NaPO}_{3}$. PD 6.60, 2.89, 4.60; 1-0127.

## 3. Formula Type $\mathrm{AH}_{2} \mathrm{XO}_{4} \cdot \mathbf{x H}_{2} \mathrm{O}$

$\mathrm{NaH}_{2}\left(\mathbf{P O}_{4}\right) \cdot \mathbf{H}_{2} \mathrm{O}$ is orthorhombic with $a: b: c=0.934: 1: 0.962$. Crystals short prisms with $\{001\}$, etc. G. 2.06. $\mathrm{X}=a ;{ }^{30} \mathrm{Y}=b$. (-) $2 \mathrm{~V}=29^{\circ} 0^{\prime} \mathrm{Li}$, $29^{\circ} 22^{\prime} \mathrm{Na}, 29^{\circ} 48^{\prime} \mathrm{Tl}, \mathrm{r}<$ v weak. $n_{\mathrm{X}}=1.4527 \mathrm{Li}, 1.4557 \mathrm{Na}, 1.4583 \mathrm{Tl}$, $n_{\mathrm{Y}}=1.4821 \mathrm{Li}, 1.4852 \mathrm{Na}, 1.4881 \mathrm{Tl}, n_{\mathrm{Z}}=1.4841 \mathrm{Li}, 1.4873 \mathrm{Na}, 1.4902$ $\mathrm{Tl}, n_{\mathrm{z}}-n_{\mathrm{X}}=0.0316 \mathrm{Na}$. Colorless. Made from the syrupy water solution. A second phase is known to be orthorhombic with $a: b: c=0.817: 1: 0.500$.
$\mathbf{N a H}_{2}\left(\mathbf{A s O}_{4}\right) \cdot \mathbf{H}_{2} \mathbf{O}$ is orthorhombic with $a: b: c=0.8171: 1: 0.498$. Crystals prismatic with $\{110\},\{111\}$, etc. G. 2.67. $\mathrm{X}=c ;{ }^{31} \mathrm{Y}=b$. ( - ) $2 \mathrm{~V}=$ $67^{\circ} 15^{\prime} \mathrm{Li}, 67^{\circ} 57^{\prime} \mathrm{Na}, 68^{\circ} 33^{\prime} \mathrm{Tl}, \mathrm{r}<\mathrm{v} . n_{\mathrm{x}}=1.5341 \mathrm{Li}, 1.5382 \mathrm{Na}, 1.5418 \mathrm{Tl}$, $n_{\mathrm{Y}}=1.5494 \mathrm{Li}, 1.5535 \mathrm{Na}, 1.5573 \mathrm{Tl}, n_{\mathrm{Z}}=1.5563 \mathrm{Li}, 1.5607 \mathrm{Na}, 1.5647$ $\mathrm{Tl}, n_{\mathrm{z}}-n_{\mathrm{X}}=0.0225 \mathrm{Na}$. Colorless. Made from water solution. A second phase is monoclinic with $a: b: c=1.1087: 1: 1.1588, \beta=92^{\circ} 22^{\prime}$.
$\mathbf{N a H}_{2}\left(\mathbf{P O}_{4}\right) \cdot \mathbf{2} \mathbf{H}_{2} \mathrm{O}$ is orthorhombic with $a: b: c=0.915: 1: 1.569$. Crystals pyramidal or brachydomatic. G. 1.92. $\mathrm{X}=c ; \mathrm{Y}=b$. (-) $2 \mathrm{~V}=82^{\circ} 50^{\prime}$; $n_{\mathrm{X}}=1.4376 \mathrm{Li}, 1.4401 \mathrm{Na}, 1.4423 \mathrm{Tl}, n_{\mathrm{Y}}=1.4600 \mathrm{Li}, 1.4629 \mathrm{Na}, 1.4655$ $\mathrm{Tl}, n_{\mathrm{X}}=1.4782 \mathrm{Li}, 1.4815 \mathrm{Na}, 1.4843 \mathrm{Tl}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0414 \mathrm{Na}$. Colorless. Made from water solution. PD 3.70, 3.06, 5.71; 10-198.
$\mathbf{N a H}_{2}\left(\mathbf{A s O}_{4}\right) \cdot \mathbf{2 H} \mathbf{H} \mathbf{O}$ is orthorhombic with $a: b: c=0.918: 1: 1.604$. Crystals pseudo-octahedral with $\{010\}$, $\{011\}$, etc. G. 2.31. $\mathrm{Y}=b ; ;^{31} \mathrm{Z}=c$. $(+) 2 \mathrm{~V}=88^{\circ} 50^{\prime}, \mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.4794 \mathrm{Na}, n_{\mathrm{Y}}=1.5021, n_{\mathrm{Z}}=1.5265$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0471 \mathrm{Na}$. Colorless.

## 4. Formula Type $\mathrm{AHXO}_{4} \cdot \mathrm{xH}_{2} \mathrm{O}$

$\mathbf{M g H}\left(\mathrm{PO}_{4}\right) \cdot 3 \mathrm{H}_{2} \mathrm{O}$ (Newberyite) is orthorhombic dipyramidal with $a: b: c=0.955: 1: 0.936$. Crystals equant or short prismatic or tabular. Perfect $\{010\}$ and poor $\{001\}$ cleavages. H. 3-3.5. G. 2.12. $\mathrm{X}=a ; \mathrm{Y}=b$.
$(+) 2 \mathrm{~V}=44^{\circ} 46^{\prime}, \mathrm{r}<$ v perceptible. $n_{\mathrm{X}}=1.514, n_{\mathrm{Y}}=1.517, n_{\mathrm{Z}}=1.533$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.019 .{ }^{24}$ Colorless. Made from a solution of magnesium phosphate in acetic acid. PD 3.45, 3.05, 5.9; 1-0597.
$\mathrm{CaH}\left(\mathrm{AsO}_{4}\right) \cdot \mathrm{H}_{2} \mathrm{O}$ (Haidingerite) is orthorhombic dipyramidal with $a: b: c=0.839: 1: 0.499$. Crystals equant or short prismatic. Perfect $\{010\}$ cleavage. H. 2-2.5. G. 2.96. $\mathrm{X}=b ; \mathrm{Y}=a$. $(+) 2 \mathrm{~V}=58^{\circ} \pm 3^{\circ}, \mathrm{r}>\mathrm{v}$ weak. ${ }^{24} n_{\mathrm{X}}=1.590, n_{\mathrm{Y}}=1.602, n_{\mathrm{Z}}=1.638$, all $\pm .003, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.048$. Colorless. Forms in the system $\mathrm{CaO}-\mathrm{As}_{2} \mathrm{O}_{3}-\mathrm{H}_{2} \mathrm{O}$ at temperatures of $60^{\circ} \mathrm{C}$. or higher.
$\mathrm{CaH}\left(\mathrm{AsO}_{4}\right) \cdot 3 \mathrm{H}_{2} \mathrm{O}$ is orthorhombic. ${ }^{10}$ G. 2.347. (-) $2 \mathrm{~V}=$ large, $n_{\mathrm{X}}=$ $1.513, n_{\mathrm{Y}}=1.523-1.525, n_{\mathrm{Z}}=1.532, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.019$. Colorless.
$\mathbf{M g H}\left(\mathrm{PO}_{4}\right) \cdot \mathbf{7 \mathrm { H } _ { 2 } \mathbf { O }}$ (Phosphorroesslerite) is monoclinic prismatic with $a=11.35, b=25.36, c=6.60 k X, \beta=95^{\circ}$. U.C. 8. Crystals equant or short prismatic. H. 2.5. G. 1.728. $\mathrm{X}=b ; \mathrm{Z} \wedge c^{32}=+6.5^{\circ}$. ( $-2 \mathrm{~V}=$ $38^{\circ} 10^{\prime}, \mathrm{r}>\mathrm{v} . n_{\mathrm{X}}=1.477, n_{\mathrm{Y}}=1.485, n_{\mathrm{Z}}=1.486, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.009$. Again: ${ }^{33} n_{\mathrm{X}}=1.470, n_{\mathrm{Y}}=1.483, n_{\mathrm{Z}}=1.485, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.015$. Colorless. Made when a magnesium sulfate solution is precipitated by phosphate ions at room temperature.
$\mathbf{M g H}\left(\mathbf{A s O}_{4}\right) \cdot \mathbf{7 H _ { 2 }} \mathbf{O}$ (Roesslerite) is monoclinic prismatic with $a: b: c=$ $0.4473: 1: 0.2598, \beta=94^{\circ} 26^{\prime}$. Crystals $\{010\}$ tablets; often in crusts or fibers. Poor $\{111\}$ cleavage. H. $2-3$. G. 1.94. $\mathrm{X} \wedge c=14^{\circ} ; \mathrm{Z}=b$. (+) $2 \mathrm{~V}=$ small; ${ }^{24} n_{\mathrm{X}}=1.525 \pm .005, n_{\mathrm{Y}}=1.53 \pm .01, n_{\mathrm{Z}}=1.550 \pm .005, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.025$. Colorless. Made from an acid solution of disodium arsenate and ammonium sulfate by adding a solution of magnesium sulfate.
$\mathrm{CaH}\left(\mathrm{PO}_{4}\right) \cdot 2 \mathrm{H}_{2} \mathrm{O}$ (Brushite) is monoclinic sphenoidal with $a=5.88$, $b=15.15, c=6.37 k X, \beta=117^{\circ} 28^{\prime}$. Crystals acicular or tabular, in some cases resembling gypsum. Perfect $\{010\}$ and $\{001\}$ cleavages. H. 2.5. G. 2.32. $\mathrm{X} \wedge c=-30^{\circ} ; \mathrm{Z}=b$. ( $+2 \mathrm{~V}=86^{\circ}, \mathrm{r}>\mathrm{v}$, with crossed dispersion. $n_{\mathrm{X}}=1.539, n_{\mathrm{Y}}=1.545, n_{\mathrm{Z}}=1.551, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.012$. Also ${ }^{33 \mathrm{a}}$ $\mathrm{X} \wedge c=-13^{\circ}, \mathrm{Y} \wedge a=+18^{\circ},(+) 2 \mathrm{~V}=87^{\circ}, n_{\mathrm{X}}=1.5412, n_{\mathrm{Y}}=1.5458$, $n_{\mathrm{Z}}=1.553$. Again: ${ }^{33 \mathrm{~b}} \mathrm{Y} \wedge a=+18^{\circ}, n_{\mathrm{X}}=1.543, n_{\mathrm{Y}}=1.548, n_{\mathrm{Z}}=$ 1.554. Colorless (or pale yellow). Made by adding sodium acid phosphat to a calcium chloride solution. PD 2.60, 4.20, 3.02; 4-0740.
$\mathrm{CaH}\left(\mathrm{AsO}_{4}\right) \cdot 2 \mathrm{H}_{2} \mathrm{O}$ (Pharmacolite) is monoclinic with $a=6.00, b=$ $15.40, c=6.29 k X, \beta=114^{\circ} 32^{\prime}$. U.C. 4. Crystals acicular; perfect $\{010\}$ cleavage. H. 2-2.5. G. 2.71. $\mathrm{X} \wedge c=-29^{\circ} ; \mathrm{Z}=b .{ }^{34}(-) 2 \mathrm{~V}=79^{\circ} 24^{\prime}$,
${ }^{32}$ Friedrich and Robitsch: Cent. Min. 1939A, p. 142.
${ }^{33}$ Alcock, Clark and Thurston: J. Soc. Chem. Ind. LXIII, p. 292 (1944).
${ }^{33 \mathrm{a}}$ Mélon and Dallemagne: Bull. Soc. Géol. Belg. LXIX, p. B19 (1946) [Min. Abst. X, p. 110].
${ }^{33 b}$ Van Tassel: Bull. Mus. Hist. Nat. Belg. XXII No. 17 (1944) [Min. Abst. IX, p. 255].
${ }^{34}$ Dufet: Bull. Soc. Fr. Min. XI, p. 187 (1888).
$\mathrm{r}>\mathrm{v} . n_{\mathrm{X}}=1.583, n_{\mathrm{Y}}=1.589, n_{\mathrm{Z}}=1.594, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.011$. Colorless, white or gray. Made by adding sodium acid arsenate to a solution of calcium chloride having an excess of HCl .

## 5. Formula Type $\mathrm{A}_{5} \mathrm{H}_{2}\left(\mathrm{XO}_{4}\right)_{4} \cdot \mathbf{x H}_{2} \mathrm{O}$ or $\mathrm{AH}_{4}\left(\mathrm{XO}_{4}\right)_{2} \cdot \mathbf{x H}_{2} \mathrm{O}$

$\mathrm{Mn}_{5} \mathrm{H}_{2}\left(\mathrm{PO}_{4}\right)_{4} \cdot \mathbf{4} \mathbf{H}_{2} \mathrm{O}$ (Hureaulite) is monoclinic prismatic with $a=$ $17.42, b=9.12, c=9.50 k X, \beta=96^{\circ} 40^{\prime}$. U.C. 4. Crystals short prismatic on $\{110\}$, also $\{100\}$ tablets or equant. Good $\{100\}$ cleavage. H. 3.5. G. 3.19. F. 3. Soluble in acid. $\mathrm{X}=b ; \mathrm{Z} \wedge c=-75^{\circ}$. (-) $2 \mathrm{~V}=75^{\circ}$, $\mathrm{r}<\mathrm{v}$ very strong with strong crossed dispersion. $n_{\mathrm{X}}{ }^{35}=1.647, n_{\mathrm{Y}}=1.654$, $n_{\mathrm{Z}}=1.660, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.013$. (With 4.56 per cent FeO.) The optic angle decreases $6.5^{\circ}$ on heating from $41^{\circ}$ to $121^{\circ} \mathrm{C}$. Color orange-red, rose-violet, pink, grayish. The orange-red type is pleochroic with X colorless, Y clear yellow to pale rose, $Z$ reddish yellow to reddish brown. Made by adding ammonia to a solution of manganese phosphate. Fe may replace Mn probably in any proportion.
$\mathbf{C a}_{5} \mathbf{H}_{2}\left(\mathbf{A s O}_{4}\right)_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ is monoclinic. ${ }^{10}$ G. 3.08. $\mathrm{Z} \wedge$ elongation $=$ ?, $n_{\mathrm{X}}=$ $1.613, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.615, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.002$. Again (for $6 \mathrm{H}_{2} \mathrm{O}$ ?) : ${ }^{9} n_{\mathrm{X}}=$ $1.60, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.64$. Colorless.
$\mathrm{Ca}_{5} \mathrm{H}_{2}\left(\mathrm{AsO}_{4}\right)_{4} \cdot \mathbf{9} \mathrm{H}_{2} \mathrm{O}$ is monoclinic (or triclinic?). ${ }^{10} \mathrm{G} .2 .78 . \mathrm{X} \wedge$ elongation $=24^{\circ} . n_{\mathrm{X}}=1.568, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.577, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.009$. Colorless.

## 6. Formula Type $A_{m} B_{n} H_{p}\left(\mathrm{XO}_{4}\right)_{q} \cdot \mathbf{x} H_{2} \mathbf{O}$

$\left(\mathrm{NH}_{4}\right)_{2} \mathbf{F e}_{2} \mathbf{H}_{4}\left(\mathbf{P O}_{4}\right)_{4} \cdot \mathbf{H}_{2} \mathrm{O}$ is monoclinic ${ }^{13}$ in $\{010\}$ plates with $\beta=109^{\circ}-$ $110^{\circ}$. G. 2.65. $\mathrm{X} \wedge c=50^{\circ} ; \mathrm{Z}=b$. $(+) 2 \mathrm{~V}=57^{\circ}, n_{\mathrm{X}}=1.655, n_{\mathrm{Y}}=$ $1.680, n_{\mathrm{Z}}=1.715, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.060$. Colorless.
$\mathrm{KFeH}_{2}\left(\mathbf{P O}_{4}\right)_{2} \cdot \mathbf{H}_{2} \mathrm{O}$ is monoclinic. ${ }^{13}$ Crystals basal plates. G. 2.63. X (nearly) $=c ; \mathrm{Y}=b .(-) 2 \mathrm{~V}=79^{\circ}, n_{\mathrm{X}}=1.592, n_{\mathrm{Y}}=1.614, n_{\mathrm{Z}}=1.630$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.038$.
$\mathrm{KAlH}_{2}\left(\mathbf{P O}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathbf{O}$ is monoclinic. ${ }^{13}$ Crystals prismatic or tabular. G. 2.52. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=7^{\circ} .(-) 2 \mathrm{~V}=50^{\circ} ; n_{\mathrm{X}}=1.522, n_{\mathrm{Y}}=1.536, n_{\mathrm{Z}}=1.539$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.017$. Colorless.
$\left(\mathbf{N H}_{4}\right)_{2} \mathrm{Al}_{2} \mathbf{H}_{4}\left(\mathbf{P O}_{4}\right)_{4} \cdot \mathbf{H}_{2} \mathbf{O}$ is triclinic ${ }^{13}$ in thin plates. G. 2.47. The optic plane makes an angle of $16^{\circ}$ with a normal to the plate. $\mathrm{Z} \wedge$ plate $=45^{\circ} \pm$. $(-) 2 \mathrm{~V}=71^{\circ}-73^{\circ} . n_{\mathrm{X}}=1.565, n_{\mathrm{Y}}=1.586, n_{\mathrm{Z}}=1.597, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.032$. Color pale green.
$\mathrm{K}_{2} \mathrm{Al}_{3} \mathbf{H}_{4}\left(\mathrm{PO}_{4}\right)_{5} \cdot \mathbf{1 1 H}_{2} \mathrm{O}$ is orthorhombic (or monoclinic?). ${ }^{13}$ Crystals platy. G. 2.24. Z normal to plates. $(+) 2 \mathrm{~V}=$ small. $n_{\mathrm{X}}=1.510, n_{\mathrm{Y}}=$ $1.510-1.511, n_{\mathrm{Z}}=1.515, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.005$. Colorless. Made by partial dehydration of $\mathrm{K}_{2} \mathrm{Al}_{6} \mathrm{H}_{10}\left(\mathrm{PO}_{4}\right)_{10} \cdot 15 \mathrm{H}_{2} \mathrm{O}$.
$\left(\mathbf{N H}_{4}\right) \mathbf{F e}_{3} \mathbf{H}_{8}\left(\mathbf{P O}_{4}\right)_{6} \cdot \mathbf{6 H} \mathbf{H} \mathbf{O}$ is hexagonal. ${ }^{13}$ Crystals thin basal plates. G.
${ }^{35}$ Larsen and Berman: U. S. Geol. Surv. Bull. 848, 1934.
2.29. Uniaxial positive with $n_{\mathrm{O}}=1.580, n_{\mathrm{E}}=1.591, n_{\mathrm{E}}-n_{\mathrm{O}}=0.011$. Color pale lavender.
$\mathrm{KFe}_{3} \mathbf{H}_{8}\left(\mathbf{P O}_{4}\right)_{6} \cdot \mathbf{6 H} \mathbf{H} \mathbf{O}$ is hexagonal. ${ }^{13}$ Crystals prismatic. G. 2.43. Uniaxial positive with $n_{\mathrm{O}}=1.595, n_{\mathrm{E}}=1.601, n_{\mathrm{E}}-n_{\mathrm{O}}=0.006$. Color pale lavender.
$\mathrm{K}_{2} \mathrm{Al}_{6} \mathrm{H}_{10}\left(\mathrm{PO}_{4}\right)_{10} \cdot \mathbf{1 5 H}_{2} \mathrm{O}$ is monoclinic. ${ }^{13}$ Crystals platy. G. 2.09. X normal to plates. $(-) 2 \mathrm{~V}=$ small. $n_{\mathrm{X}}=1.495, n_{\mathrm{Y}}=1.503-1.504, n_{\mathrm{Z}}=1.505$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.010$. Colorless.
$\mathbf{C a H}_{4}\left(\mathbf{P O}_{4}\right)_{2} \cdot \mathbf{H}_{2} \mathbf{O}$ is triclinic with $a=5.67, b=11.92, c=6.51 \AA, \alpha=$ $99^{\circ} 50^{\prime}, \beta=118^{\circ} 31^{\prime}, \gamma=83^{\circ} 9^{\prime}$. U.C. 2. Crystals $\{010\}$ plates elongated along $c$; polysynthetic twinning on $\{010\}$ common. Poor $\{100\}$ and $\{001\}$ cleavages. G. 2.22. Loses water at $109^{\circ} \mathrm{C}$. and decomposes at $153^{\circ} \mathrm{C}$. Z (nearly) parallel with (010) and $\mathrm{Z} \wedge a=2^{\circ} 40^{\prime}$ in acute $\beta$. X inclined to (010) at $37^{\circ}$ in obtuse $\alpha$. (-) $2 \mathrm{~V}=81^{\circ} 30^{\prime}, \mathrm{r}>\mathrm{v}$ very weak. ${ }^{36}$ For $\lambda=$ $425 \mathrm{~m} \mu: n_{\mathrm{X}}=1.492, n_{\mathrm{Y}}=1.512, n_{\mathrm{Z}}=1.526, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.034$. For $\lambda=$ $610 \mathrm{~m} \mu: n_{\mathrm{X}}=1.496, n_{\mathrm{Y}}=1.515, n_{\mathrm{Z}}=1.529, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.033$. Again: ${ }^{36 \mathrm{a}}$ $(-) 2 \mathrm{~V}=70^{\circ}, n_{\mathrm{X}}=1.4932, n_{\mathrm{Y}}=1.5176, n_{\mathrm{Z}}=1.5292, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.036$. PD 3.88, 3.69, 11.7; 9-347.

## D. HYDRATED NORMAL PHOSPHATES, ETC.

## 1. Formula Type $\mathrm{A}_{3} \mathrm{XO}_{4} \cdot \mathbf{x H}_{2} \mathrm{O}$

$\mathbf{N a}_{3}\left(\mathbf{V O}_{4}\right) \cdot \mathbf{1 0 H} \mathbf{2} \mathbf{O}$ is isometric. ${ }^{37}$ Crystals dodecahedral. Isotropic with $n=1.5244 \mathrm{Li}, 1.5305 \mathrm{Na}, 1.5366 \mathrm{Tl}$. Another phase is hexagonal, in basal plates. Uniaxial positive with $n_{\mathrm{O}}=1.5332 \mathrm{Li}, 1.5398 \mathrm{Na}, 1.5460 \mathrm{Tl}, n_{\mathrm{E}}=$ $1.5408 \mathrm{Li}, 1.5475 \mathrm{Na}, 1.5537 \mathrm{Tl}, n_{\mathrm{E}}-n_{\mathrm{O}}=0.0077 \mathrm{Na}$.
$\mathbf{N a}_{3}\left(\mathbf{V O}_{4}\right) \cdot \mathbf{1 2 H} \mathbf{H}_{2} \mathbf{O}$ is hexagonal ${ }^{37}$ (trigonal). Crystals resemble rhombohedrons. Uniaxial positive with $n_{\mathrm{o}}=1.5040 \mathrm{Li}, 1.5095 \mathrm{Na}, 1.5150 \mathrm{Tl}$. $n_{\mathrm{E}}=1.5173 \mathrm{Li}, 1.5232 \mathrm{Na}, 1.5293 \mathrm{Tl}, n_{\mathrm{E}}-n_{\mathrm{O}}=0.0137 \mathrm{Na}$.
$\mathbf{N a}_{3}\left(\mathbf{A s O}_{4}\right) \cdot \mathbf{1 2 H} \mathbf{H}_{2} \mathbf{O}$ is hexagonal (trigonal). ${ }^{37}$ Crystals prismatic with $\{0001\}$. G. 1.76 (1.80). Uniaxial positive with $n_{\mathrm{O}}=1.4553 \mathrm{Li}, 1.4589 \mathrm{Na}$, $1.4624 \mathrm{Tl}, n_{\mathrm{E}}=1.4630 \mathrm{Li}, 1.4669 \mathrm{Na}, 1.4704 \mathrm{Tl}, n_{\mathrm{E}}-n_{\mathrm{O}}=0.008 \mathrm{Na}$.
$\mathbf{N a}_{3}\left(\mathbf{P O}_{4}\right) \cdot \mathbf{1 2 H} \mathbf{H}_{2} \mathbf{O}$ is hexagonal (trigonal). ${ }^{30}$ Crystals long prismatic with $\{0001\}$. M.P. $70-75^{\circ}$ C. G. 1.645. Uniaxial positive with $n_{0}=1.4458$, $n_{\mathrm{E}}=1.4524, \quad n_{\mathrm{E}}-n_{\mathrm{O}}=0.0066$. Again: ${ }^{37} \quad n_{\mathrm{O}}=1.4486, \quad n_{\mathrm{E}}=1.4539$, $n_{\mathrm{o}}-n_{\mathrm{E}}=0.0053$. It contains some NaOH if formed from water solution and is actually $5\left(\mathrm{Na}_{3} \mathrm{PO}_{4} \cdot 12 \mathrm{H}_{2} \mathrm{O}\right) \cdot \mathrm{NaOH}$ according to Bell. ${ }^{38} \mathrm{PD} 4.34$, 10.3, 2.61; 10-189.
${ }^{36}$ Smith, Lehr and Brown: Am. Min. XL, p. 893 (1955).
${ }^{36 \mathrm{a}}$ Measures by Garth Volk at Univ. Wis. in 1935.
${ }^{37}$ Baker: J. Chem. Soc. London XLVII, p. 353 (1885).
${ }^{38}$ Bell: Ind. Eng. Chem. XLI, p. 2901 (1949).
$\mathbf{N a}_{3}\left(\mathbf{P O}_{4}\right) \cdot \mathbf{H}_{2} \mathbf{O}$ is uniaxial positive with $^{4} n_{\mathrm{O}}=1.497, n_{\mathrm{E}}=1.522, n_{\mathrm{E}}-$ $n_{\mathrm{o}}=0.025$. Effloresces at $180^{\circ} \mathrm{C}$. Apparently the water content may vary from about 0.5 to about 1.5 . With ${ }^{38} 0.5 \mathrm{H}_{2} \mathrm{O} \quad n_{\mathrm{O}}=1.499, n_{\mathrm{E}}=1.525$, $n_{\mathrm{E}}-n_{\mathrm{O}}=0.026$. Made by evaporating a solution (at $86^{\circ} \mathrm{C}$.) containing some NaOH .
$\mathbf{N a}_{3}\left(\mathbf{P O}_{4}\right) \cdot \mathbf{7 H _ { 2 }} \mathbf{O}$ melts at $110^{\circ} \mathrm{C}$. It is biaxial with ${ }^{4}(+) 2 \mathrm{~V}=85^{\circ}, n_{\mathrm{X}}=$ $1.462, n_{\mathrm{Y}}=1.470, n_{\mathrm{Z}}=1.478, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.016$. Made by evaporating a water solution at $83^{\circ} \mathrm{C}$. Apparently the water content may vary from about 6 to $7 \mathrm{H}_{2} \mathrm{O}$. With $6 \mathrm{H}_{2} \mathrm{O}:(-) 2 \mathrm{~V}=60^{\circ}$ calc., $n_{\mathrm{X}}=1.462, n_{\mathrm{Y}}=$ 1.473, $n_{\mathrm{Z}}=1.477, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.015$.
$\mathbf{N a}_{3}\left(\mathbf{P O}_{4}\right) \cdot \mathbf{8 H} \mathbf{H} \mathbf{O}$ is monoclinic. ${ }^{38}$ It effloresces at $86^{\circ} \mathrm{C}$. The extinction angle ( $\mathrm{X} \wedge$ elongation) is $22^{\circ}$. ( - ) $2 \mathrm{~V}=58^{\circ}$ calc. $n_{\mathrm{X}}=1.458, n_{\mathrm{Y}}=1.468$, $n_{\mathrm{Z}}=1.471, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.013$. Colorless. Made from water solution.
$\mathbf{H}_{3} \mathbf{P O}_{4} \cdot \frac{1}{2} \mathbf{H}_{2} \mathbf{O}$ is monoclinic with ${ }^{14 \mathrm{a}} a=7.94, b=12.94, c=7.38 \AA$, $\beta=109^{\circ} 25^{\prime}$. Crystals tabular $\{001\}$, rod-like along $a$. Poor $\{010\}$ cleavage. M.P. $29^{\circ}$ C. $\mathrm{Y}=b ; \mathrm{Z} \wedge a=20^{\circ}$ in acute $\beta$. $(+) 2 \mathrm{~V}=56^{\circ}, \mathrm{r}>\mathrm{v}$ very weak. $n_{\mathrm{X}}=1.485, n_{\mathrm{Y}}=1.492, n_{\mathrm{Z}}=1.519, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.034$. Colorless.

## 2. Formula Type $\mathrm{A}_{3}\left(\mathrm{XO}_{4}\right)_{2} \cdot \mathrm{XH}_{2} \mathrm{O}$ (also $\mathrm{ABXO}_{4} \cdot \mathbf{x H}_{2} \mathrm{O}$ )

$\left(\mathbf{N H}_{4}\right) \mathbf{M g}\left(\mathrm{PO}_{4}\right) \cdot 6 \mathrm{H}_{2} \mathbf{O}$ (Struvite) is orthorhombic pyramidal with $a=$ $6.09, b=6.97, c=11.18 k X$. U.C. 2. Crystals varied: equant, wedgeshaped, prismatic or tabular. Good $\{001\}$ and poor $\{100\}$ cleavages. H. 2. G. 1.71. $\mathrm{X}=b ; \mathrm{Y}=c$. $(+) 2 \mathrm{~V}=37^{\circ} 22^{\prime}, \mathrm{r}<\mathrm{v}$ strong. ${ }^{39} n_{\mathrm{X}}=1.495$, $n_{\mathrm{Y}}=1.496, n_{\mathrm{Z}}=1.504 \mathrm{Na}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.009$. Colorless or stained. Made by reaction of magnesium sulphate and acid ammonium phosphate solutions. PD 4.28, 2.93, 2.69; 5-0316.
$\mathbf{Z n}_{3}\left(\mathbf{P O}_{4}\right)_{2} \cdot \mathbf{4 H _ { 2 }} \mathbf{O}$ (Hopeite) is orthorhombic with $a=10.64, b=18.32$, $c=5.03 \mathrm{kX}$. U.C. 6. Crystals $\{010\}$ tablets or prismatic. Perfect $\{010\}$, good $\{100\}$ and poor $\{001\}$ cleavages. H. 3-3.5. G. 3.05. $\mathrm{X}=a ;{ }^{40} \mathrm{Y}=\boldsymbol{c}$. $(-) 2 \mathrm{~V}=37^{\circ}, \mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.589, n_{\mathrm{Y}}=1.598, n_{\mathrm{Z}}=1.599, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.010. Again: ${ }^{24} n_{\mathrm{X}}=1.574, n_{\mathrm{Y}}=1.582, n_{\mathrm{Z}}=1.582, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.008$. Colorless. Made from a solution of zinc phosphate in acetic acid. Hopeite crystals may show zonal growths, adjacent zones differing some in properties although apparently of the same composition. One zone has ${ }^{41}$ a higher specific gravity and birefringence and optic angle than the next. PD 9.04, 4.57, 2.86; 9-497*. Another phase of $\mathrm{Zn}_{3}\left(\mathrm{PO}_{4}\right)_{2} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ is triclinicsee beyond.
$\mathbf{M g}_{3}\left(\mathbf{P O}_{4}\right)_{2} \cdot \mathbf{8 H} \mathbf{H} \mathbf{O}$ (Bobierrite) is monoclinic with $a=9.946, b=27.654$, $c=4.639 k X, \beta=104^{\circ} 1^{\prime}$. Crystals acicular. Perfect $\{010\}$ cleavage.

[^123]H. 2-2.5. G. 2.19. $\mathrm{Y}=b ; ;^{42} \mathrm{Z} \wedge c=29^{\circ}$. $(+) 2 \mathrm{~V}=71^{\circ} \pm 3^{\circ}, \mathrm{r}<\mathrm{v}$. $n_{\mathrm{X}}=1.510, n_{\mathrm{Y}}=1.520, n_{\mathrm{Z}}=1.543, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.033$. Colorless. Made by slow precipitation of $\mathrm{MgSO}_{4}$ solution by a solution of $\mathrm{Na}_{2} \mathrm{HPO}_{4}$ and $\mathrm{NaHCO}_{3}$. Fe may replace some Mg ; with 15 per cent FeO the optic properties ${ }^{43}$ are: $(+) 2 \mathrm{~V}=57^{\circ} \pm 3^{\circ}, n_{\mathrm{X}}=1.5468, n_{\mathrm{Y}}=1.5533, n_{\mathrm{Z}}=$ $1.5820, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0352$. PD 6.70, 2.94, 2.69; $1-0122$.
$\mathbf{M g}_{3}\left(\mathbf{P O}_{4}\right)_{2} \cdot \mathbf{2 2 H}_{2} \mathbf{O}$ forms crystals which are biaxial ${ }^{33}$ with large optic angle and $n_{\mathrm{X}}=1.461, n_{\mathrm{Y}}=1.465, n_{\mathrm{Z}}=1.469$ (all $\pm 0.002$ ), $n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.008 . Colorless. Made from water solution.
$\mathbf{M g}_{3}\left(\mathbf{P O}_{4}\right)_{2} \cdot \mathbf{3}-\mathbf{5 H} \mathbf{H} \mathbf{O}$ forms acicular crystals ${ }^{33}$ in coarse spherulites. $n_{\mathrm{Y}}$ is about $1.535, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ about 0.006 . Colorless. Made by partial dehydration of $\mathrm{Mg}_{3}\left(\mathrm{PO}_{4}\right)_{2} \cdot 22 \mathrm{H}_{2} \mathrm{O}$. PD (?) 4.10, 5.2, 3.23; $1-0428$.
$\mathbf{M g}_{3}\left(\mathbf{A s O}_{4}\right)_{2} \cdot \mathbf{8 H _ { 2 }} \mathbf{O}$ (Hoernesite) is monoclinic prismatic with $a: b: c=$ $0.7676: 1: 0.3591, \beta=104^{\circ} 25^{\prime}$. Crystals prismatic. Perfect $\{010\}$ and poor $\{100\}$ cleavages. H. 1. G. 2.61. $\mathrm{X}=b ;^{24} \mathrm{Z} \wedge c=31^{\circ}$. ( + ) $2 \mathrm{~V}=60^{\circ}$, $n_{\mathrm{X}}=1.563, n_{\mathrm{Y}}=1.571, n_{\mathrm{Z}}=1.596, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.033$. Colorless. Again $:^{44}$ $\mathrm{Z} \wedge c=45^{\circ}, n_{\mathrm{Y}}=1.570, n_{\mathrm{Z}}=1.594$.
$\mathbf{F e}_{3}\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathbf{8 H _ { 2 }} \mathbf{O}$ (Vivianite) is monoclinic prismatic with $a=10.039$, $b=13.388, c=4.687 k X, \beta=104^{\circ} 18^{\prime}$. U.C. 2. Crystals prismatic or equant or $\{010\}$ tablets; often earthy. Perfect $\{010\}$ cleavage. H. 1.5-2. G. 2.68. $\mathrm{X}=b^{45} \mathrm{Z} \wedge c=+28.5^{\circ}$. $(+) 2 \mathrm{~V}=83.5^{\circ}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{x}}=$ 1.5788, $n_{\mathrm{Y}}=1.6024, n_{\mathrm{Z}}=1.6294, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0506$. Colorless when fresh and unaltered, but rapidly becomes blue or greenish blue (or even black) due to oxidation of the iron; a little oxidation leads to pleochroism with X blue, Y and Z pale yellowish green; with more oxidation a sample may become black and then flakes are pleochroic with X indigo, Y green-yellow and Z yellow-olive; then, also, $(+) 2 \mathrm{~V}=63.5^{\circ}, n_{\mathrm{X}}=1.616, n_{\mathrm{Y}}=1.656$, $n_{\mathrm{Z}}=1.675, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.059$. Made by heating ferrous phosphate in a solution of sodium phosphate. PD 6.80, 2.97, 2.71; 3-0070.
$\mathbf{C o}_{3}\left(\mathrm{AsO}_{4}\right)_{2} \cdot \mathbf{8 H}_{2} \mathbf{O}$ (Erythrite) is monoclinic prismatic with $a=10.184$, $b=13.34, c=4.73 k X, \beta=105^{\circ} 1^{\prime}$. U.C. 2 . Crystals prismatic to acicular; also earthy. Perfect $\{010\}$ and poor $\{100\}$ and $\{\overline{1} 02\}$ cleavages. H. 2. G. 3.18. $\mathrm{X}=b ; \mathrm{Z} \wedge c^{35}=+31^{\circ}$. (土) $2 \mathrm{~V}=$ approximately $90^{\circ}, \mathrm{r}>\mathrm{v}$. $n_{\mathrm{X}}=1.626, n_{\mathrm{Y}}=1.661, n_{\mathrm{Z}}=1.699, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.073$. Color red; pleochroic with $X$ pale pinkish or rose, $Y$ very pale violet or rose, $Z$ red or deep rose. Made by slow precipitation of a $\mathrm{CoSO}_{4}$ solution with

[^124]$\mathrm{Na}_{2} \mathrm{HAsO}_{4} \cdot \mathrm{Co}_{3}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ forms a complete series of mix-crystals with $\mathrm{Ni}_{3}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$. Minor amounts of $\mathrm{Ca}, \mathrm{Mg}, \mathrm{Fe}, \mathrm{Zn}$ may be present. PD 6.69, 3.21, 2.99; 10-480.
$\mathrm{Ni}_{3}\left(\mathbf{A s O}_{4}\right)_{2} \cdot \mathbf{8 H}_{2} \mathrm{O}$ (Annabergite) is monoclinic prismatic with $a=$ $10.122, b=13.284, c=4.698 k X, \beta=104^{\circ} 45^{\prime}$. U.C. 2. Usually in crystalline coatings. Perfect $\{010\}$ cleavage. H. 2.5. G.3. $\mathrm{X}=b ;{ }^{35} \mathrm{Z} \wedge c=+36^{\circ}$. $(+) 2 \mathrm{~V}=84^{\circ}, \mathrm{r}>\mathrm{v}$ rather strong. $n_{\mathrm{X}}=1.622, n_{\mathrm{Y}}=1.658, n_{\mathrm{Z}}=1.687$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.065$. Color apple green. Colorless or weakly pleochroic in flakes. Made by slow precipitation of a $\mathrm{NiSO}_{4}$ solution with $\mathrm{Na}_{2} \mathrm{HAsO}_{4}$. Forms a complete series of mix-crystals with $\mathrm{Co}_{3}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$. It may contain some Mg or Zn .
$\mathbf{Z n}_{3}\left(\mathbf{A s O}_{4}\right)_{2} \cdot \mathbf{8 H}_{2} \mathbf{O}$ (Koettigite) is monoclinic with $a=10.11, b=13.31$, $c=4.70 \mathrm{kX}, \beta=104^{\circ} 30^{\prime}$. Crystals prismatic, $\{010\}$ plates with perfect $\{010\}$ cleavage. H. 2.5-3. G. 3.33. $\mathrm{X}=b ;^{40} \mathrm{Z} \wedge c=37^{\circ}$. (-) $2 \mathrm{~V}=74^{\circ}$, $\mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{X}}=1.622, n_{\mathrm{Y}}=1.638, n_{\mathrm{Z}}=1.671, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.049$. Color carmine or brownish. Made by aging the gelatinous precipitate from mixed solutions of $\mathrm{ZnSO}_{4}$ and $\mathrm{Na}_{2} \mathrm{HAsO}_{4}$. It may contain some Co. PD 3.20, 3.00, 2.72; 1-0744*.
$\mathbf{F e}\left(\mathbf{A s O}_{4}\right)_{2} \cdot \mathbf{8} \mathrm{H}_{2} \mathbf{O}$ (Symplesite) is triclinic ${ }^{40}$ with $a=7.85, b=9.39, c=$ $4.71 k X, \alpha=99^{\circ} 55^{\prime}, \beta=97^{\circ} 57^{\prime}, \gamma=105^{\circ} 57^{\prime}$. Crystals coarse fibers radially arranged. Perfect $\{1 \overline{1} 0\}$ cleavage. H. 2.5. G. 3.01. X normal to cleavage. $\mathrm{Z} \wedge c=31^{\circ} 30^{\prime}$. (-) $2 \mathrm{~V}=86^{\circ} 30^{\prime}, \mathrm{r}>\mathrm{v}$ strong. $n_{\mathrm{X}}=1.635 \pm .005$, $n_{\mathrm{Y}}=1.668 \pm .005, n_{\mathrm{Z}}=1.702 \pm .005, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.067$. Color green, becoming greenish black or indigo-blue on oxidation. Pleochroic with X deep blue, Y nearly colorless, Z yellowish. Made hydrothermally. ${ }^{45 a}$ PD 6.79, 7.50, 8.97; 8-172.
$\mathbf{Z n}_{3}\left(\mathbf{P O}_{4}\right)_{2} \cdot \mathbf{4 H _ { 2 }} \mathbf{O}$ (Parahopeite) is triclinic pinacoidal with $a=5.755$, $b=7.535, c=5.292 k X, \alpha=93^{\circ} 17^{\prime}, \beta=91^{\circ} 55^{\prime}, \gamma=91^{\circ} 19^{\prime}$. U.C. 1 . Crystals long parallel with $c$ and tabular $\{100\}$. Common polysynthetic twinning on $\{100\}$. Perfect $\{010\}$ cleavage. H. 3.5-4. G. 3.31. X near $a$; $\mathrm{Y}^{\prime} \wedge c$ on $\{100\}=30^{\circ} .(+) 2 \mathrm{~V}$ near $90^{\circ}, \mathrm{r}<\mathrm{v}$ perceptible. $n_{\mathrm{x}^{24}}=1.614$, $n_{\mathrm{Y}}=1.625, n_{\mathrm{Z}}=1.637, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.023$. Colorless. Stable to $163^{\circ} \mathrm{C}$. Made by reaction of hot solution of $\mathrm{ZnCl}_{2}$ and sodium ammonium phosphate. PD 7.56, 2.99, 4.48; 9-491*.

## 3. Formula Type $\mathrm{AXO}_{4} \cdot \mathrm{xH}_{2} \mathrm{O}$

$2 \mathrm{CrPO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ is formed between $300^{\circ} \mathrm{C}$. and $900^{\circ} \mathrm{C}$. by heating the hexahydrate under 2000 pounds per square inch of water-vapor pressure, or by heating it dry between $200^{\circ}$ and $850^{\circ} \mathrm{C}$, or by heating either $\alpha-\mathrm{CrPO}_{4}$ or $\beta$ - $\mathrm{CrPO}_{4}$ hydrothermally at $300^{\circ}$ to $900^{\circ} \mathrm{C}$. It is ${ }^{45 \mathrm{~b}}$ olive-green and

[^125]strongly birefringent, with $n \approx 1.810 \pm .006$. The strongest X-ray powder lines are at $\mathrm{d}=3.278,3.171,1.582,2.024$, and 1.636 .
$\mathrm{AlPO}_{4} \cdot \mathbf{2 H}_{2} \mathrm{O}$ (Variscite) is orthorhombic with ${ }^{46} a=9.55, b=9.85, c=$ 8.50 kX . U.C. 8. Crystals pyramidal with $\{111\}$ and $\{001\}$. Good $\{100\}$ and poor $\{001\}$ cleavages. H. 4-4.5. G. 2.57. $\mathrm{X}=b ; \mathrm{Y}=c$. $(-) 2 \mathrm{~V}=$ moderate, ${ }^{47} \mathrm{r}<$ v perceptible. $n_{\mathrm{X}}=1.565, n_{\mathrm{Y}}=1.588, n_{\mathrm{Z}}=1.593, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.028$. Indices vary notably perhaps due to variation in water content. For example: $n_{\mathrm{X}}=1.550, n_{\mathrm{Y}}=1.565, n_{\mathrm{Z}}=1.570, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.020 . Color pale green, bluish green, colorless. Made by adding NaOH solution to acid solution of $\mathrm{AlCl}_{3}$ and dihydrogen phosphate. It forms a complete series with $\mathrm{FePO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$. PD 5.31, 4.26, 3.05; 8-157.
$\mathrm{FePO}_{4} \cdot \mathbf{2 H}_{2} \mathrm{O}$ (Strengite) is orthorhombic ${ }^{47}$ with $a=9.80, b=10.05$, $c=8.65 k X$. U.C. 8. Crystals varied in habit; often in aggregates. Good $\{100\}$ and poor $\{001\}$ cleavages. H. 3.5-4. G. 2.90. $\mathrm{X}=b ; \mathrm{Y}=c .(+) 2 \mathrm{~V}=$ small, $\mathrm{r}<\mathrm{v}$ very strong. ${ }^{24} n_{\mathrm{X}}=1.730, n_{\mathrm{Y}}=1.732, n_{\mathrm{Z}}=1.762, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.032$. Colorless or pink with X and Y colorless, Z pale pink. Made by adding NaOH solution to acid solution of $\mathrm{FeCl}_{3}$ and dihydrogen phosphate. It forms a complete series with $\mathrm{AlPO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$. PD 3.30, 3.65, 4.20; 3-0452*.
$\mathrm{FeAsO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ (Scorodite) is orthorhombic dipyramidal with ${ }^{46} a=$ $10.01, b=10.30, c=8.90 \mathrm{kX}$. U.C. 8. Crystals pyramidal or basal tablets or prismatic. Poor cleavage. H. 3.5-4. G. 3.28. $\mathrm{X}=b ; \mathrm{Y}=\mathrm{c}$. $(+) 2 \mathrm{~V}=$ $75^{\circ}$ ca., ${ }^{48} \mathrm{r}>$ v strong. $n_{\mathrm{X}}=1.784, n_{\mathrm{Y}}=1.795, n_{\mathrm{Z}}=1.814, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.030. Color pale green to brown (or bluish or yellow), faintly pleochroic with $Z>X, Y$. Made by heating iron with $\mathrm{H}_{2} \mathrm{O}$ and $\mathrm{As}_{2} \mathrm{O}_{5}$ in a closed tube up to $150^{\circ} \mathrm{C}$. A complete series probably extends to $\mathbf{A l A s O} \mathbf{O}_{4} \cdot \mathbf{2 H}_{2} \mathbf{O}$ (Mansfieldite) which has $(+) 2 \mathrm{~V}=30^{\circ} c a ., n_{\mathrm{X}}=1.622, n_{\mathrm{Y}}=1.624$, $n_{\mathrm{z}}=1.642, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.020$. Color white to gray. PD 5.56, 4.44, 3.16; 5-0216.
$\mathrm{YPO}_{4} \cdot \mathbf{2 H}_{2} \mathrm{O}$ (Weinschenkite) is monoclinic prismatic with $a=6.48$, $b=15.12, c=6.28 k X, \beta=129^{\circ} 24^{\prime}$. U.C. 4. Crystals lath-like; usually in crusts or spherulites. $\{001\}$ and $\{\overline{1} 01\}$ cleavages. G. 3.17. $\mathrm{X}=b$; $\mathrm{Z} \wedge c=35^{\circ} c a$. (+) $2 \mathrm{~V}=30^{\circ} c a .^{35} n_{\mathrm{X}}=1.600, n_{\mathrm{Y}}=1.608, n_{\mathrm{Z}}=1.645$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.045$. Again: $n_{\mathrm{X}}=1.605, n_{\mathrm{Y}}=1.612, n_{\mathrm{Z}}=1.645, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ $0.040 .{ }^{48 a}$ Colorless or white. Made by reaction of yttrium nitrate and tribasic sodium phosphate solutions. Often contains minor amounts of Er, $\mathrm{Yb}, \mathrm{Ce}$, etc., replacing some Y.
$\mathrm{CePO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ (Churchite) is probably monoclinic. Crystals minute
${ }^{46} a b c$ changed to $b a c$ to make $b>a>c$.
${ }^{47}$ Schaller: U. S. Geol. Surv. Bull. 610 (1916).
${ }^{48}$ Allen and Fahey: Am. Min. XXXIII, p. 122 (1948).
${ }^{48 \mathrm{a}}$ Milton, Murata and Knechtel: Am. Min. XXIX, p. 92 (1944).
columnar. One perfect cleavage. H. 3. G. 3.14. (+) $2 \mathrm{~V}^{24}=$ near $0^{\circ}, n_{\mathrm{X}}=$ $1.620 \pm .003, n_{\mathrm{Y}}=1.620, n_{\mathrm{Z}}=1.654, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.034$. Color gray, slightly reddish. Made from a cerium nitrate solution by adding sodium phosphate. PD 4.21, 7.50, 3.02; 8-167.
$\mathrm{CrPO}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is triclinic. Crystals prismatic. G. 2.121. ( - ) $2 \mathrm{~V}=13^{\circ}$, $n_{\mathrm{X}}{ }^{49}=1.568, n_{\mathrm{Y}}=1.591, n_{\mathrm{Z}}=1.599, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.031$.
$\mathrm{Al}\left(\mathrm{VO}_{4}\right) \cdot 3$ (or 3.5) $\mathrm{H}_{2} \mathrm{O}$ (Steigerite) is amorphous ${ }^{49 \mathrm{a}}$ (or nearly so). It forms pulverulent coatings or gum-like waxy masses. $n=1.710 \pm .005$. Color canary yellow. Made from water solution of aluminum sulfate and calcium vanadate.

## E. ANHYDROUS PHOSPHATES, ETC., CONTAINING HYDROXYL OR HALOGEN OR EXTRA OXYGEN

## 1. Formula Type $A_{2} X O_{4} Z$ or $\mathrm{ABXO}_{4} Z$

$\mathbf{M g}_{2}\left(\mathbf{P O}_{4}\right)(\mathbf{O H})$ forms needles ${ }^{33}$ with parallel extinction and positive elongation, often in fan-like clusters. $(+) 2 \mathrm{~V}=$ small, $n_{\mathrm{X}}=1.533, n_{\mathrm{Y}}=$ very near $n_{\mathrm{X}}, n_{\mathrm{Z}}=1.552$ (both $\pm .003$ ), $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.019$. Colorless. Made from a water solution of $\mathrm{Mg}_{3}\left(\mathrm{PO}_{4}\right)_{2} \cdot 22 \mathrm{H}_{2} \mathrm{O}$ (with some NaOH ) heated to $200^{\circ} \mathrm{C}$.
$\mathbf{C a}_{2}\left(\mathbf{P O}_{4}\right) \mathbf{C l}$ (Chlor-spodiosite) is orthorhombic with ${ }^{50} a=6.17, b=$ $6.89, c=10.74 \AA$. U.C. 4. Crystals oblong plates with good $\{001\}$ cleavage. G. 3.04. $\mathrm{Y}=b ; \mathrm{Z}=c$. $(-) 2 \mathrm{~V}=$ large, $n_{\mathrm{X}}=1.649, n_{\mathrm{Y}}=1.665, n_{\mathrm{Z}}=$ 1.670, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.021$. Again: ${ }^{51} n_{\mathrm{Y}}=1.658$. Also: $5^{2}(-) 2 \mathrm{~V}=75^{\circ}, n_{\mathrm{X}}=$ $1.650, n_{\mathrm{Y}}=1.663, n_{\mathrm{Z}}=1.670, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.020$. Colorless.
$\mathbf{Z n}_{2}\left(\mathbf{P O}_{4}\right)(\mathbf{O H})$ is orthorhombic(?). $\mathrm{X}=a ; ;^{53} \mathrm{Y}=b$. (-)2V $=$ large. $n_{\mathrm{X}}=1.608, n_{\mathrm{Y}}=1.624, n_{\mathrm{Z}}=1.629, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.021$. Colorless to pale brown. Made by dehydration of spencerite. PD 6.1, 3.65, 2.76; 8-158.
$\mathbf{C u}_{2}\left(\mathbf{P O}_{4}\right)(\mathbf{O H})$ (Libethenite) is orthorhombic dipyramidal with $a=$ $8.08, b=8.43, c=5.90 k X$. U.C. 4. Crystals short prismatic or brachydomatic or equant. Poor $\{100\}$ and $\{010\}$ cleavages. H. 4. G. 3.97. $\mathrm{X}=$ $b ;{ }^{24} \mathrm{Y}=c$. (-) $2 \mathrm{~V}=$ near $90^{\circ}, \mathrm{r}>\mathrm{v}$ strong. $n_{\mathrm{X}}=1.701, n_{\mathrm{Y}}=1.743$, $n_{\mathrm{Z}}=1.787$ (all $\pm .003$ ), $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.086$. Again: $:^{54}(-) 2 \mathrm{~V}=81^{\circ} 38^{\prime} \mathrm{Li}$,

[^126]$81^{\circ} 8^{\prime} \mathrm{Na}, 80^{\circ} 20^{\prime}$ blue. Color light to dark green. Made from cupric phosphate and phosphoric acid in water heated to about $200^{\circ} \mathrm{C}$. PD 4.81, 2.63, 2.91; 1-0274.
$\mathbf{Z n}_{2}\left(\mathbf{A s O}_{4}\right)(\mathbf{O H})$ (Adamite) is orthorhombic dipyramidal with $a=8.30$, $b=8.51, c=6.04 \AA$. Crystals macrodomatic, equant or varied. Good $\{101\}$ and poor $\{010\}$ cleavages. H. 3.5. G. 4.43. $\mathrm{X}=a ;{ }^{55} \mathrm{Y}=c$. $(+) 2 \mathrm{~V}=$ $87^{\circ}-90^{\circ}, \mathrm{r}<\mathrm{v}$ strong (in some cases negative), $n_{\mathrm{X}}=1.722, n_{\mathrm{Y}}=1.742$, $n_{\mathrm{Z}}=1.761, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.039$. Again: ${ }^{24}(-) 2 \mathrm{~V}=87^{\circ}, n_{\mathrm{X}}=1.708, n_{\mathrm{Y}}=$ $1.734, n_{\mathrm{Z}}=1.758, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.050$. Color pale yellow, green or white; with some cobalt it is red; with some copper, green. Optic properties vary considerably; for example, with $\mathrm{Cu}:(-) 2 \mathrm{~V}=23^{\circ}$ ca., $n_{\mathrm{X}}=1.742, n_{\mathrm{Y}}=$ $1.768, n_{\mathrm{z}}=1.773, n_{\mathrm{z}}-n_{\mathrm{X}}=0.031$. Made from hot solutions of zinc sulphate and disodium acid arsenate. PD 2.45, 4.90, 2.97; 6-0536.
$\mathbf{Z n}_{4}\left(\mathbf{P O}_{4}\right)_{2} \mathbf{O}$ is orthorhombic(?). $X=a ;{ }^{53} \mathrm{Z}=b$. (-) $2 \mathrm{~V}=30^{\circ} c a . n_{\mathrm{X}}=$ 1.630 (calc. for $2 \mathrm{~V}=30^{\circ}$ ), $n_{\mathrm{Y}}=1.656, n_{\mathrm{Z}}=1.660, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.030$. Color brown. Produced by dehydration of spencerite.
$\mathbf{M g} \mathbf{g}_{2}\left(\mathbf{P O}_{4}\right) \mathbf{F}$ (Wagnerite) is monoclinic prismatic with $a=11.90, b=$ 12.51, $c=9.63 \mathrm{kX}, \beta=108^{\circ} 17^{\prime}$. U.C. 16. Crystals prismatic or varied. Good $\{100\}$ cleavage. H. 5-5.50. G. 3.15: $\mathrm{Y}=b ;{ }^{56} \mathrm{Z} \wedge c=-21.5^{\circ}$. $(+) 2 \mathrm{~V}=28^{\circ} 24^{\prime}, \mathrm{r}>\mathrm{v}$ weak with inclined dispersion, $n_{\mathrm{X}}=1.5678, n_{\mathrm{Y}}=$ $1.5719, n_{\mathrm{Z}}=1.5824, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0146 \mathrm{Na}$. Color yellow; rarely red or greenish. Colorless in flakes. Made by fusion of $\mathrm{MgF}_{2}$ with ammonium phosphate.
$\mathbf{C a}_{4}\left(\mathbf{P O}_{4}\right)_{2} \mathbf{O}$ (Hilgenstockite) is monoclinic with $a: b: c=0.577: 1: 1.255$, $\beta=90^{\circ} \pm$. Crystals $\{010\}$ tablets with poor $\{010\},\{100\}$ and $\{001\}$ cleavages. G. 3.06. Lamellar twinning on $\{001\}$ and $\{100\}$. $\mathrm{Y}=b ; \mathrm{Z}$ near $c$. $(+) 2 \mathrm{~V}=20^{\circ}$ (red), $40^{\circ}$ (blue), $n_{\mathrm{Y}}=1.64$. Again: ${ }^{57}(+) 2 \mathrm{~V}=80^{\circ}, n_{\mathrm{X}}=$ 1.643, $n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.647, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.004$. Also: ${ }^{16}(+) 2 \mathrm{~V}=30^{\circ}, n_{\mathrm{X}}=$ $1.650, n_{\mathrm{Y}}=1.651, n_{\mathrm{Z}}=1.656, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.006$. Colorless. Found in some slags.
$\mathrm{NaAl}\left(\mathrm{AsO}_{4}\right) \mathbf{F}$ (Durangite) is monoclinic prismatic with $a=6.53, b=$ $8.46, c=7.00 k X . \beta=115^{\circ} 46^{\prime}$. Crystals prismatic or pyramidal. Distinct $\{110\}$ cleavage. H. 5. G. 3.94-4.07, higher with some $\mathrm{Fe}^{\prime \prime \prime}$. $\mathrm{X} \wedge c=-\mathbf{2 5} 5^{\circ}$, $\mathrm{Z}=b .{ }^{24}(-) 2 \mathrm{~V}=45^{\circ}, \mathrm{r}>\mathrm{v}$ with horizontal dispersion. $n_{\mathrm{X}}=1.634$, $n_{\mathrm{Y}}=1.673, n_{\mathrm{Z}}=1.685, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.051$. Color green or orange-red. Pleochroic with X orange-yellow, Y pale orange-yellow, Z nearly colorless. Made from powdered cryolite and thick arsenic acid in a closed tube at $200^{\circ} \mathrm{C}$.

[^127]
## 2. Formula Type $\mathrm{AB}_{2}\left(\mathrm{XO}_{4}\right)_{2} \mathrm{Z}$

$\mathbf{F e}^{\prime \prime} \mathbf{F e}_{2}{ }^{\prime \prime \prime}\left(\mathbf{P O}_{4}\right)_{2}(\mathbf{O H})_{2}$ (Barbosalite) $)^{57 a}$ is monoclinic $(?)^{58}$ at room temperature. It has been called ferrous ferric lazulite. G. 3.60. It has an extinction angle of $45^{\circ} ;(+?) 2 \mathrm{~V}=$ large, $n_{\mathrm{X}}=1.77, n_{\mathrm{Y}}>1.79$ (but near it), $n_{\mathrm{Z}}=1.835, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.065$. It is black and opaque except on the thin edges which are dark green; pleochroic with X and Y dark blue green and Z dark olive green. It changes to a tetragonal substance, called lipscombite, at about $110^{\circ} \mathrm{C}$. The unit cell is body centered with $a=5.37$ and $c=$ $12.81 \AA$. This change is probably accompanied by oxidation of the ferrous iron and leads to the formula $\mathrm{Fe}^{\prime \prime \prime}{ }_{8}\left(\mathrm{PO}_{4}\right)_{6}$ when completed. This compound forms small rectangular crystals with indices above 1.83 . With crossed nicols the crystals show beautiful abnormal interference colors and no extinction.

## 3. Formula Type $\mathbf{A}_{5}\left(\mathrm{XO}_{4}\right)_{3} \mathbf{Z}$

$\mathbf{C a}_{5}\left(\mathbf{P O}_{4}\right)_{3} \mathbf{F}$ (Fluorapatite) is hexagonal dipyramidal with $a=9.36$, $c=6.88 k X$. U.C. 2. Crystals prismatic, long to short. Poor basal cleavage. H. 5. G. 3.18. F. 5. Soluble in HCl or $\mathrm{HNO}_{3}$. Uniaxial negative with ${ }^{51}$ $n_{\mathrm{O}}=1.6325, n_{\mathrm{E}}=1.630, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0025 \mathrm{Na}$. Colorless. Made from fusion. In apatite F may be replaced in part or wholly by ( OH ) or Cl or perhaps O ; also the Ca may be replaced in part by Mn or Sr or Pb or in small part by $\mathrm{Na}, \mathrm{K}, \mathrm{Mg}$, Fe (or even C?). Again the P may be replaced in any amount by As; finally there are more complicated substitutions such as SiS for $\mathrm{PP}, \mathrm{Cr}^{3}+2 \mathrm{Cr}^{6}$ for $3 \mathrm{P}^{5}$, etc. With ${ }^{59} 4.23$ per cent $\mathrm{CrO}_{3}$ and 0.79 per cent $\mathrm{Cr}_{2} \mathrm{O}_{3} n_{\mathrm{O}}=1.710, n_{\mathrm{E}}=1.707, n_{\mathrm{O}}-n_{\mathrm{E}}=0.003$; pleochroic with O dark blue, E bright yellowish green. $\mathrm{PD} 2.81,2.71,1.84$; 3-0736.
$\mathbf{C a}_{5}\left(\mathbf{P O}_{4}\right)_{3} \mathbf{C l}$ (Chlorapatite) is hexagonal dipyramidal with $a=9.52$, $c=6.85 \mathrm{k} X$. U.C. 2. Crystals prismatic. H. 5. G. 3.17. Soluble in HCl or $\mathrm{HNO}_{3}$. Uniaxial negative with ${ }^{60} n_{\mathrm{O}}=1.6684, n_{\mathrm{E}}=1.6675, n_{\mathrm{O}}-n_{\mathrm{E}}=$ 0.0009. Colorless. Made from fusion. Miscible with $\mathrm{Ca}_{5}\left(\mathrm{PO}_{4}\right)_{3} \mathrm{~F}$ and also with $\mathrm{Ca}_{5}\left(\mathrm{PO}_{4}\right)_{3} \mathrm{OH}$. It may contain some Mn or Sr or $\mathrm{CO}_{3}$. PD 2.77, 2.85, 1.95; 2-0851.
$\mathrm{Ca}_{5}\left(\mathbf{P O}_{4}\right)_{3}(\mathbf{O H})$ (Hydroxylapatite) is hexagonal dipyramidal with $a=$ $9.40, c=6.93 k X$. U.C. 2. Crystals prismatic. H. 5. G. 3 ca. M.P. $1540^{\circ}$ C. Soluble in HCl or $\mathrm{HNO}_{3}$. Uniaxial negative with ${ }^{61} n_{\mathrm{O}}=1.651, n_{\mathrm{E}}=1.644$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.007$. Colorless. Made from solutions of calcium salts by am-

[^128]moniacal solutions of phosphates. PD 2.79, 2.72, 2.63; 3-0747. It may contain Mn or Sr or $\mathrm{CO}_{3}$.
$\mathrm{Ca}_{10}\left(\mathrm{PO}_{4}\right)_{6}\left(\mathrm{CO}_{3}\right) \cdot \mathrm{H}_{2} \mathrm{O}$ (Carbonate-apatite) is hexagonal dipyramidal with $a=9.41, c=6.88 k X$. U.C. 1. H. 5. G. $2.9 c a$. Soluble in HCl or $\mathrm{HNO}_{3}$. Uniaxial negative with ${ }^{62} n_{\mathrm{O}}=1.628, n_{\mathrm{E}}=1.619, n_{\mathrm{O}}-n_{\mathrm{E}}=0.009$. Again: ${ }^{63} n_{\mathrm{O}}=1.603, n_{\mathrm{E}}=1.598, n_{\mathrm{O}}-n_{\mathrm{E}}=0.005$. The indices are much lower and the birefringence is greater than those of other apatites. Colorless. PD 2.82, 2.71, 3.44; 4-0697.
$\mathrm{Sr}_{5}\left(\mathbf{P O}_{4}\right)_{3} \mathbf{F}$ is hexagonal with ${ }^{64}$ M.P. $1685^{\circ}$ C. Uniaxial negative with $n_{\mathrm{O}}=1.621, n_{\mathrm{E}}=1.619, n_{\mathrm{O}}-n_{\mathrm{E}}=0.002$. Colorless.
$\mathrm{Sr}_{5}\left(\mathbf{P O}_{4}\right)_{3} \mathrm{Cl}$ is hexagonal with ${ }^{64}$ G. 4.87. M.P. $1625^{\circ} \mathrm{C}$. Uniaxial positive with $n_{\mathrm{O}}=1.650, n_{\mathrm{E}}=1.655, n_{\mathrm{E}}-n_{\mathrm{O}}=0.005$. Again: ${ }^{5} n_{\mathrm{O}}=1.658, n_{\mathrm{E}}=$ $1.664, n_{\mathrm{E}}-n_{\mathrm{O}}=0.006$. Colorless.
$\mathbf{S r}_{10}\left(\mathbf{P O}_{4}\right)_{6}\left(\mathbf{C O}_{3}\right)$ is hexagonal. Uniaxial negative with ${ }^{64 \mathrm{a}} n_{\mathrm{O}}=1.644, n_{\mathrm{E}}=$ $1.638, n_{\mathrm{O}}-n_{\mathrm{E}}=0.006$. Colorless.
$\mathbf{B a}_{5}\left(\mathbf{P O}_{4}\right)_{3} \mathbf{F}$ is hexagonal with ${ }^{64}$ M.P. $1670^{\circ} \mathrm{C}$. Uniaxial negative with $n_{\mathrm{O}}=1.669, n_{\mathrm{E}}=1.665, n_{\mathrm{O}}-n_{\mathrm{E}}=0.004$. Colorless.
$\mathbf{B a}_{5}\left(\mathbf{P O}_{4}\right)_{3} \mathbf{C l}$ is hexagonal with ${ }^{64}$ G. 5.95. M.P. $1584^{\circ}$ C. Uniaxial negative with $n_{\mathrm{O}}=1.701, n_{\mathrm{E}}=1.699, n_{\mathrm{O}}-n_{\mathrm{E}}=0.002$. Colorless.
$\mathbf{B a}_{10}\left(\mathbf{P O}_{4}\right)_{6}\left(\mathbf{C O}_{3}\right)$ is hexagonal. Uniaxial negative with ${ }^{64 \mathrm{a}} n_{\mathrm{O}}=1.691$, $n_{\mathrm{E}}=1.683, n_{\mathrm{O}}-n_{\mathrm{E}}=0.008 \mathrm{Na}$. Colorless.
$\mathbf{P b}_{5}\left(\mathbf{P O}_{4}\right)_{3} \mathbf{C l}$ (Pyromorphite) is hexagonal dipyramidal with $a=9.95$, $c=7.31 k X$. U.C. 2. Crystals prismatic with $\{10 \overline{1} 0\}$ and $\{0001\}$; also equant or pyramidal. Traces of $\{10 \overline{1} 1\}$ cleavage. H. 3.5-4. G. 7.04. Uniaxial negative with $^{65} n_{0}=2.144$ ( $\lambda$ 405), $2.058 \mathrm{Na}, 2.041$ ( $\lambda$ 691), $n_{\mathrm{E}}=2.131 \quad(\lambda 405), 2.048 \mathrm{Na}, 2.030(\lambda 691), n_{\mathrm{O}}-n_{\mathrm{E}}=0.011 \mathrm{Na}$. Color green, yellow, brown, in section colorless or tinted with absorption $\mathrm{O}<\mathrm{E}$. Made from a fusion of lead phosphate with excess lead chloride. Cl may be replaced by OH . Miscible in all proportions with $\mathrm{Pb}_{5}\left(\mathrm{AsO}_{4}\right)_{3} \mathrm{Cl}$. PD 2.97, 2.87, 3.38; 6-0389.
$\mathbf{P b}_{5}\left(\mathbf{A s O}_{4}\right)_{3} \mathrm{Cl}$ (Mimetite) is hexagonal dipyramidal with $a=10.27$, $c=7.43 \mathrm{kX}$. U.C. 2. Crystals prismatic or acicular. Very poor prismatic cleavage. H. 3.5-4. G. 7.24. F. 1. Uniaxial negative with ${ }^{65} n_{\mathrm{o}}=2.263$ $(\lambda 405), 2.147 \mathrm{Na}, 2.124 \quad(\lambda 691), n_{\mathrm{E}}=2.239 \quad(\lambda 405), 2.128 \mathrm{Na}$, $2.106(\lambda 691), n_{\mathrm{O}}-n_{\mathrm{E}}=0.019 \mathrm{Na}$. Color pale yellow to yellowish brown, white or colorless. Colorless in section. Made from fusion of lead arsenate

[^129]with excess lead chloride. Miscible in all proportions with $\mathrm{Pb}_{5}\left(\mathrm{PO}_{4}\right)_{3} \mathrm{Cl}$. PD 3.05, 2.99, 2.10; 2-0609.
$\mathbf{P b}_{5}\left(\mathrm{VO}_{4}\right)_{3} \mathbf{C l}$ (Vanadinite) is hexagonal dipyramidal with $a=10.31$, $c=7.34 k X$. U.C. 2. Crystals prismatic. H. 3. G. 6.88. Uniaxial negative with $^{65} n_{\mathrm{O}}=2.628(\lambda 436), 2.416 \mathrm{Na}, 2.370(\lambda 691), n_{\mathrm{E}}=2.505(\lambda 436)$, $2.350 \mathrm{Na}, 2.313(\lambda 691), n_{\mathrm{O}}-n_{\mathrm{E}}=0.066 \mathrm{Na}$. Color red, brown, yellow. In section colorless or tinted with absorption $\mathrm{O}>\mathrm{E}$. Made from fusion of lead vanadate with lead chloride. It may contain some P and As replacing V ; then the indices are lower.

## F. HYDRATED PHOSPHATES, ETC., CONTAINING HYDROXYL OR HALOGEN OR EXTRA OXYGEN

## 1. Formula Type $A_{m}\left(\mathrm{XO}_{4}\right)_{p} \mathrm{Z} \cdot \mathrm{xH}_{2} \mathrm{O}$ with m:p $>3: 2$ or $A_{m} B_{n}\left(\mathrm{XO}_{4}\right)_{p} \mathbf{Z} \cdot \mathrm{xH}_{2} \mathrm{O}$ with $(m+n): p>3: 2$

$\mathrm{Na}_{7}\left(\mathrm{PO}_{4}\right)_{2} \mathbf{F} \cdot \mathbf{1 9 H}_{2} \mathrm{O}$ is isometric; crystals octahedral. G. 2.22. Isotropic with $^{37} n=1.4489 \mathrm{Li}, 1.4519 \mathrm{Na}, 1.4545 \mathrm{Tl}$. Colorless. Made from a solution of sodium phosphate, soda and sodium fluoride.
$\mathbf{N a}_{7}\left(\mathbf{A s O}_{4}\right)_{2} \mathbf{F} \cdot \mathbf{1 9 H}_{2} \mathrm{O}$ is isometric; crystals octahedral. Isotropic with ${ }^{37}$ $n=1.4657 \mathrm{Li}, 1.4693 \mathrm{Na}, 1.4726 \mathrm{Tl}$. Colorless. Made from a solution of sodium arsenate, sodium hydroxide and sodium fluoride.
$\mathrm{Na}_{7}\left(\mathrm{VO}_{4}\right)_{2} \mathbf{F} \cdot \mathbf{1 9 H}_{2} \mathrm{O}$ is isometric; crystals octahedral. Isotropic with ${ }^{37}$ $n=1.5171 \mathrm{Li}, 1.5230 \mathrm{Na}, 1.5284 \mathrm{Tl}$. Colorless. Made from fusion followed by crystallization in warm water.
$\mathbf{5}\left(\mathbf{N a}_{3} \mathrm{PO}_{4} \cdot \mathbf{1 2 \mathrm { H } _ { 2 }} \mathbf{O}\right) \cdot \mathbf{N a O H}$ is uniaxial positive with ${ }^{8} n_{\mathrm{O}}=1.447, n_{\mathrm{E}}=$ $1.452, n_{\mathrm{E}}-n_{\mathrm{O}}=0.005$. Made from water solution.
$\mathbf{5}\left(\mathbf{N a}_{3} \mathbf{P O}_{4} \cdot \mathbf{1 1 H}_{\mathbf{2}} \mathbf{O}\right) \cdot \mathbf{N a C l}$ is uniaxial positive with $^{38} n_{\mathrm{O}}=1.447, n_{\mathrm{E}}=$ 1.453, $n_{\mathrm{E}}-n_{\mathrm{O}}=0.006$. Made from water solution.
$\mathbf{4}\left(\mathbf{N a}_{3} \mathbf{P O}_{4} \cdot \mathbf{1 1 H _ { 2 }} \mathbf{O}\right) \cdot \mathbf{N a O C l}$ is uniaxial positive with ${ }^{38} n_{\mathrm{O}}=1.450, n_{\mathrm{E}}=$ $1.455, n_{\mathrm{E}}-n_{\mathrm{O}}=0.005$. Made from water solution.
$\mathrm{H}_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathbf{8 H _ { 2 }} \mathbf{O}$ (Hydrogen-autunite) is tetragonal with $a=$ $7.02, c=9.04 \AA$. Crystals square or octagonal plates. G. 3.3. Uniaxial negative with ${ }^{66} n_{\mathrm{O}}=1.579, n_{\mathrm{E}}=1.568, n_{\mathrm{O}}-n_{\mathrm{E}}=0.011$. Color lemonyellow. Made from autunite. PD 9.03, 3.80, 3.27; 8-296.
$\mathrm{H}_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2} \cdot \mathbf{8 H}_{2} \mathrm{O}$ (Hydrogen-uranospinite) is tetragonal with ${ }^{66 \mathrm{a}}$ $a=7.16, c=8.80 \pm .02 \AA$ A., U.C. 1. Crystals are basal tablets bounded by $\{100\}$. Perfect basal cleavage. G. 3.55. Uniaxial negative with $n_{0}=$ $1.612, n_{\mathrm{E}}=1.584 \pm .003, n_{\mathrm{O}}-n_{\mathrm{E}}=0.028$. Lemon-yellow in masses; O pale lemon-yellow, E nearly colorless. Made by reaction of uranyl nitrate

[^130]and arsenic acid in hot water solution. The natural mineral "troegerite" is supposed ${ }^{66 \mathrm{~b}}$ to be $\left(\mathrm{UO}_{2}\right)_{3}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$; but this may be the same ${ }^{66 \mathrm{a}}$ as hydrogen-uranospinite. Its properties were reported ${ }^{66 \mathrm{~b}}$ as follows: tetragonal, $a: c=1: 2.16$, in thin square tablets. Micaceous cleavage $\{001\}$, good cleavage $\{100\}$. Uniaxial negative, or biaxial with (-)2V very small, $n_{\mathrm{O}}=1.630$ (also reported as 1.624 ), $n_{\mathrm{E}}=1.585$ (also 1.580 ), but modern chemical and physical data have not been determined on thoroughly authenticated material. PD 8.59, 3.79, 3.30; 8-326.
$\mathbf{N a}_{2}\left(\mathbf{U O}_{2}\right)_{2}\left(\mathbf{A s O}_{4}\right)_{2} \cdot \mathbf{8 H} \mathbf{H} \mathbf{O}$ is tetragonal with ${ }^{66 \mathrm{a}} \quad a=7.12, c=8.70 \AA$. Crystals basal tablets with $\{100\}$. G. 3.80. Basal cleavage. Uniaxial negative with $n_{\mathrm{O}}=1.617, n_{\mathrm{E}}=1.586$, both $\pm 0.003, n_{\mathrm{O}}-n_{\mathrm{E}}=0.031$. Color yellow with O pale lemon yellow, E colorless. Made by base exchange with $\mathrm{H}_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$. It has been called sodium uranospinite. PD 8.42, 3.63, 3.27; 8-446.
$\left(\mathbf{N H}_{4}\right)_{2}\left(\mathbf{U O}_{2}\right)_{2}\left(\mathbf{A s O}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ is tetragonal with ${ }^{66 \mathrm{a}} a=7.21, c=8.85 \AA$. Crystals basal tablets. G. 3.60. Basal cleavage. Uniaxial negative with $n_{\mathrm{O}}=1.611, n_{\mathrm{E}}=1.601$ both $\pm 0.003, n_{\mathrm{O}}-n_{\mathrm{E}}=0.010$. Color yellow with O pale lemon yellow, E colorless. Made by base-exchange with $\mathrm{H}_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$. It has been called ammonium-uranospinite. PD 9.26, 3.86, 3.36; 8-441.
$\mathrm{NaH}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 7-8 \mathrm{H}_{2} \mathrm{O}$ is uniaxial negative with ${ }^{67} n_{\mathrm{O}}=1.580, n_{\mathrm{E}}=$ ?, $n_{\mathrm{O}}-n_{\mathrm{E}}=$ moderate. It may show abnormally $(-) 2 \mathrm{~V}=$ small. Made from autunite.
$\mathrm{Na}_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathbf{P O}_{4}\right)_{2} \cdot 6 \frac{1}{2} \mathbf{H}_{2} \mathbf{O}$ is uniaxial negative with ${ }^{67} n_{\mathrm{O}}=1.582, n_{\mathrm{E}}=$ $1.562, n_{\mathrm{O}}-n_{\mathrm{E}}=0.020$. It may be abnormally biaxial with $(-) 2 \mathrm{~V}=$ small. Made from autunite.
$\mathbf{K}_{2}\left(\mathbf{U O}_{2}\right)_{2}\left(\mathbf{P O}_{4}\right)_{2} \cdot \boldsymbol{n} \mathbf{H}_{2} \mathbf{O}$ is optically negative; the crystals are not rectangular in outline, but have an angle of $82^{\circ}$ instead of $90^{\circ}$. They show fine rectangular lamellar twinning like microcline. Uniaxial or biaxial ${ }^{67}$ with a small optic angle. $n_{\mathrm{X}}=1.553, n_{\mathrm{Y}}$ nearly $=n_{\mathrm{Z}}=1.575, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.022 . Made from autunite. (Apparently these crystals were produced by solution and redeposition rather than by base-exchange.-A.N.W.)
$\mathrm{K}_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{VO}_{4}\right)_{2} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ (Carnotite) is orthorhombic or monoclinic(?). Crystals basal plates or laths; often a powder. Perfect basal cleavage. $\mathrm{X}=c ;{ }^{24} \mathrm{Y}=b .(-) 2 \mathrm{~V}=40^{\circ} c a . n_{\mathrm{X}}=1.750, n_{\mathrm{Y}}=1.925, n_{\mathrm{Z}}=1.950$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.200$ (with nearly $3 \mathrm{H}_{2} \mathrm{O}$ ?). Again: ${ }^{68} n_{\mathrm{X}}=1.89 \pm$ calc., $n_{\mathrm{Y}}=$ $2.06, n_{\mathrm{Z}}=2.08 \mathrm{Na}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.18$ (with 1.35 per cent $\mathrm{H}_{2} \mathrm{O}$ ). Color yellow with X nearly colorless, Y and Z canary yellow. The anhydrous compound has been made by fusion of potassium metavanadate and ammonium

[^131]pyrouranate. The hydrous compound has been made by treating $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{VO}_{4}\right)_{2} \cdot n \mathrm{H}_{2} \mathrm{O}$ with potassium mercuric iodide solution. PD 6.56, 3.12, 3.53; 8-317.
$\mathbf{C a}_{2}\left(\mathbf{A s O}_{4}\right)(\mathbf{O H}) \cdot \mathbf{2 H} \mathbf{H}_{2} \mathbf{O}$ has oblique extinction. ${ }^{10}$ G. 2.695. $n_{\mathrm{X}}=1.585$, $n_{\mathrm{Y}}=?, n_{\mathrm{Z}}=1.590, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.005$.
$\mathrm{CuAl}_{6}\left(\mathrm{PO}_{4}\right)_{4}(\mathbf{O H})_{8} \cdot \mathbf{4 H}_{2} \mathrm{O}$ (Turquois) is triclinic pinacoidal with $a=$ $7.47, b=9.93, c=7.67 k X, \alpha=111^{\circ} 39^{\prime}, \beta=115^{\circ} 23^{\prime}, \gamma=69^{\circ} 26^{\prime}$. U.C. 1. Crystals rare, prismatic; usually massive. Perfect $\{001\}$ and good $\{010\}$ cleavages. H. $5-6$. G. 2.84. For X, ${ }^{69} \phi=-30^{\circ}$ and $\rho=60^{\circ}$; for Y, $\phi=63^{\circ}$ and $\rho=83^{\circ} .(+) 2 \mathrm{~V}=40^{\circ} \pm 2, \mathrm{r}<\mathrm{v}$ very strong with crossed dispersion. ${ }^{24} n_{\mathrm{X}}=1.61, n_{\mathrm{Y}}=1.62, n_{\mathrm{Z}}=1.65, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.04$. Color of massive turquois sky-blue, bluish green to apple-green or greenish gray; crystals bright blue; weakly pleochroic in thick grains with X colorless and Z pale bluè or pale green. Made by heating malachite, hydrous aluminum oxide and phosphoric acid to $100^{\circ}$ C. PD 3.68, 2.91, 6.17; 6-0214/5.

## 2. Formula Type $A_{m} \mathbf{B}_{n}\left(\mathrm{XO}_{4}\right)_{p} \mathbf{Z} \cdot \mathrm{xH}_{2} \mathbf{O}$ with ( $m+n$ ):p $=\mathbf{3 : 2}$

$\mathbf{C a}\left(\mathbf{U O}_{2}\right)_{2}\left(\mathbf{A s O}_{4}\right)_{2} \cdot \mathbf{8 H _ { 2 }} \mathbf{O}$ (Uranospinite) is tetragonal with ${ }^{66 \mathrm{a}} a=7.10$, $c=8.81 \AA$. Crystals thin basal plates. Perfect $\{001\}$ and good $\{100\}$ cleavages. H. 2-3. G. 3.65. Uniaxial negative with ${ }^{24} n_{\mathrm{O}}=1.586, n_{\mathrm{F}}=1.56$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.026$. May be biaxial (due to strain?) with $\mathrm{X}=c$ and ( - ) $2 \mathrm{~V}=$ $46^{\circ} . \mathrm{r}>\mathrm{v}$ moderate. $n_{\mathrm{X}}=1.560, n_{\mathrm{Y}}=1.582, n_{\mathrm{Z}}=1.587, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.027 . A single crystal may be biaxial with a uniaxial border. ${ }^{66 a}$ Again: $(-) 2 \mathrm{~V}=62^{\circ}, n_{\mathrm{X}}=1.55, n_{\mathrm{Y}}=1.567, n_{\mathrm{Z}}=1.572, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.022$. Color lemon-yellow to siskin-green with O pale yellow and E nearly colorless. Made by adding a solution of uranyl nitrate to one of lime in arsenic acid. Air-dried at room temperature it may have ${ }^{66 \mathrm{a}} n_{\mathrm{X}}=1.591, n_{\mathrm{Y}}=$ $1.619, n_{\mathrm{Z}}=1.621, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.030$. Hydrated in water for one week: $n_{\mathrm{O}}=1.589, n_{\mathrm{E}}=1.562, n_{\mathrm{O}}-n_{\mathrm{E}}=0.027$. Heated to $110^{\circ} \mathrm{C} .: n_{\mathrm{O}}=1.637$, $n_{\mathrm{E}}=1.615, n_{\mathrm{O}}-n_{\mathrm{E}}=0.022$. Heated to $1000^{\circ} \mathrm{C} .: n_{\mathrm{O}}=1.778, n_{\mathrm{E}}=1.765$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.013$. PD 8.85, 3.59, 3.34; 8-319*.
$\mathbf{C a}\left(\mathbf{U O}_{2}\right)_{2}\left(\mathbf{P O}_{4}\right)_{2} \cdot \mathbf{1 0}-\mathbf{1 2} \mathrm{H}_{2} \mathbf{O}$ (Autunite) is tetragonal with $^{70} a=6.989$, $c=20.63 k X$. U.C. 2. Crystals basal plates. Perfect $\{001\}$ and poor $\{100\}$ cleavages. H. 2-2.5. G. 3.1. Uniaxial negative ${ }^{71}$ with $n_{0}=1.59-1.60$, $n_{\mathrm{E}}=1.58-1.59, n_{\mathrm{O}}-n_{\mathrm{E}}=0.01$. Often abnormally biaxial with ( $-2 \mathrm{~V}=$ about $10^{\circ}-30^{\circ}$ (up to $53^{\circ}$ also) with $\mathrm{r}>\mathrm{v}$ strong and $\mathrm{X}=c{ }^{72} n_{\mathrm{X}}=1.555$, $n_{\mathrm{Y}}=1.575, n_{\mathrm{Z}}=1.578, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.023$. The optic angle decreases and indices increase with decreasing water content. Color yellow with O (or

[^132]Y and Z) yellow, E (or X) colorless or nearly so. Made from solutions of monocalcium phosphate and uranyl nitrate at low temperature. On drying or slight heating it passes to meta-autunite I with about $5-8 \mathrm{H}_{2} \mathrm{O}$ and at about $80^{\circ} \mathrm{C}$. this changes irreversibly to meta-autunite II with about 0-6 $\mathrm{H}_{2} \mathrm{O}$. The tenor of water in autunite changes very easily like that in zeolites, and, as in zeolites, base exchange occurs very easily-in fact, the Ca of autunite can be wholly (or partly) replaced ${ }^{67}$ by $\mathrm{H}_{2}, \mathrm{Na}_{2}, \mathrm{Ba}, \mathrm{Mn}, \mathrm{Cu}, \mathrm{Ni}$, $\mathrm{Co}, \mathrm{Pb}$, or Mg . These changes have been made especially in meta-autunite I. PD 10.3, 4.96, 3.59; 8-314*.
$\mathbf{C a}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathbf{3 - 8 H} \mathbf{~} \mathbf{H}_{2}$ (Meta-autunite I$)$ is tetragonal with $a=$ $6.98, c=8.42 k X$. Lamellar twinning may occur on $\{100\}$. Uniaxial negative with ${ }^{67} n_{\mathrm{O}}=1.600, n_{\mathrm{E}}=1.590, n_{\mathrm{O}}-n_{\mathrm{E}}=0.010$. Again: ${ }^{67} n_{\mathrm{O}}=1.598$, $n_{\mathrm{E}}=1.586, n_{\mathrm{O}}-n_{\mathrm{E}}=0.012$ (the variation probably due to variations in $\mathrm{H}_{2} \mathrm{O}$ ). Colorless. Made from water solution. PD 8.51, 3.50, 3.63; 8-359.
$\mathbf{M g}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathbf{P O}_{4}\right)_{2} \cdot \mathbf{8 H _ { 2 }} \mathbf{O}$ (Mg-Autunite) is tetragonal(?); basal plates isotropic or nearly so. Nearly colorless. Possibly this is saléeite which is ditetragonal dipyramidal(?) with $a=6.980, c=19.813 \AA$, and has $10 \mathrm{H}_{2} \mathrm{O}$. Uniaxial negative with ${ }^{72 \mathrm{a}} n_{\mathrm{O}}=1.574 \pm .002, n_{\mathrm{E}}=1.559 \pm .002, n_{\mathrm{O}}-$ $n_{\mathrm{E}}=0.016$. Again: ${ }^{67} n_{\mathrm{O}}=1.58$. Also, may be biaxial. Color yellow with O pale greenish yellow, E colorless. PD 9.85, 3.49, 4.95; 8-313.
$\mathbf{M n}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathbf{P O}_{4}\right)_{2} \cdot \mathbf{7 . 6} \mathbf{H}_{2} \mathrm{O}$ (Mn-Autunite) is tetragonal or pseudotetragonal. Lamellar twinning on $\{110\}$. Uniaxial negative with ${ }^{67} n_{\mathrm{O}}=$ 1.598-1.601, $n_{\mathrm{O}}-n_{\mathrm{E}}=$ weak to moderate. Made from autunite.
$\mathbf{C u}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathbf{P O}_{4}\right)_{2} \cdot \mathbf{1 2} \mathbf{H}_{2} \mathbf{O}$ (Torbernite) is tetragonal with $a=7.05, c=$ $20.5 k X$. U.C. 2. Perfect $\{001\}$ and poor $\{100\}$ cleavages. H. 2-2.5. G. 3.22. F. 2.5. Soluble in $\mathrm{HNO}_{3}$. Uniaxial negative with ${ }^{24} n_{\mathrm{O}}=1.592, n_{\mathrm{E}}=1.582$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.010$. Again: ${ }^{67} n_{\mathrm{O}}=1.608$. Also may be biaxial with small 2 V (due to strain?). Color various shades of green with O sky-blue or pale green, E green or greenish yellow. Made from water solution up to about $75^{\circ} \mathrm{C}$.; at higher temperatures metatorbernite is formed. PD 10.3, 4.94, 3.58; 8-360.
$\mathbf{C u}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathbf{8 H _ { 2 }} \mathbf{O}$ (Metatorbernite) is tetragonal with $a=6.95$, $c=8.60 \mathrm{kX}$. U.C. 1. Crystals basal tablets often in aggregates. Perfect $\{001\}$ cleavage. H. 2.5. G. 3.7. Uniaxial positive with $^{73} n_{\mathrm{O}}=1.610-1.628$, $n_{\mathrm{O}}-n_{\mathrm{E}}=$ about 0.002 for $\lambda 575$ and 0.004 for $\lambda 640$. Uniaxial negative for $\lambda<516$. Color green with O sky-blue and E green. It may be biaxial (due to strain?). Made by partial dehydration of torbernite. On further dehydration the crystals show twinning on $\{110\}$ and turn brown. PD 3.69, 8.66, 3.24; 8-309.

[^133]$\mathbf{C u}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 10-16 \mathrm{H}_{2} \mathrm{O}$ (Zeunerite) is tetragonal. Crystals basal tablets. H. 2-2.5. G. 3.2. Uniaxial negative with $n_{\mathrm{O}}=1.602$ (with $16 \mathrm{H}_{2} \mathrm{O}$ ); 1.610 (with $10 \mathrm{H}_{2} \mathrm{O}$ ), $n_{\mathrm{E}}=$ ?. Color green. Made from copper carbonate dissolved in excess arsenic acid to which uranium nitrate was added. PD 3.60, 10.3, 5.07; 8-400*.
$\mathbf{C u}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 5-8 \mathrm{H}_{2} \mathrm{O}$ (Metazeunerite) is tetragonal with $a=$ 7.13, $c=8.83 \AA$. U.C. 1. Crystals basal tablets. H. 2.5. G. 3.64. Perfect basal cleavage. Uniaxial negative with ${ }^{74} n_{\mathrm{O}}=1.647, n_{\mathrm{E}}=1.630, n_{\mathrm{O}}-$ $n_{\mathrm{E}}=0.017$. Again: $2^{24} n_{\mathrm{O}}=1.643, n_{\mathrm{E}}=1.623, n_{\mathrm{O}}-n_{\mathrm{E}}=0.020$. Also: $n_{\mathrm{o}}=1.654$ (for $5 \mathrm{H}_{2} \mathrm{O}$ ). Color green. Made by partial dehydration of zeunerite. ${ }^{74} \mathrm{PD} 8.76,3.71,3.28 ; 4-0112^{*}$.
$\mathrm{Ba}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ (Uranocircite) is tetragonal with ${ }^{75} a=6.95$, $c=8.44 \AA$. Crystals like those of autunite. Perfect $\{001\}$ and distinct $\{100\}$ cleavages. H. 2. G. 3.53. Uniaxial negative with ${ }^{67} n_{0}=1.613$, $n_{\mathrm{E}}=1.604, n_{\mathrm{O}}-n_{\mathrm{E}}=0.009$. Again: $:^{75} n_{\mathrm{O}}=1.621, n_{\mathrm{E}}=1.607, n_{\mathrm{O}}-$ $n_{\mathrm{E}}=0.014 \mathrm{Na}$. Also may be biaxial negative with small 2 V and two sets of lamellar twinning; then $n_{\mathrm{X}}=1.610 \pm .003, n_{\mathrm{Y}} \approx n_{\mathrm{Z}}=1.623 \pm .003$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.013$. When heated the biaxial sample becomes uniaxial at $100^{\circ}-150^{\circ}$ C. Color canary-yellow with X nearly colorless, Y and Z pale canary-yellow. Made from autunite. PD 3.58, 8.19, 2.08; 8-413.
$\left.\mathbf{P b}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathbf{8 . 4 H _ { 2 }} \mathbf{O}\right)$ is tetragonal (or nearly so). Crystals may be eight-sided basal plates. Uniaxial negative with ${ }^{67} n_{\mathrm{O}}=1.625-1.627, n_{\mathrm{E}}=$ ?. Also may be biaxial with small 2 V . Made from autunite.
$\mathbf{C a}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{VO}_{4}\right)_{2} \cdot \mathbf{n H}_{2} \mathrm{O}$ (Tyuyamunite) is orthorhombic with ${ }^{23} a=$ $10.40, b=19.41, c=8.26 k X$. Crystals laths or flakes. Perfect $\{010\}$ and distinct $\{001\}$ and $\{100\}$ cleavages. G. 3.67-4.35, increasing with decreasing water content. $\mathrm{X}=b ; \mathrm{Y}=c .^{76}(-) 2 \mathrm{~V}=48^{\circ} c a ., n_{\mathrm{X}}=1.75-1.80$ calc., $n_{\mathrm{Y}}=1.927-1.932, n_{\mathrm{Z}}=1.965-1.968, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.17-0.21$. On dehydration the refractive indices increase, but the optic angle does not change. Color yellow with X nearly colorless, Y pale canary-yellow, Z canary-yellow. Made by treating $\mathrm{K}_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{VO}_{4}\right)_{2} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ with a solution of calcium bicarbonate. PD 10.2, 5.02, 3.20; 6-0017.
$\mathrm{KAl}_{2}\left(\mathrm{PO}_{4}\right)_{2} \mathbf{O H} \cdot \mathbf{4 H}_{2} \mathrm{O}(?)$ (Minyulite) is orthorhombic(?). Crystals acicular. Probably a cleavage parallel to elongation. H. 3.5. G. 2.45. $\mathrm{X}=c .(+) 2 \mathrm{~V}$ large. ${ }^{77} n_{\mathrm{X}}=1.531, n_{\mathrm{Y}}=1.534, n_{\mathrm{Z}}=1.538, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.007. Colorless to white. PD 5.6, 3.37, 6.8; 2-0143.

[^134]Also described as orthorhombic ${ }^{84}$ with $a=10.40, b=10.8, c=12.75 \AA$. U.C. 16. $\mathrm{X}=b$. Biaxial negative. Is this another phase?
$\mathbf{N a P O}_{3}$ has two (or three?) crystal phases. ${ }^{4} \alpha-\mathrm{NaPO}_{3}$ crystallizes just below the melting point ( $627^{\circ} \mathrm{C}$.). It is biaxial with ( - ) $2 \mathrm{~V}=80^{\circ}, n_{\mathrm{X}}=$ $1.474, n_{\mathrm{Y}}=1.478, n_{\mathrm{Z}}=1.480, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.006$. It is also made by dehydrating $\mathrm{NaH}_{2} \mathrm{PO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$; then reported to have ${ }^{85}(-) 2 \mathrm{~V}=$ large, $n_{\mathrm{X}}=$ 1.473, $n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.486, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.013 . \beta-\mathrm{NaPO}_{3}$ is probably orthorhombic ${ }^{4} \mathrm{Y}=b ; \mathrm{Z}=a .(+) 2 \mathrm{~V}=78^{\circ}, n_{\mathrm{X}}=1.498, n_{\mathrm{Y}}=1.510, n_{\mathrm{Z}}=$ $1.529, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.031$. Also reported ${ }^{86}$ as $n_{\mathrm{X}}=1.502, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=$ $1.525 . \mathrm{NaPO}_{3}$ glass has ${ }^{4} n=1.4847$. Colorless. PD 2.86, 3.08, 4.98; 2-0776*.
$\mathbf{N a}_{4} \mathbf{C a}\left(\mathbf{P O}_{3}\right)_{6}$ is biaxial. ${ }^{87}$ M.P. $738^{\circ}$ C. $(-) 2 V=80^{\circ}, n_{\mathrm{x}}=1.518$, $n_{\mathrm{Y}}=1.564, n_{\mathrm{Z}}=1.581, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.063$. Colorless.
$\mathbf{C a A s}_{2} \mathbf{O}_{6}$ is monoclinic ${ }^{10}$ (or triclinic?) with $\beta=70^{\circ}$. G. 3.195. Extinction at $18^{\circ}\left(23^{\circ}\right.$ ?) to elongation. $n_{\mathrm{X}}=1.629, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.635, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.006 .
$\mathbf{N a P O}_{3} \cdot \mathbf{2 H}_{2} \mathbf{O}$ is triclinic with ${ }^{88}(001) \wedge(100)=64^{\circ} 16^{\prime},(001) \wedge(010)=$ $82^{\circ} 33^{\prime} ;(100) \wedge(010)=73^{\circ} 28^{\prime}$. Perfect basal cleavage. $(+) 2 \mathrm{~V}=$ large, $\mathrm{r}>\mathrm{v}$. Mean refractive index $1.400, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.009$. Also reported as biaxial with ${ }^{89}(-) 2 \mathrm{~V}=77^{\circ} \pm 3^{\circ}$. Another phase (?) is uniaxial negative ${ }^{4}$ with $n_{\mathrm{O}}=1.441, n_{\mathrm{E}}=1.432, n_{\mathrm{O}}-n_{\mathrm{E}}=0.009$.
$\mathrm{CaV}_{2} \mathrm{O}_{6} \cdot \mathbf{4 H}_{2} \mathrm{O}$ (Rossite) is triclinic with ${ }^{90} \alpha=98^{\circ} 18^{\prime}, \beta=120^{\circ} 12^{\prime}$, $\gamma=89^{\circ} 34^{\prime}$. Crystals often vertically elongated and flattened on $\{010\}$. Good $\{010\}$ cleavage. H. 2-3. G. 2.45. Y $\wedge b$ about $45^{\circ} ; \mathrm{Z}$ near $c$. $(-$ ? $) 2 \mathrm{~V}=$ large with strong dispersion. $n_{\mathrm{X}}=1.710, n_{\mathrm{Y}}=1.770, n_{\mathrm{Z}}=1.840, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.130$. Color yellow. Made from water solution.
$\mathrm{CaV}_{2} \mathrm{O}_{6} \cdot \mathbf{2 \mathrm { H } _ { 2 } \mathrm { O }}$ (Metarossite) forms flaky masses. ${ }^{50}(+) 2 \mathrm{~V}=$ large with strong dispersion. $n_{\mathrm{X}}=1.840, n_{\mathrm{Y}}>1.85, n_{\mathrm{Z}}>1.85$. Yellow to colorless in flakes. Made by partial dehydration of $\mathrm{CaV}_{2} \mathrm{O}_{6} \cdot 4 \mathrm{H}_{2} \mathrm{O}$.

## I. HYPOPHOSPHATES, ETC.

$\mathrm{K}_{2} \mathbf{H}_{2} \mathbf{P}_{2} \mathbf{O}_{6} \cdot \mathbf{3} \mathrm{H}_{2} \mathbf{O}$ is orthorhombic ${ }^{91}$ with $a: b: c=0.992: 1: 0.901$. Crystals vertical columnar with $\{100\},\{010\},\{110\},\{101\}$, etc. $\mathrm{X}=c ; \mathrm{Y}=a$.

[^135]$(-) 2 \mathrm{~V}=62^{\circ}, \mathrm{r}<\mathrm{v}$ very weak. $n_{\mathrm{X}}=1.4768, n_{\mathrm{Y}}=1.4843, n_{\mathrm{Z}}=1.4870$ $\mathrm{Na}, n_{\mathbf{z}}-n_{\mathbf{X}}=0.0102$. Colorless.
 Crystals basal tablets with $\{110\},\{221\}$, etc. $\mathrm{X} \wedge c=-36^{\circ} 30^{\prime} ; \mathrm{Z}=b$. $(-) 2 \mathrm{~V}=36^{\circ} 9^{\prime} \mathrm{Na}, \mathrm{r}<\mathrm{v}$ very weak. $n_{\mathrm{X}}=1.4893, n_{\mathrm{Y}}=1.5314, n_{\mathrm{Z}}=$ $1.5363 \mathrm{Na}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.049$. Colorless.
$\mathrm{Na}_{2} \mathrm{H}_{2} \mathbf{P}_{2} \mathrm{O}_{6} \cdot \mathbf{6} \mathrm{H}_{2} \mathrm{O}$ is monoclinic with $^{92} a: b: c=2.013: 1: 2.0381 . \beta=$ $126^{\circ} 47^{\prime}$. Crystals basal tablets or short prisms. Perfect $\{001\}$ and poor $\{110\}$ cleavages. Twinning on $\{10 \overline{1}\}$. G. 1.85. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=+35^{\circ} 17^{\prime}$ $\mathrm{Na} .(+) 2 \mathrm{~V}=55^{\circ} 36^{\prime} \mathrm{Li}, 57^{\circ} 20^{\prime} \mathrm{Na}, 58^{\circ} 10^{\prime} \mathrm{Tl} . n_{\mathrm{x}}=1.4822 \mathrm{Li}, 1.4855 \mathrm{Na}$, $1.4883 \mathrm{Tl}, n_{\mathrm{Y}}=1.4861 \mathrm{Li}, 1.4897 \mathrm{Na}, 1.4927 \mathrm{Tl}, n_{\mathrm{Z}}=1.5006 \mathrm{Li}, 1.5041$ $\mathrm{Na}, 1.5074 \mathrm{Tl}, n_{\mathrm{z}}-n_{\mathrm{X}}=0.0186 \mathrm{Na}$. Colorless. Made from water solution.
$\mathrm{Na}_{3} \mathbf{H P}_{2} \mathrm{O}_{6} \cdot \mathbf{9 H}_{2} \mathrm{O}$ is monoclinic with ${ }^{92} a: b: c=1.552: 1: 1.510, \beta=102^{\circ} 2^{\prime}$. Crystals basal tablets with $\{101\},\{034\},\{110\}$, etc. Twinning on axis $a$. G. 1.74. $\mathrm{X} \wedge c=-10^{\circ} \mathrm{Li},-11^{\circ} \mathrm{Na},-12^{\circ} \mathrm{Tl} ; \mathrm{Z}=b$. (-)2V $=82^{\circ} 2^{\prime}$ $\mathrm{Li}, 82^{\circ} 0^{\prime} \mathrm{Na}, 81^{\circ} 56^{\prime} \mathrm{Tl}, \mathrm{r}>\mathrm{v}$ very weak. $n_{\mathrm{x}}=1.4622 \mathrm{Li}, 1.4653 \mathrm{Na}$, $1.4682 \mathrm{Tl}, n_{\mathrm{Y}}=1.4705 \mathrm{Li}, 1.4738 \mathrm{Na}, 1.4769 \mathrm{Tl}, n_{\mathrm{Z}}=1.4769 \mathrm{Li}, 1.4804$ $\mathrm{Na}, 1.4836 \mathrm{Tl}, n_{\mathrm{z}}-n_{\mathrm{x}}=0.0182 \mathrm{Na}$. Colorless.
$\mathrm{Na}_{1} \mathrm{P}_{2} \mathrm{O}_{7} \cdot 10 \mathrm{H}_{2} \mathrm{O}(?)$ is monoclinic with $^{92} a: b: c=1.172: 1: 1.908, \beta=$ $100^{\circ} 16^{\prime}$. Crystals domatic, terminated by prisms, etc. Lamellar twinning on $\{001\} ;\{010\}$ and $\{101\}$ cleavages. $\mathrm{G} .1 .82 . \mathrm{Y}=b ; \mathrm{Z} \wedge c=-39.5^{\circ}$. $(+) 2 \mathrm{~V}=48^{\circ} 58^{\prime} \mathrm{Li}, 48^{\circ} 56^{\prime} \mathrm{Na}, 48^{\circ} 43^{\prime} \mathrm{Tl}, \mathrm{r}>\mathrm{v}$ very weak. $n_{\mathrm{x}}=1.4777$ $\mathrm{Na}, n_{\mathrm{Y}}=1.4789 \mathrm{Li}, 1.4822 \mathrm{Na}, 1.4852 \mathrm{Tl}, n_{\mathrm{Z}}=1.5036 \mathrm{Na}, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.0259 Na . Colorless. PD 4.38, 6.52, 5.46; 8-240/1.

## J. PYROPHOSPHATES, ETC.

$\mathbf{K}_{4} \mathbf{P}_{2} \mathbf{O}_{7}$ melts at $1105^{\circ} \mathrm{C}$. It is uniaxial positive ${ }^{93}$ with $n_{\mathrm{O}}=1.495, n_{\mathrm{E}}=$ $1.502, n_{\mathrm{E}}-n_{\mathrm{O}}=0.007$. Colorless.
$\mathbf{K}_{5} \mathbf{P}_{3} \mathbf{O}_{10}$ melts incongruently ${ }^{93}$ at $642^{\circ} \mathrm{C}$. It is uniaxial negative with $n_{0}=$ $1.520, n_{\mathrm{E}}=1.516, n_{\mathrm{O}}-n_{\mathrm{E}}=0.004$.
$\beta-\mathrm{Ca}_{2} \mathrm{P}_{2} \mathrm{O}_{7}$ is tetragonal. ${ }^{82}$ Uniaxial positive with $n_{\mathrm{O}}=1.630, n_{\mathrm{E}}=1.639$, $n_{\mathrm{E}}-n_{\mathrm{O}}=0.009$. Again: ${ }^{11} n_{\mathrm{O}}=1.624, n_{\mathrm{E}}=1.628, n_{\mathrm{E}}-n_{\mathrm{O}}=0.004$. It inverts at $1270^{\circ} \mathrm{C}$. to $\alpha-\mathrm{Ca}_{2} \mathrm{P}_{2} \mathrm{O}_{7}$ which forms equant crystals with two good cleavages and common polysynthetic twinning. ${ }^{82}$ M.P. $1358^{\circ} \mathrm{C}$. $(-) 2 \mathrm{~V}=50^{\circ}, n_{\mathrm{X}}=1.584, n_{\mathrm{Y}}=1.599, n_{\mathrm{Z}}=1.605, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.021$. Again: ${ }^{11} n_{\mathrm{X}}=1.585, n_{\mathrm{Y}}=1.60, n_{\mathrm{Z}}=1.605, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.020$. A third phase ${ }^{82}$ is known. Colorless. PD 3.00, 3.20, 3.07; 2-0647*.

[^136]$\mathrm{CaH}_{2} \mathbf{P}_{2} \mathrm{O}_{7}$ is uniaxial negative with ${ }^{11} n_{\mathrm{O}}=1.578, n_{\mathrm{E}}=1.518, n_{\mathrm{O}}-n_{\mathrm{E}}=$ 0.060. PD 3.35, 3.19, 3.74; 9-354.
$\mathbf{N a}_{2} \mathbf{H}_{2} \mathbf{P}_{2} \mathbf{O}_{7}$ forms fine needles with positive elongation. ${ }^{4} n_{1}=1.510$, $n_{2}(| |$ needles $)=1.517$.
$\mathbf{P b}_{2} \mathbf{A s}_{2} \mathbf{O}_{7}$ is orthorhombic with ${ }^{94}$ G. 6.85. M.P. $802^{\circ}$ C. Biaxial with $n_{\mathrm{Y}}=2.03$.
$\mathrm{Na}_{2} \mathrm{H}_{2} \mathrm{P}_{2} \mathrm{O}_{7} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=2.026: 1: 2.049$. $\beta=$ $123^{\circ} 19^{\prime}$. Crystals basal tablets with perfect $\{001\}$ cleavage. G. 1.86. $\mathrm{X} \wedge c=-42.5^{\circ} ; \mathrm{Z}=b .(-) 2 \mathrm{~V}=15^{\circ} 13^{\prime} \mathrm{Li}, 31^{\circ} 56^{\prime} \mathrm{Na}, 36^{\circ} 10^{\prime} \mathrm{Tl}, \mathrm{r}<\mathrm{v}$ extreme; $n_{\mathrm{X}}=1.4573 \mathrm{Li}, 1.4599 \mathrm{Na}, 1.4623 \mathrm{Tl}, n_{\mathrm{Y}}=1.4616 \mathrm{Li}, 1.4645 \mathrm{Na}$, $1.4672 \mathrm{Tl}, n_{\mathrm{Z}}=1.4617 \mathrm{Li}, 1.4649 \mathrm{Na}, 1.4677 \mathrm{Tl}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.005 \mathrm{Na}$. Colorless. Made by adding acetic acid to a warm solution of the normal salt.
$\mathrm{Na}_{4} \mathbf{P}_{2} \mathrm{O}_{7} \cdot \mathbf{1 0 H}_{2} \mathrm{O}$ is monoclinic with $a: b: c=1.287: 1: 1.895, \beta=98^{\circ} 16^{\prime}$. Crystals domatic. G. $1.82 . \mathrm{X}=b$; Z nearly exactly normal to $\{101\}$. $(+) 2 \mathrm{~V}=60.5^{\circ} . n_{\mathrm{X}}=1.4470 \mathrm{Li}, 1.4499 \mathrm{Na}, 1.4526 \mathrm{Tl}, n_{\mathrm{Y}}=1.4496 \mathrm{Li}$, $1.4525 \mathrm{Na}, 1.4551 \mathrm{Tl}, n_{\mathrm{Z}}=1.4575 \mathrm{Li}, 1.4604 \mathrm{Na}, 1.4629 \mathrm{Tl}, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.0104 Na. Colorless. Made from water solution. PD 4.38, 6.52, 5.46; 8-240/1.
$\mathbf{N a}_{4} \mathbf{P}_{2} \mathbf{O}_{7}$ is biaxial with $^{4}(+) 2 \mathrm{~V}=40^{\circ} . n_{\mathrm{X}}=1.475, n_{\mathrm{Y}}=1.477, n_{\mathrm{Z}}=$ 1.496, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.021$. Colorless.
$\mathbf{M g}_{2} \mathbf{P}_{2} \mathbf{O}_{7}$ is monoclinic ${ }^{95}$ with $a: b: c=0.795: 1: 1.088, \beta=104^{\circ} 11^{\prime}$. Crystals basal tablets with perfect $\{110\}$ and good $\{001\}$ cleavages. H. 4. G. 3.06. M.P. $1383^{\circ} \mathrm{C} . \mathrm{X} \wedge c=+15^{\circ}$ (nearly normal to $\{001\}$ ); $\mathrm{Y}=b$. $(+) 2 \mathrm{~V}=20.5^{\circ} . n_{\mathrm{X}}=1.602, n_{\mathrm{Y}}=1.604, n_{\mathrm{Z}}=1.615 \mathrm{Na}, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.013. Colorless. Made from fusion. PD 3.02, 2.98, 4.14; 8-38.
$\mathbf{M n}_{2} \mathbf{P}_{2} \mathbf{O}_{7}$ is monoclinic with ${ }^{95} a: b: c=0.783: 1: ?, \beta=105^{\circ} 01^{\prime}$. Crystals prismatic with perfect $\{110\}$ and poor $\{001\}$ cleavages. H. 4. G. 3.71. M.P. $1196^{\circ} \mathrm{C} . \mathrm{X} \wedge c=-4^{\circ} ; \mathrm{Y}=b .(+) 2 \mathrm{~V}=$ nearly $90^{\circ} . n_{\mathrm{X}}=1.695$, $n_{\mathrm{Y}}=1.704(?), n_{\mathrm{Z}}=1.710 \mathrm{Na}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.015$. Color brownish pink with X light pink, Y and Z nearly colorless to very pale yellow (in thick plates). Miscible in all proportions with $\mathrm{Mg}_{2} \mathrm{P}_{2} \mathrm{O}_{7}$. Made from fusion. PD 3.10, 2.95, 2.60; 3-0555.
$\mathbf{N a}_{5} \mathbf{P}_{3} \mathbf{O}_{10}$ has at least two phases. ${ }^{4}$ One phase ( $\alpha$ ) is biaxial with ( + ) $2 \mathrm{~V}=$ $21^{\circ}, n_{\mathrm{X}}=1.477, n_{\mathrm{Y}}=1.478, n_{\mathrm{Z}}=1.504, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.027$. The other $\left(\beta\right.$-) phase $^{4}$ is also biaxial with $(+) 2 \mathrm{~V}=57^{\circ}, n_{\mathrm{X}}=1.470, n_{\mathrm{Y}}=1.477$, $n_{\mathrm{Z}}=1.502, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.032$. Colorless. Both made from the melt, the first by very slow cooling, the second by rapid cooling. PD 2.68, 4.55, 2.60; 2-0922*.
$\mathbf{N a}_{5} \mathbf{P}_{3} \mathbf{O}_{10} \cdot \mathbf{6} \mathbf{H}_{2} \mathrm{O}$ has two cleavages at right angles. It is biaxial with ${ }^{4}$

[^137]$(+) 2 \mathrm{~V}=20^{\circ}, n_{\mathrm{X}}=1.449, n_{\mathrm{Y}}=1.450, n_{\mathrm{Z}}=1.482, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.033$. Colorless. Made from water solution.
$\mathrm{CaP}_{4} \mathrm{O}_{11}$ has the optic plane normal to a good cleavage. ${ }^{82}(-) 2 \mathrm{~V}=15^{\circ}$, $n_{\mathrm{X}}=1.470, n_{\mathrm{Y}}=1.497, n_{\mathrm{Z}}=1.499, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.029$. Colorless.
$\mathrm{Ca}_{2} \mathbf{P}_{6} \mathbf{O}_{17}$ has the optic plane normal to a good cleavage. ${ }^{82}(-) 2 \mathrm{~V}=23^{\circ}$, $n_{\mathrm{X}}=1.477, n_{\mathrm{Y}}=1.511, n_{\mathrm{Z}}=1.513, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.036$. Colorless.

## K. COMPOUND PHOSPHATES, ETC.

$\mathrm{Ca}_{10}\left(\mathrm{PO}_{4}\right)_{6} \mathrm{O} \cdot \mathrm{Ca}_{2} \mathrm{SiO}_{4}$ (Steadite) is hexagonal with fair basal cleavage. Uniaxial negative with ${ }^{16}$ mean index 1.65-1.67 and weak birefringence. Color pale buff to brown. Found in some slags.
$4\left(\mathbf{N a}_{3} \mathbf{P O}_{4} \cdot \mathbf{1 1 H _ { 2 }} \mathbf{O}\right) \cdot \mathbf{N a N O}_{3}$ is uniaxial positive with ${ }^{38} n_{\mathrm{O}}=1.444, n_{\mathrm{E}}=$ 1.450, $n_{\mathrm{E}}-n_{\mathrm{O}}=0.006$. Colorless. Made from water solution.
$\mathbf{C a}_{3}\left(\mathbf{P O}_{4}\right)_{2} \cdot \mathbf{2} \mathbf{C a}_{2} \mathbf{S i O}_{4}$ (Nagelschmidtite) is orthorhombic(?). Crystals tabular or granular. G. 3.065. M.P. about $1800^{\circ}-1900^{\circ} \mathrm{C}$. Good basal and fair $\{110\}$ cleavages. ${ }^{16}(+) 2 \mathrm{~V}=0^{\circ}-20^{\circ} . n_{\mathrm{X}}=1.642-1.680, n_{\mathrm{Y}}=1.642-$ $1.675, n_{\mathrm{Z}}=1.661-1.690, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.004-0.010$. Colorless. Made ${ }^{96}$ by sintering the powdered constituents, or by fusion. PD 2.66, 2.80, 1.94; 5-0646.
$\mathrm{Ca}_{3}\left(\mathbf{P O}_{4}\right)_{2} \cdot \mathbf{C a}_{2} \mathbf{S i O}_{4}$ (Silicocarnotite) is monoclinic ${ }^{16}$ and pseudohexagonal. M.P. $1700^{\circ}-1850^{\circ} \mathrm{C}$. ( - ) $2 \mathrm{~V}=$ large; $n_{\mathrm{X}}=1.632, n_{\mathrm{Y}}=1.636$, $n_{\mathrm{Z}}=1.640, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.008$. Color blue with X colorless, Y pale blue, Z sky-blue. Found in some slags.
$\mathbf{N a}_{3} \mathbf{P O}_{4} \cdot \mathbf{N a B O}_{2} \cdot \mathbf{1 8 H}_{2} \mathbf{O}$ is biaxial with ${ }^{38}(-) 2 \mathrm{~V}=60^{\circ}$ calc. $n_{\mathrm{X}}=1.445$, $n_{\mathrm{Y}}=1.451, n_{\mathrm{Z}}=1.453, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.008$. PD 2.78, 3.73, 2.86; 2-0841.
$\mathbf{M g}_{3} \mathbf{B}_{2}(\mathbf{O H})_{6}\left(\mathbf{P O}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ (Lueneburgite) is probably monoclinic. In fibrous masses; also in pseudo-hexagonal tablets. A prismatic cleavage with an angle of about $73^{\circ}$. H. near 2. G. 2.05. $\mathrm{Y}=b(?) .(-) 2 \mathrm{~V}=62^{\circ}$ calc. $n_{\mathrm{X}}=1.520,{ }^{24} n_{\mathrm{Y}}=1.54, n_{\mathrm{Z}}=1.545, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.025$. Color white or brownish white. Artificial. ${ }^{97}$

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## X. Silicates

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## A. INTRODUCTION

X-ray studies have proved that in silicates each silicon atom is surrounded by four oxygen atoms arranged at the corners of a tetrahedron, as illustrated in Figs. 10-1 and 10-2. In Fig. 10-1 the silicon and oxygen atoms are assumed to be of the same size so as to show their relative positions more plainly. Actually, the oxygen atoms are much larger than the silicon atoms, as shown in Fig. 10-2. If such tetrahedral groups are not


Fig. 10-1. Positions of centers of atoms in $\mathrm{SiO}_{4}$-tetrahedron.
linked directly by sharing one (or more) oxygen atoms, the formula of the substance will include one or more $\mathrm{SiO}_{4}$ groups, ${ }^{1}$ as in zircon, $\mathrm{ZrSiO}_{4}$ and forsterite, $\mathrm{Mg}_{2} \mathrm{SiO}_{4}$. No $\mathrm{SiO}_{4}$ tetrahedron is linked to a neighboring tetrahedron by sharing more than one oxygen atom, but one tetrahedron may be linked thus to one, two, three or four other tetrahedra. If it is linked to only one other, as shown in Figs. 10-3 and 10-4 the formula must contain $\mathrm{Si}_{2} \mathrm{O}_{7}$ as in $\mathrm{Ca}_{2} \mathrm{MgSi}_{2} \mathrm{O}_{7}$ (akermanite). If it is linked to two other tetrahedra it may form a trigonal ring, as in $\mathrm{BaTiSi}_{3} \mathrm{O}_{9}$ (benitoite) (Fig.

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Fig. 10-2. Packing diagram of atoms in $\mathrm{SiO}_{4}$-tetrahedron.

10-5), or a tetragonal ring (Fig. 10-6), or a hexagonal ring as in $\mathrm{Be}_{3} \mathrm{Al}_{2} \mathrm{Si}_{6} \mathrm{O}_{18}$ (beryl) (Fig. 10-7); finally it may form a continuous chain as in $\mathrm{MgSiO}_{3}$ (enstatite) (Fig. 10-8). In all these examples the formula includes $\mathrm{SiO}_{3}$ or a multiple thereof.

If the $\mathrm{SiO}_{4}$ tetrahedron is linked to three other tetrahedra, it forms a


Fig. 10-3a. Positions of centers of atoms in the type of $\mathrm{Si}_{2} \mathrm{O}_{7}$-group found in $\mathrm{Sc}_{2} \mathrm{Si}_{2} \mathrm{O}_{7}$ (thortveitite).


Fig. 10-3b. Positions of centers of atoms in the type of $\mathrm{Si}_{2} \mathrm{O}_{7}$-group found in $\mathrm{Ca}_{2} \mathrm{MgSi}_{2} \mathrm{O}_{7}$ (akermanite).


Fig. 10-4. Arrangement of atoms in $\mathrm{Si}_{2} \mathrm{O}_{7}$-group, åkermanite type.
continuous sheet, as in micas (Fig. 10-9) and the formula includes ${ }^{2}$ $(\mathrm{Si}, \mathrm{Al})_{2} \mathrm{O}_{5}$ or a multiple thereof, as in $\mathrm{KAl}_{2}(\mathrm{OH})_{2} \mathrm{Si}_{3} \mathrm{AlO}_{10}$. Finally, if linked to four other tetrahedra, it forms a continuous three-dimensional network, as in sodalite (Fig. 10-9) and the formula must include ( $\mathrm{Si}, \mathrm{Al}_{2}{ }_{2} \mathrm{O}_{4}$ or some


Fig. 10-5. Arrangement of atoms in trigonal $\mathrm{Si}_{3} \mathrm{O}_{9}$-group found in $\mathrm{BaTiSi}_{3} \mathrm{O}_{9}$ (benitoite).
multiple thereof. No other cases are known except that not all the tetrahedra in a single substance are necessarily linked to their neighbors in the
${ }^{2}$ The replacement of some Si atoms by Al will be described later.


Fig. 10-6. Arrangement of atoms in square $\mathrm{Si}_{4} \mathrm{O}_{12}$-group probably present in $\left(\mathrm{Fe}_{1-x} \mathrm{Mn}_{x}\right)-\mathrm{Ca}_{2} \mathrm{Al}_{2} \mathrm{BO}_{3} \mathrm{OHSi}_{4} \mathrm{O}_{12}$ (axinite).
same way (forming "heterosilicates"). On this basis silicates may be classified as follows: ${ }^{3}$

Class

1. Nesosilicates
2. Sorosilicates
3. Cyclosilicates
4. Inosilicates
5. Phyllosilicates
6. Tectosilicates

Links
between Oxygen
$\mathrm{SiO}_{4}$ tet- atoms for $\quad$ Examples rahedra $4(\mathrm{Si}+\mathrm{Al})$ Formula Mineral
$\begin{array}{lllll}0 & 16 & \mathrm{Mg}_{2} \mathrm{SiO}_{4} & \text { Forsterite }\end{array}$ $1 \quad 14 \quad \mathrm{Ca}_{2} \mathrm{MgSi}_{2} \mathrm{O}_{7} \quad$ Åkermanite $2 \quad 12 \quad \mathrm{BaTiSi}_{3} \mathrm{O}_{3} \quad$ Benitoite $2 \quad 12 \quad \mathrm{MgSiO}_{3} \quad$ Enstatite $3 \quad 10 \quad \mathrm{Mg}_{3}(\mathrm{OH})_{2} \mathrm{Si}_{4} \mathrm{O}_{10}$ Talc $4 \quad 8 \quad \mathrm{KSiAlO}_{4} \quad$ Kaliophilite

In the $\mathrm{SiO}_{4}$ tetrahedra of silicates some of the silicon atoms may be replaced by Al (or by Be or B) atoms. This changes the electric charge of the

[^140]tetrahedra. For example, $\mathrm{SiO}_{2}$ has zero charge; for convenience it may be written as $\mathrm{Si}_{12} \mathrm{O}_{24}$; if one quarter of the Si atoms are replaced by Al atoms, then the formula becomes $\mathrm{Si}_{9} \mathrm{Al}_{3} \mathrm{O}_{24}$ which is not neutral but has a negative charge of -3 ; if this is satisfied by K atoms the formula is $\mathrm{K}_{3} \mathrm{Si}_{9} \mathrm{Al}_{3} \mathrm{O}_{24}$, or, as usually written, $\mathrm{KAlSi}_{3} \mathrm{O}_{8}$ (orthoclase). If one-third of the Si atoms are replaced by Al atoms the formula becomes $\mathrm{Si}_{8} \mathrm{Al}_{4} \mathrm{O}_{24}$ with a charge of -4 ;


Fig. 10-7. Arrangement of atoms in hexagonal $\mathrm{Si}_{6} \mathrm{O}_{18}$-group found in $\mathrm{Al}_{2} \mathrm{Be}_{3} \mathrm{Si}_{6} \mathrm{O}_{18}$ (beryl).
if this is satisfied by K atoms the formula is $\mathrm{K}_{4} \mathrm{Si}_{8} \mathrm{Al}_{4} \mathrm{O}_{24}$ or $\mathrm{KAlSi}_{2} \mathrm{O}_{6}$ (leucite). If half the Si atoms are replaced by Al atoms, the formula becomes $\mathrm{Si}_{6} \mathrm{Al}_{6} \mathrm{O}_{24}$ with a charge of -6 ; if this charge is satisfied by Na atoms the formula is $\mathrm{Na}_{6} \mathrm{Si}_{6} \mathrm{Al}_{6} \mathrm{O}_{24}$ or $\mathrm{NaAlSiO}_{4}$ (nepheline). Thus the threedimensional framework may serve as the basis of silicates with the same Si (without Al ) to O ratio in their formulas as phyllosilicates or inosilicates or nesosilicates. Al atoms can proxy for Si atoms not only in threedimensional frameworks but in other silicate structures.

Some silicates have their silicon tetrahedra linked to their neighbors in more than one way. For example, $\mathrm{Ca}_{10}\left(\mathrm{Mg}, \mathrm{Fe}_{2}\right)_{2}(\mathrm{OH})_{4} \mathrm{Al}_{4} \mathrm{Si}_{9} \mathrm{O}_{34}$ (vesuvianite) contains single tetrahedra $\left(\mathrm{SiO}_{4}\right)$ and also pairs of tetrahedra $\left(\mathrm{Si}_{2} \mathrm{O}_{7}\right)$ in different parts of the same structure. To show this the formula may be


Fig. 10-8. Arrangement of atoms in $\mathrm{Si}_{2} \mathrm{O}_{6}$-chain found in pyroxenes such as $\mathrm{CaMgSi}_{2} \mathrm{O}_{6}$ (diopside). Two such chains, sharing lateral oxygens, form the $\mathrm{Si}_{4} \mathrm{O}_{11}$-band found in amphiboles such as $\mathrm{Ca}_{2} \mathrm{Mg}_{6} \mathrm{Si}_{8} \mathrm{O}_{22}(\mathrm{OH})_{2}$ (tremolite).
written: $\mathrm{Ca}_{10}\left(\mathrm{Mg}, \mathrm{Fe}_{2}\right)_{2} \mathrm{Al}_{4}\left\{\begin{array}{l}\left(\mathrm{SiO}_{4}\right)_{5} \\ \left(\mathrm{Si}_{2} \mathrm{O}_{7}\right)_{2}\end{array}\right\}(\mathrm{OH})_{4}$. Therefore, it could be included in the nesosilicates or the sorosilicates. Amphibole has half its tetrahedra linked to two others and half to three others; this can be shown in a generalized formula as $\mathrm{R}_{7}\left\{\begin{array}{l}\mathrm{Si}_{2} \mathrm{O}_{6} \\ \mathrm{Si}_{2} \mathrm{O}_{5}\end{array}\right\}(\mathrm{OH})_{2}$, which becomes $\left(\mathrm{Mg}, \mathrm{Fe}_{7}\right)_{7} \mathrm{Si}_{4} \mathrm{O}_{11}(\mathrm{OH})_{2}$ for anthophyllite. In a few silicates Be , like Al, may replace some Si in the


Fig. 10-9. Arrangement of atoms in $\mathrm{Si}_{2} \mathrm{O}_{5}$-sheet forming the basis of most layer-silicates.


Fig. 10-10. Positions of centers of atoms in a portion of a porous three-dimensional framework with composition $\left(\mathrm{Si}_{1-x} \mathrm{Al}_{x}\right) \mathrm{O}_{2}$. After Jaeger.
tetrahedrons; accordingly beryl may be considered to have a three-dimensional framework with the formula $\mathrm{Al}_{2}\left(\mathrm{Si}_{6} \mathrm{Be}_{3}\right) \mathrm{O}_{18}$, although it clearly has hexagonal $\mathrm{Si}_{6} \mathrm{O}_{18}$ rings also; it is a cyclosilicate only if the $\mathrm{BeO}_{4}$ tetrahedra are considered to be unlike the $\mathrm{SiO}_{4}$ tetrahedra.

Silicates which have their $\mathrm{SiO}_{4}$ tetrahedra grouped in sheets (and formulas including $\mathrm{Si}_{2} \mathrm{O}_{5}$ or a multiple) have other elements also in parallel layers. Some compounds containing no silica have structures characterized by similar sheets, as illustrated by brucite and moissanite. The number of such sheets in the unit cell is constant for one type of a compound, but may vary widely in different types of a single compound. For example, SiC (moissanite) has $6,15,21,33,51$, etc., layers in different types. ${ }^{4}$ In phyllosilicates, the Si atoms in the $\mathrm{SiO}_{4}$ tetrahedra may be replaced (in part) by Al atoms. For example, $\mathrm{Al}_{4}(\mathrm{OH})_{8} \mathrm{Si}_{4} \mathrm{O}_{10}$ (kaolinite) has five planes of atoms.

Five planes of atoms in $\mathrm{Al}_{4}(\mathrm{OH})_{8} \mathrm{Si}_{4} \mathrm{O}_{10}$ (Kaolinite).
Coordination

| Plane | with $\mathrm{O}+\mathrm{OH}$ ions | Ions | Spacing (̊) |
| :---: | :---: | :--- | :---: |
| 1 |  | $\mathrm{O}_{6}$ | 0.60 |
| 2 | Tetrahedral | $\mathrm{Si}_{4}$ | 1.59 |
| 3 |  | $\mathrm{O}_{4}(\mathrm{OH})_{2}$ | 1.06 |
| 4 | Octahedral | $\mathrm{Al}_{4}$ | 1.06 |
| 5 |  | $(\mathrm{OH})_{6}$ |  |
| 1 |  | $\mathrm{O}_{6}$ | 3.06 |

Talc and pyrophyllite each have fourteen planes of atoms per unit cell. The first group of seven planes is chemically exactly repeated in the next seven planes; however, all fourteen planes are required in the unit cell because the second group is displaced horizontally with respect to the first group. The excellent basal cleavage in such compounds is due to the lack of strong bonds between planes 7 and 8 and also between planes 14 and 1 ; there is consequently wide spacing between these planes.

Similar conditions are found in silicates such as $\mathrm{KAl}_{2}(\mathrm{OH})_{2} \mathrm{Si}_{3} \mathrm{AlO}_{10}$ (potash mica), $\mathrm{KMg}_{3}(\mathrm{OH})_{2} \mathrm{Si}_{3} \mathrm{AlO}_{10}$ (phlogopite mica). $\mathrm{Mg}_{5} \mathrm{Al}_{2} \mathrm{Si}_{3} \mathrm{O}_{10}(\mathrm{OH})_{8}$

[^141]Fourteen Planes of Atoms.

| Plane <br> number | Coordination <br> with O + OH ions. | $\mathrm{Mg}_{3}(\mathrm{OH})_{2} \mathrm{Si}_{4} \mathrm{O}_{10}$ <br> (Talc) | $\mathrm{Al}_{2}(\mathrm{OH})_{2} \mathrm{Si}_{4} \mathrm{O}_{10}$ <br> (Pyrophyllite) |
| :---: | :---: | :--- | :--- |
| 1 |  | $\mathrm{O}_{6}$ | $\mathrm{O}_{6}$ |
| 2 | Tetrahedral | $\mathrm{Si}_{4}$ | $\mathrm{Si}_{4}$ |
| 3 |  | $\mathrm{O}_{4}(\mathrm{OH})_{2}$ | $\mathrm{O}_{4}(\mathrm{OH})_{2}$ |
| 4 | Octahedral | $\mathrm{Mg}_{6}$ | $\mathrm{Ml}_{4}$ |
| 5 |  | $\mathrm{O}_{4}(\mathrm{OH})_{2}$ | $\mathrm{O}_{4}(\mathrm{OH})_{2}$ |
| 6 | Tetrahedral | $\mathrm{Si}_{4}$ | $\mathrm{Si}_{4}$ |
| 7 |  | $\mathrm{O}_{6}$ | $\mathrm{O}_{6}$ |
| 8 |  | $\mathrm{O}_{6}$ | $\mathrm{O}_{6}$ |
| 9 | Tetrahedral | $\mathrm{Si}_{4}$ | $\mathrm{Si}_{4}$ |
| 10 |  | $\mathrm{O}_{4}(\mathrm{OH})_{2}$ | $\mathrm{O}_{4}(\mathrm{OH})_{2}$ |
| 11 | Octahedral | $\mathrm{Mg}_{6}$ | $\mathrm{Al}_{4}$ |
| 12 |  | $\mathrm{O}_{4}(\mathrm{OH})_{2}$ | $\mathrm{O}_{4}(\mathrm{OH})_{2}$ |
| 13 | Tetrahedral | $\mathrm{Si}_{4}$ | $\mathrm{Si}_{4}$ |
| 14 |  | $\mathrm{O}_{6}$ | $\mathrm{O}_{6}$ |
| 1 |  | $\mathrm{O}_{6}$ | $\mathrm{O}_{6}$ |

(clinochlore-a variety of chlorite), etc. An outline of the arrangement of the silicates appears at the beginning of this chapter.

## B. TECTOSILICATES (FRAMEWORKS OF TETRAHEDRA): $\mathrm{A}_{m}\left(\mathrm{XO}_{2}\right)_{n}$

$\mathbf{S i O}_{2}$ has this type of formula (with $m=0$ ) but, although it is often considered to be the foundation of all silicates and has a related structure consisting of $\mathrm{SiO}_{4}$ tetrahedra, it is described among the oxides.
$\mathrm{NaSiAlO}_{4}{ }^{1}$ has four crystal phases. ${ }^{2}$ The high temperature or $\alpha$-phase is isometric of unknown index, presumably about 1.51 ; it is stable above $1248^{\circ} \mathrm{C}$. and inverts at $687^{\circ} \mathrm{C}$. on cooling to a metastable triclinic phase (carnegieite) which has complicated lamellar twinning and G. 2.51; M.P. $1526^{\circ}$ C. (-) $2 \mathrm{~V}=12^{\circ}-15^{\circ}, n_{\mathrm{X}}=1.509, n_{\mathrm{Y}}=1.514-, n_{\mathrm{Z}}=1.514, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.005$. On further cooling a second inversion may occur at $227^{\circ} \mathrm{C}$., marked (on heating) by an abrupt increase in birefringence. The low temperature phase (nepheline) is hexagonal with $a=9.98, c=8.44 \AA$. Crystals basal tablets or short prisms with poor $\{10 \overline{1} 0\}$ and $\{0001\}$ cleavages. G. 2.619 . M.P. $1526^{\circ}$ C., after inversion at $1248^{\circ} \mathrm{C}$. Gelatinizes with

[^142]acids. Uniaxial negative with ${ }^{2} n_{\mathrm{O}}=1.537, n_{\mathrm{E}}=1.533, n_{\mathrm{O}}-n_{\mathrm{E}}=0.004$. Again: ${ }^{3} n_{\mathrm{O}}=1.532, n_{\mathrm{E}}=1.528, n_{\mathrm{O}}-n_{\mathrm{E}}=0.004$. Also : ${ }^{3 \mathrm{a}} n_{\mathrm{O}}=1.526$, $n_{\mathrm{E}}=1.522, n_{\mathrm{O}}-n_{\mathrm{E}}=0.004$. Colorless. All these phases easily made from fusion. $\mathrm{NaSiAlO}_{4}$ and $\mathrm{KSiAlO}_{4}$ are miscible in all proportions at high temperature; they form discontinuous series at low temperature. $\mathrm{CaAl}_{2} \mathrm{Si}_{2} \mathrm{O}_{8}$ is miscible with $2 \mathrm{NaAlSiO}_{4}$ up to about 37 mol . per cent; it has no perceptible effect on $n_{\mathrm{O}}$, but increases $n_{\mathrm{E}}$, producing an isotropic condition at 23 per cent $\mathrm{CaAl}_{2} \mathrm{Si}_{2} \mathrm{O}_{8} . \mathrm{NaSiAlO}_{4}$ is miscible with $\mathrm{CaAlAlO} \mathrm{C}_{4}$ up to about 60 per cent of the latter. This produces a marked increase in the refractive



Fig. 10-11. Variations in the properties of the series, $\mathrm{NaAlSiO}_{4}-\mathrm{CaAlAlO}_{4}$. After Goldsmith, Amer. Mineral. XXXIV, p. 471 (1949).
the crystals are isotropic with 20 per cent of $\mathrm{CaAlAlO}_{4}$ with $n=1.555$; with 60 per cent of $\mathrm{CaAlAlO}_{4} n_{\mathrm{O}}=1.593, n_{\mathrm{E}}=1.600, n_{\mathrm{E}}-n_{\mathrm{O}}=0.007$. $\mathrm{HAlSiO}_{4}$ and $\mathrm{SiSiO}_{4}$ are miscible in $\mathrm{NaSiAlO}_{4}$ up to about 25 mol . per cent; they decrease the refringence, birefringence and density only a little. $\mathrm{NaSiAlO}_{4}$ saturated with about 25 per cent $\mathrm{Na}_{2} \mathrm{SiO}_{3}$ has ${ }^{5} n_{\mathrm{Z}}=1.518$ and inverts at $1163^{\circ} \mathrm{C}$. instead of at $1248^{\circ} \mathrm{C} . \mathrm{NaAlSiO}_{4}$ glass has $n=1.510$.

[^143]Pure $\mathrm{NaSiAlO}_{4}$ is rare in nature, but with about 15 to 30 mol . per cent $\mathrm{KSiAlO}_{4}$ (and often some Ca and H ) it forms the natural mineral called nepheline; since its composition is variable its properties vary as follows: $n_{\mathrm{O}}=1.536-1.549, \quad n_{\mathrm{E}}=1.532-1.544, \quad n_{\mathrm{O}}-n_{\mathrm{E}}=0.003-0.005$. PD (at $750^{\circ}$ C.) 4.29, 2.61, 1.50; 2-0259.
$\mathrm{KSiAlO}_{4}$ has three (or four?) crystal phases. At high temperature it intercrystallizes freely with $\mathrm{NaSiAlO}_{4}$-is this the isometric or the triclinic phase of the latter? Another phase, made from fusion of $\mathrm{KAlSiO}_{4}$, $\mathrm{K}_{3} \mathrm{Al}_{2}\left(\mathrm{SiF}_{4}\right)_{3}$ and $\mathrm{LiF}_{2}$, is orthorhombic ${ }^{6}$ with $a=9.01, b=15.67, c=8.57$ $\AA$. Distinct $\{001\}$ and poor $\{100\}$ cleavages. Commonly twinned to pseudo-hexagonal forms. G. 2.60. M.P. $1800^{\circ} \mathrm{C} . \mathrm{X}=a ; \mathrm{Y}=b$. (-) $2 \mathrm{~V}=$ $40^{\circ}, n_{\mathrm{X}}=1.528, n_{\mathrm{Y}}=1.536, n_{\mathrm{Z}}=1.537, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.009$. Colorless. It inverts at $1540^{\circ} \mathrm{C}$. to metastable kaliophilite which is hexagonal with $a=27.0, c=8.51 \AA$. Crystals thick prismatic with poor $\{10 \overline{1} 0\}$ and $\{0001\}$ cleavages (or parting?). H. 6. G. 2.61. M.P. $1800^{\circ}$ C. Gelatinizes with HCl . Uniaxial negative with $n_{\mathrm{O}}=1.537, n_{\mathrm{E}}=1.533, n_{\mathrm{O}}-n_{\mathrm{E}}=$ 0.004. Again: $n_{\mathrm{O}}=1.530, n_{\mathrm{E}}=1.526, n_{\mathrm{O}}-n_{\mathrm{E}}=0.004$. Colorless. Another phase (kalsilite) is also hexagonal, but trapezohedral, ${ }^{7}$ with $a=5.17$, $c=8.67 \AA$. No cleavage seen. G. 2.59. Uniaxial negative with $n_{\mathrm{O}}=1.542$, $n_{\mathrm{E}}=1.537, \quad n_{\mathrm{O}}-n_{\mathrm{E}}=0.005$. Again: ${ }^{8} \quad n_{\mathrm{O}}=1.537, n_{\mathrm{E}}=1.530, n_{\mathrm{O}}-$ $n_{\mathrm{E}}=0.007$. Colorless. $\mathrm{KSiAlO}_{4}$ glass has $n=1.508 . \mathrm{PD} 3.10,2.60,3.41$; 9-471* [which polymorph?].
$\mathrm{NaSiBO}_{4}$ is isometric. ${ }^{9}$ M.P. $760^{\circ}$ C. Isotropic with $n=1.572$. Colorless.
$\mathbf{K}_{2} \mathbf{S i A l}_{2} \mathrm{O}_{6}$ is isometric. ${ }^{10}$ Crystals octahedral. Soluble in HCl. Isotropic with $n=1.540$. Colorless. Made from fusion.
$\mathrm{CsSi}_{2} \mathrm{AlO}_{6}$ is isometric ${ }^{11}$ with $a=13.66$. Isotropic with $n=1.523$. It forms mix-crystals with $\mathrm{NaSi}_{2} \mathrm{AlO}_{6} \cdot \mathrm{H}_{2} \mathrm{O}$.
$\mathbf{T l S i}_{2} \mathbf{A l O}_{6}$ is isometric ${ }^{11}$ and isotropic with $n=1.637$. PD 3.60, 3.35, 5.54; 6-0212*.
$\mathrm{KSi}_{2} \mathrm{AlO}_{6}$ (Leucite) is isometric (above about $600^{\circ} \mathrm{C}$.) with $a=13.40 \AA$. Crystals trapezohedral $\{211\}$. H. 5.5-6. G. 2.47. M.P. $1686^{\circ}$ C. Unstable below about $600^{\circ} \mathrm{C}$. Isotropic with ${ }^{12} n=1.495$ at $750^{\circ} \mathrm{C}$. and about 1.509 at $21^{\circ} \mathrm{C}$. The low-temperature $\beta$-phase is tetragonal ${ }^{11}$ with $a=12.92$,

[^144]$c=13.70 \AA$. It is characterized by complex multiple twinning, by means of which crystals retain an external pseudo-isometric form. $n_{\mathrm{O}}=1.508$, $n_{\mathrm{E}}=1.509, n_{\mathrm{E}}-n_{\mathrm{O}}=0.001$. Again: ${ }^{11} n=1.512$. Colorless, white or gray. Made from fusion. Also made by dehydrating analcite and replacing its Na with K . Then $n=1.51$. Inclusions of glass, magnetite, etc., are common, sometimes radially arranged or parallel with leucite crystal faces. PD 5.33, 3.42, 3.24; 6-0124*.
$\mathbf{K S i}_{2} \mathrm{FeO}_{6}$ ( $\mathbf{F e}$-Leucite) is pseudo-isometric (like leucite). G. 2.59. Mean index ${ }^{13}$ is 1.619 . Birefringence higher than that of leucite. Another phase ( $\mathrm{KFeSi}_{2} \mathrm{O}_{6}$ ) is K -acmite. See p. 279.
$\mathbf{R b S i}_{2} \mathbf{A l O}_{6}\left(\cdot \mathbf{H}_{2} \mathbf{O}\right.$ ? $)$ has two phases. ${ }^{11}$ At high temperature it is tetragonal with $a=13.64, c=13.33 \AA$ and $n=1.521$. At low temperature it is also tetragonal, but with $a=13.2, c=13.6 \AA$. and $n=1.481$. It forms mixcrystals with $\mathrm{KSi}_{2} \mathrm{AlO}_{6}$. PD 3.31, 2.87, 3.61; 10-385*.
$\mathrm{LiSiAlO}_{4}$ is reported to have three hexagonal crystal phases (!) as well as one orthorhombic phase. It dissociates at $1397^{\circ} \mathrm{C}$. One phase is hexagonal scalenohedral ${ }^{14}$ with $a=13.54, c=9.01 \AA$ A. H. 6.5. ${ }^{15}$ G. 2.64. M.P. $1388^{\circ} \mathrm{C}$. Uniaxial positive with $n_{\mathrm{O}}=1.573, n_{\mathrm{E}}=1.583, n_{\mathrm{E}}-n_{\mathrm{O}}=0.010$. Again: ${ }^{15} n_{0}=1.572, n_{\mathrm{E}}=1.587, n_{\mathrm{E}}-n_{\mathrm{O}}=0.015$. White to pale gray. Made hydrothermally. Another phase is hexagonal with ${ }^{15} a=5.27$, $c=11.25 \AA$ A. U.C. 3. G. 2.35 . No cleavage. Uniaxial negative with $n_{\mathrm{O}}=$ $1.524, n_{\mathrm{E}}=1.5195, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0045$. Again: $:^{16} n_{\mathrm{O}}=1.527-1.531, n_{\mathrm{E}}=$ $1.521-1.523, n_{\mathrm{O}}-n_{\mathrm{E}}=0.006-0.008$. Made from fusion. The low temperature phase, called eucryptite, is hexagonal with distinct basal cleavage. G. 2.67. Uniaxial negative ${ }^{17}$ with $n_{\mathrm{O}}=1.545, n_{\mathrm{O}}-n_{\mathrm{E}}=$ weak. Colorless. Another phase is described as orthorhombic with Z parallel ${ }^{18}$ with elongation. $(+) 2 \mathrm{~V}=$ large, $n_{\mathrm{X}}=1.575, n_{\mathrm{Y}}=1.578, n_{\mathrm{Z}}=1.586$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.011$. Made from fusion. The glass has $n=1.530-1.535$; again: ${ }^{19}$ G. 2.429 and $n=1.541$.
$\mathbf{R b S i A l O}_{4}$ is hexagonal ${ }^{20}$ and isomorphous with nepheline. Uniaxial negative with $n_{\mathrm{O}}=1.530, n_{\mathrm{E}}=1.526, n_{\mathrm{O}}-n_{\mathrm{E}}=0.004$. Colorless. It is reported to be isometric and isotropic with ${ }^{11} n=1.531$. PD 3.18, 2.67, 2.27; 10-13.

[^145]$\mathrm{NaSiYO}_{4}$ is hexagonal with ${ }^{20} a=10.79, c=8.80 \mathrm{kX}$. Uniaxial negative with $n_{\mathrm{O}}=1.832, n_{\mathrm{E}}=1.804, n_{\mathrm{E}}-n_{\mathrm{O}}=0.028$. Colorless.
$\mathrm{NaSiLaO}_{4}$ is hexagonal with ${ }^{20} a=11.01, c=8.96 \mathrm{kX}$. Uniaxial negative with $n_{\mathrm{O}}=1.867, n_{\mathrm{E}}=1.840, n_{\mathrm{O}}-n_{\mathrm{E}}=0.027$. Colorless.
$\mathrm{NaSiPrO}_{4}$ is hexagonal ${ }^{20}$ and isomorphous with nepheline. Uniaxial negative with $n_{0}=1.889, n_{\mathrm{E}}=1.861, n_{\mathrm{O}}-n_{\mathrm{E}}=0.028$. Colorless.
$\mathrm{NaSiNdO}_{4}$ is hexagonal ${ }^{20}$ with $a=10.89, c=8.85 \mathrm{kX}$. Uniaxial negative with $n_{\mathrm{O}}=1.889, n_{\mathrm{E}}=1.861, n_{\mathrm{O}}-n_{\mathrm{E}}=0.028$. Colorless.
$\mathrm{NaSiSmO}_{4}$ is hexagonal ${ }^{20}$ and isomorphous with nepheline. Uniaxial negative with $n_{\mathrm{O}}=1.898, n_{\mathrm{E}}=1.867, n_{\mathrm{O}}-n_{\mathrm{E}}=0.031$. Colorless.
$\mathrm{KSiLaO}_{4}$ is hexagonal ${ }^{20}$ with $a=11.0, c=8.96 k X$. Uniaxial negative with $n_{\mathrm{o}}=1.867, n_{\mathrm{E}}=1.840, n_{\mathrm{O}}-n_{\mathrm{E}}=0.027$. Colorless.
$\mathrm{LiSiLaO}_{4}$ is hexagonal ${ }^{20}$ and isomorphous with nepheline. Uniaxial negative with $n_{\mathrm{O}}=1.870, n_{\mathrm{E}}=1.843, n_{\mathrm{O}}-n_{\mathrm{E}}=0.027$.
$\mathrm{CsSiAlO}_{4}$ is isotropic with ${ }^{11} n=1.574$. PD 3.23, 2.71, 2.00; 10-14.
$\mathrm{CaSi}_{2} \mathrm{La}_{2} \mathrm{O}_{8}$ is hexagonal with ${ }^{20} a=11.01, c=8.85 \AA$. Uniaxial negative with $n_{\mathrm{O}}=1.880, n_{\mathrm{E}}=1.874, n_{\mathrm{O}}-n_{\mathrm{E}}=0.006$. Colorless.
$\mathrm{CaSi}_{2} \mathrm{Nd}_{2} \mathrm{O}_{8}$ is hexagonal with ${ }^{20} a=10.89, c=8.85 \AA$. Uniaxial negative with $n_{\mathrm{O}}=1.903, n_{\mathrm{E}}=1.898, n_{\mathrm{O}}-n_{\mathrm{E}}=0.005$. Colorless.
$\mathbf{L i S i}_{4} \mathbf{A l O}_{10}$ (Petalite) is monoclinic domatic with $a=11.77, b=5.13$, $c=15.17 \AA . \beta=112^{\circ} 44^{\prime}$. Crystals $\{001\}$ or $\{010\}$ tablets or elongated along $a$. Perfect $\{001\}$ and good $\{201\}$ cleavages. H. 6.5. G. 2.42. F. 5 with phosphorescence. Insoluble except in HF. X $\wedge a(=\{001\}$ cleavage) $=2^{\circ}$ to $8^{\circ}$ in acute $\beta ; \mathrm{Z}=b$. ( + ) $2 \mathrm{~V}=83^{\circ} 34^{\prime}, \mathrm{r}<\mathrm{v}$ weak (with weak crossed dispersion also). $n_{\mathrm{X}}=1.504, n_{\mathrm{Y}}=1.510, n_{\mathrm{Z}}=1.516, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ $0.012 . n_{\mathrm{Y}}(\mathrm{F})-n_{\mathrm{Y}}(\mathrm{C})=0.007$. Color red, green or white; colorless in thin section. On heating it dissociates at $950^{\circ} \mathrm{C}$. or less. ${ }^{16}$ The glass has G. 2.29 and $n=1.495$. PD 3.73, 3.65, 3.50; 9-475*.

## Feldspar Group

The minerals of the feldspar group are tectosilicates of aluminum and potassium, sodium, calcium or barium. The potassium, sodium and calcium types are the most abundant constituents of igneous rocks. They are all monoclinic or triclinic and have perfect basal and good sidepinacoid cleavages. The chief types are:

## Monoclinic

$\mathrm{KSi}_{3} \mathrm{AlO}_{8}$ $\left\{\begin{array}{l}\text { Sanidine-high temperature } \\ \text { Adularia-low temperature }\end{array}\right\}$ Orthoclase
$\mathrm{NaSi}_{3} \mathrm{AlO}_{8} \quad$ Barbierite
$\mathrm{BaSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8} \quad$ Celsian

Triclinic
$\left.\left.\begin{array}{l}\mathrm{KSi}_{3} \mathrm{AlO}_{8} \\ \mathrm{NaSi}_{3} \mathrm{AlO}_{8}\end{array} \begin{array}{l}\text { Microcline } \\ \text { Analbite (hypothetical, but abundant in } \\ \text { anorthoclase) }\end{array}\right] \begin{array}{l}\mathrm{NaSi}_{3} \mathrm{AlO}_{8} \\ \mathrm{CaSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8}\end{array} \begin{array}{l}\text { Albite } \\ \text { Anorthite }\end{array}\right\}$ Plagioclase $\left\{\begin{array}{l}\text { high temperature } \\ \text { low temperature }\end{array}\right.$

The following artificial compounds are considered to be feldspars:
Monoclinic

| $\mathrm{RbSi}_{3} \mathrm{AlO}_{8}$ <br> $\mathrm{KSi}_{3} \mathrm{FeO}_{8}$ <br> $\cdot{ }_{\cdot} \mathrm{KSi}_{3} \mathrm{GaO}_{8}$ | intercrystallizes with orthoclase |  |
| :---: | :---: | :---: |
|  |  |  |
|  | $\mathrm{KGe}_{3} \mathrm{AlO}_{8}$ | $\mathrm{KGe}_{3} \mathrm{GaO}_{8}$ |
|  | Triclinic |  |
| $\mathrm{KSi}_{3} \mathrm{FeO}_{8}$ | $\begin{aligned} & \mathrm{SrSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8} \\ & \mathrm{MnSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8} \end{aligned}$ |  |
| $\mathrm{NaSi}_{3} \mathrm{GaO}_{8}$ | $\mathrm{CaSi}_{2} \mathrm{Ga}_{2} \mathrm{O}_{8}$ |  |
| $\mathrm{NaGe}_{3} \mathrm{AlO}_{8}$ | $\mathrm{CaGe}_{2} \mathrm{Al}_{2} \mathrm{O}_{8}$ |  |
| $\mathrm{NaGe}_{3} \mathrm{GaO}_{8}$ | $\mathrm{CaGe}_{2} \mathrm{Ca}_{2} \mathrm{O}_{8}$ |  |

High-temperature forms can be distinguished from low-temperature forms only by very careful observation of optical and crystallographic properties. They are distinct because of varying states of disorder in the arrangement of the Al and Si in tetrahedral sites, and in the arrangement of $\mathrm{Na}, \mathrm{Ca}$, and K in the non-tetrahedral sites. It is rather probable that the degree of disorder is sensitive not only to variations in temperature but also to variations of pressure, and it is possible that other factors such as the composition, pH , etc., of the medium from which the crystals form, may also affect the degree of order.
$\mathbf{K S i}_{3} \mathbf{A l O}_{8}$ has at least three crystal phases; two of them are monoclinic (often collectively called orthoclase), namely, high-temperature sanidine and low-temperature adularia. Lowest-temperature form, microcline, is triclinic. Sanidine has $a=8.4, b=12.9, c=7.1 \AA, \beta=115^{\circ} 35^{\prime}$. U.C. 4 . Crystals equant, $\{010\}$ tablets, or elongated along $a$. Perfect $\{001\}$ and distinct $\{010\}$ cleavages. H. 6. G. 2.57. Carlsbad twinning (on $\{010\}$ ) common. In some crystals of sanidine Z is normal to ( 010 ); in other crystals it is parallel with (010), the optic angle passing through $0^{\circ}$ between these two conditions, and Z and Y interchanging their position. X makes an angle of about $5^{\circ}$ to $8^{\circ}$ with $a$ (the trace of the basal cleavage in (010)) in the obtuse angle $\beta$. The optic plane may be normal to (010) in red light
and parallel thereto in blue light. If the optic plane is parallel with (010) the dispersion is inclined (weak) with $\mathrm{r}>\mathrm{v}$; if it is normal to (010) the dispersion is horizontal (weak) with $\mathrm{r}<\mathrm{v}$. ( - ) 2 V very small. $n_{\mathrm{X}}=1.520-$ $1.523, n_{\mathrm{Y}} \approx n_{\mathrm{Z}}=1.525-1.53, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.005-0.006$. Sanidine often contains some Na; the refringence, birefringence, extinction angle and specific gravity increase gradually with increase in sodium (as shown in Fig. 10-12). Colorless. Made from fusion. PD 3.25, 3.21, 3.75; 10-357*.


Fig. 10-12. Variations in the properties of the series $\mathrm{KAlSi}_{3} \mathrm{O}_{8}-\mathrm{NaAlSi}_{3} \mathrm{O}_{8}$, quenched from high temperature (sanidine-barbierite).

Adularia, the low-temperature phase of orthoclase, is also monoclinic, with $a=8.45, b=12.9, c=7.15 \AA, \beta=116^{\circ} 3^{\prime}$. Crystals much like those of sanidine. Perfect $\{001\}$ and distinct $\{010\}$ cleavages. H. 6. G. 2.57. Carlsbad twinning common (rotation about $c$, contact plane (010)). $\mathrm{X} \wedge a$ (trace of basal cleavage in (010)) is about $5^{\circ}$ in obtuse $\beta$. ( $+2 \mathrm{~V}=$ $50^{\circ}$ to $70^{\circ}$ (or even up to $85^{\circ}$ ), r $>\mathrm{v}$ with weak horizontal dispersion. $n_{\mathrm{X}}=1.519-1.526, n_{\mathrm{Y}}=1.523-1.530, n_{\mathrm{Z}}=1.524-1.533, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.005-$ 0.007 . Adularia, like sanidine, often contains some Na; the refringence,
birefringence, extinction angle and specific gravity all increase with increase of Na , as shown in Fig. 10-13. Colorless. Microcline can be changed artificially to sanidine. ${ }^{20 \mathrm{a}}$ It is triclinic pinacoidal with $a=8.44, b=13.00$, $c=7.21 \AA, \alpha=90^{\circ} 7^{\prime}, \beta=115^{\circ} 50^{\prime}, \gamma=89^{\circ} 55^{\prime}$. U.C. 4. Crystals resemble those of orthoclase but usually have two sets of multiple-twinning


Fig. 10-13. Variations in the properties of the series $\mathrm{KAlSi}_{3} \mathrm{O}_{8}-\mathrm{NaAlSi}_{3} \mathrm{O}_{8}$ stabilized at relatively low temperature (adularia-albite).
lamellae nearly at right angles. Perfect $\{001\}$ and distinct $\{010\}$ cleavages. H. 6. G. 2.55. Fusion begins at $1170^{\circ} \mathrm{C}$. (with formation of leucite) and is complete at $1530^{\circ} \mathrm{C}$. X makes an angle of about $5^{\circ}$ with the $\{001\}$ cleavage in (010) and about $15^{\circ}$ with the $\{010\}$ cleavage in (001). Z is nearly normal to $\{010\} .(-) 2 \mathrm{~V}=$ about $83^{\circ}, \mathrm{r}>\mathrm{v}$ with notable horizontal dispersion. $n_{\mathrm{X}}=1.518, n_{\mathrm{Y}}=1.522, n_{\mathrm{Z}}=1.525, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.007$. Colorless. Made by coating a (010) cleavage piece of low albite with ${ }^{21}$ powdered $\mathrm{KSi}_{3} \mathrm{AlO}_{8}$ and heating at $1060^{\circ} \mathrm{C}$. for six hours. PD 3.24, 4.21, 3.83; 10-479.

[^146]$\mathbf{R b S i}_{3} \mathbf{A l O}_{8}$ is a Rb analogue of potash feldspar, ${ }^{11}$ like sanidine. It is biaxial with $n_{\mathrm{X}}=1.524, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.529, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.005$. It forms a (continuous?) series of mix-crystals with $\mathrm{KSi}_{3} \mathrm{AlO}_{8}$ in which there is only a small change in indices; for example: crystals with $\mathrm{Rb}: \mathrm{K}=52: 48$ have a mean index of 1.524 ; with $\mathrm{Rb}: \mathrm{K}=20: 80$, the mean index is 1.521 ; and with $\mathrm{Rb}: \mathrm{K}=0: 100, n_{\mathrm{X}}=1.517, n_{\mathrm{Z}}=1.523$. Colorless. Formed hydrothermally. PD 3.31, 2.87, 3.61; 10-376.
$\mathrm{KSi}_{3} \mathrm{FeO}_{8}$ is monoclinic and triclinic ${ }^{22}$ corresponding with orthoclase and microcline. The microcline phase shows common twinning on $\{100\},\{001\}$, or $\{021\}$; G. 2.712. Extinction on (010) is at $7^{\circ}-8^{\circ}$ to $a ; Y=b . n_{\mathrm{X}}=1.601$, $n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.609, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.008$. Color yellow. Made by passing $\mathrm{SiO}_{2}$ and $\mathrm{Fe}_{2} \mathrm{O}_{3}$ into fused potassium vanadate and cooling slowly. $\mathrm{KSi}_{3} \mathrm{FeO}_{8}$ glass has $n=1.586$. PD 3.18, 4.02, 3.80; 9-462(?).

To determine more accurately the role of Al and Si in the crystal structure of feldspars artificial isomorphous compounds have been made in which Al is replaced by Ga and Si by Ge , or both; such compounds have the following properties as compared with feldspar: ${ }^{23}$

|  | $\mathrm{NaSi}_{3} \mathrm{AlO}_{8}$ | $\mathrm{NaSi}_{3} \mathrm{GaO}_{8}$ | $\mathrm{NaGe}_{3} \mathrm{AlO}_{8}$ | $\mathrm{NaGe}_{3} \mathrm{GaO}_{8}$ |
| :---: | :---: | :---: | :---: | :---: |
| M.P. | $1118{ }^{\circ} \mathrm{C}$. | $1015{ }^{\circ} \mathrm{C}$. | $1067{ }^{\circ} \mathrm{C}$. | $952^{\circ} \mathrm{C}$. |
| $n$ (glass) | 1.489 | 1.519 | 1.592 | 1.636 |
| $n_{\text {x }}$ | 1.525 | $n \mathrm{X}^{\prime} 1.552$ | 1.606 | 1.638 |
| $n_{\mathrm{z}}$ | 1.536 | $n_{\mathrm{Z}}{ }^{\prime} 1.558$ | 1.619 | 1.654 |
|  | $\mathrm{KSi}_{3} \mathrm{AlO}_{8}$ | $\mathrm{KSi}_{3} \mathrm{GaO}_{8}$ | $\mathrm{KGe}_{3} \mathrm{AlO}_{8}$ | $\mathrm{KGe}_{3} \mathrm{GaO}_{8}$ |
| M.P. | $1170{ }^{\circ} \mathrm{C}$. | $1000-1020^{\circ} \mathrm{C}$. | $1122^{\circ} \mathrm{C}$. | ca. $1000^{\circ} \mathrm{C}$. |
| $n$ (glass) | 1.488 | 1.513 | 1.578 | 1.617 |
| $n \mathbf{x}$ | 1.518 | $n \mathrm{X}^{\prime} 1.533$ | $1.590^{24}$ | 1.615 |
| $n_{\mathrm{z}}$ | 1.526 | $n_{\mathrm{z}}{ }^{\prime} 1.539$ | 1.595 | 1.628 |
|  | $\mathrm{CaSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8}$ | $\mathrm{CaSi}_{2} \mathrm{Ga}_{2} \mathrm{O}_{8}$ | $\mathrm{CaGe} \mathrm{Al}_{2} \mathrm{O}_{8}$ | $\mathrm{CaGe}_{2} \mathrm{Ga}_{2} \mathrm{O}_{8}$ |
| M.P. | $1553^{\circ} \mathrm{C}$. | Liq. temp. $1323{ }^{\circ} \mathrm{C}$. | Liq. $>1400^{\circ} \mathrm{C}$. | Liq. $1321^{\circ} \mathrm{C}$. |
| $n$ (glass) | 1.5755 | 1.633 | 1.658 | 1.745 |
| $n \mathrm{X}$ | 1.576 | $n \mathrm{X}^{\prime} 1.625$ | 1.641 | 1.705 |
| $n_{\mathrm{Z}}$ | 1.588 | $n_{\mathrm{Z}}{ }^{\prime} 1.631$ | 1.647 | 1.711 |
|  | $\mathrm{Ca}_{2} \mathrm{Si}_{4} \mathrm{Al}_{3} \mathrm{GaO}_{16}$ | $\mathrm{CaSi}_{2} \mathrm{AlGaO}_{8}$ | $\mathrm{CaSiGeAl} 2_{2} \mathrm{O}_{8}$ |  |
| M.P. | ca. $1495{ }^{\circ} \mathrm{C}$. | $1530^{\circ} \mathrm{C}$. | $1465^{\circ} \mathrm{C}$. |  |
| $n$ (glass) | 1.591 | 1.608 | 1.611 |  |
| $n \mathrm{X}^{\prime}$ | 1.591 | 1.604 | 1.608 |  |
| $n_{\mathrm{z}}{ }^{\prime}$ | 1.596 | 1.611 | 1.615 |  |

${ }^{22}$ Gaubert: C. R. Cong. Soc. Sav. Sci., p. 402 (1925); Faust: Am. Min. XXI, p. 735 (1936).
${ }^{23}$ Goldsmith: J. Geol. LVIII, p. 518 (1950).
${ }^{24}$ Correction made by J. R. Goldsmith in pers. comm. June 6 and July 6, 1955. He also suggested that the indices of the $\mathrm{Ca}-\mathrm{Ga}$ and $\mathrm{Ca}-\mathrm{Ge}$ compounds should show greater birefringence.
$\mathbf{N a S i}_{3} \mathrm{AlO}_{8}$ has three or four crystal phases. One phase is pseudo-monoclinic, but known only with $10-15$ per cent $\mathrm{KSi}_{3} \mathrm{AlO}_{8}$; it is called anorthoclase (or analbite). It has two sets of multiple twinning much like those in microcline, but finer; $\mathrm{X}^{\prime}$ makes an angle of $6^{\circ}$ to $12^{\circ}$ with $a$ in (010). The optic plane is nearly normal to $\{010\}$. (-)2V $=42^{\circ}$ to $54^{\circ}, \mathrm{r}>\mathrm{v}, n_{\mathrm{X}}=$ $1.523, n_{\mathrm{Y}}=1.528, n_{\mathrm{Z}}=1.529$. $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.006$. Again: ${ }^{25}(-) 2 \mathrm{~V}=60^{\circ}$, $n_{\mathrm{X}}=1.5198, n_{\mathrm{Y}}=1.5242, n_{\mathrm{Z}}=1.5276, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0078$. PD 3.21, 3.24, 4.11; 9-478. The triclinic phases of $\mathrm{NaSi}_{3} \mathrm{AlO}_{8}$ are the common ones (highand low-temperature albite) which intercrystallize freely with $\mathrm{CaSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8}$. See Fig. $10-14$. $\mathrm{NaSi}_{3} \mathrm{AlO}_{8}, \mathrm{CaSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8}$ and $\mathrm{KSi}_{3} \mathrm{AlO}_{8}$ are the main com-


Fig. 10-14a. Variation of refractive indices in plagioclase. The solid lines refer to properties of material heated to equilibrium at temperatures a little below the melting points and then quenched. Data of Smith, Amer. Mineral. XLIII, p. 1179 (1958), and of Smith in Hess, Geol. Soc. Amer., Mem. LXXX, p. 191 (1960). Modified from Smith's figures.
ponents of the very abundant minerals known as feldspars, and the $\mathrm{NaSi}_{3} \mathrm{AlO}_{8}-\mathrm{CaSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8}$ series is plagioclase. This series was formerly supposed to consist of units of definite composition which were named oligoclase, andesine, labradorite, and bytownite. It is now known to be a contin-
${ }^{25}$ Ho: Contr. Nat. Res. Inst. Geol. Acad. Sinica, Nanking, 1933, No. 4, p. 31 [Min. Abst. V, p. 439].
uous series ${ }^{25 a}$ which has been artificially divided so that albite means pure $\mathrm{NaSi}_{3} \mathrm{AlO}_{8}$ and also the series from 100 to 90 per cent $\mathrm{NaSi}_{3} \mathrm{AlO}_{8}$ with 0 to 10 per cent $\mathrm{CaSi}_{2} \mathrm{O}_{8}$. Oligoclase varies in composition from 90 to 70 per cent $\mathrm{NaSi}_{3} \mathrm{AlO}_{8}+10-30$ per cent $\mathrm{CaSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8}$ (expressed as $\mathrm{Ab}_{90} \mathrm{An}_{10}$ to $\mathrm{Ab}_{70} \mathrm{An}_{30}$ ). Andesine varies from $A b_{70} A n_{30}$ to $A b_{50} A n_{50}$, labradorite from $A b_{50} A n_{50}$ to


Fig. 10-14b. Variation of birefringence ( $n_{\mathrm{z}}-n_{\mathrm{x}}$ ) and optic angle $\left(2 \mathrm{~V}_{\mathrm{z}}\right)$ in plagioclase. The solid lines are for material heated to high temperature and quenched; Data of Smith, op. cit. Modified from Smith's figures.
$\mathrm{Ab}_{30} \mathrm{An}_{70}$, bytownite from $\mathrm{Ab}_{30} \mathrm{An}_{70}$ to $\mathrm{Ab}_{10} \mathrm{An}_{90}$ and anorthite from $\mathrm{Ab}_{10} \mathrm{An}_{90}$ to $\mathrm{Ab}_{0} \mathrm{An}_{100}$.
$\mathbf{A b}_{100} \mathbf{A n}_{0}$ to $\mathbf{A b}_{90} \mathbf{A} \mathbf{n}_{10}$ (High-temperature or $\boldsymbol{a}$-albite) is triclinic with $a=8.23, \quad b=13.00, \quad c=7.25 \AA, \quad \AA=94^{\circ} 3^{\prime}, \quad \beta=116^{\circ} 20^{\prime}, \gamma=88^{\circ} 9^{\prime}$. Crystals varied; often $\{010\}$ tablets or prismatic. Perfect $\{001\}$ and good $\{010\}$ cleavages. Often twinned in one or more ways. H. 6-6.5. G. 2.612.625. The extinction angle on (010) is $9^{\circ}$ to $12^{\circ 26}\left(14^{\circ}-22^{\circ}{ }^{\circ 27}\right)$; on (001) it is $0^{\circ}-2^{\circ}{ }^{26}\left(3^{\circ}-4^{\circ 27}\right)$, and the maximum extinction angle in the zone normal
${ }^{25 a}$ More accurately a multiple series or system, for in addition to the simple variation of chemical composition, various states of order and disorder are possible in the arrangement of Si and Al in tetrahedral sites, requiring in one case (anorthite) a doubled $c$-axis. Temperature of equilibrium or crystallization governs this, and can be estimated roughly from optical and crystallographic measurements.
${ }^{26}$ Tuttle and Bowen: J. Geol. LVIII, p. 572 (1950).
${ }^{27}$ Tröger: Tabellen Opt. Bestim. gestein. Miner. 1952, p. 99, 101, etc.
to (010) is $26^{\circ}-37^{\circ}$. (-) $2 \mathrm{~V}=45^{\circ}-55^{\circ} . n_{\mathrm{X}}=1.527-1.533, n_{\mathrm{Y}}=1.532-$ 1.539, $n_{\mathrm{z}}=1.534-1.542 . n_{\mathrm{z}}-n_{\mathrm{X}}=0.007-0.009$. Colorless. Made from fusion. PD 3.18, 3.75, 3.21; 10-393*. This phase seems to invert ${ }^{26}$ slowly at about $700^{\circ} \mathrm{C}$. to low-temperature or $\boldsymbol{\beta}$-albite whose crystal forms and properties are very nearly the same as those of $\alpha$-albite except for the optic angle and extinction angles. The extinction angle on (010) is $7^{\circ}-20^{\circ}$; on (001) it is $3^{\circ}$, and the maximum extinction angle ${ }^{28}$ in the zone normal to (010) is $12^{\circ}-20^{\circ} .(+) 2 \mathrm{~V}=75^{\circ}-83^{\circ} . n_{\mathrm{X}}=1.528-1.535, n_{\mathrm{Y}}=1.533-1.540$, $n_{\mathrm{Z}}=1.539-1.545, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.010$. Again: ${ }^{29}$ for pure $\mathrm{NaSi}_{3} \mathrm{AlO}_{8}: n_{\mathrm{X}}=$ $1.5274, n_{\mathrm{Y}}=1.5314, n_{\mathrm{Z}}=1.5379, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0105$. PD 3.20, 3.78, $6.39 ; 9-466^{*}$. Pure $\mathbf{N a S i}_{3} \mathbf{A l O}_{8}$ glass has G. 2.382 and $n=1.4964 \mathrm{Li}$, 1.4891 Na, 1.4916 Tl.
$\mathbf{A b}_{90} \mathbf{A n}_{10}$ to $\mathbf{A b}_{70} \mathbf{A n} \mathbf{n}_{30}$ (High-temperature or $\boldsymbol{a}$-oligoclase) is triclinic with $a=8.16, b=12.90, c=7.13 \AA, \alpha=93^{\circ} 4^{\prime}, \beta=116^{\circ} 22^{\prime}, \gamma=90^{\circ} 4^{\prime}$. Crystals varied; often $\{010\}$ tablets or prismatic. Perfect $\{010\}$ and good $\{001\}$ cleavages. H. 6-6.5. G. ${ }^{28} 2.625-2.645$. The extinction angle on (010) is $0^{\circ}-14^{\circ}$, on (001) it is $0^{\circ}-3^{\circ}$. (-) $2 \mathrm{~V}=55^{\circ}-75^{\circ}$. $n_{\mathrm{X}}=1.535-1.545$, $n_{\mathrm{Y}}=1.539-1.549, n_{\mathrm{Z}}=1.542-1.552, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.007 c a$. It seems to invert slowly at about $700^{\circ} \mathrm{C}$. to low-temperature or $\boldsymbol{\beta}$-oligoclase which differs from the $\alpha$-phase chiefly in extinction and optic angles. The $\beta$-phase has an extinction angle on (010) of $12^{\circ}-3^{\circ}$, on (001) it is $0^{\circ}-1^{\circ}$ and the maximum angle in the zone normal to (010) is $0^{\circ}-12^{\circ}$. The optic angle, $2 \mathrm{~V}_{\mathrm{X}}$, is $97^{\circ}-82^{\circ} . n_{\mathrm{X}}=1.535-1.545, n_{\mathrm{Y}}=1.54-1.549, n_{\mathrm{Z}}=1.545-1.552$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.010-0.007$. Colorless. PD 3.18, 4.03, 3.20; 9-457 ( $\alpha$ - or $\beta-$ ?).
$\mathbf{A b}_{70} \mathbf{A n} n_{30}$ to $\mathbf{A b}_{50} \mathbf{A n _ { 5 0 }}$ (High-temperature or $\boldsymbol{\alpha}$-andesine) is triclinic with $a=8.14, b=12.86, c=7.17 \AA, \alpha=93^{\circ} 23^{\prime}, \beta=116^{\circ} 28^{\prime}, \gamma=89^{\circ} 59^{\prime}$. Crystals varied. Perfect $\{010\}$ and good $\{001\}$ cleavages. H. 6-6.5. G. $2.645-2.675$. The extinction angle on (010) is $0^{\circ}-17^{\circ}$, on ( 001 ) it is $0^{\circ}-5^{\circ}$ and the maximum in the zone normal to (010) is $12^{\circ}-27^{\circ} .2 \mathrm{~V}_{\mathrm{x}}=75^{\circ}-115^{\circ}$, $n_{\mathrm{X}}=1.545-1.555, n_{\mathrm{Y}}=1.549-1.558, n_{\mathrm{Z}}=1.552-1.562, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.007$ $c a$. It seems to invert slowly at about $700^{\circ} \mathrm{C}$. to low-temperature or $\boldsymbol{\beta}$-andesine which differs from the $\alpha$-phase as follows: the extinction angle on ( 010 ) is $3^{\circ}-17^{\circ}$; on (001) it is $0^{\circ}-5^{\circ}$ and the maximum angle in the zone normal to (010) is $20^{\circ}-32^{\circ}$. $2 \mathrm{~V}_{\mathrm{x}}=82^{\circ}-105^{\circ}, n_{\mathrm{x}}=1.546-1.556$, $n_{\mathrm{Y}}=1.550-1.559, n_{\mathrm{Z}}=1.553-1.563, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.007 \mathrm{ca}$. Colorless. PD $3.21,3.18,4.04 ; 10-359$.
$\mathbf{A b}_{50} \mathbf{A n} n_{50}$ to $\mathbf{A b}_{30} \mathbf{A n} n_{70}$ (Labradorite) is triclinic with $a=8.21, b=12.95$, $c=14.16 \AA . \alpha=93^{\circ} 31^{\prime}, \beta=116^{\circ} 3^{\prime}, \gamma=89^{\circ} 59^{\prime}$. Only one phase is known. Crystals often $\{010\}$ tablets or varied. Perfect $\{010\}$ and good

[^147]\{001\} cleavages. H. 6-6.5. G. 2.66-2.72. Extinction angle on (010) is $16^{\circ}-28^{\circ}$; on (001) it is $5^{\circ}-14^{\circ}$, and the maximum extinction angle in the zone normal to (010) is $29^{\circ}-40^{\circ}$. ( + ) $2 \mathrm{~V}=75^{\circ}-90^{\circ}$, $\mathrm{r}>\mathrm{v}$. $n_{\mathrm{x}}=1.555-$ $1.563, n_{\mathrm{Y}}=1.558-1.567, n_{\mathrm{Z}}=1.563-1.572, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.008-0.009$. Colorless. Made from fusion. PD 3.20, 3.18, 4.04; 9-465*.
$\mathbf{A b}_{30} \mathbf{A n}_{70}$ to $\mathbf{A b}_{10} \mathbf{A n}_{90}$ (Bytownite) is triclinic with $a: b: c=$ $0.636: 1: 0.554 . \alpha=93^{\circ} 22^{\prime}, \beta=116^{\circ} 0^{\prime}, \gamma=94^{\circ} 4^{\prime}$. Crystals often $\{010\}$ tablets. Perfect $\{010\}$ and good $\{001\}$ cleavages. H. 6-6.5. G. 2.72-2.74. Extinction angle on (010) is $28^{\circ}-36^{\circ}$; on (001) it is $14^{\circ}-30^{\circ}$, and the maximum angle in the zone normal to ( 010 ) is $40^{\circ}-57^{\circ}$. ( -$) 2 \mathrm{~V}=77^{\circ}-90^{\circ}$, $\mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.563-1.572, n_{\mathrm{Y}}=1.567-1.578, n_{\mathrm{Z}}=1.572-1.582, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.009-0.010. Colorless. Made from fusion. PD 3.20, 4.03, 3.75; 9-467.
$\mathbf{A b}_{10} \mathbf{A n}_{90}$ to $\mathbf{A b}_{0} \mathbf{A n}_{100}$ (Anorthite) is triclinic with $a=8.21, b=12.95$, $c=14.16 \AA . \alpha=93^{\circ} 13^{\prime}, \beta=115^{\circ} 56^{\prime}, \gamma=91^{\circ} 12^{\prime}$. Crystals varied, often $\{010\}$ tablets. Perfect $\{010\}$ and good $\{001\}$ cleavages. H. 6-6.5. G. 2.742.765. Extinction angle on (010) is $37^{\circ}-40^{\circ}$; on (001) it is $30^{\circ}-39^{\circ}$. (-) $2 \mathrm{~V}=$ $77^{\circ} . n_{\mathrm{X}}=1.572-1.577, n_{\mathrm{Y}}=1.578-1.584, n_{\mathrm{Z}}=1.582-1.590, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ $0.010-0.013$. Colorless. Made from fusion.
$\mathrm{CaSi}_{2} \mathrm{Al}_{2} \mathbf{O}_{8}$ has at least three crystal phases, ${ }^{30}$ but two of these are only metastable. One such phase is made by heating $\mathrm{CaSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8}$ glass to $2000^{\circ} \mathrm{C}$. in a graphite crucible in a nitrogen atmosphere, cooling slowly to $1258^{\circ} \mathrm{C}$. and allowing to crystallize. It is also made (with $\mathrm{H}_{2} \mathrm{O}$ under pressure) at temperatures ${ }^{31}$ below $375^{\circ} \mathrm{C}$. It is hexagonal with $a=5.11, c=14.738 \AA$. U.C. 1. Crystals basal plates with perfect basal cleavage. H. 5-6. G. 2.74. Uniaxial positive ${ }^{31}$ with $n_{0}=1.585, n_{\mathrm{E}}=1.590, n_{\mathrm{E}}-n_{\mathrm{O}}=0.005$. Another metastable phase crystallizes at about $950^{\circ} \mathrm{C}$.-more easily if some $\mathrm{NaSi}_{3} \mathrm{AlO}_{8}$ is present. It is orthorhombic with $a=8.224, b=8.606$, $c=4.836 \AA$. U.C. 2 . It has poor cleavage parallel with the optic plane; conchoidal fracture. H. 6. G. 2.70. (-) $2 \mathrm{~V}=39^{\circ}, n_{\mathrm{X}}=1.553, n_{\mathrm{Y}}=1.580$, $n_{\mathrm{Z}}=1.584, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.031$. Made by crystallizing the glass. The stable phase anorthite is triclinic with $a=8.21, b=12.95, c=14.16$, $\alpha=93^{\circ} 13^{\prime}, \beta=115^{\circ} 56^{\prime}, \gamma=91^{\circ} 12^{\prime}$. Crystals often $\{010\}$ tablets. H. 6. G. 2.765. M.P. $1550^{\circ}$ C. Soluble in HCl. Multiple twinning common. The optic plane makes a large angle with (010), the Z axis being at about $43^{\circ}$ to (010) and about $50^{\circ}$ to (001), while the X axis makes an angle of about $32^{\circ}$ with (010) and about $35^{\circ}$ with (001). The extinction angle is $35^{\circ}$ on (001) and $37^{\circ}$ to $38^{\circ}$ on (010). Extinction normal to X is at $19.5^{\circ}$ to (001) and $32^{\circ}$ to (010); extinction normal to Z is at $66^{\circ}$ to (001) and $52^{\circ}$ to ${ }^{31}$ (010). (-) $2 \mathrm{~V}=77^{\circ} . n_{\mathrm{X}}=1.5755, n_{\mathrm{Y}}=1.5832, n_{\mathrm{Z}}=1.5885, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.013. Again: $n_{\mathrm{X}}=1.5768, n_{\mathrm{Y}}=1.5846, n_{\mathrm{Z}}=1.5903, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0135$.

[^148]Colorless. Made from fusion. $\mathrm{CaSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8}$ glass has G. 2.70 and $n=1.5719$ $\mathrm{Li}, 1.5755 \mathrm{Na}, 1.5786 \mathrm{Tl}$. This phase is an end-member of the plagioclase series whose properties are shown in Fig. 10-14. PD 3.21, 3.19, 4.05; 10-379*.
$\mathbf{B a S i}_{2} \mathbf{A l}_{2} \mathbf{O}_{8}$ has three crystal phases. ${ }^{32}$ The high-temperature or $\boldsymbol{a}$-phase is hexagonal. Crystals are basal plates with basal cleavage. G. 3.3. M.P. $1715^{\circ} \mathrm{C}$. Uniaxial positive with $n_{\mathrm{O}}=?, n_{\mathrm{E}}=1.5712$. Again: ${ }^{33} n=1.567$, $n_{\mathrm{E}}-n_{\mathrm{O}}=0.004$. Colorless. It may take in crystal solution up to 30 per cent $\mathrm{KSi}_{3} \mathrm{AlO}_{4}$; then $n_{\mathrm{E}}=1.5681$. Found in slags. Colorless. Made by heating celsian at $1500^{\circ}$ for four days. ${ }^{31}$ Another phase of $\mathrm{BaS}_{2} \mathrm{Al}_{2} \mathrm{O}_{8}$ (called paracelsian) is monoclinic ${ }^{34}$ and pseudo-orthorhombic with $a: b: c=$ $0.947: 1: 0.895, \beta=90^{\circ} 10^{\prime}$. Crystals often prismatic and vertically striated. Complex twinning common. Poor prismatic cleavage. G. 3.31-3.32. X nearly normal to (100); $\mathrm{Z}=b$. (-) $2 \mathrm{~V}=50^{\circ}-53^{\circ}$ ca., $\mathrm{r}<\mathrm{v} . n_{\mathrm{x}}=1.5634$ $\mathrm{Li}, 1.5702 \mathrm{Na}, 1.5734 \mathrm{Tl}, n_{\mathrm{Y}}=1.5793 \mathrm{Li}, 1.5824 \mathrm{Na}, 1.5867 \mathrm{Tl}, n_{\mathrm{Z}}=$ $1.5843 \mathrm{Li}, 1.5869 \mathrm{Na}, 1.5901 \mathrm{Tl}, n_{\mathrm{z}}-n_{\mathrm{X}}=0.0167 \mathrm{Na}$. This phase alters easily to celsian. The phase commonly found in nature (called celsian) is monoclinic prismatic with $a=8.63, b=13.10, c=7.29 \AA, \beta=115^{\circ} 9^{\prime}$. Isomorphous with orthoclase. Crystals short prismatic or $\{010\}$ plates. Perfect $\{001\}$, distinct $\{010\}$ and poor $\{110\}$ cleavages. Common Carlsbad and other twinning. H. 6. G. 3.8 ( -3.57 ?). M.P. $1640^{\circ}$ C. Soluble in HCl . $\mathrm{X} \wedge c=+3^{\circ} ; \mathrm{Y}=b ; \mathrm{Z} \wedge a$ (the $\{001\}$ cleavage) $=+28^{\circ}$. ( $+2 \mathrm{~V}=$ about $80^{\circ}, n_{\mathrm{X}}=1.587, n_{\mathrm{Y}}=1.593, n_{\mathrm{Z}}=1.600, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.013$. With 6 per cent of other isomorphous compounds: ${ }^{35}(+) 2 \mathrm{~V}=86^{\circ} 22^{\prime}, n_{\mathrm{x}}=$ $1.5835, n_{\mathrm{Y}}=1.5886, n_{\mathrm{Z}}=1.5941, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0106$. A variety ${ }^{36}$ with 4 per cent CaO has: $\mathrm{Y}=b, \mathrm{Z} \wedge a=29^{\circ},(-) 2 \mathrm{~V}=76^{\circ}, n_{\mathrm{X}}=1.572$, $n_{\mathrm{Y}}=1.5795$ calc., $n_{\mathrm{Z}}=1.584, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.012$. PD 3.29, 2.97, 3.99; 10-356.
$\mathrm{SrSi}_{2} \mathrm{Al}_{2} \mathbf{O}_{8}$ seems to be isomorphous with $\mathrm{CaSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8}$ and therefore triclinic. It is fibrous without twinning. G. 3.12. ( - ) $2 \mathrm{~V}=70^{\circ}, n_{\mathrm{X}}=1.574,{ }^{37}$ $n_{\mathrm{Y}}=1.582, n_{\mathrm{Z}}=1.586, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.012$. It may take in crystal solution ${ }^{32}$ up to 30 per cent $\mathrm{KSi}_{3} \mathrm{AlO}_{8}$ and then $n_{\mathrm{X}}=1.567, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.577$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.010$. The extinction angle normal to X is $4^{\circ}$ to $8^{\circ}$ to the cleavage and elongation direction. This angle does not vary with the potash content. The maximum extinction angle $\mathbf{Z}^{\prime}$ to elongation is $20^{\circ}$. Colorless. PD 3.27, 3.22, 3.43; 10-15.
${ }^{32}$ Dittler and Lasch: Sitz. Akad. Wiss. Wien I, 140, p. 633 (1931).
${ }^{33}$ Faber: Chem. Erde, X, p. 67 (1936)
${ }^{34}$ Spencer: Min. Mag. XXVI, p. 231 (1942); Smith: Acta Cryst. VI, p. 613 (1953).
${ }^{35}$ Strandmark: Geol. För. Förh. XXV, p. 289 (1903); XXVI, p. 97 (1904); Zeit. Krist. XLIII, p. 89 (1907).
${ }^{36}$ Segrist: Min. Mag. XXVII, p. 166 (1946).
${ }^{37}$ Eskola: Am. J. Sci. CCIV, p. 331 (1922).
$\mathbf{M n S i}_{2} \mathrm{Al}_{2} \mathbf{O}_{8}$ is probably isomorphous with anorthite and therefore triclinic. It has an extinction angle ${ }^{38}$ of $43^{\circ}$. (-) $2 \mathrm{~V}=$ ?, $n_{\mathrm{x}}=1.605, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}>1.626, n_{\mathrm{Z}}-n_{\mathrm{X}}>0.021$. Similar crystals probably with some Ca have $n_{\mathrm{X}}=1.59, n_{\mathrm{Z}}=1.61$.

## Zeolites

Zeolites are tectosilicates of aluminum and another base, usually calcium or sodium, containing water that can be largely expelled without destroying the crystal structure. The crystal easily reabsorbs its water, if exposed to water vapor, or it can absorb other materials in place of the water, such as air, ammonia, alcohol, iodine, etc. Moreover, the second base is generally readily exchangeable in a saturated solution of some other base; for example, the calcium in stilbite can be replaced by $\mathrm{Na}, \mathrm{K}, \mathrm{NH}_{4}, \mathrm{Ba}, \mathrm{Ag}$ or Cu and vice versa. Base-exchange properties make it difficult to establish chemical formulas.

Some zeolites are chemically correctly described as hydrated feldspars but they are not so closely related crystallographically as are the feldspars. The following zeolites will be included here:

| $\mathrm{NaSi} \mathrm{F}_{2} \mathrm{AlO}_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ | Analcite | Isometric |
| :---: | :---: | :---: |
| $\mathrm{Na}_{2} \mathrm{CaSi}_{10} \mathrm{Al}_{4} \mathrm{O}_{28} \cdot 20 \mathrm{H}_{2} \mathrm{O}(?)$ | Faujasite | Isometric |
| $\mathrm{KSiAlO}_{4} \cdot n \mathrm{H}_{2} \mathrm{O}$ | K-Nepheline | Hexagonal(?) |
| $\mathrm{NaSi}_{2} \mathrm{AlO}_{6} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | Gmelinite | Hexagonal |
| $\mathrm{CaSi}_{4} \mathrm{Al}_{2} \mathrm{O}_{12} \cdot 6 \mathrm{H}_{2} \mathrm{O}(?)$ | Chabazite | Hexagonal |
| $\mathrm{CaSi}_{3} \mathrm{Al}_{2} \mathrm{O}_{10} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | Levynite | Hexagonal |
| $\mathrm{NaSiAlO}_{4} \cdot n \mathrm{H}_{2} \mathrm{O}$ |  | Orthorhombic |
| $\mathrm{LiSiAlO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ |  | Orthorhombic |
| $\mathrm{BaSi}_{3} \mathrm{Al}_{2} \mathrm{O}_{10} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | Edingtonite | Orthorhombic |
| $\mathrm{CaSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | Gismondite | Orthorhombic |
| $\mathrm{NaCa}_{2} \mathrm{Si}_{5} \mathrm{Al}_{5} \mathrm{O}_{20} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | Thomsonite | Orthorhombic |
| $\mathrm{Na}_{2} \mathrm{CaSi}_{20} \mathrm{Al}_{4} \mathrm{O}_{48} \cdot 14 \mathrm{H}_{2} \mathrm{O}(?)$ | Mordenite | Orthorhombic(?) |
| $\mathrm{Na}_{2} \mathrm{Si}_{3} \mathrm{Al}_{2} \mathrm{O}_{10} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | Natrolite | Orthorhombic |
| $\mathrm{NaSi}_{3} \mathrm{AlO}_{8} \cdot \mathrm{H}_{2} \mathrm{O}$ |  | Monoclinic |
| $\mathrm{CaSi}_{3} \mathrm{Al}_{2} \mathrm{O}_{10} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | Scolecite | Monoclinic |
| $\mathrm{Na}_{2} \mathrm{Ca}_{2} \mathrm{Si}_{9} \mathrm{Al}_{6} \mathrm{O}_{30} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | Mesolite | Monoclinic |
| $\mathrm{CaSi}_{4} \mathrm{Al}_{2} \mathrm{O}_{12} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ (?) | Laumontite | Monoclinic |
| $\mathrm{Ca}_{4} \mathrm{Si}_{8} \mathrm{Al}_{8} \mathrm{O}_{32} \cdot 12 \mathrm{H}_{2} \mathrm{O}(?)$ | Phillipsite | Monoclinic |
| $\mathrm{Ba}_{2} \mathrm{Si}_{11} \mathrm{Al}_{4} \mathrm{O}_{30} \cdot 10 \mathrm{H}_{2} \mathrm{O}(?)$ | Harmotome | Monoclinic |
| $\mathrm{CaSi}_{6} \mathrm{Al}_{2} \mathrm{O}_{16} \cdot 7 \mathrm{H}_{2} \mathrm{O}(?)$ | Stilbite | Monoclinic |
| $\mathrm{CaSi}_{6} \mathrm{Al}_{2} \mathrm{O}_{16} \cdot 5 \mathrm{H}_{2} \mathrm{O}(?)$ | Heulandite | Monoclinic |
| $\mathrm{CaSi}_{5} \mathrm{Al}_{2} \mathrm{O}_{14} \cdot 4 \mathrm{H}_{2} \mathrm{O}(?)$ | Epistilbite | Monoclinic |

[^149]$\mathrm{NaSi}_{2} \mathbf{A l O}_{6} \cdot \mathbf{H}_{2} \mathbf{O}$ (Analcite) is isometric with $a=13.68 \AA$. U.C. 16. Crystals often trapezohedral or more complex. Penetration twinning common. Very poor cubic cleavage. H. 5-5.5. G. 2.22-2.29. F. 2.5 to colorless glass. Gelatinizes with HCl . Isotropic with $n=$ usually 1.486 , but variable from 1.472 to 1.489 . But large crystals are often very weakly birefringent ${ }^{39}$ with complicated twinning and (-)2V $=$ small to large, mean index $n=1.487 \mathrm{Na}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.001$. Colorless. Made in a steel bomb or even a closed tube. Natural analcite often contains excess $\mathrm{SiO}_{2}$ and $\mathrm{H}_{2} \mathrm{O}$ and $\mathrm{Al}_{2} \mathrm{O}_{3}$; also minor $\mathrm{K}_{2} \mathrm{O}, \mathrm{CaO}$, etc. ${ }^{40}$ Its birefringence increases as it loses $\mathrm{H}_{2} \mathrm{O}$ when heated; ${ }^{40}$ for example, a crystal with $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.00032$ with total $\mathrm{H}_{2} \mathrm{O} 8.2$ per cent, has $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.00072$ after losing 3.6 per cent $\mathrm{H}_{2} \mathrm{O}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.00134$ after losing 6.3 per cent $\mathrm{H}_{2} \mathrm{O}$, and $n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.00212 after losing 8.0 per cent $\mathrm{H}_{2} \mathrm{O}$. But the birefringence decreases to zero ${ }^{41}$ if the mineral is heated to $200^{\circ}-250^{\circ} \mathrm{C}$. in water vapor. PD 3.43, 5.61 , 2.93; 7-363/4*. When heated in air until cloudy and then immersed in oil, analcite is triclinic with negative birefringence ${ }^{42}$ and so much like the hightemperature form of leucite that it has been called natronleucite. The Na of analcite can be replaced more or less by other elements; with ${ }^{11} \mathrm{~K}$ it has $n=1.490$; with K and loss of water to only $1.51 \mathrm{H}_{2} \mathrm{O}^{43}$ it becomes leucite with $n=1.51$; with $\mathrm{NH}_{4}$ and the same loss of water it becomes $\mathrm{NH}_{4}$ leucite with $n=1.524$; with Ag and no loss of water it has $a=13.7 \AA$ and $n=1.56$; with Rb and loss of water to $1.9 \mathrm{H}_{2} \mathrm{O}$ it has $n=1.51$; with Tl and loss of water to $0.5 \mathrm{H}_{2} \mathrm{O}$ it has $n=1.64$.
$\mathrm{Na}_{2} \mathrm{CaSi}_{10} \mathrm{Al}_{4} \mathrm{O}_{28} \cdot \mathbf{2 0 H}_{2} \mathrm{O}$ (?) (Faujasite) is isometric hexoctahedral ${ }^{44}$ with distinct $\{111\}$ cleavage. H. 5. G. 1.92. F. 3. Decomposed by acid. Isotropic with $n=1.48 \mathrm{ca}$. Loss of a little water changes it to uniaxial positive with $n=1.48 \mathrm{ca}$. and weak birefringence; the birefringence decreases on heating and at about $150^{\circ} \mathrm{C}$. (having lost $12 \mathrm{H}_{2} \mathrm{O}$ ) the substance is again isotropic. Further heating changes it to uniaxial negative. Upon cooling in damp air the water is taken up again and the optic changes are reversed. Colorless or white. PD 15.0, 3.75, 5.68; 2-0010. K-faujasite is said to have been made ${ }^{2}$ in octahedral crystals but the index ( $n=1.394$ ) is surprisingly low.
$\mathrm{KSiAlO}_{4} \cdot \mathbf{n H}_{2} \mathbf{O}$ has been called K-nepheline hydrate. ${ }^{45}$ It is uniaxial negative with $n_{\mathrm{O}}=1.5256, n_{\mathrm{O}}-n_{\mathrm{E}}=$ very weak. Colorless. Made hydrothermally. PD 2.56, 4.47, 3.32; 2-1019 (?).

[^150]$\mathrm{LiSi}_{4} \mathbf{A l O}_{10} \cdot \mathbf{2 . 5} \mathrm{H}_{2} \mathbf{O}$ is probably tetragonal, ${ }^{18}$ but has no visible birefringence. $n=1.480$. (Possibly a phyllosilicate.)
$\mathrm{Na}_{26} \mathrm{Si}_{22} \mathrm{Al}_{18} \mathbf{O}_{84} \cdot \mathbf{1 2} \mathbf{H}_{2} \mathbf{O}$ (?) is hexagonal ${ }^{46}$ with G. 2.36. Uniaxial negative with $n_{\mathrm{O}}=1.502, n_{\mathrm{E}}=1.495, n_{\mathrm{O}}-n_{\mathrm{E}}=0.007$. Colorless.
$\mathbf{N a}_{66} \mathbf{S i}_{42} \mathbf{A l}_{38} \mathbf{O}_{169} \cdot \mathbf{2 4 H _ { 2 }} \mathbf{O}$ (?) is hexagonal. ${ }^{46}$ Crystals six-sided basal plates. Mean index $n=1.498$. Birefringence about 0.022 . Closely resembles analcite. Colorless.
$\mathbf{N a S i}_{2} \mathbf{A l O}_{6} \cdot \mathbf{3 H}_{\mathbf{2}} \mathbf{O}$ (Gmelinite) varies in composition toward chabazite, CaAl replacing some $\mathrm{NaSi} ; \mathrm{K}$ may be present. Crystals hexagonal or rhombohedral with $c / a=1.017$ and vertical striations. Distinct rhombohedral cleavage and basal parting. H. 4.5. G. 2.04-2.17. F. 3 with intumescence. Decomposed by HCl. Usually biaxial, retaining external hexagonal forms by twinning on $\{110\}$ and $\{1 \overline{1} 0\}$ of a monoclinic (or triclinic?) structure, the "rhombohedral" cleavage actually being parallel to (001), (100) and (010). Some crystals strictly uniaxial; others are uniaxial in some parts and biaxial elsewhere. ( $\pm$ ) $2 \mathrm{~V}=$ small, $n_{\mathrm{X}}=1.464-1.479, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.465-1.480, n_{\mathrm{z}}-n_{\mathrm{X}}=0.001-0.009$, usually very weak. Gmelinite from Iceland ${ }^{47}$ has $(-) 2 \mathrm{~V}=0^{\circ}-30^{\circ}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.002$; dehydrated it has $(+) 2 \mathrm{~V}<10^{\circ}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.027$. Saturated with iodine it is pleochroic with $a$ clear brown, $c$ red-brown to opaque. Saturated with bromine it has $a$ nearly colorless, $c$ reddish yellow. Heated with boiling glycerine it becomes pleochroic with $a$ colorless, $c$ red-brown. Gmelinite can have Na replaced by K with loss of 4 per cent $\mathrm{H}_{2} \mathrm{O}$ and increase of density from 2.045 to 2.090 . The change can be reversed by immersion in NaCl solution. PD 4.10, 12.0, 2.96; 9-419.
$\mathrm{CaSi}_{4} \mathrm{Al}_{2} \mathrm{O}_{12} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ (?) (Chabazite) varies in composition toward gmelinite, NaSi (and KSi ) replacing some CaAl. Crystals hexagonal with $a=13.75, c=14.94 \AA$. U.C. 4. Often simple rhombohedrons resembling cubes since the rhombohedral angle is $88^{\circ} 14^{\prime}$. Distinct rhombohedral cleavage. H. 4-5. G. 2.08-2.16. F. 3 with intumescence. Decomposed by HCl . Crystals often biaxial, the external hexagonal form being retained by twinning of a monoclinic (or triclinic?) structure which has $a: b: c=$ $0.463: 1: 0.341, \beta=96^{\circ} 29^{\prime}$. ( $\pm$ ) $2 \mathrm{~V}=0^{\circ}-32^{\circ}, n_{\mathrm{X}}=1.478-1.485, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.480-1.490, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.002-0.010$, usually very weak. These variations may be due to variations in composition, the Ca-rich samples being positive and the Na-rich negative, but Rinne found ${ }^{42}$ that fully hydrated

[^151]chabazites are positive, slight heating changes them to negative, and further heating changes them back to the positive condition, but with strong birefringence. Made by heating in a closed tube with carbonated water at $200^{\circ}$ C. Colorless. PD 2.95, 4.35, 9.5; 10-370. Hydration is easily changed; base exchange also is easily produced; for example, with ${ }^{11}$ about a third of the Ca replaced by $\mathrm{Li}, n=1.48$; with 11 per cent of the CaO replaced by $\mathrm{Ag}_{2} \mathrm{O}, n=1.49$. However, Grandjean found ${ }^{47}$ that a sample of chabazite with its normal tenor of water had: $\mathrm{X}=c$, (-) $2 \mathrm{~V}=65^{\circ}$, mean index $n=1.49, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0014$; after driving out the water it had: $(+) 2 \mathrm{~V}<12^{\circ}, \mathrm{Z}=c, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0089$; when rehydrated the birefringence decreased and the optic sign changed again. Saturated with $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{O}$ it was ${ }^{43}$ uniaxial positive with a mean $n=1.487$ and $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.004$. Saturated with iodine at $300^{\circ} \mathrm{C}$. and cooled in a desiccator it was positive and nearly uniaxial with $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.009 \pm$ and X and Y pink, Z yellow. Saturated with calomel at $500^{\circ} \mathrm{C}$. and then cooled it had: $(-) 2 \mathrm{~V}=0^{\circ}$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.045$; the calomel shattered the crystals; saturated with Hg at $300^{\circ} \mathrm{C}$. and cooled in a desiccator it had (-) $2 \mathrm{~V}=74^{\circ}, n_{\mathrm{z}}-n_{\mathrm{X}}=0.028$ and $X$ very pale yellow, $Y$ dark yellow, $Z$ darker reddish yellow; by addition of water the birefringence decreased and the mineral darkened with X brown, Y dark brown, Z opaque. The mineral took up 35 per cent Hg and then 25 per cent $\mathrm{H}_{2} \mathrm{O}$; upon heating the water went off and then the Hg without destroying the crystal. Saturated with sulfur the mineral was negative with $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.036$. Chabazite after partial dehydration can take up $\mathrm{CS}_{2}$ which causes a great increase in birefringence with a change of the interference color from gray to higher order white. After partial dehydration it can take up $\mathrm{CO}_{2}$, which changes vibration directions and increases the birefringence. Similar results can be obtained with alcohol or chloroform or benzol. The birefringence of chabazite ${ }^{48}$ decreases to practically zero when the mineral is saturated with Na , but treatment with $\mathrm{AgNO}_{3}$ or $\mathrm{CuCl}_{2}$ produces almost no change in birefringence. Chabazite has been changed artificially ${ }^{49}$ to the pure $\mathrm{Na}-, \mathrm{K}-, \mathrm{Tl}-, \mathrm{NH}_{4}-, \mathrm{Cu}-, \mathrm{Ag}-$, $\mathrm{Ba}-\mathrm{Ca}$ or Mg - compounds, but optic data are lacking.
$\mathrm{CaSi}_{3} \mathrm{Al}_{2} \mathrm{O}_{10} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ (Levynite) is hexagonal with $c / a=0.836$. Crystals rhombohedral. H. 4-4.5. G. 2.09-2.16. Easily fusible. Uniaxial negative with $n_{\mathrm{O}}=1.496, n_{\mathrm{E}}=1.491, n_{\mathrm{O}}-n_{\mathrm{E}}=0.005$. It may be biaxial $(2 \mathrm{~V}=$ $0^{\circ}-30^{\circ}$, due to strain or inversion?) and then $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0075$; dehydrated and then saturated with ${ }^{49}$ dry air it has ( $+2 \mathrm{E}=85^{\circ}-120^{\circ}, n_{\mathrm{z}}-n_{\mathrm{X}}=$ 0.0075 and $n_{\mathrm{Y}}$ much less than before; saturated with Hg it is biaxial negative with $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.030$ and $a$ dark red-brown to opaque, $c$ yellow.

[^152]tion of 3.25 per cent $\mathrm{K}_{2} \mathrm{O}$ causes practically no change in optic properties, but increases ${ }^{\text {c }}$ the specific gravity from 2.373 to 2.381 . Introduction of 10.37 per cent $\mathrm{Ag}_{2} \mathrm{O}$ gives G. 2.52, and raises the indices from $n_{\mathrm{x}}=1.529$, $n_{\mathrm{Y}}=1.531, n_{\mathrm{Z}}=1.542, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.013$ to $n_{\mathrm{X}}=1.582, n_{\mathrm{Y}}=1.588$,


Fig. 10-16. Variations in optical properties of the thomsonite series. Data from Hey, Mineral. Mag. XXIII, p. 51 (1932).
$n_{\mathrm{Z}}=1.600, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.018$. Similarly, the introduction of 11.74 per cent $\mathrm{Tl}_{2} \mathrm{O}$ gives G. 2.595, $n_{\mathrm{X}}=1.568, n_{\mathrm{Y}}=1.574, n_{\mathrm{Z}}=1.585, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.017$. Heated until cloudy and then immersed in oil thomsonite is still orthorhombic usually with unchanged optic orientation and decreased birefringence,
but much heating may cause the optic plane to become normal to (001). Colorless.
$\mathrm{Na}_{2} \mathrm{CaSi}_{20} \mathrm{Al}_{4} \mathrm{O}_{48} \cdot \mathbf{1 4 H}_{\mathbf{2}} \mathrm{O}$ (?) (Mordenite) is orthorhombic(?) with $a=$ $18.25, b=20.35, c=7.50 \AA$. U.C. 2. The ratio of Ca to Na (and K) varies notably; the tenor of $\mathrm{H}_{2} \mathrm{O}$ and of $\mathrm{SiO}_{2}$ is also variable. Crystals prismatic, vertically striated. Perfect $\{100\}$ and good $\{010\}$ cleavages. H. 5. G. 2.1. F. 3-4 to clear glass. Insoluble in HCl. Optically seems to be monoclinic since $\mathrm{X} \wedge c=4^{\circ}$, but X-rays indicate orthorhombic symmetry. $\mathrm{Z}=b$. 2 V large, ${ }^{54}$ seeming to vary through $90^{\circ} . n_{\mathrm{X}}=1.471-1.478, n_{\mathrm{Y}}=1.477$ ca., $n_{\mathrm{Z}}=1.473-1.482, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.002-0.005$. Again:55 mean index $n=$ 1.467. Colorless, yellowish or pinkish. PD 3.48, 3.22, 9.10, 6-0239/40.
$\mathrm{Na}_{2} \mathrm{Si}_{3} \mathrm{Al}_{2} \mathbf{O}_{10} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ (Natrolite) is orthorhombic with $a=18.3, b=18.6$, $c=6.57 \AA$ A. U.C. 8. Crystals prismatic, vertically striated, pseudotetragonal, acicular to fibrous along $c$. Perfect $\{110\}$ cleavage and $\{010\}$ parting. H. 5-5.5. G. 2.25. F. 2. Gelatinizes with HCl. Y $=b ; \mathrm{Z}=c$. Negative relief distinct. ( + ) $2 \mathrm{~V}=60^{\circ}-63^{\circ}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{x}}=1.473-1.480, n_{\mathrm{Y}}=$ $1.476-1.482, n_{\mathrm{Z}}=1.485-1.493, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.011-0.013$. Colorless. PD 2.86, $5.90,4.38 ; 3-0705$. Natrolite heated until cloudy and then immersed in oil becomes monoclinic, ${ }^{42}\{001\}$ becoming $\{010\}$ and the former prism faces becoming $\{101\}$ and $\{\overline{1} 01\}$; optical properties not much changed but $\mathrm{X} \wedge c=7^{\circ}$ and $\mathrm{Z}=b$. It reverts easily to its former condition on cooling in moist air. Natrolite made by base exchange from scolecite, ${ }^{56}$ but still containing 5.38 CaO , has Z parallel with elongation and a mean index, $n=1.484$ with $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.01$. When a sample of natrolite having $n_{\mathrm{X}}=1.479, n_{\mathrm{Y}}=1.482, n_{\mathrm{Z}}=1.491, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.012$ has 6.38 per cent of $\mathrm{K}_{2} \mathrm{O}$ introduced artificially ${ }^{57}$ (base exchange) it has $n_{\mathrm{X}}=1.478, n_{\mathrm{Y}}=$ $1.481, n_{\mathrm{Z}}=1.488, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.010$; when it has $19.40 \mathrm{~K}_{2} \mathrm{O}$ introduced it has G. 2.365, $n_{\mathrm{X}}=1.480, n_{\mathrm{Y}}=1.483, n_{\mathrm{Z}}=1.490, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.010$. PD 7.0, 2.96, 3.09; 3-0062. With $6.55 \mathrm{Li}_{2} \mathrm{O}$ introduced it has G. 2.135,. $n_{\mathrm{X}}=1.489, n_{\mathrm{Y}}=1.492, n_{\mathrm{Z}}=1.501, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.012 ;$ when it has 14.39 $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{O}$ introduced it has G. 2.073, $\left(n_{\mathrm{X}}+n_{\mathrm{Y}}\right) \div 2=1.507, n_{\mathrm{Z}}=1.515$; when it has $41.23 \mathrm{Ag}_{2} \mathrm{O}$ introduced it has $\mathrm{G} .3 .09, \mathrm{X}=c, n_{\mathrm{X}}=1.577$, $\left(n_{\mathrm{Y}}+n_{\mathrm{Z}}\right) \div 2=1.585$; when it has $52.23 \mathrm{Tl}_{2} \mathrm{O}$ introduced it has G .3 .92 , $\left(n_{\mathrm{X}}+n_{\mathrm{Y}}\right) \div 2=1.620, n_{\mathrm{Z}}=1.629$. PD 3.01, $4.90,4.43 ; 2-0636 . \mathrm{K}, \mathrm{Li}$ and Ag natrolite have been made also from mesolite.
$\mathrm{NaSi}_{3} \mathrm{AlO}_{8} \cdot \mathbf{H}_{2} \mathbf{O}(?)$ is monoclinic with ${ }^{50} a=8.10, b=6.10, c=4.88 \AA$, $\beta=105^{\circ} 20^{\prime}$. Crystals six-sided tablets. Perfect basal cleavage. (+)2V = ?,

[^153]mean $n=1.49, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ weak. X-ray pattern not like that of ussingite.
$\mathrm{CaSi}_{3} \mathrm{Al}_{2} \mathbf{O}_{10} \cdot \mathbf{3 H} \mathbf{H} \mathbf{O}$ (Scolecite) is monoclinic with $a=18.48, b=18.95$, $c=6.54 \AA$. $\beta=90^{\circ} 42^{\prime}$. U.C. 8. Crystals slender prismatic, vertically striated, often in fibrous masses. Good $\{110\}$ cleavage. H. 5. G. 2.3. F. 2, curling into wormlike forms (whence the name). Gelatinizes with HCl . $\mathrm{X} \wedge c=15^{\circ}-18^{\circ}$ in obtuse $\beta ; \mathrm{Z}=b$. (-) $2 \mathrm{~V}=36^{\circ} c a ., \mathrm{r}<\mathrm{v}$ distinct. $n_{\mathrm{X}}=1.5122, n_{\mathrm{Y}}=1.5187, n_{\mathrm{Z}}=1.5194, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0083$. Colorless. Made by heating constituents in a closed tube at $150^{\circ} \mathrm{C}$. Scolecite inverts at about $200^{\circ}$ to $250^{\circ} \mathrm{C}$. with a loss of one third of its water to a phase called metascolecite ${ }^{58}$ which has X normal to (010) ( $=$ (100) of scolecite) and $\mathrm{Y} \wedge c=18^{\circ},(-) 2 \mathrm{~V}=65^{\circ}, \mathrm{r}<\mathrm{v}$, mean index $n=1.523, n_{\mathrm{z}}-n_{\mathrm{X}}=$ very weak. But this phase may take on as much water ${ }^{56}$ as scolecite and then $\mathrm{Y} \wedge c=18^{\circ}$, the mean index $n=1.505, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.01 c a$. Scolecite loses all the rest of its water between $335^{\circ}$ and $345^{\circ} \mathrm{C}$. irreversibly; it then has $\mathrm{Z} \wedge c=85^{\circ}-88^{\circ}$, (-) $2 \mathrm{~V}=65^{\circ}, \mathrm{r}<\mathrm{v}, n_{\mathrm{Y}}=1.541$ and very weak birefringence. The crystal structure breaks down at about $550^{\circ} \mathrm{C}$. When Ag replaces Ca (at least to some extent) $\mathrm{X} \wedge$ elongation $=1^{\circ}-5^{\circ}$; mean index $n=1.525-1.54, n_{\mathrm{z}}-n_{\mathrm{X}}=0.01$. When Tl replaces Ca the extinction on the cleavage is $12^{\circ}$ with negative elongation and a mean index $n=1.53$.
$\mathbf{N a}_{2} \mathrm{Ca}_{2} \mathrm{Si}_{9} \mathrm{Al}_{6} \mathbf{O}_{30} \cdot \mathbf{8} \mathbf{H}_{2} \mathbf{O}$ (Mesolite) is monoclinic with $a=56.7, b=$ 6.54, $c=18.44 \AA, \beta=90^{\circ} 0^{\prime} \pm 20^{\prime}$. U.C. 8. Crystals often fibers along $b$. Perfect $\{301\}$ and $\{\overline{3} 01\}$ cleavages. H. 5. G. 2.27. F. easy, to vermicular forms. Gelatinizes with $\mathrm{HCl} . \mathrm{X} \wedge c=8^{\circ}, \mathrm{Y}=b$ ( $=$ elongation). ( + ) 2 V $=$ about $85^{\circ}$ at $15^{\circ} \mathrm{C}$., with $\mathrm{r}<\mathrm{v}$ strong, but the optic angle increases rapidly on heating, becoming $90^{\circ}$ at $20^{\circ} \mathrm{C}$. and negative above $20^{\circ}$; then measured about X it decreases rapidly becoming $0^{\circ}$ at $59^{\circ} \mathrm{C}$.; above $59^{\circ} \mathrm{C}$. the optic plane is nearly parallel with 001 . PD $2.85,3.19,6.61 ; 3-0711$. Mesolite loses half its water (reversibly) at about $250^{\circ} \mathrm{C}$.; and the remainder (irreversibly) at about $350^{\circ} \mathrm{C}$. : it is then called metamesolite and has its optic plane parallel with the elongation, while a negative acute bisectrix is nearly normal to one of the cleavages; the crystal structure breaks down at about $670^{\circ} \mathrm{C}$. At ordinary temperature $n_{\mathrm{X}}=1.5048$, $n_{\mathrm{Y}}=1.5050, n_{\mathrm{Z}}=1.5053, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0005$ (Görgey). ${ }^{59}$ Again: ${ }^{60} n_{\mathrm{X}}=$ $1.5073, n_{\mathrm{Y}}=1.5074, n_{\mathrm{Z}}=1.5075, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0002 \mathrm{Na}$. Mesolite when treated with ${ }^{60} \mathrm{~K}$-solution changes to K -natrolite with positive elongation and $n_{\mathrm{Y}}=1.483$; when treated with $\mathrm{LiNO}_{3}$ solution it becomes Li-natrolite with positive elongation, $n_{\mathrm{Y}}=1.491$ and $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.013$; when treated with $\mathrm{AgNO}_{3}$ solution it becomes Ag -natrolite with negative elongation,

[^154]$n_{\mathrm{Y}}=1.552$, and $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.002$. But it is also possible to produce base exchange ${ }^{60}$ in mesolite without causing a change to natrolite; thus by replacing one third of the Ca with Na the crystal has G .2 .22 (?), positive elongation, $n_{\mathrm{Y}}=1.499$ and $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.004$. By introducing 6.37 per cent $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{O}$ the crystal has G. 2.144, positive elongation, $n_{\mathrm{Y}}=1.511, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=$ weak. By introducing 20.86 per cent $\mathrm{Ag}_{2} \mathrm{O}$ the crystal has G. 2.63-, negative elongation, $n_{\mathrm{Y}}=1.542$ and $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.004$. By introducing 42.75 per cent $\mathrm{Tl}_{2} \mathrm{O}$ the crystal has G. $2.35 \pm$, positive elongation, $n_{\mathrm{Y}}=$ 1.588 and $n_{\mathrm{z}}-n_{\mathrm{X}}=$ very weak.
$\mathrm{CaSi}_{4} \mathrm{Al}_{2} \mathrm{O}_{12} \cdot \mathbf{4 H _ { 2 }} \mathbf{O}$ (?) (Laumontite) is monoclinic with $a=14.90, b=$ 13.12, $c=7.55 \AA, \beta=111^{\circ} 30^{\prime}$. U.C. 12. NaSi (and KSi ) can replace CaAl ta a limited extent. Apparently Ca may also be replaced in part by $\mathrm{Na}_{2}$ (or $\mathrm{K}_{2}$ ). Crystals prismatic resembling pyroxene. Twinning on $\{100\}$. Perfect $\{010\}$ and $\{110\}$ cleavages. H. 3-4. G. 2.23-2.41. F. 2.5 with swelling. Gelatinizes with $\mathrm{HCl} . \mathrm{Y}=b ; \mathrm{Z} \wedge c=8^{\circ}-11^{\circ}$ in acute $\beta$. ( -2 V $=33^{\circ}-47^{\circ}, \mathrm{r}<\mathrm{v}$ distinct, and ${ }^{61}$ weak inclined dispersion. $n_{\mathrm{x}}=1.509-$ $1.514, n_{\mathrm{Y}}=1.518-1.522, n_{\mathrm{Z}}=1.521-1.525, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.010-0.012$. Colorless (or tinted by ferric iron). Laumontite may easily lose about one eighth of its water, often then falling to a powder; it has been called then leonhardite (or caporcianite) and has $a=14.75, b=11.10, c=7.55 \AA$, $\beta=112^{\circ}$. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=8^{\circ}-35^{\circ} ;(-) 2 \mathrm{~V}=26^{\circ} 44^{\prime}, \mathrm{r}<\mathrm{v} ; n_{\mathrm{X}}=1.502-$ $1.507, n_{\mathrm{Y}}=1.512-1.516, n_{\mathrm{Z}}=1.514-1.518, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.011-0.012$. The reverse change is also easily accomplished.
$\mathrm{Ca}_{4} \mathrm{Si}_{8} \mathrm{Al}_{8} \mathrm{O}_{32} \cdot \mathbf{1 2 \mathrm { H } _ { 2 } \mathrm { O } \text { (?) (Phillipsite) is monoclinic prismatic with } a =}$ $10.00, b=14.25, c=8.62 \AA . \beta=125^{\circ} 40^{\prime}$. U.C. 1 . It commonly contains KSi (and NaSi ) replacing some CaAl ; Ba may also be present. Crystals often penetration twins resembling orthorhombic or tetragonal forms, long parallel $c$. Distinct $\{001\}$ and $\{010\}$ cleavages. H. 4-4.5. G. 2.2. F. 3 to white enamel. Gelatinizes with $\mathrm{HCl} . \mathrm{X}=b ; \mathrm{Z} \wedge c=11^{\circ}-30^{\circ}$ in acute $\beta$. $(+) 2 \mathrm{~V}=60^{\circ}$ to $80^{\circ}$ (or more?), $\mathrm{r}<\mathrm{v}$ weak. Indices vary; apparently the most siliceous crystals have the lowest indices with $n=$ about 1.48 and $\mathrm{Z} \wedge c$ about $10^{\circ}$ while the least siliceous samples have $n$ about 1.51 and $\mathrm{Z} \wedge c$ about $30^{\circ}$. A sample from Honolulu has $n_{\mathrm{X}}=1.493, n_{\mathrm{Y}}=1.497$, $n_{\mathrm{Z}}=1.500, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.007$. PD 7.64, 6.91, 3.18; 2-0084. A crystal ${ }^{62}$ with $5.5 \mathrm{CaO}, 5.7 \mathrm{Na}_{2} \mathrm{O}$ and $5.5 \mathrm{~K}_{2} \mathrm{O}$ may be changed by immersion in 2.5 per cent KCl for 24 hours at $180^{\circ} \mathrm{C}$. to contain $5.7 \mathrm{Na}_{2} \mathrm{O}$ and $12.3 \mathrm{~K}_{2} \mathrm{O}$; this causes no noticeable change in birefringence or extinction angle but lowers the indices about 0.003 . Another sample ${ }^{42}$ heated until cloudy and then immersed in oil has its extinction angle ( $\mathrm{Z} \wedge c$ ) reduced from $19^{\circ}$ to $9^{\circ}$; in moist air the change is not reversed; on further heating the birefringence

[^155]decreases distinctly, $X$ and $Z$ change places, the extinction angle ( $X \wedge c$ ) rises to $17^{\circ}$ in acute angle $\beta$, the optic sign becomes negative and the optic angle changes to almost zero.
$\mathrm{Ba}_{2} \mathrm{Si}_{11} \mathrm{Al}_{4} \mathrm{O}_{38} \cdot \mathbf{1 0} \mathrm{H}_{2} \mathrm{O}$ (?) (Harmotome) is monoclinic prismatic with ${ }^{63}$ $a=9.80, b=14.10, c=8.66 \AA, \beta=124^{\circ} 50^{\prime}$. U.C. 1. It may contain some $\mathrm{K}, \mathrm{Na}, \mathrm{Ca}$. Crystals like those of phillipsite, elongated along $c$. Distinct $\{010\}$ and poor $\{001\}$ cleavages. H. 4.5. G. 2.44-2.50. F. 3 to white glass. Decomposed by HCl. $\mathrm{X} \wedge c=58^{\circ}$ in obtuse $\beta ; \mathrm{Z}=b$. ( + ) $2 \mathrm{~V}=79^{\circ}$, $n_{\mathrm{X}}=1.503, n_{\mathrm{Y}}=1.505, n_{\mathrm{Z}}=1.508, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.005$. Colorless. PD 8.24, $7.17,6.26 ; 9-480$. On heating the extinction angle increases (to $82^{\circ}$ at $130^{\circ}$ C.). The optic angle decreases on heating, ${ }^{42}$ becoming $32^{\circ}$ at $730^{\circ} \mathrm{C}$. (Heat due to grinding in making a thin section may reduce 2 V to $32^{\circ}$.) Further heating to $400^{\circ} \mathrm{C}$. and then cooling in a desiccator changes the optic angle to $(-) 2 \mathrm{~V}=50^{\circ}$ ca., the optic plane to ( 010 ), the birefringence to 0.026 , and lowers the refringence; upon rehydration the changes are (about) reversed. If saturated with mercury vapor and then cooled the mineral can scarcely be distinguished from the dehydrated condition, but if exposed to moisture the mercury changes its state, the mineral darkens and becomes pleochroic with $a$ and $c$ blue-black or purple and $b$ clear gray, yellow or colorless. Harmotome heated until cloudy and then immersed in oil ${ }^{32}$ has its optic plane changed in position, so that $\mathrm{X} \wedge a=23^{\circ} c a$. and also has its birefringence much increased; in this condition it is said to be triclinic.
$\mathrm{CaSi}_{6} \mathrm{Al}_{2} \mathrm{O}_{16} \cdot \mathbf{7 \mathrm { H } _ { 2 } \mathrm { O } ( ? )}$ (Stilbite) is monoclinic prismatic with $a=13.60$, $b=18.13, c=11.29 \AA, \beta=129^{\circ} 10^{\prime}$. U.C. 4. Usually contains some NaSi in place of CaAl (and $\mathrm{Na}_{2}$ in place of Ca ?). Crystals twinned as crosses on $\{100\}$ to pseudorhombic forms. Perfect $\{010\}$ and poor $\{100\}$ cleavages. H. 3.5-4. G. 2.09-2.20. F. 3 with exfoliation to white enamel. Decomposed by HCl. $\mathrm{X} \wedge c=5^{\circ}\left(3^{\circ}-12^{\circ}\right)$ in acute $\beta ; \mathrm{Y}=b$. ( -$) 2 \mathrm{~V}=30^{\circ}-50^{\circ}$, $n_{\mathrm{X}}=1.484-1.492, n_{\mathrm{Y}}=1.493-1.498, n_{\mathrm{Z}}=1.495-1.501, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.009-$ 0.011 . Colorless. PD 4.08, 9.1, 4.68; 10-433. Heated until cloudy and then immersed in oil it becomes orthorhombic with $\{100\}$ as the optic plane ${ }^{64}$ and $Z=c$, but this is accomplished only after a long series of changes, as follows: normal stilbite has $\mathrm{X} \wedge c=-5^{\circ}$, and ( - ) $2 \mathrm{~V}=30^{\circ} c a$. After heating to $125^{\circ} \mathrm{C}$. it has about $5 \mathrm{H}_{2} \mathrm{O}$, and the extinction angle and optic angle are both about $0^{\circ}$; by further loss of water on heating, $X \wedge c$ gradually increases to about $+5^{\circ}$ and the optic angle gradually opens in a plane

[^156]normal to $\{010\}$, passes $90^{\circ}$ with change of sign and becomes $0^{\circ}$ about $\mathrm{Z}(=b)$ with $\mathrm{X}=c$ at about $150^{\circ} \mathrm{C}$. with about $4 \mathrm{H}_{2} \mathrm{O}$. By further loss of water on heating, Y (formerly X ) gradually moves from $c$ to $\mathrm{Y} \wedge$ $c=3^{\circ}-7^{\circ}$, the optic angle opens about $\mathrm{Z}(=b)$ in a plane normal to $\{010\}$, passes $90^{\circ}$ with a second change of sign and becomes $0^{\circ}$ about $\mathrm{X}(=a)$ at about $185^{\circ} \mathrm{C}$. with about $3 \mathrm{H}_{2} \mathrm{O}$. By further heating, Z (formerly Y ) moves toward $c$ until $\mathrm{Z} \wedge c=0^{\circ}$, the optic angle opens about X (which is in the obtuse angle $\beta$ at $83^{\circ}-87^{\circ}$ with $c$ ) in (010), passes $90^{\circ}$ with a third change of sign and becomes $0^{\circ}$ about $\mathrm{Z}(=c)$. This is the fourth uniaxial condition; it occurs at about $250^{\circ} \mathrm{C}$. with about $2 \mathrm{H}_{2} \mathrm{O}$. The mineral is now orthorhombic. With further heating the birefringence gradually decreases; with about $1 \mathrm{H}_{2} \mathrm{O}$ at about $350^{\circ} \mathrm{C}$. the mineral is still orthorhombic; with further heating it becomes microscopically isotropic. All these changes can be produced by dehydration in $\mathrm{H}_{2} \mathrm{SO}_{4}$ without heating. After complete dehydration the process is not reversible. Stilbite can be changed artificially ${ }^{48}$ by base exchange into pure $\mathrm{Ca}-, \mathrm{Na}-, \mathrm{K}^{-}, \mathrm{NH}_{4}-, \mathrm{Ba}-$, Ag -, or Cu -stilbite. Optic data on these are lacking, but after immersion in KCl solution for 24 hours at $180^{\circ} \mathrm{C}$. (probably leading to K-stilbite) it has: ${ }^{62} \mathrm{X} \wedge c=6^{\circ}$, $n_{\mathrm{X}}=1.478, n_{\mathrm{Y}}=1.481, n_{\mathrm{Z}}=1.483, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.005 . \mathrm{NH}_{4}$-stilbite is nearly isotropic with an extinction angle near zero. Ag-stilbite has weakened birefringence. Na-stilbite has birefringence about the same as Ca stilbite. Cu-stilbite is bluish green.
$\mathrm{CaSi}_{6} \mathrm{Al}_{2} \mathrm{O}_{16} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ (?) (Heulandite) is monoclinic prismatic with $a=$ 7.45, $b=17.80, c=15.85 \AA, \beta=91^{\circ} 26^{\prime}$; U.C. 4. Usually contains some NaSi replacing CaAl (and also $\mathrm{Na}_{2}$ replacing Ca secondary?); also may contain some Sr. Crystals $\{010\}$ tablets or equant. Perfect $\{010\}$ cleavage. H. 3.5-4. G. 2.2. F. 2, after swelling to vermicular forms. $\mathrm{X} \wedge c=68^{\circ}-82^{\circ}$ (also reported as $35^{\circ}$ ca.; ${ }^{65}$ also $\mathrm{X} \wedge a$ is reported ${ }^{66}$ as variable from $+89^{\circ}$ through $0^{\circ}$ to $-86^{\circ}$ in different sectors and in different crystals); $\mathrm{Z}=b$. $(+) 2 \mathrm{~V}=32^{\circ}$ ca., $\mathrm{r}>\mathrm{v}$, with distinct crossed dispersion. $n_{\mathrm{x}}=1.496-$ $1.498, n_{\mathrm{Y}}=1.497-1.499, n_{\mathrm{Z}}=1.501-1.505, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.005-0.007, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.005 .{ }^{67}$ When rich in silica $\left(\mathrm{SiO}_{2}=61.83\right): n_{\mathrm{X}}$ and $n_{\mathrm{Y}}=1.487-1.488$, $n_{\mathrm{Z}}=1.488-1.489, n_{\mathrm{z}}-n_{\mathrm{X}}=0.001$. Colorless. Made by heating the constituents at $170^{\circ} \mathrm{C}$. in carbonated water ${ }^{68}$ in a closed tube. Digestion in a KCl solution for a week produces K -heulandite ( Ca replaced by K ); in the same way $\mathrm{NH}_{4}-$, Na -heulandite, etc., can be produced-but optic data are lacking. Heating a sample from Iceland reduced the optic angle to $0^{\circ}$ at $80^{\circ} \mathrm{C}$. with about $5 \mathrm{H}_{2} \mathrm{O}$; then X and Y change places and the optic angle

[^157]increases from $0^{\circ}$ to $90^{\circ}$ and then (with change of sign) decreases again to $0^{\circ}$ at about $180^{\circ} \mathrm{C}$.; meanwhile the extinction angle decreases to $0^{\circ}$ at about $150^{\circ} \mathrm{C}$. with about $4 \mathrm{H}_{2} \mathrm{O}$ and the mineral is orthorhombic; then Y and Z change places and the optic angle increases to pass through $90^{\circ}$ once more and become uniaxial positive at about $280^{\circ} \mathrm{C}$. with about $2 \mathrm{H}_{2} \mathrm{O}$. With further heating the optic plane changes position again. Above $350^{\circ} \mathrm{C}$. a second orthorhombic form exists with weaker birefringence. Studying another sample from Iceland Slawson ${ }^{69}$ concluded that the mineral is always biaxial but seems to be uniaxial in some cases because the optic plane rotates through the position of the black cross. The relations between temperature, optic angle and rotation of the optic plane from the position at ordinary temperature are about as follows, as derived from Slawson's curves:

| Temp. C. | 2 E | Rotation |
| :---: | :---: | :---: |
| $25^{\circ}$ | $74^{\circ} 38^{\prime}$ | $0^{\circ}$ |
| $100^{\circ}$ | $80^{\circ}$ | $10^{\circ}$ |
| $150^{\circ}$ | $66^{\circ}$ | $13^{\circ}$ |
| $200^{\circ}$ | $34^{\circ}$ | $45^{\circ}$ |
| $250^{\circ}$ | $61^{\circ}$ | $96^{\circ}$ |
| $300^{\circ}$ | $120^{\circ}$ | $114^{\circ}$ |

Gaubert found that the optic properties are influenced by three different factors, ${ }^{70}$ namely, "optic anomalies" (probably due to variations in composition), temperature, and tenor of water. Change in temperature from $0^{\circ}$ to $109^{\circ}$ without change in tenor of water causes a rotation of the optic plane with increase in the optic angle. Loss of water without change of temperature causes a decrease of the optic angle, the mineral becoming uniaxial with a loss of 1.8 per cent $\mathrm{H}_{2} \mathrm{O}\left(=\frac{1}{2} \mathrm{H}_{2} \mathrm{O}\right.$ in the formula); with a loss of 2.2 per cent $\mathrm{H}_{2} \mathrm{O}$ the optic angle is about $20^{\circ}$ in a plane normal to the original condition; with a loss of 3 per cent $\mathrm{H}_{2} \mathrm{O}$ the optic angle is very large in a new plane. Heulandite at $230^{\circ} \mathrm{C}$. has indices as follows: $n_{\mathrm{x}}=$ $1.4651, n_{\mathrm{Y}}=1.4733, n_{\mathrm{Z}}=1.4747, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0096$. At $-79^{\circ} \mathrm{C}$. the optic angle is nearly $0^{\circ}$ and the optic plane is nearly parallel with 001 . Heulandite heated in boiling glycerine and then plunged into methylene iodide has $7^{71}$ G. $2.19,(+) 2 \mathrm{~V}=45^{\circ} 56^{\prime}, n_{\mathrm{X}}=1.5004, n_{\mathrm{Y}}=1.5015$, $n_{\mathrm{Z}}=1.5078, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0074$. Heated in the same way and plunged into acetylene tetrabromide it has G. 2.16, $n_{\mathrm{X}}=1.4994, n_{\mathrm{Y}}=1.5009$, $n_{\mathrm{Z}}=1.5071, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0077, \therefore(-) 2 \mathrm{~V}=52^{\circ}$, calc.
${ }^{69}$ Slawson: Am. Min. X, p. 305 (1925).
${ }^{70}$ Gaubert: C. R. Acad. Sci. Paris CLXXXVII, p. 1057 (1928); ibid., CXC, p. 802 (1930); Wyart: ibid., CXCI, p. 1343 (1930); also Bull. Soc. Fr. Min. LII, p. 162 (1929).
${ }^{71}$ Gaubert: Bull. Soc. Fr. Min. XXX, p. 104 (1907).
$\mathrm{CaSi}_{5} \mathrm{Al}_{2} \mathrm{O}_{14} \cdot 4 \mathbf{H}_{2} \mathbf{O}(?)$ (Epistilbite) is monoclinic with $a: b: c=$ $0.4194: 1: 0.2881, \beta=90^{\circ} 40^{\prime}$. Usually contains some NaSi replacing CaAl ; it is closely related to heulandite but not the same. Crystals prismatic with common twinning. Perfect $\{010\}$ cleavage. H. 4. G. 2.25. F. 5 with intumescence. Decomposed by $\mathrm{HCl} . \mathrm{Y}=b ; \mathrm{Z} \wedge c=10^{\circ}$ in acute $\beta$. $(+) 2 \mathrm{~V}=44^{\circ}, \mathrm{r}<$ v marked. $n_{\mathrm{X}}{ }^{52}=1.505, n_{\mathrm{Y}}=1.515, n_{\mathrm{Z}}=1.519, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.014$. Colorless. When heated until cloudy and then immersed in oil, ${ }^{42}$ it becomes orthorhombic with $\mathrm{X}=b$ and $\mathrm{Y}=a$; in an intermediate condition it must be uniaxial. Upon reabsorption of water it reverts to its original condition.
$\mathbf{A l}(\mathbf{O H})_{2} \mathbf{S i A l O}_{4}$ is only a sample of the possible ratios of $\mathrm{Al}_{2} \mathrm{O}_{3} \cdot \mathrm{SiO}_{2}$ and $\mathrm{H}_{2} \mathrm{O}$ in alumina-silica hydrogels. Such gels are apparently amorphous ${ }^{71 \mathrm{a}}$ and isotropic. After ignition $n=1.48$ to 1.68 increasing with increase in alumina; thus, if $\mathrm{Al}_{2} \mathrm{O}_{3}: \mathrm{SiO}_{2}=0: 1, n=1.48-1.485$; if the ratio is $1: 6.5$, $n=1.48-1.49$; if it is $1: 4.3, n=1.495-1.505$; if $1: 2.8, n=1.520-1.535$; if $1: 1.9, n=1.535-1.545$; if $1: 0.9, n=1.58-1.595$; if $1: 0, n=1.68$. The determination of the refractive index of the colloidal constituent of clay might be used to determine whether the alumina is present as a hydrate or as a silicate.

## Sodalite Group

The sodalite group includes four minerals which are tectosilicates of aluminum and sodium with some $\mathrm{NaCl}, \mathrm{NaOH}, \mathrm{NaS}_{2}, \mathrm{Na}_{2} \mathrm{SO}_{4}$ or $\mathrm{CaSO}_{4}$. They are isometric with rather complicated formulas as follows:

| $6 \mathrm{NaSiAlO}_{4} \cdot 2 \mathrm{NaCl}$ | or | $\mathrm{Na}_{4} \mathrm{ClSi}_{3} \mathrm{Al}_{3} \mathrm{O}_{12}$ | Sodalite |
| :--- | :--- | :--- | :--- |
| $6 \mathrm{NaSiAlO}_{4} \cdot 2 \mathrm{NaOH}$ | or | $\mathrm{Na}_{4}(\mathrm{OH}) \mathrm{Si}_{3} \mathrm{Al}_{3} \mathrm{O}_{12}$ | OH-Sodalite |
| $6 \mathrm{NaSiAlO}_{4} \cdot 2 \mathrm{NaS}_{2}$ | or | $\mathrm{Na}_{4} \mathrm{~S}_{2} \mathrm{Si}_{3} \mathrm{Al}_{3} \mathrm{O}_{12}$ | Lazurite |
| $6 \mathrm{NaSiAlO}_{4} \cdot 2 \mathrm{CaSO}_{4}$ | or | $\mathrm{Na}_{3} \mathrm{CaSO}_{4} \mathrm{Si}_{3} \mathrm{Al}_{3} \mathrm{O}_{12}$ | Hauynite |
| $6 \mathrm{NaSiAlO}_{4} \cdot \mathrm{Na}_{2} \mathrm{SO}_{4}$ | or | $\mathrm{Na}_{8} \mathrm{SO}_{4} \mathrm{Si}_{6} \mathrm{Al}_{6} \mathrm{O}_{24}$ | Noselite |

$\mathbf{N a}_{4} \mathbf{C l S i}_{3} \mathrm{Al}_{3} \mathbf{O}_{12}$ (Sodalite) is isometric with $a=8.87 \AA$. U.C. 2. Crystals dodecahedral; often granular. Poor $\{110\}$ cleavage. H. 5.5-6. G. 2.35. F. 3.5-4.0 to colorless glass. Gelatinizes even in acetic acid. Isotropic with $n=1.483$ (to 1.488 ). A Bolivian sample ${ }^{72}$ had $n=1.4806 \mathrm{Li}, 1.4837 \mathrm{Na}$, 1.4868 Tl . Rarely birefringent about inclusions. Colorless, gray, yellow, blue, greenish, pale red. In thin flakes colorless, yellow, blue or pink. Some samples are pink when freshly broken, fading quickly on exposure to light. Some sodalite fluoresces in ultraviolet light. Made ${ }^{73}$ by heating
${ }^{71 \mathrm{a}}$ Šplíchal: Min. Abst. I, p. 288 (1922).
${ }^{72}$ Brendler: Am. Min. XIX, p. 28 (1934.)
${ }^{73}$ Friedel and Friedel: Bull. Soc. Fr. Min. XIII, p. 129 (1890). See also Medved: J. Chem. Phys. XXI, p. 1309 (1953).
muscovite with soda and NaCl to $500^{\circ}$ C. PD 3.63, 2.08, 6.3; 3-0338. $\mathrm{Na}_{4} \mathrm{OHSi}_{3} \mathrm{Al}_{3} \mathrm{O}_{12}$ (OH-Sodalite) is isometric with $a=8.77-8.90 \AA$. Isotropic with $n=1.495$.
$\mathbf{N a}_{4} \mathbf{S S i}_{3} \mathrm{Al}_{3} \mathbf{O}_{12}$ (Lazurite) is isometric with $a=9.11 \AA$. U.C. 2. Often in dodecahedrons or cubes. The tenor of $S$ is variable. Ca may also be present. The Na can be replaced by ${ }^{74} \mathrm{~K}, \mathrm{NH}_{4}, \mathrm{Rb}, \mathrm{Cs}, \mathrm{Ag}, \mathrm{Mg}, \mathrm{Ca}, \mathrm{Sr}, \mathrm{Ba}, \mathrm{Zn}$, methyl, ethyl or butyl, but optic data are lacking. Poor $\{110\}$ cleavage. H. 5-5.5. G. 2.38-2.45. Isotropic with $n=1.500$. Color rich Berlin blue or azure blue or greenish blue or violet blue. The richly colored varieties are highly prized. Made abundantly for use in "ultramarine" paint.
$\mathrm{Na}_{3} \mathrm{CaSO}_{4} \mathrm{Si}_{3} \mathrm{Al}_{3} \mathrm{O}_{12}$ (Hauynite) is isometric with $a=9.10$. U.C. 6. Crystals often twinned; also dodecahedral, etc. Rather distinct $\{110\}$ cleavage. H. 5.5-6. G. 2.4-2.5. Isotropic with $n=1.4961$. Color blue, green, red, yellow. Made by heating muscovite with soda and $\mathrm{CaSO}_{4}$ to $500^{\circ} \mathrm{C}$. PD 3.72, 2.63, 6.45; 2-0331.
$\mathbf{N a}_{8} \mathbf{S O}_{4} \mathbf{S i}_{6} \mathrm{Al}_{6} \mathbf{O}_{24}$ (Noselite or Nosean) is isometric with $a=9.05 \AA$. Crystals often dodecahedral; often granular. H. 5.5. G. 2.3-2.4. Gelatinizes easily with acids. Isotropic with $n=1.486-1.494$; rarely birefringent (due to strain?). Colorless, white, gray, blue, brown, red or black from inclusions or alteration products. PD 3.69, 2.61, 2.13; 2-0339.
$\mathbf{N a}_{8}\left(\mathbf{W O}_{4}\right) \mathbf{S i}_{6} \mathbf{A l}_{6} \mathbf{O}_{24}$ ( $\mathbf{W O}_{4}$-Nosean) is isometric ${ }^{74 \mathrm{a}}$ with $a=9.16 \mathrm{kX}$. Crystals cubo-octahedral. Isotropic with $n=1.490$. Colorless. Made by crystallization between $800^{\circ}$ and $1000^{\circ} \mathrm{C}$.

## Scapolite Group

The scapolite group includes a main series of tectosilicates of aluminum and sodium or calcium with NaCl or $\mathrm{CaCO}_{3}$ but NaCl may be replaced at least in part by $\mathrm{NaF}, \mathrm{KCl},\left(\mathrm{KOH}\right.$ ?), $\mathrm{NaHCO}_{3}$ or $\mathrm{NaHSO}_{4}$ while $\mathrm{CaCO}_{3}$ may be replaced in part by $\mathrm{CaSO}_{4}, \mathrm{MgCO}_{3}, \mathrm{CaCl}_{2}$ or perhaps $\mathrm{CaF}_{2}$. The chief compounds are:

| $3 \mathrm{NaSi}_{3} \mathrm{AlO}_{8} \cdot \mathrm{NaCl}$ | or | $\mathrm{Na}_{4} \mathrm{ClSi}_{9} \mathrm{Al}_{3} \mathrm{O}_{24}$ | Marialite |
| :--- | :--- | :--- | :--- |
| $3 \mathrm{CaSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8} \cdot \mathrm{CaCO}_{3}$ | or | $\mathrm{Ca}_{4} \mathrm{CO}_{3} \mathrm{Si}_{6} \mathrm{Al}_{6} \mathrm{O}_{24}$ | Meionite |

Scapolite is sometimes called wernerite and the marialite-meionite series is divided as follows:

| Marialite | $\mathrm{Ma}_{100} \mathrm{Me}_{0}$ | to | $\mathrm{Ma}_{80} \mathrm{Me}_{20}$ | $c / a=0.446$ |
| :--- | :--- | :--- | :--- | :--- |
| Dipyre | $\mathrm{Ma}_{80} \mathrm{Me}_{20}$ | to | $\mathrm{Ma}_{50} \mathrm{Me}_{50}$ | $c / a=0.444$ |
| Mizzonite | $\mathrm{Ma}_{50} \mathrm{Me}_{50}$ to | $\mathrm{Ma}_{20} \mathrm{Me}_{80}$ | $c / a=0.442$ |  |
| Meionite | $\mathrm{Ma}_{20} \mathrm{Me}_{80}$ to | $\mathrm{Ma}_{0} \mathrm{Me}_{100}$ | $c / a=0.439$ |  |

[^158]$\mathbf{N a} \mathbf{a}_{4} \mathbf{C l S i}_{9} \mathrm{Al}_{3} \mathbf{O}_{24}$ (with $0-20 \% \mathrm{Ca}_{4} \mathrm{CO}_{3} \mathrm{Si}_{6} \mathrm{Al}_{6} \mathrm{O}_{24}$ ) (Marialite) is tetragonal dipyramidal with $c / a=0.446 . \mathrm{NaCl}$ may be replaced at least in part by $\mathrm{NaF}, \mathrm{KCl},\left(\mathrm{KOH}\right.$ ?), $\mathrm{NaHCO}_{3}$ or $\mathrm{NaHSO}_{4}$. Crystals long prismatic, vertically striated. Distinct $\{100\}$ and poor $\{110\}$ cleavages. H. 5.5-6. G. 2.58-2.60. Uniaxial negative (as found in nature-but the pure compound may be positive-see Fig. 10-17), with $n_{\mathrm{O}}=1.532-1.545, n_{\mathrm{E}}=1.534-1.538$,


Fig. 10-17. Properties of the scapolite series $\mathrm{Na}_{4} \mathrm{Al}_{3} \mathrm{Si}_{9} \mathrm{O}_{24} \mathrm{Cl}-\mathrm{Ca}_{4} \mathrm{Al}_{6} \mathrm{Si}_{6} \mathrm{O}_{24} \mathrm{CO}_{3}$.
$n_{\mathrm{O}}-n_{\mathrm{E}}=-0.002-0.007$. Colorless. Refringence, birefringence and specific gravity all increase in scapolite with increase of Ca. PD 3.44, 3.03, 3.78; 2-0412.
$\mathbf{8 0}-\mathbf{5 0 \%} \mathrm{NaClSi}_{9} \mathrm{Al}_{3} \mathrm{O}_{24}+\mathbf{2 0 - 5 0 \%} \mathrm{Ca}_{4} \mathrm{CO}_{3} \mathrm{Si}_{6} \mathrm{Al}_{6} \mathrm{O}_{24}$ (the portion of the scapolite or wernerite series called dipyre) is tetragonal dipyramidal with $c / a=0.444$. Variations in composition noted above. Crystals prismatic with distinct $\{100\}$ and poor $\{110\}$ cleavages. H. 5.5-6. G. 2.6-2.67. Uniaxial negative with $n_{\mathrm{O}}=1.545-1.57, \quad n_{\mathrm{E}}=1.538-1.55, \quad n_{\mathrm{O}}-n_{\mathrm{E}}=$ $0.007-0.02$. Colorless.
$\mathbf{5 0}-\mathbf{2 0 \%} \mathrm{Na}_{4} \mathrm{Si}_{9} \mathrm{Al}_{3} \mathrm{O}_{24}+\mathbf{5 0 - 8 0 \%} \mathrm{Ca}_{4} \mathrm{CO}_{3} \mathrm{Si}_{6} \mathrm{Al}_{6} \mathrm{O}_{24}$ (the portion of the scapolite or wernerite series known as mizzonite) is tetragonal dipyramidal with $c / a=0.442$. Variation in composition as noted above. Crystals prismatic with distinct $\{100\}$ and poor $\{110\}$ cleavages. H. 5.5-6. G. 2.67-2.73. Uniaxial negative with $n_{\mathrm{O}}=1.57-1.59, \quad n_{\mathrm{E}}=1.55-1.56, \quad n_{\mathrm{O}}-n_{\mathrm{E}}=$ 0.02-0.03. Colorless.
$\mathbf{C a}_{4} \mathrm{CO}_{3} \mathrm{Al}_{6} \mathrm{Si}_{6} \mathrm{O}_{24}$ (with $0-20 \% \mathrm{Na}_{4} \mathrm{ClSi}_{9} \mathrm{Al}_{3} \mathrm{O}_{24}$ ) (Meionite) is tetragonal dipyramidal with $c / a=0.4393 . \mathrm{CaCO}_{3}$ may be replaced in part by $\mathrm{CaSO}_{4}$,
$\mathrm{MgCO}_{3}, \mathrm{CaCl}_{2}$ or $\mathrm{CaF}_{2}$. Crystals long prismatic, vertically striated. Distinct $\{100\}$ and poor $\{110\}$ cleavages. H. 5.5-6. G. 2.70-2.75. M.P. $1100^{\circ}-1200^{\circ} \mathrm{C}$. Decomposed by HCl. Uniaxial negative with $n_{\mathrm{O}}=$ $1.590-1.600, n_{\mathrm{E}}=1.560-1.563, n_{\mathrm{O}}-n_{\mathrm{E}}=0.030-0.037$. Colorless. Made by crystallizing a glass ${ }^{75}$ of the given composition in a steel bomb with a 10 per cent NaCl solution. PD 3.47, 3.08, 2.07; 2-0405.
$\mathbf{N a}_{3} \mathrm{CaCO}_{3}(\mathrm{OH})_{2} \mathrm{Si}_{3} \mathrm{Al}_{3} \mathrm{O}_{12}$ (Cancrinite) is hexagonal pyramidal with $a=12.75, c=5.18 \AA$. U.C. 2. $\mathrm{CO}_{3}$ may be replaced by $\mathrm{SO}_{4}$ or $\mathrm{Cl} ; \mathrm{Ca}$ by $\mathrm{NaH}, \mathrm{KH}$, etc. Crystals prismatic with perfect $\{10 \overline{1} 0\}$ cleavage. H. 5-6. G. 2.42-2.5. F. 2 with intumescence. Effervesces and gelatinizes with acids. Uniaxial negative with ${ }^{76} n_{\mathrm{O}}=1.550, n_{\mathrm{E}}=1.519$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.031$. With $\mathrm{CaCO}_{3}$ replaced in part by $\mathrm{Na}_{2} \mathrm{CO}_{3}$ (or $\mathrm{NaHCl}_{3}$ ?) and $\mathrm{Ca}: \mathrm{Na}=1: 1, n_{\mathrm{O}}=$ $1.525, n_{\mathrm{E}}=1.505, n_{\mathrm{O}}-n_{\mathrm{E}}=0.020$. With NaOH , but no $\mathrm{CaCO}_{3} n_{\mathrm{O}}=$ $1.500, n_{\mathrm{E}}=1.497, n_{\mathrm{O}}-n_{\mathrm{E}}=0.003$. With AgOH in place of NaOH , $n_{\mathrm{O}}=1.647, n_{\mathrm{E}}$ nearly equals $n_{\mathrm{o}}$. But with $\mathrm{AgOH}, n_{\mathrm{o}}$ may also $=1.670$, $n_{\mathrm{E}}=1.649$, and $n_{\mathrm{O}}-n_{\mathrm{E}}=0.021$. With increasing Na and $\mathrm{SO}_{4}$ the refringence, birefringence and specific gravity all decrease. Colorless. PD 3.19, 4.61, 3.61; 3-0503. Made by heating under pressure a mixture of sodium silicate, alumina and sodium carbonate; also by treating nephelite and labradorite with sodium carbonate at high temperatures.

## C. PHYLLOSILICATES (SHEETS OF TETRAHEDRA): <br> $$
\mathrm{A}_{m}\left(\mathrm{X}_{2} \mathrm{O}_{5}\right)_{n} Z_{q}
$$

$\mathbf{K}_{2} \mathbf{M g S i}_{5} \mathbf{O}_{12}(?)$ has two phases. ${ }^{1}$ The $\alpha$-phase is isometric with $a=13.39$ A. M.P. $1089^{\circ}$ C. Crystals octahedrons, cubes, etc. Isotropic with $n=$ 1.501. The $\beta$-phase forms fibers with G. 2.395 and very weak birefringence (about 0.001 or 0.002 ) and $n=1.505 \mathrm{Na}$. PD 3.25, 3.38, $5.34 ; 10-21$. The glass has G. 2.38 and $n=1.498$. Colorless. Made from fusion.
$\mathbf{C a C u S i}_{4} \mathbf{O}_{10}$ is tetragonal with G. 3.04, ${ }^{2} 2.95 .^{3}$ Uniaxial negative with $n_{\mathrm{O}}=1.6354, n_{\mathrm{E}}=1.6053, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0301$. Color azure blue with O deep blue, E pale rose. Made from fusion and called Vestorian blue; supposed to be the equivalent of an artificial blue pigment used by the early Egyptians.
$\mathrm{FeBaSi}_{4} \mathrm{O}_{10}$ (Gillespite) is ditetragonal dipyramidal ${ }^{4}$ with $a=7.495$, $c=16.05 \AA$. U.C. 4. Perfect $\{001\}$ and poor $\{100\}$ cleavages. H. 3. G. 3.4.

[^159]F. easy. Uniaxial negative with $n_{\mathrm{O}}=1.621, n_{\mathrm{E}}=1.619, n_{\mathrm{O}}-n_{\mathrm{E}}=0.002$. Color rose-red with O pale pink, E deep rose-red. Leached by HCl all the Fe and Ba are removed leaving hydrous silica ( $8 \mathrm{SiO}_{2} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ ) in glistening scales resembling those produced from biotite by treatment with $\mathrm{H}_{2} \mathrm{SO}_{4}$. They have G. 1.8-2.0 and are uniaxial negative ${ }^{5}$ (or slightly biaxial) with variable indices (due to variable tenor of $\mathrm{H}_{2} \mathrm{O}$ ?) such as $n_{0}=1.465$, $n_{\mathrm{E}}=1.455, n_{\mathrm{O}}-n_{\mathrm{E}}=0.010$ and $n_{\mathrm{O}}=1.449, n_{\mathrm{E}}=1.441, n_{\mathrm{O}}-n_{\mathrm{E}}=$ 0.008. Colorless. PD 3.39, 4.41, 3.22; 3-0402.
$\mathbf{K}_{8} \mathbf{C a S i}_{10} \mathbf{O}_{25}$ is hexagonal; ${ }^{6}$ plates have parallel extinction. Uniaxial negative with $n_{\mathrm{O}}=1.548, n_{\mathrm{E}}=1.537, n_{\mathrm{O}}-n_{\mathrm{E}}=0.011$. Colorless.
$\mathbf{K}_{2} \mathbf{M g}_{5} \mathbf{S i}_{12} \mathbf{O}_{30}$ is hexagonal. ${ }^{1}$ Crystal six-sided tablets often with second order pyramids. No cleavage. G. 2.58. M.P. $1174^{\circ}$ C. Uniaxial positive with $n_{\mathrm{O}}=1.543, n_{\mathrm{E}}=1.550 \pm 0.002, n_{\mathrm{E}}-n_{\mathrm{O}}=0.008 \mathrm{Na}$. Nearly the same indices as those of quartz. Colorless. Made from fusion.
$\mathbf{K}_{2} \mathbf{M g S i}_{3} \mathbf{O}_{8}$ (?) is hexagonal. ${ }^{1}$ M.P. $1134^{\circ}$ C. Uniaxial negative with $n_{\mathrm{O}}=$ $1.530, n_{\mathrm{E}}=1.524, n_{\mathrm{O}}-n_{\mathrm{E}}=0.006$. It inverts to a second phase (on cooling) which has G. 2.56 and a "gross index" of 1.527. Colorless. Made from fusion. PD 3.10, 3.21, 2.67; 10-30 ( $\beta$-phase); 3.12, 3.99, 2.61; 10-20 ( $\alpha$-phase).
$\mathbf{K}_{8} \mathbf{C a S i}_{10} \mathbf{O}_{25}$ is hexagonal. ${ }^{7}$ Crystals platy. M.P. $946^{\circ}$ C. Uniaxial negative with $n_{\mathrm{O}}=1.551, n_{\mathrm{E}}=1.539, n_{\mathrm{O}}-n_{\mathrm{E}}=0.012$. Colorless. Made from fusion.
$\mathbf{K}_{2} \mathbf{P b}_{4} \mathbf{S i}_{8} \mathbf{O}_{21}$ (?) forms fibers or laths with parallel extinction. ${ }^{8}$ Indices $n_{\mathrm{X}}=1.69 \pm 0.01, n_{\mathrm{Z}}=1.79 \pm 0.01$.". . extinction is parallel and the optic axis is parallel with the longitudinal axis [of the fibers]." ${ }^{9}$
$\mathbf{N a}_{2} \mathbf{S i}_{2} \mathbf{O}_{5}$ has at least two crystal phases. The high temperature $\alpha$-phase is orthorhombic ${ }^{10}$ with $a=15.45, b=4.909, c=6.43 \AA$. U.C. 4. Crystals $\{100\}$ plates with perfect $\{100\}$ and distinct $\{010\}$ cleavages. G. 2.48, M.P. $874^{\circ} \mathrm{C}$. Inverts reversibly at $678^{\circ} \mathrm{C} . \mathrm{X}=a ; \mathrm{Y}=b$. ( - ) $2 \mathrm{~V}=$ $50^{\circ}-55^{\circ} . n_{\mathrm{X}}=1.497, n_{\mathrm{Y}}=1.505, n_{\mathrm{Z}}=1.508, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.011$. Again: ${ }^{11}$ $n_{\mathrm{X}}=1.504, n_{\mathrm{Y}}=1.514, n_{\mathrm{Z}}=1.518, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.014$. The glass has $n=$ 1.504. Colorless. Made from fusion. The low temperature phase is monoclinic ${ }^{10}$ with $a=12.31, b=4.849, c=8.124 \AA, \beta=104^{\circ} 7^{\prime}$. Crystals thin

[^160]$\{100\}$ pseudo-hexagonal plates. Perfect $\{100\}$ and distinct $\{010\}$ cleavages. Very commonly twinned on $\{100\}$, G. 2.6. ( $-2 \mathrm{~V}=48^{\circ}$ calc. ${ }^{10}$ $n_{\mathrm{X}}=1.500, n_{\mathrm{Y}}=1.510, n_{\mathrm{Z}}=1.515, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.015 . \mathrm{Z}=b ; \mathrm{X}$ nearly normal to $\{100\}, \mathrm{Y} \approx c$. Colorless.
$\mathbf{K}_{2} \mathbf{S i}_{2} \mathbf{O}_{5}$ is orthorhombic. ${ }^{12,13}$ Crystals six-sided plates with angles of about $40^{\circ}$ and $80^{\circ}$; if these plates are basal, the cleavages are: $\{001\}$ perfect, $\{010\}$ distinct, $\{100\}$ imperfect. Lamellar twinning nearly parallel with elongation $b$. Crystals from fusion are elongated parallel with Z; from solution parallel with Y. Crystals hygroseopic. G. 2.538. M.P. $1036^{\circ} \mathrm{C}$. $\mathrm{X}=c ; \mathrm{Y}=b .(-) 2 \mathrm{~V}=$ rather large. $n_{\mathrm{X}}=1.503, n_{\mathrm{Y}}=1.509 c a ., n_{\mathrm{Z}}=$ 1.513, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.010$. The glass has G. 2.474. Colorless. Made from fusion and from solution.
$\mathbf{L i}_{2} \mathbf{S i}_{2} \mathbf{O}_{5}$ is orthorhombic with ${ }^{10} a=5.80, b=14.66, c=4.81$. U.C. 4. Crystals rectangular tablets with three rectangular cleavages, one being perfect, the others nearly perfect. G. 2.454 . M.P. $1032^{\circ} \mathrm{C}$. (incongruently). Y normal to the best cleavage; Z parallel to the two best cleavages. ${ }^{14}$ $(+) 2 \mathrm{~V}=50^{\circ}-60^{\circ}, n_{\mathrm{X}}=1.547, n_{\mathrm{Y}}=1.550, n_{\mathrm{Z}}=1.558, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.011$. Again: ${ }^{15} n_{\mathrm{X}}=1.525, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.545, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.020$. Colorless. Made from fusion. PD 3.67, 3.75, 1.98; 4-0436.
$\mathrm{LiKSi}_{2} \mathrm{O}_{5}$ is orthorhombic(?). M.P. $870^{\circ} \mathrm{C} .{ }^{16} 2 \mathrm{~V}=53^{\circ}, n_{\mathrm{x}}=1.536$, $n_{\mathrm{Y}}=?, n_{\mathrm{Z}}=1.540, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.004$. Colorless.
$\mathbf{L i}_{2} \mathbf{K}_{4} \mathbf{S i}_{6} \mathbf{O}_{15}$ is orthorhombic(?). M.P. $815^{\circ}$ C. (two or three inversions ${ }^{16}$ ). $(-?) 2 \mathrm{~V}=85^{\circ}-90^{\circ} . n_{\mathrm{X}}=1.510, n_{\mathrm{Y}}=1.5125 c a . n_{\mathrm{Z}}=1.515, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.005 . Colorless.
$\mathbf{B a}_{2} \mathbf{S i}_{3} \mathbf{O}_{8}$ (?) is orthorhombic ${ }^{17}$ and granular with three pinacoids; cleavages, ${ }^{18}$ one (assumed to be $\{001\}$ ) perfect, the others poor. Lamellar twinning on a prism face inclined $30^{\circ}$ to $a$. G. 3.93. M.P. $1450^{\circ} \mathrm{C} . \mathrm{X}=c ; \mathrm{Y}=a$. $(+) 2 \mathrm{~V}=54^{\circ} . n_{\mathrm{x}}=1.617 \mathrm{C}, 1.620 \mathrm{D}, 1.627 \mathrm{~F}, n_{\mathrm{Y}}=1.622 \mathrm{C}, 1.625 \mathrm{D}$, $1.632 \mathrm{~F}, n_{\mathrm{Z}}=1.641 \mathrm{C}, 1.645 \mathrm{D}, 1.652 \mathrm{~F}, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.025 \mathrm{D}$. Colorless. Made from fusion. PD 3.79, 3.33, 3.28; 6-0206. It forms a complete series of mix-crystals with $\mathrm{BaSi}_{2} \mathrm{O}_{5}$ whose properties vary continuously as shown in Fig. 10-18.
$\mathbf{N a} \mathbf{a}_{2} \mathbf{C a}_{3} \mathbf{S i}_{6} \mathbf{O}_{16}(?)$ (Devitrite) is orthorhombic; ${ }^{19}$ crystals often prismatic.

[^161]It dissociates to $\mathrm{CaSiO}_{3}$ and liquid at $1045^{\circ} \mathrm{C}$. Z parallel with elongation. $(+) 2 \mathrm{~V}=75^{\circ} . n_{\mathrm{X}}=1.564, n_{\mathrm{Y}}=1.570, n_{\mathrm{Z}}=1.579, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.015$. Colorless. Made from fusion. Similar acicular devitrification products of glass have been described under the name rivaite by Zambonini ${ }^{20}$ and


Fig. 10-18. Variations in properties of the series $\mathrm{BaSi}_{2} \mathrm{O}_{5}-\mathrm{Ba}_{2} \mathrm{Si}_{3} \mathrm{O}_{8}$. Modified from data of Eskola, Am. Jour. Sci. IV, p. 331 (1922).
under the name réaumurite by Lacroix. ${ }^{21}$ Rivaite is reported to have the optic plane normal to the elongation and $Z$ normal to the laths with (-) $2 \mathrm{~V}=$ small; $n_{\mathrm{Y}}=1.56, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ weak. This is probably wollastonite according to Bowen. ${ }^{22}$ Réaumurite has Z parallel with the elongation according to Gaubert ${ }^{23}$ with biaxial character and $n_{\mathrm{X}}=1.540, n_{\mathrm{Z}}=$ $1.545-1.55, n_{\mathrm{Z}}-n_{\mathrm{X}}$ weak.
$\mathbf{K}_{2} \mathrm{Ca}_{3} \mathbf{S i}_{6} \mathbf{O}_{16}$ forms orthorhombic ${ }^{24}$ needles and long prisms and plates. $\mathrm{Z}=$ elongation, $(-) 2 \mathrm{~V}=$ ?. $n_{\mathrm{X}}=1.56, n_{\mathrm{Z}}=1.57, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.01 . \mathrm{De}-$ composes above $960^{\circ} \mathrm{C}$ to $\mathrm{K}_{2} \mathrm{Ca}_{2} \mathrm{Si}_{6} \mathrm{O}_{15}$ and glass. Made from fusion.
$\mathbf{K}_{2} \mathbf{C a}_{2} \mathbf{S i}_{6} \mathbf{O}_{15}$ forms stout prisms ${ }^{24}$ with highly inclined extinction. ( + ) 2 V $=$ large, $n_{\mathrm{X}}=1.575, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.59$. Decomposes above $1115^{\circ} \mathrm{C}$. to wollastonite $+\mathrm{CaSiO}_{3}+$ glass. Made from fusion.
$\mathbf{K}_{2} \mathbf{P b S i}_{4} \mathbf{O}_{10}$ forms rectangular plates with parallel extinction. M.P. $\mathbf{7 5 7}^{\circ}$

[^162]C. $(+) 2 \mathrm{~V}=75^{\circ}$ ca. $n_{\mathrm{X}}=1.590, n_{\mathrm{Y}}=1.612, n_{\mathrm{Z}}=1.650$, all $\pm 0.005$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.06$. The glass has $n=1.606$; it softens at $463^{\circ} \mathrm{C}$. PD 3.70, 3.22, 3.08; 3-0317.
$\mathbf{N a}_{6} \mathbf{B e}_{6} \mathbf{S i}_{14} \mathbf{O}_{37}$ (?) is orthorhombic ${ }^{25}$ with G. 2.55. $n_{\mathrm{X}}=1.532, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.545, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.013$ and $(+) 2 \mathrm{E}=60^{\circ}$; therefore $(+) 2 \mathrm{~V}=38^{\circ}$ and $n_{\mathrm{Y}}=1.533$.
$\mathbf{K H S i}_{2} \mathbf{O}_{5}$ is orthorhombic ${ }^{26}$ in pseudo-hexagonal prismatic to tabular crystals. G. 2.417. M.P. $515^{\circ} \mathrm{C}$. Good $\{100\}$ and $\{010\}$ cleavages. $\mathrm{X}=b$, $\mathrm{Y}=c, \mathrm{Z}=a . \quad(+) 2 \mathrm{~V}=40^{\circ}$ ca. $n_{\mathrm{X}}=1.495, n_{\mathrm{Y}}=1.501$ calc. $n_{\mathrm{Z}}=$ $1.535, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.040$. Hardly soluble in water even at $100^{\circ} \mathrm{C}$. Alters with reduction of index to 1.480 . Loses weight $\left(\mathrm{H}_{2} \mathrm{O}\right)$ when heated in air at $420^{\circ}$ C. Colorless. Made hydrothermally.
$\mathbf{K}_{4} \mathbf{C a S i}_{6} \mathbf{O}_{15}$ is monoclinic or triclinic $7^{7}$ crystals prisms or plates with slightly inclined extinction. M.P. $959^{\circ} \mathrm{C} .(-) 2 \mathrm{~V}=60^{\circ} \pm 5^{\circ} . n_{\mathrm{x}}=1.535$, $n_{\mathrm{Y}}=1.541, n_{\mathrm{Z}}=1.543, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.008$. Colorless. Made from fusion.
$\mathbf{N a}_{2} \mathbf{M g}_{2} \mathbf{S i}_{6} \mathbf{O}_{15}$ is monoclinic. ${ }^{7} \mathrm{Z} \wedge c=24^{\circ}$. (+) $2 \mathrm{~V}=$ large. $n_{\mathrm{X}}=1.540$, $n_{\mathrm{Y}}=1.5425$ calc., $n_{\mathrm{Z}}=1.546, n_{\mathrm{Z}}-\dot{n}_{\mathrm{X}}=0.006$. Colorless. Made from fusion.
$\mathbf{K}_{2} \mathbf{C a}_{2} \mathbf{S i}_{9} \mathbf{O}_{21}(?)$ is monoclinic ${ }^{24}$ or triclinic. Crystals prismatic with slightly inclined extinction. (-) $2 \mathrm{~V}=$ large. $n_{\mathrm{X}}=1.515, n_{\mathrm{Y}}=1.526$ est., $n_{\mathrm{z}}=1.535, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.020$. Colorless. Made from fusion.
$\mathbf{K}_{4} \mathbf{C a S i}_{6} \mathbf{O}_{15}$ is monoclinic ${ }^{24}$ or triclinic; crystals are plates with inclined extinction. (-) $2 \mathrm{~V}=60^{\circ} \pm 5^{\circ} . n_{\mathrm{X}}=1.535, n_{\mathrm{Y}}=1.541, n_{\mathrm{Z}}=1.543, n_{\mathrm{Z}}-$ $n_{\mathrm{x}}=0.008$. Colorless. Made from fusion.
$\mathbf{B a S i}_{2} \mathbf{O}_{5}$ (Sanbornite) is triclinic ${ }^{27}$ with angles $\alpha, \beta$ and $\gamma$ not far from $90^{\circ}$. It has perfect $\{001\}$ and poor $\{010\}$ and $\{100\}$ cleavages; polysynthetic twinning on $\{010\}$. H. 5. G. 4.19. The optic plane is nearly normal to $\{010\}$; Z is nearly normal to $\{001\}$. Extinction angle on (001) is $3.5^{\circ}$ and on (010) it is $5.5^{\circ}$. (-) $2 \mathrm{~V}=66^{\circ}$ ca. $n_{\mathrm{X}}=1.597, n_{\mathrm{Y}}=1.616, n_{\mathrm{Z}}=1.624$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.027$. Colorless. $\mathrm{BaSi}_{2} \mathrm{O}_{5}$ is also orthorhombic ${ }^{28}$ with three pinacoidal cleavages. M.P. $1420^{\circ}$ C. G. ${ }^{18} 3.73$ and $\mathrm{X}=b ; \mathrm{Y}=a$ (nearly the same as sanbornite). $(-) 2 \mathrm{~V}=75^{\circ}$ ca., $n_{\mathrm{X}}=1.595 \mathrm{C}, 1.597 \mathrm{D}, 1.602 \mathrm{~F}$, $n_{\mathrm{Y}}=1.610 \mathrm{C}, 1.612 \mathrm{D}, 1.617 \mathrm{~F}, n_{\mathrm{Z}}=1.618 \mathrm{C}, 1.621 \mathrm{D}, 1.632 \mathrm{~F}, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.024 \mathrm{D} . \mathrm{PD} 4.05,2.22,3.17 ; 10-45$ ( $\alpha$-, or high-temp. form) : 3.09, 4.0, 3.32; 10-46 ( $\beta$-form). The glass has $n=1.6085$. $\mathrm{BaSi}_{2} \mathrm{O}_{5}$ forms a continuous series of mix-crystals with $\mathrm{BaSi}_{3} \mathrm{O}_{8}$ in which the optic properties vary continuously as shown in Fig. 10-18.

[^163]$\mathrm{K}_{2} \mathrm{Si}_{2} \mathrm{O}_{5} \cdot \mathbf{H}_{2} \mathrm{O}$ is granular. ${ }^{26}$ It dissociates at $405^{\circ}$ C., altered by $\mathrm{H}_{2} \mathrm{O}$ below $280^{\circ} \mathrm{C}$. Soluble in water. ( + ) $2 \mathrm{~V}=$ very small. Mean index, $n$, estimated at $1.50, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ strong. Colorless.
$\mathrm{CaSi}_{2} \mathrm{O}_{5} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ (Okenite) is triclinic in minute blade-shaped crystals; often fibrous. Perfect $\{010\}$ cleavage. Twinning on $\{010\}$. H. 5. G. 2.28-2.33. F. 2.5. Gelatinizes with HCl . Extinction parallel with $c$ in $\{010\}$, but it may reach $34^{\circ}$ in the vertical zone. Positive elongation. Optically negative(?). Indices vary notably (due to variable tenor of $\mathrm{H}_{2} \mathrm{O}$ ?), $n_{\mathrm{z}}$ from $1.536^{29}$ to $1.553 .{ }^{30}$ Color white or pale. Made by recrystallization $\mathrm{in}^{31}$ carbonated water in a sealed tube. PD 21., 8.8, 3.56; 9-469*.
$\mathrm{Na}_{2} \mathrm{Al}_{2} \mathrm{Si}_{2} \mathrm{O}_{8} \cdot \mathrm{H}_{2} \mathrm{O}$ (?) (Lembergite) is orthorhombic ${ }^{32}$ with a prism angle of $112^{\circ}$; it seems to be closely related to kaolinite and chemically it is called nepheline hydrate. ${ }^{33}(+) 2 \mathrm{~V}=66^{\circ} 45^{\prime}, \mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.569, n_{\mathrm{Y}}=1.570$, $n_{\mathrm{Z}}=1.573, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.004$. The optic sign changes to negative on heating to $115^{\circ}$ (dehydrated). Produced artificially and said to occur in nature. PD 3.40, 4.39, 2.95; 10-460* (identity?).
$\mathbf{M g}_{3}(\mathbf{O H})_{2} \mathrm{Si}_{4} \mathrm{O}_{10}$ (Talc) is monoclinic with $a=5.27, b=9.13, c=$ $18.88 \AA, \beta=100^{\circ} 15^{\prime}$. U.C. 4. It often contains a little $\mathrm{FeO}, \mathrm{Al}_{2} \mathrm{O}_{3}$ and extra $\mathrm{H}_{2} \mathrm{O}$. Crystals rare; usually in compact masses. Perfect $\{001\}$ cleavage. H. 1. G. 2.82. F. 6, after exfoliation. $X$ nearly normal to $\{001\}$; $\mathrm{Z}=b .(-) 2 \mathrm{~V}=0^{\circ}-30^{\circ}, \mathrm{r}>\mathrm{v} . n_{\mathrm{X}}=1.540, n_{\mathrm{Y}}$ nearly $=n_{\mathrm{Z}}=1.575$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.035$. Indices vary (due to Fe or $\mathrm{H}_{2} \mathrm{O}$ ?); for example: ${ }^{34} n_{\mathrm{x}}=$ $1.538-1.545, n_{\mathrm{Z}}=1.575-1.590, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.030-0.050$. After losing half its water below red heat the optic properties are nearly the same; the rest of the water is lost between $875^{\circ}$ and $960^{\circ} \mathrm{C}$. Color pale green or colorless. Made under pressure at moderate temperatures. PD 2.49, 4.58, 1.53; 3-0881.
$\mathrm{Fe}_{3}(\mathbf{O H})_{2} \mathbf{S i}_{4} \mathbf{O}_{10}$ (Minnesotaite) is the iron analogue of talc. ${ }^{35}$ It is monoclinic with $a=5.4, b=2.4, c \sin \beta=19.1 \AA$. Forms colorless needles with positive elongation, or plates showing nearly centered acute bisectrix interference figures with ( -$) 2 \mathrm{~V}<5^{\circ} . n_{\mathrm{X}}=1.586$ (earlier reported 1.580), $n_{\mathrm{Y}}=n_{\mathrm{Z}}=1.618$ (earlier, 1.615), $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.032$. Natural material usually contains $\mathrm{Fe}^{\prime \prime \prime}$, Mg , and excess of $\mathrm{H}_{2} \mathrm{O}$. H. 2.5. G. 3-3.1. Greenalite decomposes to minnesotaite + fayalite at $470^{\circ} \mathrm{C}$., minnesotaite decom-

[^164]poses to fayalite and quartz at slightly higher temperatures. PD 9.53, 2.52, 4.77; 6-0025.
$\mathbf{M g}_{6}(\mathbf{O H})_{8} \mathbf{S i}_{4} \mathbf{O}_{10}$ (Chrysotile) is monoclinic prismatic with $a=14.66$, $b=9.24, c=5.33, \beta=93^{\circ} 16^{\prime}$. U.C. 1. Crystals fibrous and flexible in the variety called asbestos. Poor $\{110\}$ cleavages at $130^{\circ}$. H. 2-2.5. G. 2.36-2.50. F. 6. $\mathrm{Y}=b ; \mathrm{Z} \wedge c$ (elongation) $=$ nearly $0^{\circ} .(+) 2 \mathrm{~V}=30-35^{\circ}$ (but may seem smaller due to superposition of lamellae). $n_{\mathrm{x}}=1.542$, $n_{\mathrm{Y}}=1.543$ calc., $n_{\mathrm{Z}}=1.555, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.013$. Again: $:^{36} n_{\mathrm{X}}=1.53-1.54$, $n_{\mathrm{z}}=1.54-1.55$. With some Ni or Fe indices may be up to .02 higher. Color green, yellow, gray. Made by hydrothermal methods ${ }^{36 \mathrm{a}}$ under pressure at temperatures below $500^{\circ} \mathrm{C}$.
$(\mathrm{Ni}, \mathrm{Mg})_{6}(\mathrm{OH})_{6} \mathrm{Si}_{4} \mathrm{O}_{11} \cdot \mathrm{H}_{2} \mathrm{O}$ (Garnierite) is monoclinic like chrysotile. With 47 per cent NiO it has $(+) 2 \mathrm{~V}=0^{\circ}-10^{\circ} . n_{\mathrm{X}}=1.622, n_{\mathrm{Y}} \approx n_{\mathrm{Z}}=$ $1.630, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.008-0.010$. Color dark green with $\mathrm{X}<\mathrm{Z}$. PD 9.8, 1.52, 2.65; 2-0060.
$\mathbf{F e}^{\prime \prime}{ }_{9} \mathrm{Fe}^{\prime \prime \prime}{ }_{2}(\mathbf{O H})_{16} \mathrm{Si}_{8} \mathrm{O}_{20}$ (?) (Greenalite) is monoclinic, ${ }^{37}$ resembling chrysolite with $a=14.5, b=18.6, c=$ ? Crystallization mostly submicroscopic but distinct to X-rays. Granular. G. $3 \pm$. Isotropic, or nearly so, with $n=1.660 \mathrm{C}, 1.674 \mathrm{D}, 1.686 \mathrm{~F}$. Hawley ${ }^{37 \mathrm{a}}$ found $n$ as low as $=1.650$ (on submicroscopic material containing some opal?). PD 2.57, 7.12, 3.56; 2-1012. Color green to yellow or brown.
$\mathbf{M g}_{3} \mathrm{Si}_{4} \mathrm{O}_{11} \cdot \mathrm{nH}_{2} \mathrm{O}$ (Sepiolite) is monoclinic with $a=23.2, b=15.7$, $c=5.32 \AA, \beta=90^{\circ}-93^{\circ}$. Always finely fibrous often with amorphous and other material, the mixture being called meerschaum, with mean index of about 1.54 . H. $2-2.5$. G. 2 . Z very near $c .(-) 2 \mathrm{~V}=$ very near $0^{\circ} . n_{\mathrm{X}}=$ $1.515-1.520, n_{\mathrm{Y}} \approx n_{\mathrm{Z}}=1.525-1.529, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.009 \pm$. Heated above $100^{\circ}$ C. $n_{\mathrm{z}}$ becomes 1.535 ca . Color white or pale. Made under pressure;; ${ }^{37 \mathrm{~b}}$ also found in boiler deposits. ${ }^{370}$
$\mathrm{Mg}_{6} \mathrm{Al}(\mathbf{O H})_{8} \mathrm{Si}_{3} \mathrm{AlO}_{10}$ (Clinochlore) is monoclinic with $a=5.2-5.3$, $b=9.2-9.3, c=28.3-28.6 \AA . \beta=96^{\circ} 50^{\prime} c a$. Often contains a little Fe (for $\mathbf{M g}$ ). It is a variety of chlorite. Crystals lamellar with perfect basal cleavage. H. 2-2.5. G. 2.7. $\mathrm{Y}=b ; \mathrm{X}$ nearly normal to $\{010\} .(+) 2 \mathrm{~V}=$ $0^{\circ}-40^{\circ} . n_{\mathrm{Y}}=1.57-1.58, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.004-0.010 \mathrm{ca}$. Nearly always green (but it can be gray, olive, pink or white) with X and Y pale green, Z pale yellow-green to colorless. Made by hydrothermal methods ${ }^{36 \mathrm{a}}$ under pressure at $520^{\circ}-680^{\circ} \mathrm{C}$.

[^165]$\mathbf{M g}_{3}(\mathbf{O H})_{4} \mathbf{S i}_{2} \mathbf{O}_{5}$ (Antigorite) is monoclinic prismatic with $a=5.3$, $b=9.25, c=13.52 \AA, \beta=91^{\circ} 4^{\prime}$. U.C. 2. It is a chief component of the chlorite group, and may contain a little Fe and Al. Usually lamellar with perfect $\{001\}$ cleavage. H. 2-2.5. G. 2.62. $\mathrm{Y}=b ; \mathrm{X}$ nearly normal to $\{001\}$. $(-) 2 \mathrm{~V}=$ moderate. $n_{\mathrm{Y}}=1.55-1.58, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.004-0.010$. Color greenish, brownish or yellowish. Made artificially. ${ }^{38}$ PD 7.30, 3.63, 2.52; 7-417*.
$\mathrm{AlOHSi}_{2} \mathbf{O}_{5}$ ( $\mathbf{P y r o p h y l l i t e}$ ) is monoclinic prismatic with $a=5.15, b=$ $8.88, c=18.60 \AA, \beta=99^{\circ} 55^{\prime}$. U.C. 8. Lamellar masses with perfect $\{001\}$ cleavage. H. 1-1.5. G. 2.84. F. 6 after enlarging. X normal to cleavage; Z parallel to elongation of blades. ( - ) $2 \mathrm{~V}=53-60^{\circ}, \mathrm{r}>\mathrm{v}$ weak. $n_{\mathrm{x}}=$ $1.552, n_{\mathrm{Y}}=1.588, n_{\mathrm{Z}}=1.600, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.048$. Colorless or stained. Made by hydrothermal methods under pressure. PD 3.07, 4.43, 2.42; 3-0574.

## Mica Group

The mica group consists of phyllosilicates of aluminum and potassium (rarely sodium), usually with magnesium, iron or lithium. All micas also contain some OH or F or both. Micas are normally monoclinic, but may be hexagonal or triclinic. They have very perfect basal cleavage giving thin elastic laminae. The chief components are:

| $\mathrm{K}_{2} \mathrm{Mg}_{6}(\mathrm{OH})_{4} \mathrm{Si}_{6} \mathrm{Al}_{2} \mathrm{O}_{20}$ | Phlogopite |
| :--- | :--- |
| $\mathrm{K}_{2} \mathrm{Mg}_{5} \mathrm{Al}^{(\mathrm{OH})_{4} \mathrm{Si}_{5} \mathrm{Al}_{3} \mathrm{O}_{20}}$ | Eastonite |
| $\mathrm{NaAl}_{2}(\mathrm{OH})_{2} \mathrm{Si}_{3} \mathrm{AlO}_{10}$ | Paragonite |
| $\mathrm{KAl}_{2}(\mathrm{OH})_{2} \mathrm{Si}_{3} \mathrm{AlO}_{10}$ | Muscovite |

The following micas have been made containing fluorine in place of hydroxyl:

| $\mathrm{NH}_{4} \mathrm{Mg}_{3} \mathrm{~F}_{2} \mathrm{Si}_{3} \mathrm{AlO}_{10}$ | $\mathrm{NH}_{4} \mathrm{O}_{10} \mathrm{~F}$-Phlogopite |
| :--- | :--- |
| $\mathrm{K}(\mathrm{Fe}, \mathrm{Mg})_{3} \mathrm{~F}_{2} \mathrm{Si}_{3} \mathrm{AlO}_{10}$ | F-Biotite |
| $\mathrm{KLiFeAl}(\mathrm{F}, \mathrm{OH})_{2} \mathrm{Si}_{3} \mathrm{AlO}_{10}$ | F-Zinnwaldite |

Several of the micas have been observed with two or more distinct crystal structures, differing in the pattern or sequence in which successive layers fit over one another. Such stacking-polymorphs would differ very little in their respective lattice energies; with few exceptions (as when the stacking sequence produces rhombohedral or hexagonal symmetry), they cannot be distinguished optically.
$\mathbf{K M g}_{3}(\mathbf{O H})_{2} \mathbf{S i}_{3} \mathbf{A l O}_{10}$ (Phlogopite) has three (or more) phases, two

[^166]being monoclinic (one layer or two layers) and one, three-layer trigonal, The one-layer monoclinic phase has $^{39} a=5.31, b=9.20, c=10.31 \AA$. $\beta=99^{\circ} 54^{\prime}$. Perfect $\{001\}$ cleavage with $\{010\}$ and $\{111\}$ parting. H. 2.5-3. G. 2.79. X nearly $\perp\{001\}$. $\mathrm{Y}=b$. ( -$) 2 \mathrm{~V}=0^{\circ}-10^{\circ} c a . n_{\mathrm{X}}=1.548$, $n_{\mathrm{Y}} \approx n_{\mathrm{Z}}=1.588, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.040$. Colorless-but in nature it often contains some Fe (replacing Mg ) and then is yellowish brown or greenish and pleochroic with X colorless, Y and Z reddish brown. Made from components under considerable pressure. PD 9.94, 3.35, 2.61; 10-495* (1Mtype).
$\mathrm{K}_{2} \mathrm{Mg}_{5} \mathrm{Al}(\mathbf{O H})_{4} \mathrm{Si}_{5} \mathrm{Al}_{3} \mathrm{O}_{20}$ (Eastonite) forms a complete series with $\mathrm{K}_{2} \mathrm{Mg}_{6}(\mathrm{OH})_{4} \mathrm{Si}_{6} \mathrm{AlO}_{20}$ and in both the Mg can be replaced in whole or in any amount by Fe; these four are the end-members of the biotite system of micas. Crystals have three (or more) phases, but are usually monoclinic and almost hexagonal. Perfect basal cleavage; also $\{010\}$ and $\{011\}$ parting. H. 2.5-3. G. 2.86. F. 5. X very nearly normal to $\{001\}$ (cleavage). $\mathrm{Y}=b .(-) 2 \mathrm{~V}=$ small, $\mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{X}}=1.542, n_{\mathrm{Y}}=1.577 c a . n_{\mathrm{Z}}=$ $1.578, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.036$. Color pale, but usually with enough iron to be yellow or brown. Made under high pressure at rather high temperature. ${ }^{39}$ PD 10.1, 3.37, 2.66; 2-0045 ("biotite").
$\mathrm{KMg}_{3} \mathbf{F}_{2} \mathbf{S i}_{3} \mathbf{A l O}_{10}$ (F-Phlogopite) is monoclinic domatic with $a=5.299$, $b=9.188, c=10.135 \AA, \beta=99^{\circ} 55^{\prime}$. U.C. 4. This is phlogopite mica with OH replaced by F . With Mg replaced by Fe it is F -biotite. Crystals six-sided prisms; often lamellar. Perfect $\{001\}$ cleavage, with $\{010\}$ and $\{111\}$ parting. H. 2.5-3. G. 2.85. X nearly normal to $\{001\} ; \mathrm{Y}=b$. $(-) 2 \mathrm{~V}=9^{\circ}-14^{\circ}, \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{x}^{40}}=1.519, n_{\mathrm{Y}}=1.545, n_{\mathrm{Z}}=1.547$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.028$. Again: ${ }^{41} n_{\mathrm{X}}=1.522, n_{\mathrm{Y}}=1.5485, n_{\mathrm{Z}}=1.549, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.027$. Also $:^{42} n_{\mathrm{X}}=1.544, n_{\mathrm{Y}}=1.546, n_{\mathrm{Z}}=1.566, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.029 . Also ${ }^{43}$ (with 6.43 CaO ): $n_{\mathrm{X}}=1.520, n_{\mathrm{Y}} \approx n_{\mathrm{Z}}=1.558, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.038 . Colorless. Made ${ }^{40,41}$ by heating the components in a sealed container. PD 9.96, 3.33, 1.99; 10-494.
$\mathbf{N H}_{4} \mathbf{M g}_{3} \mathbf{F}_{2} \mathbf{S i}_{3} \mathbf{A l O}_{4}\left(\mathbf{N H}_{4}-\mathbf{P h l o g o p i t e}\right)$ has been made from vermiculite. ${ }^{44}$ It has: $n_{\mathrm{X}}=1.54 \pm, 1.55,1.56, n_{\mathrm{Y}} \approx n_{\mathrm{Z}}=1.57+, 1.58,1.59, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.03.
$\mathbf{K}(\mathbf{F e}, \mathbf{M g})_{3} \mathbf{F}_{2} \mathbf{S i}_{3} \mathbf{A l O}_{10}$ ( $\mathbf{F}$-Biotite) with $\mathrm{Fe}: \mathbf{M g}=2: 1$ is monoclinic like phlogopite; it is a F-biotite and has: $:^{43}(-) 2 \mathrm{~V}=0^{\circ}, n_{\mathrm{X}}=1.551, n_{\mathrm{Y}}=$
${ }^{39}$ Yoder and Eugster: Am. Min. XXXIX, p. 326 (1954) and Geochim. Cosmochim. Acta VI, p. 157 (1954).
${ }^{40}$ Van Valkenburg and Pike: J. Res. Nat. Bur. Stand. XLVIII, p. 360 (1952).
${ }^{41}$ Kohn and Hatch: Am. Min. XL, p. 10 (1955).
${ }^{42}$ Noda: Bull. Chem. Soc. Japan, XXIII, p. 40 (1950).
${ }^{43}$ Grigoriev: Cent. Min. A, 1934, p. 219.
${ }^{44}$ Gruner: Am. Min. XXIV, p. 428 (1939).
$n_{\mathrm{Z}}=1.596, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.045$. Color brown. Made from components ${ }^{43}$ with $\mathrm{CaF}_{2}$ at high temperature $\left(1200^{\circ} \mathrm{C}\right.$.).
$\mathbf{N a A l}_{2}(\mathbf{O H})_{2} \mathbf{S i}_{3} \mathbf{A l O}_{10}$ (Paragonite) is monoclinic with $a=5.12, b=$ 8.87, $c=19.33 \AA, \beta$ not far from $90^{\circ}$. Often contains some K in place of Na. H. 2. G. 2.85. F. 6. Insoluble. X nearly normal to $\{001\} ;{ }^{45} \mathrm{Z}=b$. (-) $2 \mathrm{~V}=$ $40^{\circ}$ ca. $n_{\mathrm{X}}=1.564-1.577, \quad n_{\mathrm{Y}}=1.599-1.605, \quad n_{\mathrm{Z}}=1.600-1.609, \quad n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.028-0.038$. Colorless. PD 1.48, 2.51, 3.18; 10-420*.
$\mathbf{K A l}_{2}(\mathbf{F}, \mathbf{O H})_{2} \mathbf{S i}_{3} \mathbf{A l O}_{10}$ (Muscovite) is monoclinic prismatic with $a=$ $5.18, b=9.02, c=20.04 \AA, \beta=95^{\circ} 30^{\prime}$. U.C. 4. The natural mineral usually contains OH with little or no F ; the F-bearing type is easier to make. Crystals usually tabular with six sides; often lamellar massive. Perfect $\{001\}$ cleavage; also $\{110\}$ and $\{010\}$ parting. H. 2.5-3. G. 2.76-3.0. F. 5.7 to gray or yellow glass. Insoluble. X makes an angle of $0^{\circ}-2^{\circ}$ with a normal to $\{001\} ; Z=b$. (-) $2 \mathrm{~V}=45^{\circ} c a ., \mathrm{r}>\mathrm{v}$ distinct. $n_{\mathrm{X}}=1.552, n_{\mathrm{Y}}=1.582, n_{\mathrm{Z}}=1.588, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.036$. Colorless (or, with some $\mathrm{Fe}^{\prime \prime \prime}$, brown). Made ${ }^{46}$ by heating in a sealed container. PD 10.1, 3.36, 4.49; 7-25*.
$\mathrm{KLiFeAl}(\mathbf{F}, \mathbf{O H})_{2} \mathbf{S i}_{3} \mathbf{A l O}_{10}$ (Zinnwaldite) is monoclinic prismatic with $a=5.26, b=9.07, c=20.10 \AA, \beta=100^{\circ}$. U.C. 4. Crystals usually short prisms or lamellar. Perfect $\{001\}$ cleavage. H. 2.5-4. G. 3.0 ca. F. 1.5-2.5. $\mathrm{X} \wedge c=0^{\circ}-4^{\circ} ; \mathrm{Y}=b .(-) 2 \mathrm{~V}=30^{\circ} c a . n_{\mathrm{X}}=1.55 c a ., n_{\mathrm{Y}}=1.58 c a$, $n_{\mathrm{Z}}=1.58 \mathrm{ca} ., n_{\mathrm{Z}}-n_{\mathrm{X}}=0.03 \mathrm{ca}$. Color violet, yellow, gray, brown and pleochroic with X yellowish or reddish, Y and Z brownish gray or brown. Made ${ }^{47}$ by fusion of $\mathrm{KAlSiO}_{4}$ with potassium fluosilicate. PD 10.0, 2.62, $3.34 ; 10-435^{*}$.
$\mathbf{A l}_{4}(\mathbf{O H})_{8} \mathbf{S i}_{4} \mathbf{O}_{10}$ has three phases. ${ }^{47 a}$ The low temperature $\gamma$-phase (kaolinite) is triclinic pinacoidal with $a=5.14, b=8.93, c=7.37 \AA$, $\alpha=91^{\circ} 48^{\prime}, \beta=104^{\circ} 30^{\prime}, \gamma=90^{\circ}$. U.C. 2. Crystals pseudo-hexagonal flakes often curved in vermicular groups with twinning as in mica. Perfect $\{001\}$ cleavage. H. 2.-2.5. G. 2.61. F. 7. Insoluble in acids. Loses water at about $450^{\circ} \mathrm{C}$. X makes an angle of $3^{\circ}$ with a normal to $\{001\} ; \mathrm{Z}=b$. $(-) 2 \mathrm{~V}=20^{\circ}-55^{\circ}, \mathrm{r}>\mathrm{v}$ weak. $n_{\mathrm{X}}=1.561, n_{\mathrm{Y}}=1.565, n_{\mathrm{Z}}=1.566$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.006$. With more $\mathrm{H}_{2} \mathrm{O}(18.7 \%) n_{\mathrm{X}}=1.526, n_{\mathrm{Y}}=?, n_{\mathrm{Z}}=$ $1.543, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.017$. Colorless or rarely tinted buff. PD 7.15, 3.57, $2.33 ; 5-0143 / 4^{*}$. Made by heating the constituents ${ }^{48}$ in an autoclave at

[^167]200-260 atmospheres for 288 hours. It has also been made at ordinary temperature while dickite (the $\beta$-phase) has been made at $350^{\circ}$ and nacrite (the $\alpha$-phase) is probably stable at still higher temperatures. Dickite is monoclinic domatic with $a=5.15, b=8.95, c=28.68 \AA ., \beta=96^{\circ} 49^{\prime}$. U.C. 4. Crystals basal scales with perfect $\{001\}$ cleavage. H. 2.5-3. G. 2.62. F. 7. Loses water at about $550^{\circ} \mathrm{C} . \mathrm{X} \wedge \perp\{001\}=+15^{\circ}$ to $20^{\circ}\left(3^{\circ}\right.$ greater for red than for blue); $\mathrm{Z}=b$. ( $+2 \mathrm{~V}=68^{\circ}-80^{\circ}, \mathrm{r}<\mathrm{v} . n_{\mathrm{x}}=1.560$, $n_{\mathrm{Y}}=1.562, n_{\mathrm{Z}}=1.566, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.006$. Extinction angle in (010) (Y $\wedge a=$ trace of cleavage) distinctly greater in red than in violet light. Colorless. PD 7.15, 3.58, 2.33; 10-446*. Made at $350^{\circ}$ C. Nacrite is also monoclinic domatic with $a=5.15, b=8.95, c=28.70 \AA, \beta=91^{\circ} 43^{\prime}$. U.C. 4. Pseudohexagonal by twinning. Perfect $\{001\}$ and good $\{010\}$ and $\{110\}$ cleavages. H. 2.5-3. G. 2.5 ca . F. 7, but exfoliates. Retains part of its water to $600^{\circ} \mathrm{C}$. or more. $\mathrm{Y} \wedge a=10^{\circ}-12^{\circ} ; \mathrm{Z}=b$. (-) $2 \mathrm{~V}=40^{\circ}, \mathrm{r}>\mathrm{v}$. Also (+)2V $=90^{\circ}$ ca. $\mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=1.557, n_{\mathrm{Y}}=1.562, n_{\mathrm{Z}}=1.563, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.006$. With $0.34 \mathrm{Fe}_{2} \mathrm{O}_{3}:(-) 2 \mathrm{~V}=80^{\circ}, n_{\mathrm{X}}=1.560, n_{\mathrm{Y}}=1.563$, $n_{\mathrm{Z}}=1.566, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.006$. On dehydration $n_{\mathrm{X}}$ is still 1.561 at $350^{\circ} \mathrm{C}$., 1.540 at $400^{\circ}$ C., 1.509 at $500^{\circ}$ C., then suddenly increases to 1.528 at $800^{\circ}$ C. PD 7.23, 3.59, 1.49; 7-320*.
$\mathrm{KCa}_{4} \mathrm{FSi}_{8} \mathrm{O}_{20} \cdot \mathbf{8 H _ { 2 }} \mathbf{O}$ (Apophyllite) is ditetragonal dipyramidal with $a=9.00, c=15.8 \AA$. U.C. 2. Na may replace some K and OH some F . Crystals prismatic with perfect $\{001\}$ and poor $\{110\}$ cleavages. H. 4.5-5. G. 2.3-2.4. F. 1.5 with exfoliation. Decomposed to silica by HCl. Uniaxial and positive or, less commonly, negative; sometimes basal sections are divided into sectors some of which are biaxial with axial planes crossed for red and blue light as in brookite; the biaxial condition may be produced by lateral pressure or change of temperature. Strikingly abnormal interference colors and interference figures are due to marked dispersion of the birefringence, which may be zero in any part of the spectrum, the corresponding color then being absent in the interference tints. The abnormal colors may disappear at about $275^{\circ} \mathrm{C}$. (due to inversion?). Wenzel ${ }^{49}$ found:

|  | Positive |  |  | Isotropic (Na) |  |  | Negative |  |  |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $n_{\mathrm{O}}$ | $n_{\mathrm{E}}$ | $n_{\mathrm{Z}}-n_{\mathrm{O}}$ | $n_{\mathrm{O}}$ | $n_{\mathrm{E}}$ | $n_{\mathrm{E}}-n_{\mathrm{O}}$ | $n_{\mathrm{O}}$ | $n_{\mathrm{E}}$ | $n_{\mathrm{O}}-n_{\mathrm{E}}$ |
| Li | 1.532 | 1.534 | 0.002 | 1.5381 | 1.5384 | 0.003 | 1.5415 | 1.5415 | 0.0000 |
| Na | 1.535 | 1.537 | 0.002 | 1.5418 | 1.5418 | 0.0000 | 1.5433 | 1.5429 | 0.0004 |
| Tl | 1.538 | 1.540 | 0.002 | 1.5438 | 1.5438 | 0.0000 | 1.5448 | 1.5439 | 0.0009 |

Colorless or stained by impurities. Made by heating the powdered mineral to about $160^{\circ} \mathrm{C}$. under pressure ${ }^{50}$ in water with $\mathrm{CO}_{2}$. Biaxial types ${ }^{51}$ with

[^168]OH (in place of F ) are positive with $\mathrm{r}<\mathrm{v}$ and have higher indices than those which have $\mathrm{r}>\mathrm{v}$. PD 3.94, 2.98, 1.58; 7-170.
$\mathbf{C a}_{4}(\mathbf{O H})_{2} \mathbf{S i}_{6} \mathbf{O}_{15} \cdot \mathbf{3} \mathbf{H}_{2} \mathbf{O}$ (Gyrolite) is hexagonal with ${ }^{52} a=9.72, c=$ $132.8 \AA$. Crystals lamellar with perfect basal cleavage. H. 3-4. G. $2.34-2.45$. F. difficult, with swelling. Soluble in acid. Uniaxial negative with $^{53} n_{\mathrm{O}}=1.545, n_{\mathrm{E}}=1.535, n_{\mathrm{O}}-n_{\mathrm{E}}=0.010$. Again: ${ }^{54} n_{\mathrm{O}}=1.548$, $n_{\mathrm{E}}=1.536, n_{\mathrm{O}}-n_{\mathrm{E}}=0.012$. Colorless or white. Made by hydrothermal methods. PD 22., 3.12, 11.0; 9-449.
$(\mathbf{M g}, \mathbf{F e})_{3}(\mathbf{O H})_{2} \mathbf{S i}_{3} \mathrm{AlO}_{10} \cdot 4 \mathbf{H}_{2} \mathrm{O}(?)$ (Vermiculite) is monclinic with $a=$ $5.33, b=9.18, c=28.85 \AA, \beta=93^{\circ} 15^{\prime}$. Composition uncertain and variable. Crystals lamellar with much swelling when heated. X is normal to $\{001\}$. (-) $2 \mathrm{~V}=0^{\circ}-8^{\circ} .{ }^{.55} \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{X}}=1.525, n_{\mathrm{Y}} \approx n_{\mathrm{Z}}=1.545, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.020$ with $4.24 \mathrm{Fe}_{2} \mathrm{O}_{3}$ and 0.68 FeO . And with $6.35 \mathrm{Fe}_{2} \mathrm{O}_{3}$ and 8.61 FeO (also $1.74 \mathrm{TiO}_{2}$ ) $n_{\mathrm{Y}}>1.586$. Color brown or green with X colorless, Y and Z pale brown. Mg can be replaced by Ni artificially. ${ }^{56}$ With 11.25 NiO a sample had: ${ }^{57}(-) 2 \mathrm{~V}=0^{\circ}-8^{\circ}, \mathrm{r}>\mathrm{v}$ weak, $n_{\mathrm{X}}=1.542, n_{\mathrm{Y}} \approx n_{\mathrm{Z}}=$ $1.573, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.031$. Pleochroic with X pale green, Y and Z pale yellowish to brownish green. PD 14.2, 3.52, 1.53; 10-418*.
$\mathrm{KFe}_{2}(\mathrm{Fe}, \mathbf{M g}, \mathrm{Al})_{5} \mathrm{Si}_{8} \mathrm{O}_{20} \cdot \mathbf{4 \mathrm { H } _ { 2 } \mathrm { O } ( ? )}$ (Stilpnomelane) varies notably in composition and the formula is quite uncertain. The Fe may be nearly all ferrous or ferric. It is monoclinic with $a=5.39, b=9.40, c \sin \beta=12.12 \AA$, $\beta=97^{\circ}$ ca. U.C. 1. Perfect $\{001\}$ cleavage. H. 1.5. G. 2.6-2.83. X nearly normal to $\{001\}$. (-) 2 V very small, $n_{\mathrm{X}}=1.546, n_{\mathrm{Y}} \approx n_{\mathrm{Z}}=1.576, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.030$ and G. 2.59 for a ferrous iron sample and $n_{\mathrm{X}}=1.625, n_{\mathrm{Y}} \approx$ $n_{\mathrm{Z}}=1.735, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.110$ and G. 2.83 for a ferric iron sample. A sample from Lahn with G. 2.823, $n_{\mathrm{X}}=1.565, n_{\mathrm{Y}} \approx n_{\mathrm{Z}}=1.623$ and $n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.058 , after oxidizing before the blowpipe had $n=1.77$ and after base exchange ${ }^{58}$ of Tl for K (in Clerici solution) had G. 3.066, $n_{\mathrm{x}}=1.574$, $n_{\mathrm{Y}} \approx n_{\mathrm{Z}}=1.651, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.077$; and after this had been heated in the oxidizing flame it had $n=1.80$. PD 11.9, 4.04, 3.03; $2-0036$.
$\mathrm{Al}(\mathrm{OH}) \mathrm{Si}_{2} \mathrm{O}_{5} \cdot 2 \mathrm{H}_{2} \mathrm{O}(?)$ (Leverrierite) is one of the formulas in the montmorillonite system; it is monoclinic (or orthorhombic?) with ${ }^{59} a=5.15$, $b=8.95, c=15-15.5 \AA$. It varies much in composition. Crystals thin lamellar or vermicular with perfect basal cleavage. H. 1.5. G. 2.5-2.6. X is

[^169](nearly) normal to $\{001\} ; \mathrm{Y}=b$. ( - ) $2 \mathrm{~V}=0^{\circ}-33^{\circ}$ (rarely large). Optic properties vary with tenor of MgO and $\mathrm{H}_{2} \mathrm{O}$ but much more with tenor of $\mathrm{Fe}_{2} \mathrm{O}_{3}$. Data follow: ${ }^{60}$

| $\frac{100 \mathrm{Fe}^{\prime \prime \prime}}{\mathrm{Fe}^{\prime \prime \prime}+\mathrm{Al}}$ | $=1.4$ | 9.3 | 42.9 | 81.9 | 87.4 |
| :--- | :--- | :--- | :--- | :--- | :--- |
| $(-) 2 \mathrm{~V}$ | $=$ | $12^{\circ}-25^{\circ}$ | $30^{\circ}$ |  | $26^{\circ}$ |
| $n_{\mathrm{X}}$ | $=1.488$ | 1.543 | 1.559 | 1.589 | 1.585 |
| $n_{\mathrm{Y}}$ | $=$ | $1.565-$ | $1.588-$ | 1.600 | 1.593 |
| $n_{\mathrm{Z}}$ | $=1.513$ | 1.565 | 1.588 | 1.610 | 1.608 |
| $n_{\mathrm{Z}}-n_{\mathrm{X}}$ | $=0.025$ | 0.022 | 0.029 | 0.021 | 0.023 |

Without Fe montmorillonite is colorless, but it is often colored dark olive green to yellow, orange or brown by iron; then pleochroic with X colorless, yellow-green or yellow-brown, Y brown, green or yellow, Z brown, green or yellow. PD 14., 4.41, 2.51; 3-0016*.
$\mathrm{Fe}(\mathrm{OH}) \mathrm{Si}_{2} \mathrm{O}_{5} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ (Nontronite) is monoclinic(?) with $a=5.23, b=$ $9.11, c=15-15.5 \AA$. In nature it often contains some Na and Al. Crystals thin lamellar with perfect basal cleavage. H. 1.5. G. 2.6. X nearly normal to $\{001\} ; \mathrm{Y}=b .(-) 2 \mathrm{~V}=40^{\circ} c a .^{61} n_{\mathrm{X}}=1.617, n_{\mathrm{Y}}=1.637$ calc., $n_{\mathrm{Z}}=$ $1.640, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.023$. Color green, yellow or brown and pleochroic. It forms a complete series with $\mathrm{Al}(\mathrm{OH}) \mathrm{Si}_{2} \mathrm{O}_{5} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ (Leverrierite). With increasing Al the indices and optic angle decrease and for $\mathrm{Al}(\mathrm{OH}) \mathrm{Si}_{2} \mathrm{O}_{5} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ $(-) 2 \mathrm{~V}=10^{\circ}$ ca. $n_{\mathrm{X}}=1.485, n_{\mathrm{Y}}=1.509$ calc., $n_{\mathrm{Z}}=1.510, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.025 . The properties also vary with varying tenor of $\mathrm{H}_{2} \mathrm{O}$; for example, for a sample with about 60 per cent of Fe replaced by Al, $n_{\mathrm{Y}}$ at $15^{\circ}=$ 1.585 , at $75^{\circ}=1.615$, at $160^{\circ}=1.655$, and at $290^{\circ}=1.69$. Nontronite decomposes at $350^{\circ} \mathrm{C}$. The nontronite-leverrierite series is part of the montmorillonite system. PD 15.6, 4.55, 1.82; 2-0004*.
$\mathbf{K}_{2} \mathbf{C a}_{3} \mathbf{S i}_{6} \mathbf{O}_{16}$ has $^{61 a}$ two phases. The high temperature $\alpha$-phase is orthorhombic. ${ }^{10}$ Crystals prismatic with parallel extinction. Decomposes at $1115^{\circ} \mathrm{C} .(+) 2 \mathrm{~V}=$ large. $n_{\mathrm{X}}=1.575, n_{\mathrm{Y}}=1.582$ est., $n_{\mathrm{Z}}=1.590, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.015$. Colorless. The low temperature $\beta$-phase is also orthorhombic. Crystals acicular with parallel extinction. Inverts at $960^{\circ} \mathrm{C}$. (-) $2 \mathrm{~V}=$ ? $n_{\mathrm{X}}=1.56, n_{\mathrm{Y}}=?, n_{\mathrm{Z}}=1.57, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.01$. Colorless.
$\mathrm{NaBe}(\mathrm{OH}) \mathrm{Si}_{3} \mathrm{O}_{7}$ is dimorphous. ${ }^{61 \mathrm{~b}}$ One phase (epididymite) is orthorhombic with $a=12.63, b=7.32, c=13.58 \AA$. Crystals basal plates. Twinning on $\{001\}$. Perfect $\{001\}$ and $\{100\}$ cleavages. H. 6. G. 2.548.

[^170]F. 3. $\mathrm{Y}=c ; \mathrm{Z}=a .(+) 2 \mathrm{~V}=31^{\circ}, \mathrm{r}>\mathrm{v} . n_{\mathrm{X}}=1.5440, n_{\mathrm{Y}}=1.5441$, $n_{\mathrm{Z}}=1.5464, n_{\mathrm{z}}-n_{\mathrm{x}}=0.0024$. Colorless. The other phase (eudidymite) is monoclinic prismatic with $a=12.62, b=7.37, c=13.99 \AA, \beta=103^{\circ} 43^{\prime}$. Crystals basal plates with lamellar twinning on $\{001\}$. Perfect $\{001\}$ and poor $\{110\}$ cleavages. H. 6. G. 2.553. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=-58.5^{\circ} .(+) 2 \mathrm{~V}=$ $30^{\circ}, \mathrm{r}>\mathrm{v}$ distinct. $n_{\mathrm{X}}=1.545, n_{\mathrm{Y}}=1.546, n_{\mathrm{Z}}=1.551, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.006$. Colorless.
$\mathbf{K}_{2} \mathrm{Ca}_{2}\left(\mathbf{S i}_{3} \mathbf{O}_{7}\right)_{3}$ is monoclinic or triclinic. ${ }^{61 \mathrm{a}}$ Crystals prisms or plates with a small extinction angle. (-) $2 \mathrm{~V}=$ large. $n_{\mathrm{X}}=1.51 .5, n_{\mathrm{Y}}=1.53$ (est.), $n_{\mathrm{Z}}=1.535, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.020$. Colorless.
\[

$$
\begin{aligned}
& \text { D. INOSILICATES (CHAINS OF TETRAHEDRA): } \\
& \mathrm{A}_{m}\left(\mathrm{XO}_{3}\right)_{n} \text { OR } \mathrm{A}_{m}\left(\mathrm{X}_{4} \mathrm{O}_{11}\right)_{n} Z_{q}
\end{aligned}
$$
\]

$\mathbf{N a}_{4} \mathrm{CaSi}_{3} \mathbf{O}_{9}$ is isometric, ${ }^{1}$ Crystals octahedral, etc. Decomposes at $1141^{\circ}$ C. Isotropic with $n=1.571$. Colorless. PD 2.68, 1.89, 1.54; 1-1064.
$\mathbf{K}_{4} \mathrm{CaSi}_{3} \mathbf{O}_{9}$ is isometric(?). Crystals octahedral. ${ }^{2}$ Decomposes at $1005^{\circ} \mathrm{C}$. Isotropic with $n=1.572$. Colorless.
$\mathbf{K}_{4} \mathbf{B e}_{3} \mathbf{S i}_{4} \mathbf{O}_{12}$ is isometric with ${ }^{3}$ G. 2.53 and $n=1.523$; also weakly birefringent like leucite.
$\mathbf{L i}_{4} \mathbf{K}_{10} \mathbf{S i}_{7} \mathbf{O}_{21}$ is isometric. ${ }^{4}$ M.P. $900^{\circ}$ C. Isotropic with ${ }^{5} n=1.540$. Colorless.
$\mathbf{L i}_{2} \mathbf{S i O}_{3}$ has at least two crystal phases; one is tetragonal ${ }^{6}$ with $a=9.39$, $c=5.92 \AA$. Crystals acicular. Uniaxial positive with $n_{\mathrm{O}}=1.587, n_{\mathrm{E}}=$ $1.599, n_{\mathrm{E}}-n_{\mathrm{O}}=0.012$. Again: ${ }^{7} n_{\mathrm{O}}=1.591, n_{\mathrm{E}}=1.611, n_{\mathrm{E}}-n_{\mathrm{O}}=$ 0.020. Colorless. Another phase is pseudo-hexagonal and orthorhombic with $^{8} a=5.43, b=9.41, c=4.66 \AA$. Crystals prismatic with poor cleavage parallel with elongation. G. 2.48. M.P. $1202^{\circ} \mathrm{C} . \mathrm{Y}=b ; \mathrm{Z}=c .(+) 2 \mathrm{~V}=$ small. $n_{\mathrm{X}} \approx n_{\mathrm{Y}}=1.65, n_{\mathrm{Z}}=1.67 \mathrm{ca} ., n_{\mathrm{Z}}-n_{\mathrm{X}}=0.02 \mathrm{ca}$. Colorless. Made from fusion with LiCl. The glass has G. 2.35 and $n=1.548$. PD 4.70, 2.72, 1.57; 4-0273.
$\mathbf{N a}_{10} \mathbf{F e}_{2} \mathrm{Si}_{8} \mathbf{O}_{24}$ is hexagonal. ${ }^{9}$ Crystals are prismatic. M.P. $838^{\circ}$ C. Uni-

[^171]axial positive with $n_{\mathrm{O}}=1.609, n_{\mathrm{F}}=1.625, n_{\mathrm{E}}-n_{\mathrm{O}}=0.016$. Colorless. The glass has $n=1.583$.
$\mathbf{Z n S i O}_{3}$ is hexagonal or orthorhombic. ${ }^{10}$ It forms masses of needles somewhat like mullite. M.P. $1429^{\circ}$ C. G. 3.52. $n_{\mathrm{X}}=1.616, n_{\mathrm{Z}}=1.623, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.007$. Found in some fireclay zinc retorts. ${ }^{10}$
$\mathbf{B a S i O}_{3}$ is orthorhombic ${ }^{11}$ in needles or grains. G. 4.4. M.P. $1604^{\circ} \mathrm{C}$. Cleavage normal to $\mathrm{Z} .(+) 2 \mathrm{~V}=29^{\circ}, \mathrm{r}>$ v strong. $n_{\mathrm{X}}=1.669 \mathrm{C}, 1.673 \mathrm{D}$, $1.682 \mathrm{~F}, n_{\mathrm{Y}}=1.670 \mathrm{C}, 1.674 \mathrm{D}, 1.684 \mathrm{~F}, n_{\mathrm{Z}}=1.673 \mathrm{C}, 1.678 \mathrm{D}, 1.688 \mathrm{~F}$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.005 \mathrm{D}$. Colorless. Made from fusion. PD 3.43, 3.36, 3.73; 6-0247.
$\mathbf{B a}_{2} \mathbf{S i}_{3} \mathbf{O}_{8}(?)$ is orthorhombic and isomorphous with $\mathrm{BaSiO}_{3}$. It has three pinacoidal cleavages, ${ }^{11}$ the best being normal to Z. G. 3.93. $(+) 2 \mathrm{~V}=58^{\circ}$, $n_{\mathrm{X}}=1.620, n_{\mathrm{Y}}=1.625, n_{\mathrm{Z}}=1.645, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.025$. Colorless. Made from fusion. PD 3.79, 3.33, 3.28; 6-0206. It forms a series of mix-crystals with $\mathrm{BaSiO}_{3}$. (See also p. 256.)
$\mathbf{N a}_{2} \mathbf{S i O}_{3}$ is orthorhombic ${ }^{12}$ in needles with prismatic cleavage. M.P. $1086^{\circ}$ C. G. 2.61. Z parallel with prisms. ( -$) 2 \mathrm{~V}=80^{\circ}, n_{\mathrm{X}}=1.513, n_{\mathrm{Y}}=$ $1.520, n_{\mathrm{Z}}=1.528, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.015$. Again: ${ }^{13} n_{\mathrm{X}}=1.49, n_{\mathrm{Y}}=1.50, n_{\mathrm{Z}}=$ $1.51, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.02$. Colorless. PD 3.04, 2.40, 2.57; 1-0836.
$\mathbf{L i N a S i O}_{3}$ is orthorhombic ${ }^{14}$ in prisms with prismatic cleavage and positive elongation. M.P. $847^{\circ} \mathrm{C} .(+) 2 \mathrm{~V}=$ large, $n_{\mathrm{X}}=1.552, n_{\mathrm{Y}}=1.557$, $n_{\mathrm{Z}}=1.571, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.019$. It forms a complete series of mix-crystals with $\mathrm{Na}_{2} \mathrm{SiO}_{3}$ whose optic properties are shown in Fig. 10-19.
$\mathbf{N a} \mathbf{a}_{2} \mathbf{T i}_{2} \mathbf{S i}_{2} \mathbf{O}_{9}$ (Lorenzenite) is orthorhombic ${ }^{15}$ with $a=8.66, b=14.42$, $c=5.18 \AA$. Crystals acicular with distinct $\{010\}$ cleavage. H. 6. G. 3.43. F. easy. $\mathrm{X}=b ; \mathrm{Y}=a$. $(-) 2 \mathrm{~V}=38^{\circ}-40^{\circ}, \mathrm{r}>\mathrm{v}$ distinct. $n_{\mathrm{X}}=1.91$, $n_{\mathrm{Y}}=2.01, n_{\mathrm{Z}}=2.02, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.12$. Brown to black with X and Y pale reddish yellow, Z pale yellow. Synthesized. ${ }^{15}$
$\mathbf{K}_{2} \mathbf{S i O}_{3}$ is orthorhombic(?). M.P. $960^{\circ} \mathrm{C}$. Z parallel cleavage. $(+) 2 \mathrm{~V}=$ $35^{\circ}, \mathrm{r}<$ v strong. $n_{\mathrm{X}}=1.520, n_{\mathrm{Y}}=1.521, n_{\mathrm{Z}}=1.528, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.008$. Colorless. Made from fusion.
$\mathrm{Al}_{4} \mathrm{OSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{12}$ (Mullite) is orthorhombic with ${ }^{16} a=7.49, b=7.63, c=$ $2.87 \AA$. It often contains more $\mathrm{Al} ; \mathrm{Fe}^{\prime \prime \prime}$ and Ti may be present; also F and OH . Crystals prismatic with distinct $\{010\}$ cleavage. G. 3.0. M.P. $1810^{\circ}$ C.

[^172]

Fig. 10-19. Variations in properties of the series $\mathrm{Na}_{2} \mathrm{SiO}_{3}-\mathrm{NaLaSiO}_{3}-\mathrm{Li}_{2} \mathrm{SiO}_{3}$. Modified after Kracek. ${ }^{14}$
$\mathrm{Y}=b ; \mathrm{Z}=c$. Optic properties vary notably with varying tenor of $\mathrm{Fe}_{2} \mathrm{O}_{3}$ and $\mathrm{TiO}_{2}$. Data follow:

| $\mathrm{Fe}_{2} \mathrm{O}_{3}$ | $\mathrm{TiO}_{2}$ | (+)2V | $n_{\text {x }}$ | $n_{\text {Y }}$ | $n_{\mathrm{z}}$ | $n_{\mathrm{z}}-n_{\text {x }}$ | Authority |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.0 (art.) | 0.0 | $45^{\circ}-50^{\circ}$ | 1.642 | 1.644 | 1.654 | 0.012 | Bowen ${ }^{17}$ |
| 0.50 | 0.79 | ? | 1.651 | ? | 1.668 | 0.017 | Bowen ${ }^{18}$ |
| 0.86 | 1.12 | ? | 1.653 | ? | 1.672 | 0.019 | Bowen ${ }^{18}$ |
| ? | 1.86 | ? | 1.648 | ? | 1.679 | 0.031 | Sawatari ${ }^{19}$ |

Colorless to pink or red with X and Y colorless, Z rose-pink. A second phase ${ }^{20}$ has $\mathrm{X}=c, n_{\mathrm{X}}=1.600, n_{\mathrm{Z}}=1.610$. Rare in nature, but very com-
${ }^{17}$ Bowen and Grieg: J. Am. Ceram. Soc. VII, p. 238 (1924).
${ }^{18}$ Bowen, Grieg and Zies: J. Wash. Acad. Sci. XIV, p. 183 (1924).
${ }^{19}$ Sawatari: Min. Abst. VI, p. 70 (1935).
${ }^{20}$ Hugill: Trans. Brit. Ceram. Soc. XXXIX, p. 121 (1940) [Min. Abst. VIII, p. 95].
mon in porcelain, etc., being the only compound of $\mathrm{Al}_{2} \mathrm{O}_{3}$ and $\mathrm{SiO}_{2}$ stable at high temperature. PD 3.38, 2.20, 3.41; 6-0258/9*.
$\mathbf{N a}_{8} \mathbf{C a}_{3} \mathbf{S i}_{5} \mathbf{O}_{17}$ is orthorhombic(?) in rectangular crystals with pinacoids and prisms. Melts incongruently at $1125^{\circ} \mathrm{C} .(+) 2 \mathrm{~V}=$ large. ${ }^{21}$ Mean index $n=1.620, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.002$. Colorless. Made from fusion. PD 3.98, 2.88, 2.73; 10-53.
$\mathbf{L i}_{2} \mathbf{K}_{10} \mathbf{S i}_{7} \mathbf{O}_{20}$ is orthorhombic(?) M.P. $880^{\circ}$ C. $2 \mathrm{~V}=13^{\circ} . n_{\mathrm{X}}=1.550$, $n_{\mathrm{Y}}=?, n_{\mathrm{Z}}=1.555, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.005$. Colorless.

Pyroxene Group
The pyroxene group includes compounds very closely related in crystallographic and other physical properties as well as in chemical composition although they crystallize in two crystal systems (orthorhombic and monoclinic). In all of them the common crystal form is the unit prism with angles of about $87^{\circ}$ and $93^{\circ}$ and with good prismatic cleavage parallel with these faces. Chemically the pyroxenes are metasilicates, $\mathrm{ABX}_{2} \mathrm{O}_{6}$, where $\mathrm{A}=\mathrm{Ca}$, $\mathrm{Na}, \mathrm{Mn}, \mathrm{Mg}, \mathrm{Fe} ; \mathrm{B}=\mathrm{Mg}, \mathrm{Fe}, \mathrm{Mn}, \mathrm{Al}$, and minor amounts of $\mathrm{Ti}, \mathrm{Cr}, \mathrm{V}$, etc.; $\mathrm{X}=\mathrm{Si}, \mathrm{Al}$, and probably $\mathrm{Ti}, \mathrm{Fe}^{\prime \prime \prime}$, V . All of these except V are common in natural pyroxenes. The chief pyroxene components are as follows:

|  | Orthorhombic |
| :--- | :--- |
| $\mathrm{MgSiO}_{3}$ | Protoenstatite <br> Enstatite |
| $(\mathrm{Mg}, \mathrm{Fe}) \mathrm{SiO}_{3}$ | Hypersthene |
| $(\mathrm{Fe}, \mathrm{Mg}) \mathrm{SiO}_{3}$ | Ferrosilite |
| $m(\mathrm{Ca}, \mathrm{Mg}, \mathrm{Fe})_{2} \mathrm{Si}_{2} \mathrm{O}_{6}+n(\mathrm{Al}, \mathrm{Fe})_{4} \mathrm{O}_{6}$ | Mellonite-Artificial only |
|  | Monoclinic |

$\mathbf{M g S i O}_{3}$ has three crystal phases. One, called protoenstatite, is stable ${ }^{23}$ above $990^{\circ} \mathrm{C}$.; another, known as enstatite, is stable below $990^{\circ} \mathrm{C}$.; a third, called clinoenstatite, is metastable below $985^{\circ} \mathrm{C}$. and stable above $1160^{\circ} \mathrm{C}$. Protoenstatite is orthorhombic with $a=9.25, b=8.92, c=5.25 \AA$. It was made by heating $\mathrm{MgSiO}_{3}$ with LiF at $1100^{\circ} \mathrm{C}$. for a week. Crystals are laths with Z parallel to elongation $(c) .(+) 2 \mathrm{~V}=70^{\circ} c a$. The refractive indices have not been measured but are said to be about the same as those of enstatite. PD 3.16, 1.96, 1.49; 3-0523. Enstatite is also orthorhombic with ${ }^{24} a=18.20, b=8.89, c=5.20 \AA$. Crystals short prismatic or $\{100\}$ or $\{010\}$ tablets. Distinct $\{110\}$ cleavages at about $88^{\circ} ;\{010\}$ or rare $\{100\}$ parting. H. 5.5. G. $3.1-3.3 . \mathrm{Y}=b ; \mathrm{Z}=c .(+) 2 \mathrm{~V}=55^{\circ} c a ., \mathrm{r}<\mathrm{v}$ weak. $n_{\mathrm{X}}=1.650, \quad n_{\mathrm{Y}}=1.653, \quad n_{\mathrm{Z}}=1.658, \quad n_{\mathrm{Z}}-n_{\mathrm{X}}=0.008$. Colorless. Made from fusion at temperatures below $990^{\circ}$ C. PD 3.17, 2.87, 2.49; 7-216. Clinoenstatite is monoclinic with $a=9.12, b=8.86, c=5.24 \AA$, $\beta=92^{\circ} 45^{\prime}$. Crystals short prismatic or $\{100\}$ tablets. Good $\{110\}$ cleavages at about $88^{\circ}$. Common twinning on $\{100\}$. Begins to dissociate at $1557^{\circ}$ and melts at $1577^{\circ}$. H. 6. G. 3.2. $\mathrm{X}=b ; \mathrm{Z} \wedge c=22^{\circ}$. (+) $2 \mathrm{~V}=53^{\circ}$. $n_{\mathrm{X}}=1.651, n_{\mathrm{Y}}=1.654, n_{\mathrm{Z}}=1.660, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.009$. Colorless. Made from $\mathrm{MgSiO}_{3}$ with Ca - or Mg -vanadate. PD 2.87, 2.97, 1.60; 3-0696.
$\mathbf{M g S i O}_{3}$ forms a continuous series of mix-crystals (solid solutions) in both its orthorhombic (enstatite) and its monoclinic phase with $\mathrm{FeSiO}_{3}$, to at least 85 per cent of the latter. Orthorhombic $\mathrm{MgSiO}_{3}$ with not over $13 \%$ (by some writers the limit is set at $20 \%$ ) to $50 \%$, hypersthene; with $50 \%$ to $87 \%$ (or $80 \%$ ) ferrohypersthene, and with more $\mathrm{FeSiO}_{3}$, ferrosilite or orthoferrosilite. The whole series has been named enstenite. ${ }^{25}$ Ferrohypersthene is pale to olive green, or brown. Hypersthene is green to brown, and pleochroic with X brownish red, Y reddish yellow, and Z green or blue. Optic data ${ }^{26}$ follow:

[^173]|  | Enstatite | Hypersthene |  | Ferrohypersthene | Ferrosilite |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Boundary limits | $\mathrm{x}=0.87$ |  | $\mathrm{x}=0.50$ | $\mathrm{x}=0.13$ |  |
| $x=\mathrm{Mg} /\left(\mathrm{Mg}+\mathrm{Fe}^{\prime \prime}+\mathrm{Fe}^{\prime \prime \prime}\right)$ | 1.00 | 0.75 | 0.50 | 0.25 | 0.00 |
| $a$ | 18.228 | 18.279 | 18.330 | 18.382 | 18.433 |
| $b$ | 8.805 | 8.869 | 8.932 | 9.001 | 9.065 |
| $c$ | 5.185 | 5.203 | 5.222 | 5.240 | 5.258 |
| $n_{\text {X }}$ | 1.6569 | 1.6843 | 1.7117 | 1.7390 | 1.7664 |
| $n_{\mathbf{Y}}$ (calc.) | 1.6585 | $1.692_{0}$ | $1.724_{5}$ | $1.752_{4}$ | $1.770_{6}$ |
| $n_{\mathrm{Z}}$ | 1.6650 | 1.6959 | 1.7268 | 1.7576 | 1.7885 |
| $n_{\mathrm{Z}}-n_{\mathrm{X}}$ | 0.0081 | 0.0116 | 0.0151 | 0.0186 | 0.0221 |
| $2 \mathrm{~V}_{\mathrm{z}}$ | $53^{\circ}$ | $111^{\circ}$ | $133^{\circ}$ | $111{ }^{\circ}$ | $53^{\circ}$ |
| 2 Vx | $127^{\circ}$ | $69^{\circ}$ | $47^{\circ}$ | $69^{\circ}$ | $127^{\circ}$ |
| G | 3.215 | 3.352 | 3.588 | 3.775 | 3.962 |

Data in the above table are for "Bushveld type" ${ }^{26}$ specimens having an average of about $2.75 \%$ (wt.) of $\left(\mathrm{Fe}^{\prime \prime \prime}, \mathrm{Al}\right)_{2} \mathrm{O}_{3}$. The optic sign is ( - ) in the middle three-fourths of the series, but ( + ) for the last 0.13 at each end. Exsolution lamellae containing clinopyroxene that holds most of the Ca that was probably in solid solution in the enstenite when it formed at high temperature, are fairly common in orthopyroxenes of the Bushveld type, which cooled slowly after crystallizing. The lamellae commonly cause a characteristic bronze-like luster. Materials containing less of the sesquioxide components have lower refractive indices, smaller $c$, and larger $a$ and $b$. Many natural specimens have significantly higher tenor of sesquioxides ( $\mathrm{Al}, \mathrm{Fe}^{\prime \prime \prime}$ ) substituting for Mg , and Al for Si (or perhaps OH for O ) to maintain valency balance. $2 \mathrm{~V}_{\mathrm{x}}$ seems to be a few degrees larger in specimens from volcanic lavas that presumably cooled quickly, but the cause of this difference has not been determined. PD 3.20, 2.89, 1.49; 2-0520 ("hypersthene").
( $\left.\mathbf{C a}, \mathbf{M g}, \mathbf{F e}^{\prime \prime}, \mathbf{F e}^{\prime \prime \prime}, \mathbf{A l}\right)_{2}(\mathbf{S i}, \mathbf{A l})_{2} \mathbf{O}_{6}$ (Mellorite) is formed in ceramic materials. It is orthorhombic with perfect prismatic cleavages at $88^{\circ}$. It is probably a pyroxene. $(+) 2 \mathrm{~V}=75^{\circ} \mathrm{ca}$. (calc.). $n_{\mathrm{X}}=1.92, n_{\mathrm{Y}}=1.95 \mathrm{ca}$., $n_{\mathrm{Z}}=2.00, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.08$. Strongly pleochroic with sage green to deep reddish brown in longitudinal sections, and pale yellow-brown to deep reddish brown in cross sections.
( $\left.\mathbf{M g}_{1-x} \mathbf{F e}_{\mathrm{x}}\right)_{2} \mathbf{S i}_{2} \mathrm{O}_{6}$ (Clinoenstenite) is monclinic. It rarely forms macroscopic crystals. Colorless to yellow, brown, green, or black, with increasing Fe. Pleochroism faint to strong, X yellowish green, Y brownish pink, Z greenish; again, X and Y smoky brown, Z pale yellow; again, X pink or flesh colored, Y pale yellowish green, Z pale green. Made from fusion.

Properties of intermediate members of the series may be obtained by linear interpolation between either end and the middle of the series, whose constants were obtained by algebraic extrapolation using many clinopyroxenes as basis, and least squares procedures to obtain the several regression coefficients, and assuming an ordered distribution of Fe and Mg in the lattice.

Lattice Constants-See Fig. 10-20

| Reference | Clinoenstatite, $\mathrm{x}=0$ |  |  | Clino- <br> hypersthene, $\mathrm{x}=0.5$ |  |  | Clino-$\text { ferrosilite, } \mathrm{x}=1$ |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 27 | 27a | 27b | 27 | 27a | 27b | 27 | 27a | 27b |
| $\begin{aligned} & a \\ & a \sin \beta \\ & b \\ & c \\ & \beta \end{aligned}$ | 9.618 |  | 9.618 | 9.717 |  | 9.69 | 9.84 |  | 9.7 |
|  |  | 9.03 |  |  | 9.18 |  |  | 9.33 |  |
|  | 8.826 | 8.84 | 8.828 | 8.994 | 8.97 | 8.95 | 9.118 | 9.10 | 9.1 |
|  | 5.187 |  | 5.186 | 5.244 |  | 5.25 | 5.257 |  | ? |
|  | $108^{\circ} 25^{\prime}$ |  | $108^{\circ} 22^{\prime}$ | $109^{\circ} 03^{\prime}$ |  | $>108^{\circ} 33^{\prime}$ | $107^{\circ} 25^{\prime}$ |  | $109^{\circ} \pm$ |
|  | Optical Properties-See Fig. 10-21a, 10-21b |  |  |  |  |  |  |  |  |
| Reference | 27e | 27 |  | 28 | 27 |  | 28 | 27 |  |
| $n \mathrm{x}$ | 1.651 | $1.6484 \pm .0031$ |  | 1.710 | $1.7079 \pm .0043$ |  | 1.763 | $1.7677 \pm .0045$ |  |
| $n_{\text {Y }}$ | 1.654 | 1.6503 . 0030 |  | 1.715 | 1.7089 . 0041 |  | 1.763+ | 1.7691 .0042 |  |
| $n_{\text {z }}$ | 1.660 | 1.6605 . 0033 |  | 1.735 | 1.7370 . 0045 |  | 1.794 | 1.7976 . 0046 |  |
| $n_{\mathrm{z}}-n_{\mathrm{x}}$ | 0.009 | 0.0121 . 0045 |  | 0.025 | 0.0291 . 0059 |  | 0.031 | 0.0299 .0061 |  |
| $\mathrm{Z}<c$ | 22 | $\left\lvert\, \begin{aligned} & 22.4 \\ & 3.209 \end{aligned}\right.$ | $\begin{array}{r} 1.9 \\ .044 \end{array}$ | 40 | $\begin{array}{\|l\|} \hline 41.4 \\ 3.519 \end{array}$ | 1.9.046 | 34.5 | $\begin{array}{\|l\|} \hline 44.1 \\ 3.797 \end{array}$ | $\begin{array}{r} 2.7 \\ .069 \end{array}$ |
| G | 3.19 |  |  |  |  |  |  |  |  |

Clinoenstenite containing small amounts of Ca and Al is very common in nature in the minerals known as pigeonite (with $\mathrm{Mg}>\mathrm{Fe}$ ) and ferropigeonite (with $\mathrm{Mg}<\mathrm{Fe}$ ). Replacement of Mg by Ca in position A of the generalized formula $\mathrm{ABC}_{2} \mathrm{O}_{6}$ increases the indices, birefringence, extinction angle, and specific gravity and decreases the optic angle 2 V . Replacement of Fe by Ca in position A decreases these constants, except that the extinction angle is virtually unaffected. Ca almost certainly cannot fit into position B in pigeonite. Pigeonite, like clinoenstenite, has $\mathrm{X}=b$, as long as the already small optic angle 2 V is not reduced to (and beyond)

[^174]


Fig. $10-21 \mathrm{a}, 10-21 \mathrm{~b}$. Variations

Al (per six oxygens) replace Si , and $\mathrm{x}_{3}$ atoms of Al replace Mg in position B, $\mathrm{x}_{4}$ atoms of $\mathrm{Fe}^{\prime \prime \prime}$ replace Mg in B , and $\mathrm{x}_{5}$ atoms of Ti replace Mg in B , then we can write,

$$
\begin{aligned}
& n_{\mathrm{X}}=n_{\mathrm{X}}^{\prime}+0.0460 \mathrm{x}_{1}-0.0341 \mathrm{x}_{3}+0.0810 \mathrm{x}_{4}+0.1186 \mathrm{x}_{5} \\
& n_{\mathrm{Y}}=n_{\mathrm{Y}}^{\prime}+0.0469 \mathrm{x}_{1}-0.0567 \mathrm{x}_{3}+0.0889 \mathrm{x}_{4}+0.1198 \mathrm{x}_{5} \\
& n_{\mathrm{z}}=n_{\mathrm{z}}^{\prime}+0.0387 \mathrm{x}_{1}-0.0714 \mathrm{x}_{3}+0.0815 \mathrm{x}_{4}+0.1251 \mathrm{x}_{5}
\end{aligned}
$$

where the primed $n$ 's are values obtained from Fig. 10-21, assuming that all Al not replacing Si , and all $\mathrm{Fe}^{\prime \prime \prime}$ and Ti are counted as Mg in reading the chart. With Fe and Ti , the color tends to be darker than without them. For example, X greenish yellow, Y brownish red or violet, Z greenish yellow, reddish, or violet.

Some observed values for analyzed specimens of natural augite are:

| FeO | $(+) 2 \mathrm{~V}$ | $n_{\mathrm{X}}$ | $n_{\mathrm{Y}}$ | $n_{\mathrm{Z}}$ | $n_{\mathrm{Z}}-n_{\mathrm{X}}$ | $\mathrm{Z} \wedge c$ | G |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $0.8^{38}$ | $59^{\circ}$ | 1.678 | 1.685 | 1.703 | 0.025 | $40^{\circ}$ | 3.18 |
| $4.6^{39}$ | $59^{\circ}$ | 1.687 | 1.694 | 1.713 | 0.026 | $41^{\circ}$ |  |
| $24.6^{40}$ | $49^{\circ}$ | 1.726 | 1.732 | 1.753 | 0.027 | $44^{\circ}$ | 3.48 |

Artificial $\mathrm{CaMgSi}_{2} \mathrm{O}_{6}$ (Diopside) may take $\mathrm{Al}_{2} \mathrm{O}_{3}$ or $\mathrm{Fe}_{2} \mathrm{O}_{3}$ or $\mathrm{TiO}_{2}$ in crystal solution with results as follows: ${ }^{41}$

| $\mathrm{CaMgSi}_{2} \mathrm{O}_{6}$ | $\mathrm{Al}_{2} \mathrm{O}_{3}$ | $n_{\mathrm{X}}$ | $n_{\mathrm{Z}}$ | $n_{\mathrm{Z}}-n_{\mathrm{X}}$ |
| :---: | :---: | :---: | :---: | :---: |
| 100 | 0 | 1.664 | 1.694 | 0.030 |
| 95 | 5 | 1.667 | 1.690 | 0.023 |
| 90 | 10 | 1.668 | 1.693 | 0.025 |
| $\mathrm{CaMgSi}_{2} \mathrm{O}_{6}$ | $\mathrm{Fe}_{2} \mathrm{O}_{3}$ |  |  |  |
| 98 | 2 | 1.670 | 1.702 | 0.032 |
| 96 | 4 | 1.677 | 1.705 | 0.028 |
| 94 | 6 | 1.684 | 1.710 | 0.027 |
| 92 | 8 | 1.691 | 1.716 | 0.025 |
| $\mathrm{CaMgSi}_{2} \mathrm{O}_{6}$ | $\mathrm{TiO}_{2}$ |  |  |  |
| 98 | 2 | 1.667 | 1.695 | 0.028 |
| 96 | 4 | 1.677 | 1.704 | 0.027 |

Expressed in another way, $\mathrm{Al}_{2} \mathrm{O}_{3}$, etc., probably enters diopside in the

[^175]form of coupled substitution of Al for Mg and Al for Si , respectively, in octahedral and tetrahedral coordination. With 40 molecular percent ${ }^{42}$ of $\mathrm{CaAlSiAlO}_{6}, \mathrm{Z} \wedge c=35^{\circ},(+) 2 \mathrm{~V}=62^{\circ}, n_{\mathrm{X}}=1.684$, and $n_{\mathrm{Z}}=1.714$.
$\mathbf{C a M n S i}_{2} \mathbf{O}_{6}$ (Johannsenite) is monoclinic ${ }^{43}$ and isostructural with diopside. Crystals prismatic to fibrous. Good prismatic cleavage. G. 3.6 calc., $3.2-3.5$ measured. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=48^{\circ}$. ( + ) $2 \mathrm{~V}=70^{\circ} c a$. $n_{\mathrm{X}}=$ $1.710, n_{\mathrm{Y}}=1.719, n_{\mathrm{Z}}=1.738, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.028$. Color brownish or grayish. Made by inversion of bustamite at about $830^{\circ} \mathrm{C}$.
$\mathrm{NaFeSi}_{2} \mathrm{O}_{6}$ (Acmite or Aegirine) is monoclinic with $a: b: c=$ 1.099:1:0.601, $\beta=106^{\circ} 49^{\prime}$. Crystals long prismatic, often vertically striated. Distinct prismatic cleavages at $87^{\circ}$. H. 6-6.5. G. ${ }^{27} 3.584$. M.P. $990^{\circ} \mathrm{C}$. $\mathrm{Z} \wedge c^{27}=104^{\circ}$, being $2^{\circ}$ less in red than in blue. (The natural mineral, being partly $\mathrm{CaMgSi}_{2} \mathrm{O}_{6}$, etc., has $\mathrm{X} \wedge c=$ about $5^{\circ}-2^{\circ}$.) $\mathrm{Y}=b$. (-) $2 \mathrm{~V}=$ $60^{\circ}$ calc., $\mathrm{r}>\mathrm{v}$. By regressions, ${ }^{27} n_{\mathrm{X}}=1.7710, n_{\mathrm{Y}}=1.8103, n_{\mathrm{Z}}=1.8271$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0561$. Color brown or green and pleochroic with absorption $\mathrm{X}>\mathrm{Y}>\mathrm{Z} . \mathrm{PD} 2.99,2.54,6.5 ; 3-0621$. Made from fusion ${ }^{9}$ with NaCl . $\mathrm{NaFeSi} \mathrm{I}_{2} \mathrm{O}_{6}$ forms a continuous solid solution series with $\mathrm{CaMgSi}_{2} \mathrm{O}_{6}$ whose properties are as follows:

| $\mathrm{Fe}_{2} \mathrm{O}_{3}$ | $2 \mathrm{~V}_{\mathrm{Z}}$ | $n_{\mathrm{X}}$ | $n_{\mathrm{Y}}$ | $n_{\mathrm{Z}}$ | $n_{\mathrm{Z}}-n_{\mathrm{X}}$ | $\mathrm{Z} \wedge c$ | G. |
| :--- | ---: | :---: | :--- | :---: | :---: | :---: | :---: |
| $0^{44}$ | $58^{\circ}$ | 1.664 | 1.6715 | 1.694 | 0.030 | $38.5^{\circ}$ | 3.275 |
| $?^{45}$ | $70^{\circ}$ | 1.683 |  | 1.714 | 0.031 | $44^{\circ}$ |  |
| $?^{45}$ | $95^{\circ}$ | 1.726 | 1.748 calc. | 1.766 | 0.040 | $71^{\circ}$ |  |
| $21.73^{46}$ | $99^{\circ}$ | 1.742 | 1.768 | 1.787 | 0.045 |  | 3.52 |
| $32.0^{47}$ | $114^{\circ}$ | 1.762 | 1.799 | 1.814 | 0.052 |  |  |
| $34.6^{48}$ | $120^{\circ}$ | 1.776 | 1.816 | 1.836 | 0.060 | $\left\{\begin{array}{l}98^{\circ} \text { (red) } \\ 100^{\circ} \text { (blue) }\end{array}\right.$ | 3.55 |

$\mathrm{KFeSi}_{2} \mathrm{O}_{\mathbf{6}}$ (K-Acmite) is monoclinic. Crystals prismatic. $\mathrm{X} \wedge c=$ $0^{\circ}-2^{\circ} ; \mathrm{Y}=b$. (-) $2 \mathrm{~V}=$ ?, mean index ${ }^{49} n>1.80, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.03$ est. Color yellow-green; pleochroic. Made in a steel bomb. Another phase $\left(\mathrm{KSi}_{2} \mathrm{FeO}_{6}\right)$ is Fe -leucite-see p. 227.
$\mathrm{NaAlSi}_{2} \mathrm{O}_{6}$ (Jadeite) is monoclinic and isostructural with diopside, with which it forms solid solutions. The cell ${ }^{49 \mathrm{a}}$ has $a=9.45, b=8.57, c=5.25$,

[^176]$\beta=107^{\circ} 15 \frac{1}{2}$. It also forms solid solutions with acmite, $\mathrm{NaFeSi}_{2} \mathrm{O}_{6}$. Natural jadeite is found only in deep-seated rocks. Thermodynamic calculations ${ }^{49 \mathrm{~b}}$ indicate that it can form only under conditions of moderately low temperature and very high pressure. Distinct cleavages at $87^{\circ}$. H. 6-7. G. 3.3-3.5 (by regression ${ }^{27} 3.27 \pm .05$ ). $\mathrm{Y}=b, \mathrm{Z} \wedge c=98^{\circ}$ in red light, $100^{\circ}$ in blue (by regression $104^{\circ} \pm 2^{\circ}$ ). A specimen from Tibet ${ }^{49 \mathrm{c}}$ gave $\mathrm{Z} \wedge c=34.5^{\circ},(+) 2 \mathrm{~V}=70^{\circ} . n_{\mathrm{X}}=1.655(1.6560 \pm .0051$ by regression $)$, $n_{\mathrm{Y}}=1.659 \quad(1.6647), \quad n_{\mathrm{Z}}=1.667 \quad(1.6743 \pm .0057), \quad n_{\mathrm{Z}}-n_{\mathrm{X}}=0.012$ ( $0.0183 \pm .0076$ ). PD 2.83, 2.42, 2.92; 9-463*.
$\boldsymbol{\mu}-\left(\mathbf{C a}_{1-x} \mathbf{S r}_{x}\right) \mathbf{S i O}_{3}{ }^{49 \mathrm{~d}}$ is apparently uniaxial positive with $n_{0}=1.623 \pm$ $.002, n_{\mathrm{E}}=1.630 \pm .002$ for $x=0.19$, and $n_{\mathrm{O}}=1.639, n_{\mathrm{E}}=1.650$ for $n=0.41$ (originally given as for crystallization from glasses having $25 \%$ and $50 \%$ by weight, respectively, of $\mathrm{SrSiO}_{3}$ ). Formed from glasses at $350^{\circ} \mathrm{C}$. to $855^{\circ}$ C., under pressures of water vapor from zero to 20,000 pounds per square inch. The phase has also been found in devitrified glasses for which the content (by weight) of $\mathrm{SrSiO}_{3}$ is as low as $2.5 \%$.
$\mathrm{LiAlSi}_{2} \mathrm{O}_{6}$ (Spodumene) is another clinopyroxene, with $a=9.50, b=$ 8.30, $c=5.24 k X, \beta=110^{\circ} 28^{\prime}$. U.C. 4. The glass has $n=1.518$ and G. 2.37. Crystals prismatic, often flattened on $\{100\}$ and vertically striated. Distinct $\{110\}$ cleavage at $87^{\circ}$. H. 6-7. G. $3.0-3.2$. M.P. $1380^{\circ} \mathrm{C}$., after inversion at $720^{\circ} \mathrm{C} . \mathrm{Y}=b ; \mathrm{Z} \wedge c=23^{\circ}-26^{\circ} .(+) 2 \mathrm{~V}=58^{\circ}-66^{\circ} c a, \mathrm{r}<\mathrm{v}$, with horizontal dispersion. Like other pyroxenes spodumene seems to take $\mathrm{Al}_{2} \mathrm{O}_{3}$ (and $\mathrm{Fe}_{2} \mathrm{O}_{3}$ ) in crystal solution perhaps as $\mathrm{HAlSi}_{2} \mathrm{O}_{6}$ (up to about 20 per cent!).

| $\mathrm{LiAlSi}_{2} \mathrm{O}_{6} \%$ | $87.3^{50}$ | $81.3^{51}$ | $79.1^{52}$ | $75.9^{52}$ |
| ---: | :---: | :---: | :---: | :---: |
| $n_{\mathrm{X}}$ | 1.661 | 1.653 | 1.656 | 1.648 |
| $n_{\mathrm{Y}}$ | 1.666 | 1.659 | 1.660 | 1.655 |
| $n_{\mathrm{Z}}$ | 1.676 | 1.677 | 1.672 | 1.662 |
| $n_{\mathrm{Z}}-n_{\mathrm{x}}$ | 0.015 | 0.024 | 0.016 | 0.014 |
| $\mathrm{Z} \wedge c$ | $?$ | $25^{\circ}$ | $23^{\circ}$ | $24^{\circ}$ |
| G | 3.13 | 3.14 | 3.097 | 3.023 |

Color white, yellowish, greenish, emerald green or lilac; deeply colored varieties are pleochroic with $\mathrm{X}>\mathrm{Y}>\mathrm{Z}$. The low temperature phase ${ }^{6}$ has been made at about $400^{\circ} \mathrm{C}$. and the high temperature phase is easily

[^177]made from fusion ${ }^{53}$ and also by heating the natural mineral above $720^{\circ} \mathrm{C}$. The inversion is not reversible; it is accompanied by a notable increase in volume of about 30 per cent, the density decreasing from about 3.2 to 2.41. M.P. $1423^{\circ}$ C. After inversion $\mathrm{LiAlSi}_{2} \mathrm{O}_{6}$ is tetragonal, uniaxial positive with $n_{\mathrm{O}}=1.519, n_{\mathrm{E}}=1.524, n_{\mathrm{E}}-n_{\mathrm{O}}=0.005$. Again ${ }^{54} n_{\mathrm{O}}=1.516$, $n_{\mathrm{E}}=1.522, n_{\mathrm{E}}-n_{\mathrm{O}}=0.006$. With some excess $\mathrm{SiO}_{2}: n_{\mathrm{O}}=1.516, n_{\mathrm{E}}=$ 1.517, $n_{\mathrm{E}}-n_{\mathrm{O}}=0.001$. PD 2.96, 2.83, 2.48; 9-29 (which phase?).
$\mathrm{BaSiO}_{3} \cdot \mathbf{6 H}_{2} \mathrm{O}$ is orthorhombic dipyramidal ${ }^{55}$ with $a: b: c=0.8555: 1: 0.563$. Crystals prismatic and varied. G. 2.59-2.60. $\mathrm{X}=a ;{ }^{56} \mathrm{Y}=b$. ( - ) $2 \mathrm{~V}=$ $39^{\circ} 40^{\prime}, \mathrm{r}>\mathrm{v}$ strong. $n_{\mathrm{X}}=1.542, n_{\mathrm{Y}}=$ about $1.548, n_{\mathrm{Z}}=$ about 1.549 , $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.007 \mathrm{Na}$. Colorless. Made from solution.
 $(+) 2 \mathrm{~V}=$ moderate. $n_{\mathrm{X}}=1.600, n_{\mathrm{Y}}=1.601, n_{\mathrm{Z}}=1.605, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.005. Colorless. PD*. (Many "calcium metasilicate hydrates" are listed.)
$\mathrm{CaSiO}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ (Tobermorite) is orthorhombic ${ }^{57}$ with $^{58} a=11.3, b=$ $22.6, c=7.33 \AA$. G. 2.44. H. 2.5. Perfect $\{010\}$ and good $\{100\}$ cleavages. $\mathrm{X}=b ; \mathrm{Y}=c$ (elongation). (+) $2 \mathrm{~V}=$ small, $n_{\mathrm{X}}=1.570, n_{\mathrm{Y}}=1.571$, $n_{\mathrm{Z}}=1.575, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.005$. Colorless. PD 10.0, 3.05, 2.93; 6-0020*.
$\mathbf{C a S i O}_{3} \cdot \mathbf{2 H}_{2} \mathrm{O}$ (Plombierite) is orthorhombic ${ }^{57}$ (?) but usually mainly an uncrystallized gel. Mean refractive index, $n_{\mathrm{Y}}=1.550$. PD 3.09, 2.81, $1.83 ; 10-416$.
$6 \mathrm{CaO} \cdot 3 \mathrm{SiO}_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ forms platy or prismatic crystals with negative elongation and extinction angle $15^{\circ} .(-) 2 \mathrm{~V}<30^{\circ} . n_{\mathrm{X}}=1.650, n_{\mathrm{Y}}=1.661$, $n_{\mathrm{Z}}=1.664$. Formed, and stable, at temperatures up to $800^{\circ} \mathrm{C}$., and moderate pressures of water vapor. X-ray powder data include lines at $d=$ 2.290, 3.435, 3.067, 2.986, 2.823. ${ }^{\text {58a }}$
$9 \mathrm{CaO} \cdot 6 \mathrm{SiO}_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ is difficult to distinguish from rankinite. $n_{\mathrm{x}}=1.649$, $n_{\mathrm{z}}=1.654$. Stable at temperatures up to $800^{\circ}$ C., under moderate water vapor pressures. X-ray powder data include stronger lines at $d=2.883$, 3.057, 2.673, 2.424, 1.964, 1.833. ${ }^{\text {58a }}$
$\mathbf{8 C a O} \cdot 3 \mathrm{SiO}_{2} \cdot \mathbf{3 \mathrm { H } _ { 2 }} \mathbf{O}$ (?) forms poorly developed crystals with inclined extinction of about $18^{\circ}$ and negative elongation. $(+?) 2 \mathrm{~V}=$ very small. $n_{\mathrm{X}}=1.630, n_{\mathrm{Z}}=1.636$. X-ray powder data include stronger lines at $\mathrm{d}=$ $1.690,5.435,3.043,4.220,2.920,2.716 .{ }^{58 a}$ It appears to be a calcium analogue of chondrodite.
$\mathrm{K}_{2} \mathrm{SiO}_{3} \cdot \mathbf{0 . 5 H}_{2} \mathrm{O}$ is orthorhombic(?). M.P. $>660^{\circ}$ C. Easily soluble in
${ }^{53}$ Hatch: Am. Min. XXVIII, p. 471 (1943).
${ }^{54}$ Roy and Osborn: J. Am. Chem. Soc. LXXI, p. 2086 (1949).
${ }^{55} a b c$ changed to $b c a$ to make $b>a>c$.
${ }^{56}$ Wahl: Zeit. Krist. XXXVI, p. 156 (1902).
${ }^{57}$ McConnell: Min. Mag. XXX, p. 293 (1954).
${ }^{58} a b c$ changed to $a c b$ to make $b>a>c$.
${ }^{58 \mathrm{a}}$ Roy: Am. Min., XLIII, p. 1009 (1958).
water. Z parallel cleavage and elongation. ( + ? $) 2 \mathrm{~V}=$ near $90^{\circ}$. Mean index ${ }^{59} n=1.50$ (est.), $n_{\mathrm{Z}}-n_{\mathrm{X}}=$ strong. Colorless. Made in a steel bomb.
$\mathbf{K}_{2} \mathbf{S i O}_{3} \cdot \mathbf{H}_{2} \mathbf{O}$ is orthorhombic(?). Crystals equant. Decomposes at $370^{\circ} \mathrm{C}$. to form $\mathrm{K}_{2} \mathrm{SiO}_{3} \cdot 0.5 \mathrm{H}_{2} \mathrm{O} .(+) 2 \mathrm{~V}=$ small. Mean index $n=1.50$ est., $n_{\mathrm{z}}-n_{\mathrm{x}}=$ strong. Colorless. Made in a steel bomb.
$\mathbf{N a}_{2} \mathbf{S i O}_{3} \cdot 9 \mathbf{H}_{2} \mathbf{O}$ is orthorhombic with ${ }^{60} a: b: c=0.692: 1: 0.342$. Crystals equant or $\{100\}$ tablets. No good cleavage. G. 1.646. M.P. $48^{\circ} \mathrm{C} . \mathrm{X}=c$; $\mathrm{Y}=b .(+?) 2 \mathrm{~V}=\operatorname{near} 90^{\circ} . n_{\mathrm{X}}=1.451, n_{\mathrm{Y}}=1.455+, n_{\mathrm{Z}}=1.460, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.009$. Colorless. Made from solution. PD 2.79, 3.83, 2.92; 1-1007.
$\mathrm{Na}_{2} \mathrm{SiO}_{3} \cdot \mathbf{8} \mathrm{H}_{2} \mathrm{O}$ is monoclinic prismatic ${ }^{60}$ with $a: b: c=0.664: 1: 0.715$, $\beta=114^{\circ} 37^{\prime}$. Crystals prismatic or $\{\overline{1} 01\}$ plates. G. 1.67 . M.P. $48^{\circ} \mathrm{C}$. $\mathrm{X} \wedge c=12^{\circ} ; \mathrm{Y}=b .(-) 2 \mathrm{~V}=63^{\circ}, n_{\mathrm{X}}=1.457+, n_{\mathrm{Y}}=1.463, n_{\mathrm{Z}}=$ $1.465+, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.008 \pm$. Dispersion (F-C) for $n_{\mathrm{Y}}=0.0090+$. Colorless. Made from solution in water.
$\mathrm{Na}_{2} \mathbf{S i O}_{3} \cdot \mathbf{6} \mathrm{H}_{2} \mathbf{O}$ has two phases; crystals grown at room temperature are monoclinic sphenoidal. Crystals triangular $\{100\}$ plates with $\{\overline{1} \overline{1} 1\},\{2 \overline{1} \overline{1}\}$, etc. They invert at $63^{\circ}$ and melt at $70^{\circ} \mathrm{C} . \mathrm{X} \wedge c=22^{\circ} ; \mathrm{Z}=b .(+) 2 \mathrm{~V}=$ large. $n_{\mathrm{X}}=1.465, n_{\mathrm{Y}}=1.473, n_{\mathrm{Z}}=1.485, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.020$. Crystals grown at $50^{\circ} \mathrm{C}$. are monoclinic prismatic with $a: b: c=1.921: 1: 1.073$, $\beta=102^{\circ} 9^{\prime}$. Crystals short prismatic ${ }^{5}$ or tabular. G. 1.807. Y $\wedge c=20^{\circ}$; $\mathrm{Z}=b . n_{\mathrm{X}}=1.488, n_{\mathrm{Y}}=$ ? $, n_{\mathrm{Z}}=1.495, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.007$. Colorless. Made from solution.
$\mathrm{CaSiO}_{3} \cdot \mathbf{1 . 5 H}_{2} \mathrm{O}$ (Crestmoreite) is monoclinic with $\{100\}$ (?) cleavage. ${ }^{61}$ H. 3. G. 2.6. F. easy. Decomposed by HCl. $\mathrm{Z} \wedge$ elongation $=12^{\circ}$. $(-) 2 \mathrm{~V}=$ large, ${ }^{62} \mathrm{r}>$ v. $n_{\mathrm{X}}=1.593, n_{\mathrm{Y}}=1.603, n_{\mathrm{Z}}=1.607, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.014 . Color snow white. Found in boiler deposits. This is said to be an intimate intergrowth of tobermorite and wilkeite. ${ }^{57}$
$\mathbf{N a}_{2} \mathbf{S i O}_{3} \cdot 5 \mathrm{H}_{2} \mathbf{O}$ is triclinic pinacoidal with $a: b: c=0.736: 1: 0.901, \alpha=$ $128^{\circ} 8^{\prime}, \beta=98^{\circ} 13^{\prime}, \gamma=109^{\circ} 50^{\prime}$. Crystals $\{100\}$ plates with $\{010\},\{001\}$, etc. G. 1.75. M.P. $72^{\circ} \mathrm{C} .(+) 2 \mathrm{~V}=70^{\circ}, \mathrm{r}>\mathrm{v}$ weak. ${ }^{57} n_{\mathrm{X}}=1.447, n_{\mathrm{Y}}=$ 1.454, $n_{\mathrm{Z}}=1.467, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.020$. Colorless. Made from solution. PD 3.33, 3.19, 6.40; 3-0432.

## Amphibole Group

The minerals of the amphibole group are orthorhombic or monoclinic inosilicates of magnesium, iron and calcium often with sodium, aluminum

[^178]and ferric iron (containing also $\mathrm{OH}, \mathrm{F}$ or extra O ). They usually show vertical elongation and also have good prismatic cleavage at an angle of about $124^{\circ}$. The chief compounds are:

Orthorhombic
$(\mathrm{Mg}, \mathrm{Fe})_{7}(\mathrm{OH})_{2} \mathrm{Si}_{8} \mathrm{O}_{22} \quad$ Anthophyllite
Monoclinic

| $\mathrm{Fe}_{3} \mathrm{O}_{2}(\mathrm{OH})_{2}$ |
| :---: |
| $\mathrm{Mg}, \mathrm{Fe}_{5} \mathrm{Si}_{8} \mathrm{O}_{22}(\mathrm{OH})_{2}$ $\mathrm{Mg}, \mathrm{Fe}_{3} \mathrm{Al}_{2} \mathrm{Si}_{6} \mathrm{Al}_{2} \mathrm{O}_{22}$ |
| $\mathrm{Ca}_{2}\left(\mathrm{Mg}, \mathrm{Fe}_{3}{ }_{3} \mathrm{Al}_{2} \mathrm{Si}_{6}\right.$ |
| ${ }_{2}\left(\mathrm{Mg}, \mathrm{Fe}^{\text {) }} \mathrm{Si}_{7} \mathrm{AlO}_{22}(\right.$ |
| $\mathrm{aCa}_{2}(\mathrm{Mg}, \mathrm{Fe})_{4} \mathrm{AlSi}_{6} \mathrm{Al}_{2} \mathrm{O}_{22}(\mathrm{OH})_{2}$ |
| $\mathrm{a}_{2} \mathrm{Mg}_{3} \mathrm{Al}_{2} \mathrm{Si}_{8} \mathrm{O}_{22}(\mathrm{OH})_{2}$ |


| Cummingtonite |  |
| :---: | :---: |
| Tremolite |  |
| Tschermakite |  |
| Edenite | Hornblend |
| Hastingsite |  |
| Glaucophane |  |

Other amphiboles are found in nature, such as $\mathrm{Na}_{2} \mathrm{Fe}^{\prime \prime}{ }_{2} \mathrm{Fe}^{\prime \prime \prime}{ }_{2}(\mathrm{OH})_{2} \mathrm{Si}_{8} \mathrm{O}_{22}$, called riebeckite; these can probably be made artificially.
$\mathbf{M g}_{7} \mathrm{Si}_{8} \mathrm{O}_{22}\left(\mathbf{O H}, \mathrm{~F}_{2}\right.$ has two crystal phases, one being orthorhombic and the other monoclinic. In nature such crystals usually contain little or no fluorine, but artificial products contain little or no hydroxyl, though otherwise they are the same in composition and very similar in properties. The orthorhombic phase, called anthophyllite, has $a=18.52, b=18.04$, $c=5.27 \AA$. Crystals prismatic with $\{110\}$ cleavage at $125^{\circ} 37^{\prime}$. G. 2.9-3.2. H. $5.5-6$. F. $4-6 . \mathrm{Y}=b ; \mathrm{Z}=c .(+) 2 \mathrm{~V}=$ large. $n_{\mathrm{X}}=1.584, n_{\mathrm{Y}}=1.590$, $n_{\mathrm{Z}}=1.597, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.013$. PD 3.05, 3.24, 8.26; 9-455. With fluorine in place of hydroxyl the indices are about 0.02 less. Orthorhombic $\mathrm{Mg}_{2} \mathrm{Si}_{8} \mathrm{O}_{22}(\mathrm{OH})_{2}$ forms a continuous solid solution series with $\mathrm{Fe}_{7} \mathrm{Si}_{8} \mathrm{O}_{22}(\mathrm{OH})_{2}$ to at least 50 per cent of the latter; with about 20 mol. per cent of the Fe component $n_{\mathrm{X}}=1.618, n_{\mathrm{Y}}=1.628, n_{\mathrm{Z}}=1.638, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.020$; with about 40 mol . per cent of Fe, $n_{\mathrm{X}}=1.641, n_{\mathrm{Y}}=1.650, n_{\mathrm{Z}}=1.660, n_{\mathrm{Z}}-$ $n_{\mathrm{x}}=0.019$. Orthorhombic $\mathrm{Mg}_{7 \mathrm{Si}_{8} \mathrm{O}_{22}(\mathrm{OH})_{2} \text { also intercrystallizes with }}$ $\mathrm{Mg}_{5} \mathrm{Al}_{2} \mathrm{Si}_{6} \mathrm{Al}_{2} \mathrm{O}_{22}(\mathrm{OH})_{2}$ which raises the indices and changes the optic sign to negative.
$\left(\mathrm{Mg}_{1-\mathrm{x}} \mathrm{Fe}_{\mathrm{x}}\right)_{7} \mathrm{Si}_{8} \mathrm{O}_{22}(\mathrm{OH}, \mathrm{F})_{2}$ (kupfferite for $\mathrm{x}<.2$, cummingtonite for $.2<\mathrm{x}<.8$, grunerite for $\mathrm{x}>.8$ ) is monoclinic with $a=19.4-18.8, b=$ $17.8-17.9, c=5.25-5.27, \beta=106^{\circ}$. The naturally occurring hydroxyl series is unknown with $\mathrm{x}<.25$. With $\mathrm{x}=.40,^{63}(+) 2 \mathrm{~V}=65^{\circ}, n_{\mathrm{x}}=1.640$,

[^179]$n_{\mathrm{Y}}=1.647, n_{\mathrm{Z}}=1.665, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.025$, and $\mathrm{Z} \wedge c=20^{\circ}$. With 77.5 mol. per cent $\mathrm{Fe},{ }^{63} 2 \mathrm{~V}=90^{\circ} c a, n_{\mathrm{X}}=1.666, n_{\mathrm{Y}}=1.684, n_{\mathrm{Z}}=1.704$, $n_{\mathrm{z}}-n_{\mathrm{X}}=0.038$ and $\mathrm{Z} \wedge c=14^{\circ}$. With 100 mol . per cent $\mathrm{Fe},{ }^{63}(-) 2 \mathrm{~V}=$ $86^{\circ}, n_{\mathrm{X}}=1.686, n_{\mathrm{Y}}=1.709, n_{\mathrm{Z}}=1.729, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.043$ and $\mathrm{Z} \wedge c=$ $10^{\circ}$. This is called grunerite. The Mg component is called kupfferite. Color pale to dark brown (darker with increasing Fe ) with X colorless or pale yellow, Y pale yellow to brownish, Z brownish yellow to (greenish) brown. The artificial F-cummingtonite series is complete. Its properties may be summarized as follows:

| Mol. \% Mg | Mol. \% Fe | $n_{\mathrm{X}}$ | $n_{\mathrm{Y}}$ | $n_{\mathrm{Z}}$ | $n_{\mathrm{Z}}-n_{\mathrm{X}}$ | $\mathrm{Z} \wedge c$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 100 | 0 | 1.583 | 1.590 | 1.598 | 0.015 | $8^{\circ}$ |
| 73 | 27 | 1.604 | 1.613 | 1.623 | 0.019 | $20^{\circ}$ |
| 48 | 52 | 1.625 | 1.634 | 1.645 | 0.020 | $23^{\circ}$ |
| 25 | 75 | 1.647 | 1.657 | 1.671 | 0.024 | $16^{\circ}$ |
| 0 | 100 | 1.665 | 1.676 | 1.690 | 0.025 | $12^{\circ}$ |

Cummingtonite, like anthophyllite, may contain some $\mathrm{Al}_{2} \mathrm{O}_{3}$ [as ( $\left.\mathrm{Mg}, \mathrm{Fe}_{5}\right)_{5} \mathrm{Al}_{2} \mathrm{Si}_{6} \mathrm{Al}_{2}(\mathrm{OH}, \mathrm{F})_{2}$ ]. It may also contain MnO at least to 14 per cent and ZnO at least to 10 per cent. Colorless (with no Fe ), grading to dark brown (with no Mg ); pleochroic about the same as the hydroxyl series. Made by fusion with some NaF added as a catalyst. PD 2.75, 3.07, 8.38; 7-382.

A general formula for the hornblende system is $\mathrm{A}_{0-1} \mathrm{~B}_{2} \mathrm{C}_{5} \mathrm{D}_{8} \mathrm{O}_{22} \mathrm{E}_{2}$, where $A$ is Na (or K in part); B is usually Ca or Na , also Mn , and perhaps K ; C is $\mathrm{Mg}, \mathrm{Fe}^{\prime \prime}, \mathrm{Mn}, \mathrm{Fe}^{\prime \prime \prime}, \mathrm{Al}$, or $\mathrm{Ti} ; \mathrm{D}$ is Si with up to about $25 \% \mathrm{Al}$, perhaps also $\mathrm{Fe}^{\prime \prime \prime}$, or $\mathrm{Ti}^{\mathrm{iv}}$; and E is $\mathrm{OH}, \mathrm{F}, \mathrm{Cl}, \mathrm{O}$ or perhaps $\mathrm{H}_{2} \mathrm{O}$. Other elements are commonly present in traces in natural specimens. Many different compositions containing F in position E are easily made; it is also possible to oxidize some of the iron in position C with concomitant change of OH to O by removal of H , and vice versa. Numerous special endmembers have received names, of which the most important follow ("chlor-," "fluor-," or "oxy-" prefixed to a name refers to position E):

$$
\begin{aligned}
& \mathrm{Ca}_{2} \mathrm{Mg}_{6} \mathrm{Si}_{8} \mathrm{O}_{22}(\mathrm{OH})_{2}=\text { tremolite } \\
& \mathrm{Ca}_{2} \mathrm{Fe}_{2} \mathrm{Si}_{8} \mathrm{O}_{22}(\mathrm{OH})_{2}=\text { ferrotremolite } \\
& \mathrm{Ca}_{2} \mathrm{Mg}_{3} \mathrm{Al}_{2} \mathrm{Si}_{6} \mathrm{Al}_{2} \mathrm{O}_{22}(\mathrm{OH})_{2}=\text { tschermakite } \\
& \mathrm{Ca}_{2} \mathrm{Fe}_{3} \mathrm{Al}_{2} \mathrm{Si}_{6} \mathrm{Al}_{2} \mathrm{O}_{22}(\mathrm{OH})_{2}=\text { ferrotschermakite } \\
& \mathrm{Na}_{2} \mathrm{Mg}_{3} \mathrm{Al}_{2} \mathrm{Si}_{8} \mathrm{O}_{22}(\mathrm{OH})_{2}=\text { glaucophane } \\
& \mathrm{Na}_{2} \mathrm{Fe}_{3} \mathrm{Fe}_{2} \mathrm{Si}_{8} \mathrm{O}_{22}(\mathrm{OH})_{2}=\text { riebeckite } \\
& \mathrm{NaCa}_{2} \mathrm{Mg}_{5} \mathrm{Si}_{21} \mathrm{AlO}_{22}(\mathrm{OH})_{2}=\text { edenite } \\
& \mathrm{NaCa}_{2} \mathrm{Fe}_{5} \mathrm{Si}_{7} \mathrm{AlO}_{22}(\mathrm{OH})_{2}=\text { ferroedenite } \\
& \mathrm{NaCa}_{2} \mathrm{Mg}_{4} \mathrm{AlSi}_{6} \mathrm{Al}_{2} \mathrm{O}_{22}(\mathrm{OH})_{2}=\text { pargasite } \\
& \mathrm{NaCa}_{2} \mathrm{Fe}_{4} \mathrm{AlSi}_{6} \mathrm{Al}_{2} \mathrm{O}_{22}(\mathrm{OH})_{2}=\text { hastingite }
\end{aligned}
$$

$$
\begin{aligned}
& \mathrm{NaNa}_{2} \mathrm{Mg}_{4} \mathrm{AlSi}_{8} \mathrm{O}_{22}(\mathrm{OH})_{2}=\mathrm{Mg} \text {-arfvedsonite } \\
& \mathrm{NaNa}{ }_{2} \mathrm{Fe}_{4} \mathrm{AlSi}_{8} \mathrm{O}_{22}(\mathrm{OH})_{2}=\text { arfvedsonite } \\
& \text { etc. }
\end{aligned}
$$

Tremolite is monoclinic with $a=9.8, b=17.9, c=5.28, \beta=105^{\circ} 12^{\prime}$. Crystals long prismatic to acicular or fibrous. Perfect $\{110\}$ cleavage at $124^{\circ}$. Also $\{010\}$ and $\{100\}$ or $\{001\}$ parting. H. $5-6$. G. 2.98. $\mathrm{Y}=b$; $\mathrm{Z} \wedge c=18^{\circ} c a$. (-) $2 \mathrm{~V}=88^{\circ}, n_{\mathrm{X}}=1.599, n_{\mathrm{Y}}=1.613, n_{\mathrm{Z}}=1.625, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.026$. Colorless. Artificial fluor-tremolite ${ }^{64}$ has $\mathrm{Y}=b ; \mathrm{Z} \wedge c=21^{\circ}$. $(-) 2 \mathrm{~V}=86^{\circ} 30^{\prime} . n_{\mathrm{X}}=1.581 . n_{\mathrm{Y}}=1.593, n_{\mathrm{Z}}=1.602, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.021$. With $9.1 \mathrm{Al}_{2} \mathrm{O}_{3} \mathrm{Z} \wedge c=20.5^{\circ}, n_{\mathrm{X}}=1.573, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.594, n_{\mathrm{Z}}-$ $n_{\mathrm{x}}=0.021$. PD 2.69, 3.10, $8.4 ; 9-437^{*}$. With more than one tenth of the magnesium replaced by iron the mineral is called actinolite and has G. 3.0-3.18. (-) $2 \mathrm{~V}=80^{\circ} c a . \mathrm{Z} \wedge c=17^{\circ}-15^{\circ} . n_{\mathrm{X}}=1.615-1.655, n_{\mathrm{Y}}=$ $1.625-1.665, n_{\mathrm{Z}}=1.64-1.68, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.025 c a$. PD 2.71, 3.11, 8.42; $7-366$. Tremolite with no iron is colorless, but it grades into actinolite which is green with X pale yellow, Y yellow-green, Z emerald-green.

Tremolite may also have half its Ca replaced by $\mathrm{Na}_{2}$; it is then called soda-tremolite or richterite. PD 8.55, 2.71, 3.38; 10-456*. Fluor-richterite ${ }^{64 \mathrm{a}}$ made from fusion has $a=9.823, b=17.957, c=5.268 \AA, \beta=$ $104^{\circ} 20^{\prime}$. PD 3.13, 8.42, 2.80; 10-428*. Crystals acicular with prismatic cleavage. G. 3.035. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=22^{\circ}$. (-) $2 \mathrm{~V}=72^{\circ} . n_{\mathrm{X}}=1.603, n_{\mathrm{Y}}=$ $1.614, n_{\mathrm{Z}}=1.622, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.019$. Colorless.

Common hornblende varies remarkably in composition including (as endmembers) not only tremolite, tschermakite and hastingsite, but also edenite ( $\mathrm{NaCa}_{2} \mathrm{Mg}_{5} \mathrm{Si}_{7} \mathrm{AlO}_{22}(\mathrm{OH})_{2}$ ) and corresponding ferrous and ferric iron formulas. Heating ferrous hornblende to about $850^{\circ} \mathrm{C}$. expels H from OH and oxidizes the iron, changing the properties substantially. This heating also changes the color from green to dark brown.

Since hornblende is so variable in composition its properties also vary, but all varieties are monoclinic prismatic with $a: b: c$ about $=0.55: 1: 0.29$, $\beta=106^{\circ}$. Crystals usually long prismatic to acicular. Perfect $\{110\}$ cleavage at $124^{\circ}$. Also pinacoidal parting. H. 5-6. G. 3.0-3.5 increasing with iron content. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=10^{\circ}-30^{\circ}$ (unless it is oxidized), being smallest in ferrotremolite and largest in hastingsite. $2 \mathrm{~V}_{\mathrm{X}}$ is about $40^{\circ}$ in ferroedenite and hastingsite and about $130^{\circ}$ in edenite. The refringence ( $n_{\mathrm{z}}$ ) ranges from about 1.63 in tremolite and edenite to about 1.75 in ferrotschermakite. The birefringence varies from about 0.02 to about 0.03 . Endmembers have approximately the following properties: ${ }^{65}$

[^180]| Endmember | Name | Sign, 2 V | $n_{\text {Z }}$ | $n_{\mathrm{Z}}-n_{\mathrm{X}} \mathrm{Z} \wedge c$ |  | G |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{Ca}_{2} \mathrm{Mg}_{55 \mathrm{Si}_{8} \mathrm{O}_{22}(\mathrm{OH})_{2}}$ | Tremolite | $-88^{\circ}$ | 1.628 | 0.03 | $18^{\circ}$ | 2.9 |
| $\mathrm{NaCa}_{2} \mathrm{Mg}_{5} \mathrm{Si}_{7} \mathrm{AlO}_{22}(\mathrm{OH})_{2}$ | Edenite | $+50^{\circ}$ | 1.63 | 0.02 | $25^{\circ}$ | 3.0 |
| $\mathrm{NaCa}_{2} \mathrm{Mg}_{4} \mathrm{AlSi}_{6} \mathrm{Al}_{2} \mathrm{O}_{22}(\mathrm{OH})_{2}$ | Hastingsite | $+85^{\circ}$ | 1.64 | 0.02 | $28^{\circ}$ | 3.1 |
| $\mathrm{Ca}_{2} \mathrm{Mg}_{3} \mathrm{Al}_{2} \mathrm{Si}_{6} \mathrm{Al}_{2} \mathrm{O}_{22}(\mathrm{OH})_{2}$ | Tschermakite | $-80^{\circ}$ | 1.657 | 0.02 | $20^{\circ}$ | 3.1 |
| $\mathrm{Ca}_{2} \mathrm{Fe}_{5} \mathrm{Si}_{8} \mathrm{O}_{22}(\mathrm{OH})_{2}$ | Ferrotremolite | $-75^{\circ}$ | 1.735 | 0.025 | $12^{\circ}$ | 3.4 |
| $\mathrm{NaCa}_{2} \mathrm{Fe}_{5} \mathrm{Si}_{7} \mathrm{AlO}_{22}(\mathrm{OH})_{2}$ | Ferroedenite | $-20^{\circ}$ | 1.73 | 0.02 | $15^{\circ}$ | 3.4 |
| $\mathrm{NaCa}_{2} \mathrm{Fe}^{\prime \prime}{ }_{4} \mathrm{Fe}^{\prime \prime \prime} \mathrm{Si}_{6} \mathrm{Al}_{2} \mathrm{O}_{22}(\mathrm{OH})_{2}$ | Ferrohastingsite | $-35^{\circ}$ | 1.74 | 0.02 | $18^{\circ}$ | 3.4 |
| $\mathrm{Ca}_{2} \mathrm{Fe}^{\prime \prime}{ }_{3} \mathrm{Fe}^{\prime \prime \prime}{ }_{2} \mathrm{Si}_{6} \mathrm{Al}_{2} \mathrm{O}_{22}(\mathrm{OH})_{2}$ | Ferrotschermakite | $-70^{\circ}$ | 1.75 | 0.03 | $18^{\circ}$ |  |

When any kind of hornblende is heated to about $800^{\circ} \mathrm{C}$. the hydrogen may be driven off; this has important effects upon varieties with significant amounts of iron. Barnes ${ }^{66}$ has shown that the change is accompanied by oxidation of the iron. After heating a sample of actinolite with about 20 per cent of the iron molecule the extinction angle had changed from $15^{\circ}$ to $10^{\circ}$, the optic angle from $73^{\circ}$ to $56^{\circ}$ and the indices from $n_{\mathrm{X}}=1.6133$, $n_{\mathrm{Y}}=1.6313, n_{\mathrm{Z}}=1.6413, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.028$ to $n_{\mathrm{X}}=1.6301, n_{\mathrm{Y}}=1.6634$, $n_{\mathrm{Z}}=1.6728, n_{\mathrm{Z}}-n_{\mathrm{x}}=0.0427$; also the color changed from green to brown with X greenish brown, Y deep brown, Z dark brown. Except for the color change these modifications in the $\mathrm{Mg}_{5}$ to $\mathrm{Mg}_{4} \mathrm{Fe}$ series are summarized in relation to composition in Fig. 10-22.
$\mathbf{N a C a}_{2} \mathbf{M g}_{5} \mathrm{Si}_{7} \mathbf{A l O}_{22} \mathbf{F}_{2}$ (Fluor-edenite) is monoclinic with ${ }^{67} a=9.85$, $b=18.00 . c=5.28 \AA, \beta=104^{\circ} 50^{\prime}$. Crystals acicular with prismatic cleavage. G. 3.077. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=18^{\circ}$. (-) $2 \mathrm{~V}=69^{\circ}$. $n_{\mathrm{X}}=1.605, n_{\mathrm{Y}}=$ 1.617, $n_{\mathrm{Z}}=1.624, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.019$. Colorless. Made from fusion. PD 3.13, 8.41, 3.27; 10-431.
$\mathbf{N a C a}_{2} \mathbf{M g}_{5} \mathbf{S i}_{7} \mathbf{B o}_{22} \mathbf{F}_{2}$ (Fluor-boron-edenite) is monoclinic with ${ }^{67} a=$ $9.81, b=17.96, c=5.27 \AA, \beta=104^{\circ} 27^{\prime}$. Crystals acicular with prismatic cleavage. G. 3.042. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=12^{\circ}$. (-) $2 \mathrm{~V}=75^{\circ} . n_{\mathrm{X}}=1.588, n_{\mathrm{Y}}=$ $1.598, n_{\mathrm{Z}}=1.605, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.017$. Colorless. Made from fusion. PD 3.12, 8.39, 3.26; 10-427.
$\mathbf{K}_{2} \mathbf{S i}_{4} \mathbf{O}_{9}$ is monoclinic(?). Crystals platy. ${ }^{68}$ Twinning common. G. 2.335. M.P. $765^{\circ}$ C. after inversion at $592^{\circ}$ C. Extinction inclined. ( + ) $2 \mathrm{~V}=$ rather large. $n_{\mathrm{X}}=1.477, n_{\mathrm{Y}}=1.479$ (est. from sign and $n_{\mathrm{X}}, n_{\mathrm{Z}}$ ), $n_{\mathrm{Z}}=$ $1.482, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.005$. Colorless. Made from fusion. The glass has G. 2.38 and $n_{\mathrm{X}}=1.495$.

[^181]

Fig. 10-22. Changes in optical properties associated with oxidation of ferrous to ferric iron by heating amphiboles in air. Data of Barnes (Amer. Mineral. XV, p. 393, 1930) on analyzed clinoamphiboles as summarized by Winchell (Amer. Mineral. XVI, p. 250, 1931; ibid., XXV, p. 27, 1945).

## E. CYCLOSILICATES (RINGS OF TETRAHEDRA):

$$
\mathrm{A}_{m}\left(\mathrm{XO}_{3}\right)_{n}, \mathrm{~A}_{m}\left(\mathrm{Si}_{3} \mathrm{O}_{9}\right)_{n}, \mathrm{~A}_{m}\left(\mathrm{Si}_{4} \mathrm{O}_{12}\right)_{n}, \quad \text { OR } \quad \mathrm{A}_{m}\left(\mathrm{Si}_{6} \mathrm{O}_{18}\right)_{n}
$$

$\mathrm{BaTiSi}_{3} \mathbf{O}_{9}$ (Benitoite) is hexagonal ${ }^{1}$ with $a=6.60, c=9.71 \AA$. Crystals pyramidal or tabular with poor $\{10 \overline{1} 1\}$ cleavage. H. 6-6.5. G. 3.65. F. 3, to transparent glass. Soluble in HF. Uniaxial positive with $n_{0}=1.757$, $n_{\mathrm{E}}=1.804, n_{\mathrm{E}}-n_{\mathrm{O}}=0.047$. Color blue, purple, colorless, varying even in a single crystal. Colored parts are pleochroic with O colorless, E purple, indigo, or greenish blue. Made hydrothermally. ${ }^{2}$
$\mathbf{C a}_{2} \mathbf{B a S i}_{3} \mathbf{O}_{9}$ is hexagonal(?) with good prismatic cleavage. ${ }^{3}$ Uniaxial negative with $n_{0}=1.677 \mathrm{C}, 1.681 \mathrm{D}, 1.685 \mathrm{Tl}, 1.690 \mathrm{~F}, n_{\mathrm{E}}=1.664 \mathrm{C}$, $1.668 \mathrm{D}, 1.672 \mathrm{Tl}, 1.678 \mathrm{~F}, n_{\mathrm{O}}-n_{\mathrm{E}}=0.013$. Colorless. Made from fusion.
$\mathbf{S r}_{3} \mathbf{S i}_{3} \mathbf{O}_{9}$ is hexagonal. ${ }^{3}$ Crystals basal plates with fair basal cleavage. M.P. $1580^{\circ}$ C. G. 3.65. Uniaxial positive with $n_{\mathrm{O}}=1.596 \mathrm{C}, 1.599 \mathrm{D}$, $1.602 \mathrm{Tl}, 1.606 \mathrm{~F}, n_{\mathrm{E}}=1.634 \mathrm{C}, 1.637 \mathrm{D}, 1.641 \mathrm{Tl}, 1.646 \mathrm{~F}, n_{\mathrm{E}}-n_{\mathrm{O}}=$ 0.038 D. Colorless. Made from fusion. PD 2.92, 2.073 .57 ; 6-0415. The glass has G. 3.54 and $n=1.632$. Only one crystal phase known, though it forms a series with monoclinic $\mathrm{Ca}_{3} \mathrm{Si}_{3} \mathrm{O}_{9}$ in which the twinning of the latter is indistinct in mix-crystals containing 37.5, 56.25 and $62.5 \mathrm{Sr}_{3} \mathrm{Si}_{3} \mathrm{O}_{9}$ and absent in crystals with more Sr . Data on mix-crystals follow:

| Wt. $\% \mathrm{CaSiO}_{3}$ | 100 | 75 | 50 | 25 | 0 |
| ---: | :---: | :---: | :---: | :---: | :---: |
| Wt. $\% \mathrm{SrSiO}_{3}$ | 0 | 25 | 50 | 75 | 100 |
| $n_{\mathrm{X}}$ | 1.610 D | 1.608 | 1.606 | 1.602 | 1.599 |
| $n_{\mathrm{z}}$ | 1.654 D | 1.651 | 1.646 | 1.642 | 1.637 |
| $n_{\mathrm{Z}}-n_{\mathrm{X}}$ | 0.044 | 0.043 | 0.040 | 0.040 | 0.038 |

$\mathbf{N a}_{2} \mathbf{C a}_{2} \mathbf{S i}_{3} \mathbf{O}_{9}$ forms rectangular crystals ${ }^{4}$ with lamellar twinning. M.P. $1284^{\circ}$ C. $n_{\mathrm{X}}=1.596, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.599, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.003$. Colorless. PD 2.63, 1.86, 3.37; 1-1078. (See also p. 270, footnote 22.)
$\mathbf{B e}_{3} \mathbf{A l}_{2}\left(\mathbf{S i}_{6} \mathbf{O}_{18}\right)$ (Beryl) is hexagonal with $a=9.21, c=9.17 \AA$. The formula of beryl is simplified; other elements often present in small amounts include $\mathrm{Na}, \mathrm{K}, \mathrm{Li}, \mathrm{Cs}, \mathrm{H}$. Crystals prismatic with poor basal cleavage. H. 7.5-8. G. 2.66-2.85. M.P. about $1420^{\circ}$ C. Uniaxial negative, but some crystals have a very small optic angle ( 2 E up to $10^{\circ}$ ); in such cases the hexagonal form is due to twinning of three or six orthorhombic units as in aragonite. In cross sections the center of such twins may be uniaxial.

[^182]PD 2.87 3.25, 7.98; 9-430. Refringence, birefringence and density vary considerably with the tenor of alkalies which may reach 7 per cent.

| Alkalies | Minimum | Maximum |
| :--- | :---: | :---: |
| $n_{\mathrm{O}}$ | 1.568 | 1.602 |
| $n_{\mathrm{E}}$ | 1.564 | 1.594 |
| $n_{\mathrm{O}}-n_{\mathrm{E}}$ | 0.004 | 0.008 |
| G | 2.66 | 2.85 |

Artificial beryl glass has $n=1.526$ and G. 2.385. With 2 per cent ${ }^{5}$ of $\mathrm{Cr}_{2} \mathrm{O}_{3}$ synthetic emerald has $n_{\mathrm{O}}=1.578, n_{\mathrm{E}}=1.573 \mathrm{Na}$. Color green, blue, yellow, white and pink. Green beryl is the gem called emerald. Colorless in thin section; more or less pleochroic in thin section with $0<\mathrm{E}$, or, rarely, $0>\mathrm{E}$.
$\mathrm{NaMg}_{3} \mathrm{Al}_{6}(\mathrm{OH})_{4}\left(\mathrm{BO}_{3}\right)_{3} \mathbf{S i}_{6} \mathrm{O}_{18}$ (Tourmaline) is hexagonal (ditrigonal pyramidal) with $a=15.8-16.0, c=7.1-7.2$. Tourmaline varies greatly in composition and the formula is still uncertain. It is approximately as given above for dravite, $\mathbf{N a F e}_{3} \mathbf{A l}_{6}(\mathbf{O H})_{4}\left(\mathrm{BO}_{3}\right)_{3} \mathbf{S i}_{6} \mathrm{O}_{18}$ for schorlite, $\mathrm{Na}_{2} \mathrm{Li}_{3} \mathrm{Al}_{5}(\mathbf{O H})_{4}\left(\mathrm{BO}_{3}\right)_{3} \mathrm{Si}_{6} \mathrm{O}_{18}$ for elbaite, $\mathrm{NaMn}_{3} \mathrm{Al}_{6}(\mathbf{O H})_{4}\left(\mathrm{BO}_{3}\right)_{3} \mathrm{Si}_{6} \mathrm{O}_{18}$ for tsilaisite, and $\mathrm{CaMg}_{4} \mathrm{Al}_{5}(\mathbf{O H})_{4}\left(\mathrm{BO}_{3}\right)_{3} \mathbf{S i}_{6} \mathrm{O}_{18}$ for uvite). There is a continuous series from dravite to schorlite (and to uvite) and also from schorlite to elbaite, but none is known from dravite to elbaite. As in other silicates $\mathrm{Al}_{2}$ may proxy for MgSi to a limited extent. Tourmaline may contain some $\mathrm{Cr}, \mathrm{Fe}^{\prime \prime \prime}, \mathrm{K}, \mathrm{F}$. Tourmaline crystals are usually prismatic, vertically elongated and striated; some crystals show distinct hemimorphism. Difficult $\{11 \overline{2} 0\}$ and $\{10 \overline{1} 1\}$ cleavages. H. 7-7.5. G. 2.9-3.2. Dravite has a fusibility of about 4, and schorlite of about 5.5 , but elbaite is infusible. Insoluble even in HF. Uniaxial negative, but (under strain?) may be slightly biaxial, 2 E up to $10^{\circ}$. Data follow:

|  | Dravite |  | Schorlite |  | Elbaite |  | $\begin{gathered} \text { With } \\ \mathrm{Cr}_{2} \mathrm{O}_{3}= \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Average | Range | Average | Range | Average | Range | 10.86 |
| $n_{0}$ | 1.650 | 1.63-1.655 | 1.668 | 1.64-1.69 | 1.646 | 1.635-1.65 | 1.687 |
| $n_{\text {E }}$ | 1.628 | $1.61-1.63$ | 1.639 | 1.62-1.66 | 1.625 | 1.615-1.63 | 1.641 |
| $n_{0}-n_{\text {E }}$ | 0.022 | 0.022-0.025 | 0.029 | 0.025-0.034 | 0.021 | 0.015-0.023 | 0.046 |
| G |  | 3.03-3.10 |  | $3.12-3.22$ |  | $3.01-3.13$ | 3.12 |

Color black, brown, less commonly blue, green, red, colorless. A single crystal may vary in color-in zones or at opposite ends of the vertical axis. Pleochroism variable, but the absorption is always $\mathrm{O}>$ E. PD 2.58, 4.00,

[^183]4.26; 3-0842*. Made by a hydrothermal method ${ }^{6}$ with fused tourmaline and solutions of magnesium and alkali borates in a steel bomb at temperatures of $400^{\circ}$ to $500^{\circ} \mathrm{C}$. The glass of iron tourmaline has G. 2.67 and $n=$ 1.582.
$\mathbf{M g}_{2} \mathbf{A l}_{3} \mathbf{S i}_{5} \mathbf{A l O}_{18}$ (Cordierite) has two or more crystal phases. The high temperature $\alpha$-phase ${ }^{7}$ (made by devitrifying glass at about $1200^{\circ}$ C.) is isostructural with beryl and has $a=9.782, c=9.365 \AA$. Uniaxial negative with $n_{\mathrm{O}}=1.528, n_{\mathrm{E}}=1.524, n_{\mathrm{O}}-n_{\mathrm{E}}=0.004$. Also anomalously biaxial. It has been named ' $\alpha$-indialite" because found in India (near a burning coal seam). The low temperature $\beta$-phase is also (probably) hexagonal with $a=9.792, c=9.349 \AA$. Uniaxial negative with $n_{\mathrm{O}}=1.541, n_{\mathrm{E}}=$ 1.537, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.004$. This is named $\boldsymbol{\beta}$-indialite. Both phases of "indialite" may invert to (pseudo-hexagonal) orthorhombic cordierite by slight deformation, and low temperature $\beta$-cordierite inverts to $\alpha$-cordierite at about $800^{\circ} \mathrm{C}$. $\alpha$-Cordierite has ${ }^{8} a=9.7, b=17.1, c=9.3 \AA$. Crystals prismatic. $\mathrm{X}=c ; \mathrm{Y}=a$. Optic angle varies through $90^{\circ}$ so the sign can be plus or minus. $2 \mathrm{~V}_{\mathrm{X}}=70^{\circ}-100^{\circ}$, ( $\mathrm{r}<\mathrm{v}$ weak when $2 \mathrm{~V}_{\mathrm{X}}<90^{\circ}$ ). $n_{\mathrm{X}}=$ $1.53-1.54, n_{\mathrm{Y}}=1.545 \mathrm{ca} . n_{\mathrm{Z}}=1.54-1.55, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.01 \mathrm{ca} . \beta$-Cordierite is also orthorhombic with similar axial lengths. Distinct $\{010\}$ and poor $\{100\}$ and $\{001\}$ cleavages. Twinning in three or six parts is common. H. 7-7.5. G. 2.57-2.66. $\mathrm{X}=c ; \mathrm{Y}=a .2 \mathrm{~V}_{\mathrm{X}}=40^{\circ}-105^{\circ} . n_{\mathrm{X}}=1.52-1.55$. $n_{\mathrm{Y}}=1.525-1.526 c a ., n_{\mathrm{Z}}=1.53-1.57, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.01 c a$. These variations in refringence are due chiefly to the fact that Fe may replace Mg in any amount, but this does not explain the variations in optic angle. (With no Fe: $n_{\mathrm{X}}=1.537, n_{\mathrm{Z}}=1.541, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.004$.) Cordierite is usually light to dark blue but may be greenish, yellow or brown. Color usually absent in thin section, but in thick plates:

> X clear yellow, green, brown or reddish
> Y dark violet, dark blue, green, dark brown
> Z clear blue of various shades, yellow, brown.

When rich in iron: X colorless, Y and Z violet even in thin section. Made hydrothermally. PD 8.58, 3.38, 3.04; 9-472*.
$\mathbf{F e}_{2} \mathbf{A l}_{3} \mathbf{S i}_{5} \mathbf{A l O}_{18}$ (Fe-Cordierite) is orthorhombic ${ }^{9}$-see above. Also $(-) 2 \mathrm{~V}=$ large. $n_{\mathrm{X}}=1.551, n_{\mathrm{Y}}=1.564, n_{\mathrm{Z}}=1.574, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.023$. PD 8.54, 4.06, 3.43; 9-473.
${ }^{6}$ Frondel, Hurlbut and Collette: Am. Min. XXXII, p. 680 (1947).
${ }^{7}$ Miyashiro, Iiyama, Yamasaki and Miyashiro: Am. J. Sci. CCLIII, p. 185 (1955). This description of the crystallization products of ( $\mathrm{Mg}, \mathrm{Fe}_{2} \mathrm{Al}_{3} \mathrm{Si}_{3} \mathrm{AlO}_{18}$ (given briefly above) is interesting but needs further study. See also Karkhanavala and Hummel: J. Am. Ceram. Soc. XXXVI, p. 389 (1953).
${ }^{8} a b c$ changed to $b a c$ to make $b>a>c$.
${ }^{9}$ Schairer and Yagi: Am. J. Sci. Bowen Vol. p. 471 (1952).
$\mathbf{M n}_{2} \mathbf{A l}_{3} \mathbf{S i}_{5} \mathbf{A l O}_{18}$ (Mn-Cordierite). X parallel length of needles. M.P. $1200^{\circ} \mathrm{C} .(-) 2 \mathrm{~V}=$ small. $n_{\mathrm{X}}=1.537, n_{\mathrm{Y}} \approx n_{\mathrm{Z}}=1.558, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.021$.
$\mathbf{C a}_{5} \mathbf{M g}_{2} \mathbf{S i}_{6} \mathbf{O}_{19}$ (?) is orthorhombic ${ }^{10}(?)$ in elongated grains. It dissociates at about $1365^{\circ} \mathrm{C}$. It may form mix-crystals with $\mathrm{CaSiO}_{3}$, etc. Elongation parallel to $\mathrm{Y} .(+) 2 \mathrm{~V}=80^{\circ} \pm, n_{\mathrm{X}}=1.621, n_{\mathrm{Y}}=1.627, n_{\mathrm{Z}}=1.635, n_{\mathrm{Z}}-$ $n_{\mathrm{x}}=0.014$. Colorless. Made from fusion.
$\mathbf{P b}_{3} \mathbf{S i}_{3} \mathbf{O}_{9}$ (Alamosite) is monoclinic ${ }^{11}$ with $a: b: c=1.375: 1: 0.924, \beta=$ $95^{\circ} 50^{\prime}$. Crystals fibrous parallel with $b$ with $\{010\}$ cleavage. H. 4.5. G. 6.49. M.P. $764^{\circ} \mathrm{C}$. Soluble in $\mathrm{HNO}_{3}$ leaving silica jelly. $\mathrm{Y}=b$. ( - ) $2 \mathrm{~V}=$ $65^{\circ}, \mathrm{r}<\mathrm{v}$ strong with weak inclined dispersion. $n_{\mathrm{x}}=1.947, n_{\mathrm{Y}}=1.961$, $n_{\mathrm{Z}}=1.968, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.023$ (meas.). Colorless or white with adamantine luster. PD 3.58, 3.36, 5.82; 3-0344.
$\mathrm{Ca}_{3} \mathbf{S i}_{3} \mathbf{O}_{9} \cdot \mathbf{H}_{2} \mathrm{O}$ (Xonotlite) is monoclinic ${ }^{12}$ with $a=8.55, b=7.34$, $c=7.03 \mathrm{kX}, \beta$ near $90^{\circ}$. U.C. 2. Crystals long parallel with $b$, with cleavage, probably $\{001\}$. H. 6.5. G. 2.71. F. 2.5. Soluble in $\mathrm{HCl} . \mathrm{Y}$ (nearly) $=$ $a ; \mathrm{Z}=b .(+) 2 \mathrm{~V}=$ very small. $n_{\mathrm{X}} \approx n_{\mathrm{Y}}=1.583, n_{\mathrm{Z}}=1.593, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.010. Colorless to pink; color may fade on exposure to light. Found in boiler deposits. PD 3.09, 1.96, 2.83; 3-0568.
$\mathbf{C a}_{3} \mathbf{S i}_{3} \mathbf{O}_{9}$ has three phases. The high temperature $\alpha$-phase (called pseudowollastonite) is pseudo-orthorhombic and triclinic with $a=6.90$, $b=11.58, c=19.65 \AA, \alpha \approx 90^{\circ}, \beta=90^{\circ} 48^{\prime}, \gamma \approx 90^{\circ}$. U.C. 8. Stable between $1200^{\circ} \mathrm{C}$. and $1540^{\circ} \mathrm{C}$. which is M.P. Crystals are pseudo-hexagonal plates or laths with negative elongation and Z normal to plates. H. 5. G. 2.905. (+) $2 \mathrm{~V}=$ very small, ${ }^{13} n_{\mathrm{X}}=1.610, n_{\mathrm{Y}}=1.611, n_{\mathrm{Z}}=1.654$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.044$. It may show lamellar twinning on $\{001\}$ with $\mathrm{X} \wedge a=$ $2^{\circ}$. Colorless. PD 3.20, 2.79, 1.96; 10-486. Found in slags and made from fusion. It inverts at $1125^{\circ} \mathrm{C}$. to the $\beta$-phase (called parawollastonite) which is monoclinic with $a=15.33, b=7.28, c=7.07 \AA, \beta=95^{\circ} 25^{\prime}$. Crystals often $\{100\}$ or $\{001\}$ tablets with perfect $\{100\}$ and good $\{001\}$ and $\{\overline{1} 02\}$ cleavages; also poor $\{\overline{1} 01\}$ and $\{101\}$ cleavage or parting. Twinning on $\{100\}$. H. 4.5-5. G. 2.915. PD 2.97, 3.83, 3.52; 10-489. Inverts to the $\alpha$-phase at $1200^{\circ} \mathrm{C}$ and melts at $1540^{\circ} \mathrm{C}$. Decomposed by HCl. $\mathrm{X} \wedge c=34^{\circ} ; \mathrm{Y}=b$. ( - ) $2 \mathrm{~V}=35^{\circ}-40^{\circ}, \mathrm{r}>\mathrm{v}$ weak with distinct inclined dispersion. $n_{\mathrm{X}}=1.614, n_{\mathrm{Y}}=1.629, n_{\mathrm{Z}}=1.631, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.017$. Colorless or nearly so. Easily made from the $\alpha$-phase. The $\gamma$ - (or $\beta^{\prime}-$ ) phase ${ }^{14}$ (the mineral wollastonite) is triclinic with $a=7.88, b=7.27$, $c=7.03 \AA, \alpha$ about $90^{\circ}, \beta=95^{\circ} 16^{\prime}, \gamma=103^{\circ} 22^{\prime}$. Crystals often $\{100\}$

[^184]or $\{001\}$ tablets with perfect $\{100\}$ and good $\{001\}$ and $\{\overline{1} 02\}$ cleavages. H. 4.5-5. G. 2.915. M.P. $1540^{\circ} \mathrm{C} . \mathrm{X}^{\prime} \wedge c=31^{\circ}$. The optic plane makes an angle of $4^{\circ}$ with $b$, the axis of the cleavage zone. (-) $2 \mathrm{~V}=39^{\circ}, \mathrm{r}>\mathrm{v}$. $n_{\mathrm{X}}=1.620, n_{\mathrm{Y}}=1.632, n_{\mathrm{Z}}=1.634, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.014$. Colorless or nearly so. PD 2.97, 3.83, 3.52; 10-487. The glass has $n=1.628$ D. Wollastonite can have Fe (and Mn ) replacing some Ca . With 8.3 FeO and 1.2 MnO , G. 3.1 and $X^{\prime} \wedge c=44^{\circ}$ in a section normal to the cleavage zone; also $(-) 2 \mathrm{~V}=60^{\circ} ; n_{\mathrm{X}}=1.640, n_{\mathrm{Y}}=1.650$ calc., $n_{\mathrm{Z}}=1.653, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.013 . With ${ }^{15} 67$ mol. per cent $\mathrm{Fe}_{3} \mathrm{Si}_{3} \mathrm{O}_{9}:(-) 2 \mathrm{~V}=85^{\circ} ; n_{\mathrm{X}}=1.716, n_{\mathrm{Y}}=$ 1.725 ca., $n_{\mathrm{Z}}=1.734, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.018$. With about 64 per cent: ${ }^{16}$ $(-) 2 \mathrm{~V}=72.5^{\circ} ; n_{\mathrm{X}}=1.705, n_{\mathrm{Y}}=1.718, n_{\mathrm{Z}}=1.725, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.020$. Wollastonite is found in slags and made from fusion.
$\mathbf{C a}(\mathbf{F e}, \mathbf{M n}, \mathbf{M g})_{2} \mathrm{Si}_{3} \mathrm{O}_{9} \quad$ (Vogtite) is triclinic ${ }^{17}$ with $a: b: c=$ 1.093:1:0.729, $\alpha=99^{\circ} 37^{\prime}, \beta=99^{\circ} 21^{\prime}, \gamma=83^{\circ} 53^{\prime}$. Crystals $\{110\}$ plates with perfect $\{110\}$ and $\{1 \overline{1} 0\}$ cleavages. G. 3.39 . The optic axes are nearly normal to the cleavages; extinction normal to X is at $5^{\circ}$ and normal to Z is at nearly $0^{\circ} .(-) 2 \mathrm{~V}=65^{\circ} 30^{\prime} . n_{\mathrm{Y}}=1.701, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.018\left(\therefore n_{\mathrm{X}}=\right.$ $1.685, n_{\mathrm{z}}=1.703$, calc.-A.N.W.). Color pale yellow, not pleochroic. Forms in acid steel-furnace slags.
$\mathrm{CaMn}_{4} \mathrm{Si}_{5} \mathbf{O}_{15}$ (Rhodonite) is triclinic pinacoidal ${ }^{18}$ with $a=7.77, b=$ $12.45, c=6.74 k X, \alpha=85^{\circ} 10^{\prime}, \beta=94^{\circ} 4^{\prime}, \gamma=111^{\circ} 29^{\prime}$. Crystals often $\{001\}$ tablets with perfect $\{100\}$ and $\{010\}$ and good $\{001\}$ cleavages. H. 5.5-6. G. 3.75. M.P. about $1200^{\circ}$ C. Properties of the pure compound have not been measured but are approximately as follows: $(t) 2 \mathrm{~V}=60^{\circ}$, $\mathrm{r}<\mathrm{v}$ weak; $n_{\mathrm{X}}=1.729, n_{\mathrm{Y}}=1.731, n_{\mathrm{Z}}=1.739, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.010$. PD 2.94, 2.97, 2.76; 5-0614. The glass has $n=1.700$ and G. 3.48. Natural rhodonite usually contains $4-40 \mathrm{~mol}$. per cent of ( $\mathrm{Ca}, \mathrm{Fe}, \mathrm{Zn}, \mathrm{Mg})_{3} \mathrm{Si}_{3} \mathrm{O}_{9}$. With 17 per cent $\mathrm{Ca}_{3} \mathrm{Si}_{3} \mathrm{O}_{9}$ and 6 per cent $\mathrm{Fe}_{3} \mathrm{Si}_{3} \mathrm{O}_{9} \mathrm{X}$ is normal to a plane making angles of $51^{\circ} 40^{\prime}$ with $\{001\}$ and $51^{\circ} 47^{\prime}$ with $\{010\} ; \mathrm{Z}$ is normal to a plane making angles of $80^{\circ} 55^{\prime}$ with $\{001\}$ and $50^{\circ} 7^{\prime}$ with $\{010\}$; the extinction on $\{110\}$ is at $32^{\circ} 26^{\prime}$ to $\{100\}$ and $44^{\circ} 16^{\prime}$ to $\{001\}$; the extinction on $\{1 \overline{1} 0\}$ is at $10^{\circ} 48^{\prime}$ to $\{110\}$ and $97^{\circ} 56^{\prime}$ to $\{001\}$; the extinction on $\{001\}$ is at $54^{\circ} 27^{\prime}$ to $\{100\}$ and $39^{\circ} 37^{\prime}$ to $\{010\}$. With 25 per cent $\mathrm{Ca}_{3} \mathrm{Si}_{3} \mathrm{O}_{9}$ : $(+) 2 \mathrm{~V}=63^{\circ} ; n_{\mathrm{Y}}=1.708, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0103$. With 50 per cent $\mathrm{Ca}_{3} \mathrm{Si}_{3} \mathrm{O}_{9}$. $(+) 2 \mathrm{~V}=43^{\circ} ; n_{\mathrm{Y}}=1.678, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0106$. With about 50 per cent $(\mathrm{Fe}, \mathrm{Zn})_{3} \mathrm{Si}_{3} \mathrm{O}_{9}:(+) 2 \mathrm{~V}=45^{\circ} ; n_{\mathrm{X}}=1.742, n_{\mathrm{Y}}=1.745, n_{\mathrm{Z}}=1.759, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.017$. With 50 per cent $\mathrm{Mg}_{3} \mathrm{Si}_{3} \mathrm{O}_{9}:(+) 2 \mathrm{~V}=43^{\circ} ; n_{\mathrm{Y}}=1.678$,

[^185]$n_{\mathrm{z}}-n_{\mathrm{X}}=0.010 c a$. Color pink, red, yellow, gray; alters easily and then brown to black. Colorless in thin section, but in thick plates $\mathbf{X}$ clear reddish yellow, Y pinkish red, Z pale reddish yellow.
$\mathrm{Ca}_{2} \mathbf{P b S i}_{3} \mathbf{O}_{9}$ is biaxial with ${ }^{19}$ G. 3.99 and $n_{\mathrm{X}}=1.795$.
$\mathbf{C a}_{3} \mathbf{M n}_{3}\left(\mathbf{S i}_{3} \mathbf{O}_{9}\right)_{2}$ (Bustamite) is triclinic ${ }^{19 \mathrm{a}}$ with $a=7.64, b=7.16, c=$ $6.87 k X, \alpha=92^{\circ} 8^{\prime}, \beta=94^{\circ} 54^{\prime}, \gamma=101^{\circ} 35^{\prime}$. Closely related to low temperature $\mathrm{Ca}_{3} \mathrm{Si}_{3} \mathrm{O}_{9}$ but apparently not forming an isomorphous series with it. Perfect $\{100\}$, good $\{110\}$ and $\{1 \overline{1} 0\}$ and poor $\{010\}$ cleavages. X nearly normal to $\{100\}$ in which $Z^{\prime} \wedge c=36^{\circ}$. (-) $2 \mathrm{~V}=44^{\circ}, \mathrm{r}<\mathrm{v}$ weak with strong crossed dispersion. ${ }^{20} n_{\mathrm{X}}=1.662, n_{\mathrm{Y}}=1.674, n_{\mathrm{Z}}=1.676$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.014$. PD 2.89, 1.78, 1.67; 3-0693. It may contain Fe and Mg . With $^{21} \mathrm{Ca}: \mathrm{Fe}+\mathrm{Mg}: \mathrm{Mn}=34: 18: 48$, G. 3.43. (-) $2 \mathrm{~V}=35^{\circ}$. $n_{\mathrm{x}}=$ $1.692, n_{\mathrm{Y}}=1.705, n_{\mathrm{Z}}=1.707, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.015$. Color pink, fading in light. It inverts below $830^{\circ} \mathrm{C}$. to $\mathrm{CaMnSi}_{2} \mathrm{O}_{6}$ (johannsenite) which is a pyroxene.
$\mathbf{H N a C a} \mathbf{2 i}_{3} \mathbf{O}_{9}$ (Pectolite) is triclinic ${ }^{22}$ with $a=7.91, b=7.08, c=7.05$ $\AA, \alpha=90^{\circ} 24^{\prime}, \beta=95^{\circ} 14^{\prime}, \gamma=102^{\circ} 42^{\prime}$. Crystals long parallel $a$. Perfect $\{010\}$ and $\{001\}$ cleavages. H. 4.5-5. G. 2.74-2.88. F. 2. $\mathrm{X}^{\prime} \wedge c=10^{\circ}$ ( $19^{\circ}$-Palache ${ }^{23}$ ) nearly in the plane of $\beta$. Z nearly normal to $\{010\}$ and $\mathrm{Z}^{\prime} \wedge b=13^{\circ}$. Elongation positive. $(+) 2 \mathrm{~V}=60^{\circ} c a . n_{\mathrm{X}}=1.595,{ }^{24} n_{\mathrm{Y}}=$ $1.604, n_{\mathrm{Z}}=1.632, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.037$. PD 2.89, 3.08, 1.71;2-0759. In nature it may contain some $\mathrm{Fe}, \mathrm{Mg}, \mathrm{Mn}$ replacing Ca. For example with ${ }^{25} 1.50$ per cent ( $\mathrm{Fe}, \mathrm{Mn}$ ) O it has: $(+) 2 \mathrm{~V}=53^{\circ} 34^{\prime} ; n_{\mathrm{X}}=1.610, n_{\mathrm{Y}}=1.614$, $n_{\mathrm{Z}}=1.642, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.032$. Colorless or white. Found in boiler deposits.
$\mathbf{H N a}(\mathbf{C a}, \mathbf{M n})_{2} \mathbf{S i}_{3} \mathbf{O}_{9}$ (Schizolite) is triclinic with ${ }^{26} a=8.09, b=7.24$, $c=7.05 k X, \alpha=90^{\circ}\left(11 ?^{\prime}\right), \beta=95^{\circ} 22^{\prime}, \gamma=101^{\circ} 56^{\prime} . \mathrm{Mn}$ may exceed $\mathrm{Ca} ; \mathrm{Fe}, \mathrm{Ce}, \mathrm{K}$ may be present in the natural mineral. Schizolite is probably a manganoan pectolite, but a series is not yet known. Crystals like those of pectolite. Perfect $\{100\}$ and $\{001\}$ cleavages. H. 5-5.5. G. 2.97-3.13. $\mathrm{Y} \wedge a=9^{\circ}$; Z near $b$. Elongation $\pm .(+) 2 \mathrm{E}=82^{\circ} 40^{\prime}, \mathrm{r}<\mathrm{v}$ distinct. $n_{\mathrm{X}}=1.631, n_{\mathrm{Y}}=1.636, n_{\mathrm{Z}}=1.660, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.029$. Again: ${ }^{27}(+) 2 \mathrm{~V}=$

[^186]$51^{\circ}, n_{\mathrm{X}}=1.633$ calc., $n_{\mathrm{Y}}=1.641, n_{\mathrm{Z}}=1.677, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.044$. Color light red, altering to brown.
$\mathbf{H C a}_{2} \mathbf{F e}^{\prime \prime} \mathbf{F e}^{\prime \prime \prime} \mathbf{S i}_{5} \mathbf{O}_{15}$ (Babingtonite) is triclinic ${ }^{28}$ with $a=7.36, b=$ 11.52, $c=6.58 k X, \alpha=91^{\circ} 31^{\prime}, \beta=93^{\circ} 51^{\prime}, \gamma=104^{\circ} 4^{\prime}$. Structurally related to rhodonite. Crystals short prisms with perfect $\{001\}$ and poor $\{1 \overline{1} 0\}$ cleavages. H. 5.5-6. G. 3.36. F. 3 to black magnetic glass. Insoluble in acids. The optic plane is nearly parallel with $\{1 \overline{1} 0\}$ and nearly normal to $\{001\}$; extinction is at $44^{\circ}$ on $\{\overline{1} 11\}$, at $31^{\circ}$ on $\{1 \overline{1} 1\}$ and at about $40^{\circ}$ on $\{1 \overline{1} 0\} .(+) 2 \mathrm{~V}=76^{\circ}, \mathrm{r}>$ v strong. $n_{\mathrm{X}}=1.720, n_{\mathrm{Y}}=1.731, n_{\mathrm{z}}=1.753$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.033 \mathrm{Na}$. Again: $(+) 2 \mathrm{~V}=60^{\circ}-65^{\circ}, n_{\mathrm{X}}=1.713, n_{\mathrm{Y}}=1.726$, $n_{\mathrm{Z}}=1.746, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.033$. Color greenish or brownish in mass; in thin sections X dark emerald to bluish green, Y pale violet-brown or lilac, Z dark to pale brown or grass green. Formed in Bessemer slags; also a laboratory product. ${ }^{29}$

## F. SOROSILICATES (GROUPS OF TETRAHEDRA): <br> $\mathrm{A}_{m}\left(\mathrm{X}_{2} \mathrm{O}_{7}\right)_{n}$

$\mathbf{C a}_{2} \mathbf{M g S i}_{2} \mathbf{O}_{7}$ (Åkermanite) is tetragonal scalenohedral with $a=7.840$, $c=5.015 \AA$. Crystals short prismatic with poor $\{001\}$ cleavage. H. 5-6. G. 2.95. M.P. $1458^{\circ}$ C. Uniaxial positive with ${ }^{1} n_{\mathrm{O}}=1.632, n_{\mathrm{E}}=1.639$, $n_{\mathbf{E}}-n_{\mathrm{O}}=0.007$. Colorless. Made from fusion. PD 2.87, 1.76, 3.09; 4-0681. $\mathrm{Ca}_{2} \mathrm{MgSi}_{2} \mathrm{O}_{7}$ forms a continuous series of mix-crystals (called melilite) with $\mathrm{Ca}_{2} \mathrm{AlSiAlO}_{7}$ (gehlenite). Data follow:

| Wt. per cent |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{Ca}_{2} \mathrm{MgSi}_{2} \mathrm{O}_{7}$ | $\mathrm{Ca}_{2} \mathrm{AlSiAlO}_{7}$ | $n_{\mathrm{O}}$ | $n_{\mathrm{E}}$ | Sign | $n$ of glass |
| 100 | 0 | 1.632 | 1.639 | + | 1.641 |
| 90 | 10 | 1.637 | 1.643 | + |  |
| 75 | 25 | 1.643 | 1.647 | + |  |
| 60 | 40 | 1.648 | 1.649 | + |  |
| 56 | 50 | 1.653 | 1.652 | - | 1.638 |
| 40 | 60 | 1.657 | 1.654 | - |  |
| 20 | 80 | 1.664 | 1.657 | - |  |
| 0 | 100 | 1.669 | 1.658 | - | 1.638 |

$\mathbf{C a}_{2} \mathbf{M g S i}_{2} \mathbf{O}_{7}$ also forms mix-crystals with $\mathbf{C a}_{2} \mathbf{Z n S i}_{2} \mathbf{O}_{7}$ (hardystonite) and at least a partial series with $\mathrm{Ca}_{2} \mathrm{MnSi}_{2} \mathrm{O}_{7}, \mathrm{Ca}_{2} \mathrm{Fe}^{\prime \prime} \mathrm{Si}_{2} \mathrm{O}_{7}$ and $\mathrm{Ca}_{2} \mathrm{Fe}^{\prime \prime \prime} \mathrm{SiAlO}_{7}$. With 1.70 NiO and 0.21 CoO , uniaxial negative ${ }^{2}$ with $n_{\mathrm{O}}=1.656, n_{\mathrm{E}}=1.652, n_{\mathrm{O}}-n_{\mathrm{E}}=0.004$.

[^187]$\mathrm{Ca}_{2} \mathrm{FeSi}_{2} \mathrm{O}_{7}$ (Ferroåkermanite) is tetragonal. G. 3.23. Poor $\{001\}$ cleavage. Uniaxial negative with ${ }^{3} n_{\mathrm{O}}=1.690, n_{\mathrm{E}}=1.673, n_{\mathrm{O}}-n_{\mathrm{E}}=$ 0.017. Stable only below $775^{\circ} \mathrm{C} .80$ per cent $\mathrm{Ca}_{2} \mathrm{FeSi}_{2} \mathrm{O}_{7}$ with 20 per cent $\mathrm{Ca}_{2} \mathrm{MgSi}_{2} \mathrm{O}_{7}$ has $n_{\mathrm{O}}=1.670, n_{\mathrm{E}}=1.658, n_{\mathrm{O}}-n_{\mathrm{E}}=0.012$. Justite is found in slags; it is about 50 per cent $\mathrm{Ca}_{2} \mathrm{FeSi}_{2} \mathrm{O}_{7}$ with about 35 per cent $\mathrm{Ca}_{2}(\mathrm{Zn}, \mathrm{Mn}) \mathrm{Si}_{2} \mathrm{O}_{7}$; it has $n_{\mathrm{O}}=1.670, n_{\mathrm{E}}=1.657, n_{\mathrm{O}}-n_{\mathrm{E}}=0.013$.
$\mathrm{Ca}_{2} \mathrm{AlSiAlO}_{7}$ (Gehlenite) is tetragonal with $a=7.69, c=5.10 \AA$. Crystals short prismatic with good $\{001\}$ cleavage. H. 5-6. G. 3.04. M.P. $1590^{\circ} \mathrm{C}$. Uniaxial negative with $n_{\mathrm{O}}=1.669, n_{\mathrm{E}}=1.658, n_{\mathrm{O}}-n_{\mathrm{E}}=$ 0.011. Colorless. Made from fusion. PD 2.85, 1.75, 3.07; $9-216^{*}$. The glass has G. 2.884 and $n=1.638$. Forms mix-crystals with $\mathrm{Ca}_{2} \mathrm{MgSi}_{2} \mathrm{O}_{7}$ (åkermanite) whose properties are given above. Also with $\mathrm{Ca}_{2} \mathrm{ZnSi}_{2} \mathrm{O}_{7}$ (hardystonite) and $\mathrm{Ca}_{2} \mathrm{FeSi}_{2} \mathrm{O}_{7}$; also a partial series with $\mathrm{NaCaAlSi} \mathrm{O}_{7}, \mathrm{Ca}_{2} \mathrm{MnSi}_{2} \mathrm{O}_{7}$. $\mathrm{Ca}_{2} \mathrm{AlSiAlO}_{7}$ with 30 mol. per cent of $\mathrm{NaCaAlSi}_{2} \mathrm{O}_{7}$ is uniaxial negative with $n_{\mathrm{O}}=1.644, n_{\mathrm{E}}=1.628, n_{\mathrm{O}}-n_{\mathrm{E}}=0.016 . \mathrm{Ca}_{2} \mathrm{AlSiAlO}_{7}$ can take up to 15 per cent $\mathrm{Na}_{2} \mathrm{Si}_{3} \mathrm{O}_{7}$ in solid solution and then ${ }^{4}$ it is uniaxial negative with $n_{\mathrm{O}}=1.644, n_{\mathrm{E}}=1.628, n_{\mathrm{O}}-n_{\mathrm{E}}=0.016$. But $\mathrm{Na}_{2} \mathrm{Si}_{3} \mathrm{O}_{7}$ does not intercrystallize with $\mathrm{Ca}_{2} \mathrm{MgSi}_{2} \mathrm{O}_{7}$.
$\mathbf{C a}_{2} \mathbf{F e}^{\prime \prime \prime} \mathbf{S i A l O}_{7}$ (Ferrigehlenite) is tetragonal with $a=7.54, c=4.855$ A. M.P. $1285^{\circ}$ C. Uniaxial negative ${ }^{5}$ with $n_{\mathrm{O}}=1.666, n_{\mathrm{E}}=1.661, n_{\mathrm{O}}-$ $n_{\mathrm{E}}=0.005$.
$\mathbf{C a}_{2} \mathbf{Z n S i}_{2} \mathbf{O}_{7}$ (Hardystonite) is tetragonal scalenohedral with $a=7.83$, $c=4.99 \AA . \mathrm{H} .3-4$. G. 3.40. Basal cleavage and $\{100\}$ and $\{001\}$ parting. Uniaxial negative with ${ }^{6} n_{\mathrm{O}}=1.6718, n_{\mathrm{E}}=1.6624, n_{\mathrm{O}}-n_{\mathrm{E}}=0.0094$. Color white.
$\mathbf{N a C a A l S i} \mathbf{O}_{2} \mathbf{O}_{7}$ is tetragonal with ${ }^{7} a=8.511, c=4.807 \AA$. It decomposes at $1080^{\circ}$ C. Uniaxial negative with $n_{\mathrm{O}}=1.580, n_{\mathrm{E}}=1.575, n_{\mathrm{O}}-n_{\mathrm{E}}=$ 0.005. Colorless.
$\mathbf{K}_{2} \mathbf{P b}_{2} \mathbf{S i}_{2} \mathbf{O}_{7}$ forms hexagonal ${ }^{8}$ plates with basal cleavage. M.P. $918^{\circ}$ C. Uniaxial negative with $n_{\mathrm{O}}=1.93, n_{\mathrm{E}}=1.72, n_{\mathrm{O}}-n_{\mathrm{E}}=0.21$. PD 2.98, 7.5, 4.08; 3-0625. The glass has $n=1.775$. It softens at $395^{\circ} \mathrm{C}$. Made from fusion.
$\mathbf{N a C a B e S i} \mathbf{O}_{6} \mathbf{F}$ (Leucophanite) is orthorhombic ${ }^{9}$ and pseudo-tetragonal with $a=7.38, b=7.38, c=9.96 k X$. Crystals basal tablets with perfect $\{001\}$ and $\{010\}$ cleavages. Common twinning on $\{110\}$ or $\{001\}$. H. 4.

[^188]G. 2.96. $\mathrm{X}=c ; \mathrm{Y}=a$. (-) $2 \mathrm{~V}=39^{\circ}, \mathrm{r}>\mathrm{v} . n_{\mathrm{X}}=1.571, n_{\mathrm{Y}}=1.595$, $n_{\mathrm{Z}}=1.598, n_{\mathrm{Z}}-n_{\mathrm{x}}=0.027$. Color white, green or yellow. Colorless in section. Made from fusion of $\mathrm{BeCO}_{3}, \mathrm{CaCO}_{3}, \mathrm{SiO}_{2}$ and NaF .
$\mathbf{N a}_{6} \mathbf{S i}_{2} \mathbf{O}_{7} \cdot \mathbf{1 1 H}_{2} \mathrm{O}$ is orthorhombic with $a: b: c=0.884: 1: 1.10$. Crystals prismatic or varied. M.P. $88^{\circ} . \mathrm{X}=a ; \mathrm{Y}=b .(+) 2 \mathrm{~V}=65^{\circ} . n_{\mathrm{X}}=1.504$, $n_{\mathrm{Y}}=1.510, n_{\mathrm{Z}}=1.524, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.020$. Colorless.
$\mathbf{N a}_{6} \mathbf{S i}_{2} \mathbf{O}_{7}$ is orthorhombic(?). ${ }^{10}$ G. 2.96. M.P. $1122^{\circ}$ C. ( + ) $2 \mathrm{~V}=$ ?, $n_{\mathrm{X}}=$ $1.524, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.529, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.005$. Colorless. Made from fusion. The glass has G. 2.6.
$\mathbf{L i K}_{5} \mathbf{S i}_{2} \mathbf{O}_{7}$ is orthorhombic(?). M.P. $830^{\circ}$ C. $n_{\mathrm{X}}=1.515 . n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=$ $1.520, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.005$.
$\mathbf{N a}_{2} \mathbf{Z r S i}_{2} \mathbf{O}_{7}$ forms long needles, perhaps monoclinic, ${ }^{11}$ with a very small extinction angle. $n_{\mathrm{X}}=1.688, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.710, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.022$. Colorless.
$\mathbf{Z n}_{4}(\mathbf{O H})_{2} \mathbf{S i}_{2} \mathbf{O}_{7} \cdot \mathbf{H}_{2} \mathbf{O}$ (Hemimorphite) is orthorhombic with ${ }^{12} a=8.38$, $b=10.70, c=5.11 k X$. Crystals often in sheaflike aggregates. Perfect $\{110\}$ and poor $\{101\}$ cleavages. H. 5. G. 3.45. F. 6, glows brightly. Gelatinizes with $\mathrm{HCl} . \mathrm{Y}=a ; \mathrm{Z}=c .(+) 2 \mathrm{~V}=46^{\circ}, \mathrm{r}>\mathrm{v}$ strong. $n_{\mathrm{X}}=$ $1.614, n_{\mathrm{Y}}=1.617, n_{\mathrm{Z}}=1.636, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.022$. Colorless, white, pale blue or green, gray, brown. PD 3.10, 6.60, 3.29; 5-0555.
$\mathbf{N a}_{2} \mathbf{C a}_{2} \mathbf{S i}_{2} \mathbf{O}_{7}$ is probably monoclinic. ${ }^{13}$ Crystals laths often twinned with inclined extinction. $2 \mathrm{~V}=$ large; all indices near 1.665, $n_{\mathrm{z}}-n_{\mathrm{x}}=0.003$. Colorless. PD 2.76, 2.71, 2.61; 10-16.
$\mathbf{N a} \mathbf{a}_{2} \mathbf{M g}_{2} \mathrm{Si}_{2} \mathrm{O}_{7}$ is monoclinic ${ }^{14}$ with $\mathrm{Z} \wedge c=38^{\circ}$. ( + ) $2 \mathrm{~V}=$ large; $n_{\mathrm{X}}=$ $1.641, n_{\mathrm{Y}}=1.646$ (est.), $n_{\mathrm{Z}}=1.654, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.013$. Colorless.
$\mathbf{C a}_{3} \mathbf{S i}_{2} \mathbf{O}_{7}$ (Rankinite) is monoclinic. ${ }^{15}$ Dissociates to $\mathrm{Ca}_{2} \mathrm{SiO}_{4}$ at about $1475^{\circ} \mathrm{C} . \mathrm{X} \wedge a=15^{\circ} ; \mathrm{Y}=b .(+) 2 \mathrm{~V}=64^{\circ} c a . n_{\mathrm{X}}=1.641, n_{\mathrm{Y}}=1.645 \pm$, $n_{\mathrm{Z}}=1.650, n_{\mathrm{z}}-n_{\mathrm{X}}=0.009 \mathrm{Na}$. Colorless. PD 3.14, 2.69, 3.77; 9-327. Made from fusion at about $1450^{\circ} \mathrm{C}$.
$\mathbf{C u}_{4} \mathbf{S i}_{2} \mathbf{O}_{7} \mathbf{F}_{2}$ (Cuspidine) is monoclinic ${ }^{16}$ with $a: b: c=0.724: 1: 1.934$, $\beta=90^{\circ} 38^{\prime}$. Crystals small pseudo-rhombic with good $\{001\}$ cleavage. Lamellar twinning. H. 5-6. G. $2.95 c a$. Soluble in $\mathrm{HNO}_{3} . \mathrm{Y}=b ; \mathrm{Z} \wedge c=$ $6^{\circ} .(+) 2 \mathrm{~V}=63^{\circ}, \mathrm{r}>$ v. $n_{\mathrm{X}}=1.592, n_{\mathrm{Y}}=1.595, n_{\mathrm{Z}}=1.606, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.014. Colorless or pink. Made from fusion. It forms a complete series with custerite.

[^189]$\mathrm{Cu}_{4}(\mathbf{O H})_{2} \mathbf{S i}_{2} \mathbf{O}_{7}$ (Custerite) is monoclinic ${ }^{17}$ with $a: b: c=0.724: 1: 1.934$, $\beta=90^{\circ} 38^{\prime}$. Three directions of cleavage on $\{001\}$ and $\{110\}$ make a pseudocubic form. Lamellar twinning. H. 5-6. G. $2.95 c a . \mathrm{X}=b ; \mathrm{Z} \wedge c=6.5^{\circ}$. $(+) 2 \mathrm{~V}=60^{\circ}, \mathrm{r}>\mathrm{v} ; n_{\mathrm{X}}=1.586, n_{\mathrm{Y}}=1.589, n_{\mathrm{Z}}=1.598, n_{\mathrm{Z}}-n_{\mathrm{X}}=$ 0.012. Colorless or greenish gray. It forms a series with cuspidine.
$\mathbf{C a}_{3} \mathbf{S i}_{2} \mathrm{O}_{7} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ (Afwillite) is monoclinic sphenoidal with ${ }^{18} a=11.39$, $b=5.47, c=13.09 \AA, \beta=98^{\circ} 26^{\prime}$. Crystals elongated along $b$ with perfect $\{001\}$ and poor $\{100\}$ cleavages. H. 4. G. 2:63. Soluble in HCl. X $\wedge c=$ $-31.2^{\circ}$ red, $-30^{\circ} \mathrm{Na},-29.9$ blue; $\mathrm{Y}=b .(+) 2 \mathrm{~V}=54^{\circ} 40^{\prime}, \mathrm{r}<\mathrm{v} . n_{\mathrm{X}}=$ 1.6169, $n_{\mathrm{Y}}=1.6204, n_{\mathrm{Z}}=1.6336, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0167$. Again: ${ }^{19} n_{\mathrm{X}}=$ $1.614, n_{\mathrm{Y}}=1.617, n_{\mathrm{Z}}=1.630, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.016$. Colorless. PD 3.19, 2.84, 2.74; 9-454. Forms at low temperature (up to $160^{\circ}$ C.).

## G. NESOSILICATES (ISOLATED TETRAHEDRA): $\mathrm{A}_{m}\left(\mathrm{XO}_{4}\right)_{n} \mathrm{Z}_{q}$

Nesosilicates have $\mathrm{SiO}_{4}$ (or a multiple) in their formulas because the $\mathrm{SiO}_{4}$ tetrahedra have no oxygen atoms in common.

## Garnet Group

The garnet group consists of silicates whose formulas may be summarized as $\mathrm{A}_{3} \mathrm{~B}_{2}\left(\mathrm{SiO}_{4}\right)_{3}$ in which A may be $\mathrm{Ca}, \mathrm{Mg}, \mathrm{Fe}^{\prime \prime}$ or $\mathrm{Mn}^{\prime \prime}$ and B may be $\mathrm{Al}, \mathrm{Fe}^{\prime \prime \prime}$, or Cr . Ti may be present in limited amounts and also $\mathrm{Mn}^{\prime \prime \prime}$. Finally $\mathrm{SiO}_{4}$ may be replaced by $\mathrm{PO}_{4}$ to about 4 per cent $\mathrm{P}_{2} \mathrm{O}_{5}$ or by $2 \mathrm{H}_{2} \mathrm{O}$ as in hibschite and artificial $3 \mathrm{CaO} \cdot \mathrm{Al}_{2} \mathrm{O}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$. There are six chief types of garnet of which at least four have been produced artificially; the six are:

| Species | Subspecies | Composition | $a(\AA)$ |
| :---: | :---: | :---: | :---: |
| Pyralspite | Pyrope | $\mathrm{Mg}_{3} \mathrm{Al}_{2}\left(\mathrm{SiO}_{4}\right)_{3}$ | 11.44 |
|  | Almandite | $\mathrm{Fe}_{3} \mathrm{Al}_{2}\left(\mathrm{SiO}_{4}\right)_{3}$ | 11.53 |
|  | Spessartite | $\mathrm{Mn}_{3} \mathrm{Al}_{2}\left(\mathrm{SiO}_{4}\right)_{3}$ | 11.59 |
| Ugrandite | Uvarovite | $\mathrm{Ca}_{3} \mathrm{Cr}_{2}\left(\mathrm{SiO}_{4}\right)_{3}$ | 12.05 |
|  | Grossularite | $\mathrm{Ca}_{3} \mathrm{Al}_{2}\left(\mathrm{SiO}_{4}\right)_{3}$ | 11.84 |
|  | Andradite | $\mathrm{Ca}_{3} \mathrm{Fe}_{2}\left(\mathrm{SiO}_{4}\right)_{3}$ | 12.04 |

Garnet crystals found in nature very rarely approach any single formula but are crystal solutions of two or more end-members, but pyralspite intercrystallizes to only a limited extent with ugrandite.
$\mathbf{M g}_{3} \mathrm{Al}_{2} \mathrm{Si}_{3} \mathbf{O}_{12}$ (Pyrope) is isometric hexoctahedral with $a=11.44 \AA$. Crystals rare. No cleavage. H. 7-7.5. G. 3.51. F. 4. Isotropic with $n=$
${ }^{17}$ Tilley: Min. Mag. XXVIII, p. 90 (1947).
${ }^{18}$ Gottfried: Zeit. Krist. LXXXIV, p. 172 (1933).
${ }^{19}$ Heller and Taylor: J. Chem. Soc. London 1952, p. 1018 and 2535.
1.705. Color brown, red or black (some Fe is nearly always present). PD 2.58, 1.54, 1.07; 2-1008.
$\mathbf{F e}_{3} \mathbf{A l}_{2} \mathbf{S i}_{3} \mathbf{O}_{12}$ (Almandite) is isometric with $a=11.53 \AA$. Crystals often dodecahedral with striated faces. No cleavage. H. 7-7.5. G. 4.32. F. 3. Isotropic with $n=1.830$. Color brown, red black. Made under water vapor pressure. ${ }^{1}$ PD 2.57, 1.54, 2.87; 9-427.
$\mathbf{M n}_{3} \mathbf{A l}_{2} \mathbf{S i}_{3} \mathbf{O}_{12}$ (Spessartite) is isometric with $a=11.59 \AA$. Crystals usually dodecahedral. No cleavage. H. 7-7.5. G. 4.18. M.P. $1200^{\circ}$ C. Isotropic with $n=1.80$. Color red. PD 2.60, 1.56, 1.61; 10-354*. Spessartite forms a complete solid solution series with yttrogarnet, $\mathrm{Y}_{3} \mathrm{Al}_{2} \mathrm{Al}_{3} \mathrm{O}_{12}$ $\left(3 \mathrm{Y}_{2} \mathrm{O}_{3} \cdot 5 \mathrm{Al}_{2} \mathrm{O}_{3}\right)$ which is isometric ( $a=12.01 \AA$ ), in dodecahedral isotropic crystals with $n=1.823$. PD 2.69, 1.67, 4.89; 8-178. $\mathrm{Y}_{3} \mathrm{Al}_{2} \mathrm{Al}_{3} \mathrm{O}_{12}$ inverts at about $1970^{\circ}$ C. to a tetragonal (?) phase called yttroalumite which melts at about $2110^{\circ} \mathrm{C}$. ( - ) $2 \mathrm{~V}=0^{\circ}, n_{\mathrm{O}}=1.942, n_{\mathrm{E}}=1.927$, $n_{\mathrm{O}}-n_{\mathrm{E}}=0.015$. Yttroalumite also may be biaxial (due to strain?). PD 2.62, 3.70, 1.50; $9-310 . \mathrm{Mn}_{3} \mathrm{Al}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$ glass has $n=1.655 . \mathrm{Y}_{3} \mathrm{Al}_{2} \mathrm{Al}_{3} \mathrm{O}_{12}$ has G. 3.92 and $n=1.719$ (by extrapolation). Made at high temperature under high pressure. ${ }^{2}$
$\mathbf{C a}_{3} \mathbf{C r}_{2} \mathbf{S i}_{3} \mathbf{O}_{12}$ (Uvarovite) is isometric with $a=12.05 \AA$. Crystals dodecahedral or varied. No cleavage. H. 7.5. G. 3.78. F. 7. Isotropic with $n=1.86$. Color green. Made from fusion. ${ }^{3} \mathrm{PD} 2.65,1.59,2.97 ; 7-70$.
$\mathbf{C a}_{3} \mathbf{A l}_{2} \mathbf{S i}_{3} \mathbf{O}_{12}$ (Grossularite) is isometric with $a=11.84 \AA$. Crystals usually dodecahedral; also trapezohedral. No cleavage. H. 6.5-7. G. 3.53. F. 3. Isotropic with $n=1.735$. But the isometric condition is stable above about $800^{\circ} \mathrm{C}$. and only metastable ${ }^{4}$ at lower temperatures so that, while tiny crystals are usually isotropic, larger crystals are often anisotropic retaining their external isometric faces by means of complex twinning. For example a dodecahedral crystal may contain twelve rhombic pyramids in which each has the optic plane parallel with the long diagonal of the rhombic face and the obtuse bisectrix normal to that face, the optic angle being about $50^{\circ}-90^{\circ}$ with $\mathrm{r}>\mathrm{v}$, and $n_{\mathrm{Z}}-n_{\mathrm{X}}$ about 0.003 . Colorless, yellow, brown, red. PD 2.65, 1.58, 2.96; 3-0826. Made under pressure at high temperature. $\mathrm{Ca}_{3} \mathrm{Al}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$ forms a continuous series of mix-crystals with $\mathrm{Ca}_{3} \mathrm{Fe}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$ and probably also with $\mathrm{Ca}_{3} \mathrm{Cr}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$, the densities and refractive indices varying continuously as follows:

|  | $\mathrm{Ca}_{3} \mathrm{Fe}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$ |  | $\mathrm{Ca}_{3} \mathrm{Al}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$ |  | $\mathrm{Ca}_{3} \mathrm{Cr}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$ |
| :--- | :---: | :--- | :--- | :--- | :--- |
| G. | 3.83 | $\leftrightarrow$ | 3.53 | $\leftrightarrow$ | 3.78 |
| $n$ | 1.895 | $\leftrightarrow$ | 1.735 | $\leftrightarrow$ | 1.86 |

${ }^{1}$ Yoder: Am. Min. XL, p. 342 (1955).
${ }^{2}$ Yoder and Keith: Am. Min. XXXVI, p. 519 (1951).
${ }^{3}$ Hummel: Am. Min. XXXV, p. 324 (1950).
${ }^{4}$ Merwin in Wright: U. S. Geol. Surv. Prof. Pap. 87, p. 108 (1915).
$\mathrm{Ca}_{3} \mathrm{Al}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$ also forms mix-crystals in all proportions with $\mathrm{Ca}_{3} \mathrm{Al}_{2} \mathrm{O}_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}^{5}\left(\mathrm{Ca}_{3} \mathrm{Al}_{2}\left(\mathrm{H}_{4} \mathrm{O}_{4}\right)_{3}\right.$ or $\left.\mathrm{Ca}_{3} \mathrm{Al}_{2}\left(\mathrm{H}_{2}\right)_{3} \mathrm{O}_{6}(\mathrm{OH})_{6}\right)$. This compound is isometric and isotropic ${ }^{6}$ with G. 2.52 and $n=1.605 . \mathrm{Ca}_{3} \mathrm{Al}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$ with $\mathrm{Ca}_{3} \mathrm{Al}_{2} \mathrm{O}_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ in the ratio about $2: 1$ has H .6 .5 , G. 3.13 and $n=$ 1.67-1.68; also may be weakly birefringent; it has been named hibschite.
$\mathbf{C a}_{3} \mathbf{F e}_{2} \mathbf{S i}_{3} \mathbf{O}_{12}$ (Andradite) is isometric with $a=12.04 \AA$. Crystals usually dodecahedral. No cleavage. H. 6.5-7. G. 3.83. Isotropic with $n=1.895$. But, like $\mathrm{Ca}_{3} \mathrm{Al}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$, the isometric condition is stable above about $800^{\circ} \mathrm{C}$. and only metastable at lower temperatures. ${ }^{4}$ So twinning is common with weak birefringence and a large optic angle. See $\mathrm{Ca}_{3} \mathrm{Al}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$. Color brown to red or even black. PD 2.70, 3.02, 1.61; 10-288. Made under pressure at high temperature. Forms a continuous series of mix-crystals with $\mathrm{Ca}_{3} \mathrm{Al}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$-see the latter. Also forms similar series with $\mathrm{Ca}_{3} \mathrm{Fe}_{2} \mathrm{O}_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}^{5}$ $\left(\mathrm{Ca}_{3} \mathrm{Fe}_{2}\left(\mathrm{H}_{4} \mathrm{O}_{4}\right)_{3}\right.$ or $\left.\mathrm{Ca}_{3} \mathrm{Fe}_{2}\left(\mathrm{H}_{2}\right)_{3} \mathrm{O}_{6}(\mathrm{OH})_{6}\right)$. This compound is isometric and isotropic ${ }^{6}$ with $n=1.710$.
$\mathbf{N a}_{2} \mathbf{C a S i O}_{4}$ is isometric ${ }^{7}$ with $a=7.493 k X$. G. 2.79. F. high. Isotropic with $n \approx 1.60$. Colorless. PD 2.66, 1.53, 1.87; 2-0951. Made from fusion.
$\mathbf{N a}_{2} \mathbf{M g S i O}_{4}$ is isometric ${ }^{8}$ and isotropic with $n=1.523$.
$\mathbf{K}_{2} \mathbf{Z n S i O}_{4}$ is isometric ${ }^{9}$ and isotropic with $n=1.622$.
$\mathbf{Z r S i O}_{4}$ (Zircon) is tetragonal with ${ }^{10} a=6.60, c=5.88 k X$. Crystals often prismatic with pyramids. Poor $\{110\}$ cleavage. G. 4.66-4.7. H. 7.5. F. 7. It may contain some $\mathrm{Fe}_{2} \mathrm{O}_{3}, \mathrm{ThO}_{2}, \mathrm{Y}_{2} \mathrm{O}_{3}, \mathrm{HfO}_{2}, \mathrm{U}_{2} \mathrm{O}_{3}, \mathrm{H}_{2} \mathrm{O}$, etc., which cause variations in refractive indices. PD 3.30, 4.43, $2.52 ; 6-0266$. Also crystals gradually alter to an amorphous state (called metamict) apparently due to the effects of radioactivity of $U$ and $T h$ in them. As this alteration progresses the properties change as follows:

|  | Normal <br> Zircon | Partly altered <br> Zircon (Hyacinth) | Much altered <br> Zircon (Malacon) |
| ---: | :---: | :---: | :---: |
| $n_{\mathrm{O}}$ | $1.92-1.96$ | $1.90-1.92$ | $1.76-1.90$ |
| $n_{\mathrm{E}}$ | $1.96-2.02$ | $1.92-1.96$ | $1.76-1.92$ |
| $n_{\mathrm{E}}-n_{\mathrm{O}}$ | $0.04-0.06$ | $0.02-0.04$ | $0.00-0.02$ |
| G. | $4.6-4.71$ | $4.2-4.6$ | $3.9-4.2$ |
| H. | 7.5 | 7 ca. | $6-7$ |

[^190]Color yellow, brown, gray, rarely green or colorless. In thin section colorless to pale brown or gray. Made by heating ${ }^{11} \mathrm{SiO}_{2}+\mathrm{ZrO}_{2}$ to about $2600^{\circ}-2800^{\circ} \mathrm{C}$.
$\mathrm{Na}_{4} \mathbf{Z r}_{2}\left(\mathbf{S i O}_{4}\right)_{3}$ is hexagonal ${ }^{12}$ with rhombohedral habit. G. 2.88. M.P. $1540^{\circ} \mathrm{C}$. Uniaxial negative with $n_{\mathrm{O}}=1.715 \mathrm{D}, n_{\mathrm{E}}=1.692, n_{\mathrm{O}}-n_{\mathrm{E}}=$ 0.023 . Colorless. Made from fusion.
$\mathrm{Be}_{2} \mathrm{SiO}_{4}$ (Phenacite) is hexagonal ${ }^{13}$ with $a=12.40, c=8.24 \AA$. Crystals rhombohedral or prismatic; twinning common on $\{10 \overline{1} 0\}$. Distinct $\{11 \overline{2} 0\}$ cleavage. H. 7.5. G. 2.98. M.P. $1560^{\circ}$ C. Uniaxial positive with $n_{\mathrm{O}}=1.654$, $n_{\mathrm{E}}=1.670, n_{\mathrm{E}}-n_{\mathrm{O}}=0.016$. Colorless, yellow, rose or brown; colorless in thin section. PD 3.12, 3.66, 2.52; 9-431.
$\mathbf{Z n}_{2} \mathbf{S i O}_{4}$ (Willemite) is hexagonal with $a=12.49, c=8.26 \AA$. Space group $R \overline{3}$. Crystals hexagonal prisms with $\{0001\}$ and $\{11 \overline{2} 0\}$ cleavages. H. 5.5. G. 3.9-4.2. M.P. $1510^{\circ}$ C. Uniaxial positive with ${ }^{14} n_{0}=1.695$ $n_{\mathrm{E}}=1.715, n_{\mathrm{E}}-n_{\mathrm{O}}=0.020 \mathrm{Na}$. With some $\mathrm{TiO}_{2}: n_{\mathrm{O}}=1.701, n_{\mathrm{E}}=$ 1.724, $n_{\mathrm{E}}-n_{\mathrm{O}}=0.023$. In lead slags crystals may contain up to 36 per cent $\mathrm{Fe}_{2} \mathrm{SiO}_{4}$; with also ${ }^{15} 7$ per cent $\mathrm{Mg}_{2} \mathrm{SiO}_{4}: n_{\mathrm{O}}=1.701, n_{\mathrm{E}}=1.726$, $n_{\mathrm{E}}-n_{\mathrm{O}}=0.025 \mathrm{Na}$; this variety is pleochroic with 0 reddish violet, E bluish violet. Green fluorescence is common. PD 2.63, 2.83, 3.49; 8-492. Another phase ${ }^{16}\left(\beta-\mathrm{Zn}_{2} \mathrm{SiO}_{4}\right)$ has $(-) 2 \mathrm{~V}=49^{\circ}$, mean index $n=1.700$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.009$. Yellow fluorescence. A third phase ( $\gamma-\mathrm{Zn}_{2} \mathrm{SiO}_{4}$ ) has $(-) 2 \mathrm{~V}=40^{\circ}, n_{\mathrm{X}}=1.685, n_{\mathrm{Y}}=1.700, n_{\mathrm{Z}}=1.703, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.018$. Red fluorescence.
$\mathbf{Z n}_{2} \mathbf{G e O}_{4}$ is hexagonal ${ }^{16}$ (forming a complete series ot mix-crystals with $\mathrm{Zn}_{2} \mathrm{SiO}_{4}$ ). It melts at $1490^{\circ} \mathrm{C}$. and has G. 4.82. It is uniaxial positive with $n_{\mathrm{O}}=1.769, n_{\mathrm{E}}=1.802, n_{\mathrm{E}}-n_{\mathrm{O}}=0.033$. PD 2.90, 2.70, 1.87; 3-0689.
$\mathrm{K}_{2} \mathrm{CaSiO}_{4}$ is hexagonal..$^{17}$ M.P. $1630^{\circ}$ C. Crystals hexagonal bipyramids. Uniaxial positive with $n_{\mathrm{O}}=1.600, n_{\mathrm{E}}=1.605, n_{\mathrm{E}}-n_{\mathrm{O}}=0.005$. Colorless.
$\mathbf{K}_{2} \mathbf{C a}_{23} \mathbf{S i}_{12} \mathbf{O}_{48}$ is probably hexagonal. Complex twinning common. Uniaxial positive with ${ }^{18} n_{\mathrm{O}}=1.695, n_{\mathrm{E}}=1.703, n_{\mathrm{E}}-n_{\mathrm{O}}=0.008$. Colorless. With some iron in solid solution: $n_{\mathrm{O}}=1.713, n_{\mathrm{E}}=1.722, n_{\mathrm{E}}-n_{\mathrm{O}}=$ 0.009 . This may be $\alpha-\mathrm{Ca}_{2} \mathrm{SiO}_{4}$ with some $\mathrm{K}_{4} \mathrm{SiO}_{4}$ in crystal solution.
$\mathrm{Ca}_{2} \mathbf{S i O}_{4}$ has four crystal phases. ${ }^{19}$ The high temperature $\alpha$-phase is stable below (and near) the melting point ( $2130^{\circ} \mathrm{C}$.). On cooling it inverts to

[^191]$\alpha^{\prime}-\mathrm{Ca}_{2} \mathrm{SiO}_{4}$ (bredigite) and that inverts to $\beta-\mathrm{Ca}_{2} \mathrm{SiO}_{4}$ (larnite) at $1420^{\circ} \mathrm{C}$. which inverts to $\gamma-\mathrm{Ca}_{2} \mathrm{SiO}_{4}$ (shannonite) at $675^{\circ} \mathrm{C}$.
$\alpha-\mathrm{Ca}_{2} \mathrm{SiO}_{4}$ is hexagonal with $^{20} a=5.44$ and $c=7.02 \mathrm{kX}$. The pure compound inverts at high temperature to $\alpha^{\prime}-\mathrm{Ca}_{2} \mathrm{SiO}_{4}$, but with other compounds in solid solution it is metastable; for example, with $13.58 \mathrm{Mg}_{2} \mathrm{SiO}_{4}$ and $5.62 \mathrm{Fe}_{2} \mathrm{SiO}_{4}$ it is uniaxial positive with $n_{\mathrm{O}}=1.724, n_{\mathrm{E}}=1.738, n_{\mathrm{E}}-$ $n_{\mathrm{O}}=0.014$. The pure compound has a mean index, $n$, below 1.707 and weak birefringence. Colorless. Made from fusion, but inverts if pure.
$\alpha^{\prime}-\mathrm{Ca}_{2} \mathrm{SiO}_{4}$ (Bredigite) is orthorhombic ${ }^{21}$ with $a=11.08, b=18.55$, $c=6.76 \mathrm{kX}$. Common pseudo-hexagonal twinning. Distinct $\{110\}$ cleavage. The pure compound melts at $2130^{\circ} \mathrm{C}$.; on cooling it promptly inverts to larnite at $1420^{\circ} \mathrm{C}$. and then to shannonite at $675^{\circ} \mathrm{C}$., but with some $\mathrm{Mg}, \mathrm{Ba}, \mathrm{Mn}, \mathrm{Na}$ or K (one or more) in crystal solution it is metastable and with $6.8 \mathrm{MgO}, 6.9 \mathrm{BaO}$ and 3.4 MnO it has $\mathrm{X}=b, \mathrm{Y}=a,(+) 2 \mathrm{~V}=$ $30^{\circ} \pm 10^{\circ}, n_{\mathrm{X}}=1.712, n_{\mathrm{Y}}=1.716, n_{\mathrm{Z}}=1.725, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.013 . \mathrm{PD}$ $2.75,1.96,2.19 ; 7-348^{*}$. A colored variety has X violet, Y and Z colorless to pale green and $(+) 2 \mathrm{~V}=33^{\circ}, n_{\mathrm{X}}=1.725, n_{\mathrm{Y}}=1.728, n_{\mathrm{Z}}=1.740$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.015$. Indices vary with variations in composition at least as much as $n_{\mathrm{X}}=1.712-1.725, n_{\mathrm{Y}}=1.716-1.728, n_{\mathrm{Z}}=1.725-1.740$. The mineral, bredigite, is not found as pure $\mathrm{Ca}_{2} \mathrm{SiO}_{4}$, but always contains other elements. Found in slags.
$\beta-\mathrm{Ca}_{2} \mathrm{SiO}_{4}$ (Larnite) is monoclinic ${ }^{20}$ with $a=5.48, b=6.76, c=9.28$ $k X, \beta=94^{\circ} 50^{\prime}$. Stable between $1420^{\circ}$ and $675^{\circ}$ C.; metastable below $675^{\circ}$ C. Crystals have distinct $\{100\}$ cleavage and common lamellar twinning on $\{100\}$. $\mathrm{X} \wedge c=13^{\circ}-14^{\circ} ; \mathrm{Z}=b .(+) 2 \mathrm{~V}=$ moderate, $n_{\mathrm{X}}=1.707$, $n_{\mathrm{Y}}=1.715, n_{\mathrm{Z}}=1.730, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.023$. Colorless. Made from fusion. PD 2.80, 2.74, 2.78; 9-351*.
$\gamma-\mathrm{Ca}_{2} \mathrm{SiO}_{4}$ (Shannonite ${ }^{22}$ ) is orthorhombic ${ }^{20}$ with $a=6.78, b=5.06$, $c=11.28 \mathrm{kX}$. Crystals have prismatic cleavage. G. 2.97. Y parallel prisms. $(+) 2 \mathrm{~V}=52^{\circ}, n_{\mathrm{X}}=1.642 \pm 0.002, n_{\mathrm{Y}}=1.645 \pm 0.002, n_{\mathrm{Z}}=1.654 \pm$ $0.002, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.015$. Colorless. PD 2.73, 1.91, 3.01; 9-369*. Also described ${ }^{23}$ as probably monoclinic with a small extinction angle on fine twinning and $(-) 2 \mathrm{E}=52^{\circ}$. It can take about 10 per cent of $\mathrm{Fe}_{2} \mathrm{SiO}_{4}$ into solid solution and then ${ }^{24} n_{\mathrm{X}}=1.653, n_{\mathrm{Z}}=1.677, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.024$. With

[^192]some $\mathrm{Fe}_{2} \mathrm{SiO}_{4}, \mathrm{Mn}_{2} \mathrm{SiO}_{4}$ and $\mathrm{Mg}_{2} \mathrm{SiO}_{4}$ in solid solution the indices may reach ${ }^{25} n_{\mathrm{X}}=1.66, n_{\mathrm{Y}}=1.68, n_{\mathrm{Z}}=1.69$.
$\mathbf{C a}_{2} \mathbf{S i O}_{4}$ forms a complete solid solution series ${ }^{26}$ with $\mathrm{Ba}_{2} \mathrm{SiO}_{4}$, the properties increasing regularly from G. $3.28, n_{\mathrm{X}}=1.717, n_{\mathrm{Z}}=1.735$ for $\mathrm{Ca}_{2} \mathrm{SiO}_{4}$ to G. 5.2, $n_{\mathrm{X}}=1.810, n_{\mathrm{Z}}=1.830$ for $\mathrm{Ba}_{2} \mathrm{SiO}_{4}$. It forms a similar series with ${ }^{27} \mathrm{Sr}_{2} \mathrm{SiO}_{4}$. The data for $\mathbf{S r}_{2} \mathbf{S i O}_{4}$ are: G. $3.84, n_{\mathrm{X}}=1.727, n_{\mathrm{Z}}=$ 1.756. $\mathrm{Ca}_{2} \mathrm{SiO}_{4}$ can take some $\mathrm{Na}_{4} \mathrm{SiO}_{4}$ in solid solution. With ${ }^{28} 2.7 \mathrm{Na}_{2} \mathrm{O}$, $n_{\mathrm{X}}=1.698, n_{\mathrm{Z}}=1.713$.
$\mathbf{B a}_{2} \mathbf{S i O}_{4}$ is orthorhombic(?); granular without cleavage or twinning; ${ }^{29}$ melting point about that of Pt. $n_{\mathrm{X}}=1.810, n_{\mathrm{Z}}=1.830, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.02$. Colorless. Made from fusion. PD 3.03, 2.95, 2.91; 6-0366.

## Olivine Group

The compounds of the olivine group are orthosilicates of divalent bases crystallizing in the orthorhombic system. There is a continuous series from $\mathrm{Mg}_{2} \mathrm{SiO}_{4}$ to $\mathrm{Fe}_{2} \mathrm{SiO}_{4}$ and from $\mathrm{Fe}_{2} \mathrm{SiO}_{4}$ to $\mathrm{Mn}_{2} \mathrm{SiO}_{4}$ and perhaps from $\mathrm{Mg}_{2} \mathrm{SiO}_{4}$ to $\mathrm{Mn}_{2} \mathrm{SiO}_{4}$. As in the carbonates there is a double salt between each of these three and $\mathrm{Ca}_{2} \mathrm{SiO}_{4}$ and no series to that compound. The chief types are the following:

| Species | Subspecies | Formula |
| :---: | :---: | :---: |
| Olivine | Forsterite | $\mathrm{Mg}_{2} \mathrm{SiO}_{4}$ |
|  | Chrysolite, etc. | $(\mathrm{Mg}, \mathrm{Fe})_{2} \mathrm{SiO}_{4}$ |
|  | Fayalite | $\mathrm{Fe}_{2} \mathrm{SiO}_{4}$ |
|  | Knebelite | $(\mathrm{Fe}, \mathrm{Mn})_{2} \mathrm{SiO}_{4}$ |
|  | Tephroite | $\mathrm{Mn}_{2} \mathrm{SiO}_{4}$ |
|  | Picrotephroite | $(\mathrm{Mn}, \mathrm{Mg}){ }_{2} \mathrm{SiO}_{4}$ |
|  | Artificial | $\mathrm{CaFeSiO}_{4}$ |
|  | Monticellite | $\mathrm{CaMgSiO}_{4}$ |
|  | Glaucochroite | $\mathrm{CaMnSiO}_{4}$ |

It is probable that $\mathrm{CaFeSiO}_{4}, \mathrm{CaMgSiO}_{4}$ and $\mathrm{CaMnSiO}_{4}$ are miscible in crystals in all proportions, like the three types of dolomite.
$\mathbf{M g}_{2} \mathbf{S i O}_{4}$ (Forsterite) is orthorhombic with $a=4.77, b=10.26, c=$ $5.99 \AA$. Crystals usually somewhat elongated parallel to $c$; rarely parallel to $a$; commonly with good development of $\{110\},\{010\},\{021\}$, etc. Twin-
${ }^{25}$ Bowen, Schairer, and Posnjak: Am. J. Sci. XXY, p. 273 (1933).
${ }^{26}$ Toropov and Konovalov: C. R. Acad. Sci. U.S.S.R. XX, p. 663 (1938) [Min. Abst. X, p. 265].
${ }^{27}$ Toropov and Konovalov: C. R. Acad. Sci. U.S.S.R. XL, p. 155 (1943) [Min. Abst. IX, p. 134].
${ }^{28}$ Segnit: Am. J. Sci. CCLI, p. 586 (1953).
${ }^{29}$ Eskola: Am. J. Sci. CCIV, p. 331 (1922).
ning rare. Distinct $\{010\}$ and poor $\{100\}$ cleavages. H. 6.5-7. G. 3.2. M.P. $1890^{\circ} \mathrm{C} . \mathrm{X}=b ; \mathrm{Y}=c .(+) 2 \mathrm{~V}=81^{\circ}, n_{\mathrm{X}}=1.635, n_{\mathrm{Y}}=1.651, n_{\mathrm{Z}}=$ $1.670, n_{\mathrm{Z}}-n_{\mathrm{x}}=0.035$. Colorless. Made from fusion. With 20 mol . per cent $^{30} \mathrm{Fe}_{2} \mathrm{SiO}_{4}:(-) 2 \mathrm{~V}=87^{\circ}, n_{\mathrm{X}}=1.674, n_{\mathrm{Y}}=1.692, n_{\mathrm{Z}}=1.712, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.038$. With 40 per cent $\mathrm{Fe}_{2} \mathrm{SiO}_{4}:(-) 2 \mathrm{~V}=78^{\circ}, n_{\mathrm{X}}=1.712, n_{\mathrm{Y}}=$ $1.735, n_{\mathrm{Z}}=1.753, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.041 . \mathrm{Mg}_{2} \mathrm{SiO}_{4}$ and $\mathrm{LiAlSiO}_{4}$ are miscible ${ }^{30 \mathrm{a}}$ in limited amounts, $\mathrm{Mg}_{2} \mathrm{SiO}_{4}$ experimentally to about 25 per cent in $\mathrm{LiAlSiO}_{4}$ and $\mathrm{LiAlSiO}_{4}$ to about 40 per cent in $\mathrm{Mg}_{2} \mathrm{SiO}_{4}$. The refractive indices in the series $\left(\mathrm{Mg}_{1-\mathrm{x}} \mathrm{Fe}_{\mathrm{x}}\right)_{2} \mathrm{SiO}_{4}$ are accurately predictable by linear interpolation between the end-members.
$\mathbf{F e}_{2} \mathbf{S i O}_{4}$ (Fayalite) is orthorhombic with $a=4.80, b=10.59, c=6.16$ $\AA$. Crystals like those of $\mathrm{Mg}_{2} \mathrm{SiO}_{4}$. Distinct $\{010\}$ and poor $\{100\}$ cleavages. G. 4.4. M.P. $1205^{\circ}$ C. $\mathrm{X}=b ; \mathrm{Y}=c$. $(-) 2 \mathrm{~V}=47^{\circ}, n_{\mathrm{X}}=1.824, n_{\mathrm{Y}}=$ 1.864, $n_{\mathrm{Z}}=1.875, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.051$. Color olive green; easily alters to reddish brown or black. PD 2.49, 2.82, 3.54; 9-307*. Made from fusion. With 20 mol. per cent ${ }^{30} \mathrm{Mg}_{2} \mathrm{SiO}_{4}:(-) 2 \mathrm{~V}=58^{\circ}, n_{\mathrm{X}}=1.786, n_{\mathrm{Y}}=1.822$, $n_{\mathrm{Z}}=1.833, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.047$. With 40 per cent $\mathrm{Mg}_{2} \mathrm{SiO}_{4}:(-) 2 \mathrm{~V}=69^{\circ}$, $n_{\mathrm{X}}=1.748, n_{\mathrm{Y}}=1.778, n_{\mathrm{Z}}=1.792, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.044$. With 22 per cent $\mathrm{Ca}_{2} \mathrm{SiO}_{4}: n_{\mathrm{X}}=1.772, n_{\mathrm{Z}}=1.823$. An impure sample from slag has $(-) 2 \mathrm{~V}=53^{\circ}, n_{\mathrm{X}}=1.817, n_{\mathrm{Y}}=1.84, n_{\mathrm{Z}}=1.863, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.046$.
$\mathbf{M n}_{2} \mathbf{S i O}_{4}$ (Tephroite) is orthorhombic with $a=4.86, b=10.62, c=$ 6.22 A. Crystals like those of $\mathrm{Mg}_{2} \mathrm{SiO}_{4}$. Distinct $\{010\}$ and poor $\{100\}$ cleavages. G. 4.2. M.P. near $1300^{\circ} \mathrm{C} . \mathrm{X}=b ; \mathrm{Y}=c$. (-) $2 \mathrm{~V}=50^{\circ} c a$., $n_{\mathrm{X}}=1.78, n_{\mathrm{Y}}=1.805, n_{\mathrm{Z}}=1.82, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.04 c a$. Color ash-gray, reddish brown or red. PD 2.56, 3.61, 2.86; $9-485$. In thick sections X brownish red, Y reddish, Z greenish blue with $\mathrm{X}<\mathrm{Z}<\mathrm{Y}$. Made from fusion. With some ${ }^{30} \mathrm{Fe}_{2} \mathrm{SiO}_{4}$ : (-) $2 \mathrm{~V}=50^{\circ}$ ca., $n_{\mathrm{X}}=1.80$ ca., $n_{\mathrm{Y}}=1.84$ $c a ., n_{\mathrm{Z}}=1.85 c a ., n_{\mathrm{Z}}-n_{\mathrm{X}}=0.05 c a$. With some $\mathrm{Mg}_{2} \mathrm{SiO}_{4}:(-) 2 \mathrm{~V}=$ $85^{\circ}, n_{\mathrm{X}}=1.71, n_{\mathrm{Y}}=1.727, n_{\mathrm{Z}}=1.74, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.03$. With some $\mathrm{Ca}_{2} \mathrm{SiO}_{4}:(-) 2 \mathrm{~V}=62.5^{\circ}, n_{\mathrm{X}}=1.723, n_{\mathrm{Y}}=1.752$ calc., $n_{\mathrm{Z}}=1.759, n_{\mathrm{Z}}-$ $n_{\mathrm{X}}=0.026$. With 17 per cent $\mathrm{MnO}, 10$ per cent ZnO and some FeO : $(-) 2 \mathrm{~V}=77^{\circ}, n_{\mathrm{X}}=1.758, n_{\mathrm{Y}}=1.786, n_{\mathrm{Z}}=1.804, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.046$.
$\mathbf{C a F e S i O}_{4}$ is orthorhombic ${ }^{31}$ with $a: b: c=0.437: 1: 0.577$. G. 3.33. Gelatinizes with HCl. M.P. $1208^{\circ} \mathrm{C} . \mathrm{X}=b ; \mathrm{Y}=c$. $(-) 2 \mathrm{~V}=49^{\circ}$, $\mathrm{r}>\mathrm{v}$ moderate. $n_{\mathrm{X}}=1.696, n_{\mathrm{Y}}=1.734, n_{\mathrm{Z}}=1.743, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.047$. Also reported with $n_{\mathrm{x}}>1.74$. Color pale yellow. Made in a steel bomb. A related type with 35.11 per cent $\mathrm{CaO}, 18.97 \mathrm{FeO}$ and 11.21 MnO has: G. 3.34, $n_{\mathrm{X}}=1.6749, n_{\mathrm{Y}}=1.7004$ (636), 1.7054 (578), 1.7133 (513), $1.7162(470), n_{\mathrm{Z}}=1.7105, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.0356$.

[^193]$\mathrm{CaMgSiO}_{4}$ (Monticellite) is orthorhombic with $a=4.815, b=11.08$, $c=6.37 \AA$. Crystals prismatic; also granular. Poor $\{010\}$ cleavage. G. 3.2. Gelatinizes with HCl. Decomposes at $1300^{\circ} \mathrm{C} . \mathrm{X}=b ;{ }^{32} \mathrm{Y}=c .(+) 2 \mathrm{~V}=$ $85^{\circ}, n_{\mathrm{X}}=1.639, n_{\mathrm{Y}}=1.646, n_{\mathrm{Z}}=1.653, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.014$. PD 1.81, 1.59, 2.66; 3-1107/8*. Colorless. Made from fusion at about $1490^{\circ}$ C. With 10 per cent ${ }^{33} \mathrm{Mg}_{2} \mathrm{SiO}_{4}:(+) 2 \mathrm{~V}=85^{\circ}-90^{\circ}, n_{\mathrm{X}}=1.638-1.640, n_{\mathrm{Y}}=1.646$, $n_{\mathrm{z}}=1.651-1.655, n_{\mathrm{z}}-n_{\mathrm{X}}=0.015$. With 16 per cent $\mathrm{MgFeSiO}_{4}:$ $(-) 2 \mathrm{~V}=74.5^{\circ}, n_{\mathrm{X}}=1.663, n_{\mathrm{Y}}=1.674, n_{\mathrm{Z}}=1.680, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.018$.
$\mathbf{C a M n S i O}_{4}$ (Glaucochroite) is orthorhombic ${ }^{34}$ with $a=4.91, b=11.12$, $c=6.49 \AA$. Crystals prismatic with poor $\{001\}$ cleavage. H. 6. G. 3.48. M.P. $1355^{\circ} \mathrm{C}$. Gelatinizes with $\mathrm{HCl} . \mathrm{X}=b ; \mathrm{Y}=c,(-) 2 \mathrm{~V}=61^{\circ}, \mathrm{r}>\mathrm{v}$. $n_{\mathrm{X}}=1.685, n_{\mathrm{Y}}=1.723, n_{\mathrm{Z}}=1.736, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.051$. Color bluish green; colorless in thin section. Again: ${ }^{35}(-) 2 \mathrm{~V}=68^{\circ}, n_{\mathrm{X}}=1.699, n_{\mathrm{Y}}=1.724$ calc., $n_{\mathrm{Z}}=1.734, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.035$.
$\mathrm{Ni}_{2} \mathrm{SiO}_{4}$ is orthorhombic ${ }^{36}$ with ( + ) $2 \mathrm{~V}=60^{\circ}$ calc., $n_{\mathrm{X}}=1.976, n_{\mathrm{Y}}=$ 1.987, $n_{\mathrm{Z}}=2.019, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.043$. PD 2.75, 1.73, 1.48; 3-0780.
$\mathrm{Cd}_{2} \mathbf{S i O}_{4}$ forms irregular crystals with ${ }^{37} n>1.74$ and moderate birefringence. Colorless.
$\mathbf{P b}_{2} \mathbf{S i O}_{4}$ is orthorhombic(?). Crystals prismatic with good basal cleavage normal to the prism faces. M.P. $743^{\circ}$ C. Parallel extinction. ( - ) $2 \mathrm{~V}=$ $80^{\circ} c a ., n_{\mathrm{X}}=2.13, n_{\mathrm{Y}}=2.15, n_{\mathrm{Z}}=2.18, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.05$. PD 3.21, 3.11, 2.98; $3-0494$. [Indices and optic sign inconsistent. A.N.W.]
$\mathbf{L i}_{4} \mathbf{S i O}_{4}$ is pseudo-hexagonal and probably orthorhombic. Crystals granular. Lamellar twinning common, rarely in two sets. G. 2.39 . M.P. $1255^{\circ} \mathrm{C}$. with decomposition. Large extinction angle on twinning. ( + ) $2 \mathrm{~V}=$ small. ${ }^{38}$ $n_{\mathrm{X}}=1.594, n_{\mathrm{Y}}=1.60 \mathrm{ca} . n_{\mathrm{Z}}=1.614, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.020$. Again: ${ }^{39} n_{\mathrm{X}}=$ $1.602 \pm 0.002, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.610 \pm 0.002$. PD 2.66, 3.97, 2.59; 4-0727. Colorless, but may be colored pink by $\mathrm{Li}_{2} \mathrm{O}$ or deep lilac by Ni if made in a nickel crucible; then pleochroic. Made from fusion.
$\mathbf{N a}_{4} \mathbf{S i O}_{4}$ has two phases. The high temperature $\alpha$-phase ${ }^{40}$ is monoclinic(?). It decomposes at $1089^{\circ} \mathrm{C}$.; on cooling it inverts at $960^{\circ} \mathrm{C}$. Crystals have lamellar twinning; Z is nearly normal to the twinning lines and extinction

[^194]varies up to $8^{\circ}$ with the twinning planes. Biaxial(?) with $n_{\mathrm{x}}=1.524$, $n_{\mathrm{Y}}=?, n_{\mathrm{Z}}=1.537, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.013$. The low temperature $\beta$-phase ${ }^{41}$ forms acute-angled plates $\left\{010\right.$ ?\} with extinction at about $15^{\circ}$ to the short edge. G. 2.58. ( $-2 \mathrm{~V}=$ ?, mean index, $n=1.536 \pm, n_{\mathrm{z}}-n_{\mathrm{X}}=$ rather weak. Colorless. Made from fusion.
$\mathbf{C a}_{3} \mathbf{A l S i A l O}_{8}$ is orthorhombic(?). ${ }^{23}$ Crystallizes as fibers and grains. Z parallel with fibers. ( + ) $2 \mathrm{~V}=$ rather large, $n_{\mathrm{x}}=1.675, n_{\mathrm{Y}}=1.679 \mathrm{ca}$. $n_{\mathrm{z}}=1.685, n_{\mathrm{z}}-n_{\mathrm{x}}=0.010$. Colorless. Made from glass at about $1300^{\circ}$ C.; it dissociates at $1335^{\circ} \mathrm{C}$. to $\mathrm{Ca}_{2} \mathrm{SiO}_{4}$ and $\mathrm{CaAl}_{2} \mathrm{O}_{4}$.
$\mathrm{Sr}_{2} \mathrm{SiO}_{4}$ is probably monoclinic, ${ }^{29}$ commonly twinned on $\{100\}$. G. 3.84. F. 7. $\mathrm{X} \wedge c=17^{\circ} ; \mathrm{Z}=b .(+) 2 \mathrm{~V}=32^{\circ} 30^{\prime} . n_{\mathrm{X}}=1.722 \mathrm{C}, 1.7275 \mathrm{D}$, $1.740 \mathrm{~F}, n_{\mathrm{Y}}=1.727 \mathrm{C}, 1.732 \mathrm{D}, 1.744 \mathrm{~F}, n_{\mathrm{Z}}=1.752 \mathrm{C}, 1.756 \mathrm{D}, 1.766 \mathrm{~F}$, $n_{\mathrm{z}}-n_{\mathrm{x}}=0.0285 \mathrm{D}$. No inversion found. Colorless. PD 2.87, 2.83, 2.29; 10-34. Made from fusion. It forms a continuous series with $\mathrm{Ca}_{2} \mathrm{SiO}_{4}$ (probably the $\beta$-phase).
$\mathbf{C a}_{3} \mathbf{M g}\left(\mathbf{S i O}_{4}\right)_{2}$ (Merwinite) is monoclinic with $^{42} a=5.20, b=9.20$, $c=6.78 \AA$. Multiple lamellar twinning common in two sets intersecting at $43^{\circ}$. Perfect $\{010\}$ cleavage. H. 6. G. 3.15. M.P. $1598^{\circ}$ C. Gelatinizes with $\mathrm{HCl} . \mathrm{X} \wedge c=36^{\circ} ; \mathrm{Z}=b$. ( + ) $2 \mathrm{~V}=66^{\circ} c a .{ }^{43} n_{\mathrm{X}}=1.706, n_{\mathrm{Y}}=$ $1.712, n_{\mathrm{z}}=1.724, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.018$. Again: ${ }^{32}(+) 2 \mathrm{~V}=69^{\circ}, n_{\mathrm{X}}=1.708$, $n_{\mathrm{Y}}=1.714, n_{\mathrm{Z}}=1.725, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.017$. Colorless. PD 2.66, 1.90, 1.53; 4-0728. Found in slags. Perhaps only a solid solution ${ }^{42}$ of $\mathrm{Mg}_{2} \mathrm{SiO}_{4}$ in $\beta-\mathrm{Ca}_{2} \mathrm{SiO}_{4}$.
$\mathrm{Ca}_{2} \mathrm{SiO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ (Hillebrandite) is orthorhombic ${ }^{44}$ with $a=9.22, b=$ $9.34, c=10.61 \AA$. Crystals fibrous with prismatic cleavage. H. 5.5. G. 2.69. Soluble in HCl. $\mathrm{Y}=a ; \mathrm{Z}=c .(-) 2 \mathrm{~V}=42^{\circ}$ calc., $\mathrm{r}<\mathrm{v}$ strong. $n_{\mathrm{X}}=1.605, n_{\mathrm{Y}}=1.61 c a ., n_{\mathrm{Z}}=1.612, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.007$. Color porcelain white or greenish. PD 2.92, 4.76, 3.33; 9-51*. In Portland cement. After heating to $500^{\circ} \mathrm{C}$. it loses water and becomes $\gamma-\mathrm{Ca}_{2} \mathrm{SiO}_{4}$.
$\mathbf{C a}_{2} \mathbf{S i O}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ has another orthorhombic phase ${ }^{45}$ which forms $\{100\}$ laths with prismatic cleavage. H. 5. G. 2.8. Cruciform twins not rare. $\mathrm{Y}=a$; $\mathrm{Z}=c .(+) 2 \mathrm{~V}=68^{\circ}$ calc. $n_{\mathrm{X}}=1.614, n_{\mathrm{Y}}=1.620, n_{\mathrm{Z}}=1.633, n_{\mathrm{Z}}-$ $n_{\mathrm{x}}=0.019 \mathrm{Na}$. Colorless. Forms on quartz in lime water at $170^{\circ} \mathrm{C} . \mathrm{PD}$ 3.04, 2.70, 1.90; 3-0594*.
$\mathbf{C a}_{2} \mathbf{S i O}_{\mathbf{4}} \cdot \mathbf{n H}_{\mathbf{2}} \mathbf{O}$ is orthorhombic(?). Crystals are fine needles ${ }^{46}$ with Z
${ }^{41}$ Morey and Fenner: J. Am. Chem. Soc. XXXVI, p. 215 (1914).
${ }^{42}$ Bredig: J. Phys. Chem. XLIX, p. 537 (1945).
${ }^{43}$ Larsen and Foshag: Am. Min. VI, p. 143 (1921).
${ }^{44}$ Heller: Acta Cryst. V, p. 724 (1952). abcchanged to bac.
${ }^{45}$ Thorvaldson and Shelton: Can. J. Res. I, p. 148 (1929).
${ }^{46}$ Vigfusson, Bates and Thorvaldson: Can. J. Res. XI, p. 520 (1934).
$\mathbf{M g}(\mathbf{F}, \mathbf{O H})_{2} \cdot \mathbf{4} \mathbf{M g}_{2} \mathbf{S i O}_{4}$ (Clinohumite) is monoclinic with $a=10.27$, $b=4.745, c=13.68, \beta=100^{\circ} 50^{\prime}$. Crystals complex and varied with poor $\{001\}$ cleavage. Lamellar twinning on $\{001\}$ common. H. 6. G. 3.2. F. 7. $\mathrm{X} \wedge a=7^{\circ}-20^{\circ} ; \mathrm{Z}=b$. (+) $2 \mathrm{~V}=76^{\circ}, \mathrm{r}>\mathrm{v}$ weak. $n_{\mathrm{X}}=1.608, n_{\mathrm{Y}}=$ 1.618, $n_{\mathrm{Z}}=1.636, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.028$ (measured $^{50}$ on the pure artificial F compound). Data on the natural mineral follow:

| $\mathrm{FeO}+\mathrm{MnO}$ | $\mathrm{TiO}_{2}$ | $(+) 2 \mathrm{~V}$ | $n_{\mathbf{X}}$ | $n_{\mathbf{Y}}$ | $n_{\mathbf{Z}}$ | $n_{\mathbf{Z}}-n_{\mathbf{X}}$ | $\mathrm{X} \wedge a$ | Authority |
| :---: | :---: | :--- | :---: | :---: | :---: | :---: | :---: | :--- |
| 4.83 | $?$ | near $90^{\circ}$ | 1.625 | 1.638 | 1.653 | 0.028 | $?$ | Larsen $^{49}$ |
| 15.44 | 0.06 | $76^{\circ}$ | 1.652 | 1.633 | $?$ | $?$ | $12^{\circ}-15^{\circ}$ | Larsen $^{49}$ |
| 5.18 | 1.92 | $62^{\circ}$ | 1.664 | 1.673 | 1.698 | 0.034 | $7.5^{\circ}$ | Larsen $^{49}$ |
| 6.50 | 5.20 | $58^{\circ}$ | 1.691 | 1.700 | 1.724 | 0.033 | $?$ | Quervain $^{53}$ |

Color brown, yellow, white. Color in thin section like humite. But with Ti the color becomes brownish red with X deep reddish yellow to blood red, Y and Z orange yellow and $\mathrm{X}>\mathrm{Y}>\mathrm{Z}$. Made from fusion.
$\mathbf{C a}_{3} \mathbf{O S i O}_{4}$ is hexagonal(?) with poor basal cleavage. Uniaxial negative ${ }^{54}$ with $n_{\mathrm{O}}=1.722, n_{\mathrm{E}}=1.716, n_{\mathrm{O}}-n_{\mathrm{E}}=0.006$. Also reported to have $(-) 2 \mathrm{~V}=0^{\circ}$ or very small with $^{32} n_{0}=1.724, n_{\mathrm{E}}=1.719, n_{\mathrm{O}}-n_{\mathrm{E}}=$ 0.005. Colorless. Found in Portland cement. PD 2.78, 2.60, 2.19; 9-352.
$\mathbf{N a}_{2} \mathbf{Z r O S i O}_{4}$ is orthorhombic ${ }^{12}$ often in pseudo-hexagonal twins of prismatic form with positive elongation. G. 3.605. M.P. (incongruently) $1477^{\circ} \mathrm{C} .(-) 2 \mathrm{~V}=$ small. $n_{\mathrm{X}}=1.741, n_{\mathrm{Y}}=$ slightly less than $1.790, n_{\mathrm{Z}}=$ $1.790, n_{\mathrm{z}}-n_{\mathrm{X}}=0.049$. Colorless.
$\mathbf{N a}_{12} \mathbf{F e}_{8} \mathbf{O}_{8} \mathbf{S i}_{5} \mathbf{O}_{20}$ forms rounded grains $5^{55}$ with M.P. $1091^{\circ} \mathrm{C}$. They show intricate polysynthetic twinning. $n_{\mathrm{Y}}=1.96, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.01 \pm$.
$\mathbf{N a}_{6} \mathbf{O S i O}_{4}$ is orthorhombic ${ }^{17}(?)$. Crystals have acute angles and distinct cleavage. M.P. $1122^{\circ}$ C. (+?) $2 \mathrm{~V}=$ ?, $n_{\mathrm{X}}=1.524, n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.529$, $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.005$. Colorless. Made from fusion.
$\left(\mathbf{U O}_{2}\right)_{2} \mathbf{S i O}_{4} \cdot 2 \mathbf{H}_{2} \mathbf{O}$ (?) (Soddyite) is orthorhombic with $a: b: c=$ $0.796: 1: 0.669$. Crystals prismatic. H. $3-4$. G. 4.63 . ( $-2 \mathrm{~V}=$ ?, $n_{\mathrm{x}}=$ $1.645, n_{\mathrm{Y}}=1.662, n_{\mathrm{Z}}=$ ? Again: $n_{\mathrm{X}}=1.65, n_{\mathrm{Y}}=1.68, n_{\mathrm{Z}}=1.71, n_{\mathrm{Z}}-$ $n_{\mathrm{x}}=0.06$. Color yellow; rarely pleochroic. Made from solution ${ }^{55 \mathrm{a}}$ at $180^{\circ} \mathrm{C}$. and higher.
$\mathbf{P b}_{4} \mathbf{O}_{2} \mathbf{S i O}_{4}$ has three crystal phases. ${ }^{56}$ The high temperature $\alpha$-phase is stable above $720^{\circ} \mathrm{C}$. It forms irregular plates. M.P. $725^{\circ} \mathrm{C} .(+) 2 \mathrm{~V}=40^{\circ}$ $c a ., n_{\mathrm{X}}=2.31, n_{\mathrm{Y}}=2.34, n_{\mathrm{Z}}=2.38, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.07$. PD 3.10, 3.03,

[^195]1.68; 3-0554. The $\beta$-phase is stable between $720^{\circ} \mathrm{C}$. and $155^{\circ} \mathrm{C}$. It forms minute, probably prismatic grains having an average refractive index of about 2.34 and medium birefringence. The $\gamma$-phase is stable below $155^{\circ} \mathrm{C}$. It is very much like the $\beta$-phase but has weaker birefringence. PD 3.02, 3.13, 1.82; 3-0602.
$\mathbf{A l}_{2} \mathbf{O S i O}_{4}$ has three crystal phases, all three being metastable at ordinary temperature. The $\alpha$-phase is sillimanite which dissociates to mullite and liquid at about $1545^{\circ} \mathrm{C}$. and then to corundum and liquid at about $1810^{\circ} \mathrm{C}$. The $\beta$-phase is andalusite which changes to mullite and glass at about $1300^{\circ} \mathrm{C}$. The $\gamma$-phase is kyanite which changes to mullite and glass at about $1300^{\circ} \mathrm{C}$. more easily than andalusite.
$\alpha-\mathrm{Al}_{2} \mathrm{OSiO}_{4}$ (Sillimanite) is orthorhombic with $a=7.43, b=7.58$, $c=5.74 \AA$. Crystals nearly square prisms often vertically striated, with perfect $\{010\}$ cleavage. H. 7.5. G. 3.25. M.P. $1816^{\circ} \mathrm{C} . \mathrm{Y}=b ; \mathrm{Z}=c$. $(+) 2 \mathrm{~V}=25^{\circ}-30^{\circ}, \mathrm{r}>\mathrm{v}$ strong. $n_{\mathrm{X}}=1.655-1.661, n_{\mathrm{Y}}=1.658-1.670$, $n_{\mathrm{Z}}=1.677-1.684, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.020-0.023 . \mathrm{F}-\mathrm{C}$ for $n_{\mathrm{Y}}=0.0107$. The index of refraction is lower in dark colored crystals. For example, in a pale brown crystal $n_{\mathrm{X}}=1.6612$ and $n_{\mathrm{z}}=1.6837$, and in a dark brown crystal $n_{\mathrm{X}}=1.6549$ and $n_{\mathrm{Z}}=1.6773$. Colorless, yellowish, greenish, brown, blue. Colorless in thin section; in thick sections:

| X | Pale brownish | Brownish yellow | Very pale yellow |
| :--- | :--- | :--- | :--- |
| Y | Brown | Grayish green | Colorless or greenish |
| Z | Dark brown | Violet blue | Sapphire blue |

Made hydrothermally under pressure; ${ }^{57}$ also made from kyanite and andalusite. ${ }^{58}$ PD 3.36, 2.20, 3.41; 10-369*.
$\beta-\mathrm{Al}_{2} \mathrm{OSiO}_{4}$ (Andalusite) is orthorhombic with $a=7.76, b=7.90, c=$ $5.56 \AA$. Crystals nearly square prisms with good $\{110\}$ cleavage at $90^{\circ} 48^{\prime}$. H. 7. ca. G. 3.1-3.2. Changes to mullite and glass at about $1300^{\circ} \mathrm{C} . \mathrm{X}=c$; $\mathrm{Y}=b$. Andalusite may have up to one tenth of its normal Al replaced by $\mathrm{Mn}, \mathrm{Fe}, \mathrm{Ti}$ and this modifies the properties as follows:

| $\frac{100(\mathrm{Mn}+\mathrm{Fe}+\mathrm{Ti})}{\mathrm{Al}+\mathrm{Mn}+\mathrm{Fe}+\mathrm{Ti}}$ | $(-) 2 \mathrm{~V}$ | $n_{\mathbf{X}}$ | $n_{\mathbf{Y}}$ | $n_{\mathbf{Z}}$ | $n_{\mathbf{Z}}-n_{\mathbf{X}}$ | G | Authority |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1.1 | $86^{\circ}$ | 1.634 | 1.639 | 1.645 | 0.011 | 3.13 | Macdonald ${ }^{59}$ |
| 2.8 | $75^{\circ}$ | 1.637 | 1.641 | 1.646 | 0.009 | 3.16 | Macdonald $^{59}$ |
| 10.3 | $71^{\circ}$ | 1.662 | 1.671 | 1.691 | 0.029 | 3.22 | Wüling ${ }^{60}$ |

[^196]Color red, violet, gray, yellow, green; when altered may be brown, gray, black. Pleochroism variable even in one crystal. Colorless in thin section; in a thick section it may be:

| X | Rose red | Blood red | Yellow |
| :--- | :--- | :--- | :--- |
| Y | Colorless or yellow | Oil green | Green |
| Z】 | Colorless or yellow | Olive green | Greenish yellow |

Made between $450^{\circ}$ and $650^{\circ}$ C. under water pressure ${ }^{61}$ of 10,000 to $30,000 \mathrm{psi}$. PD 4.61, 1.49, 5.71; 3-0165*.
$\gamma-\mathrm{Al}_{2} \mathrm{OSiO}_{4}$ (Kyanite) is triclinic with $a=7.09, b=7.72, c=5.56 \mathrm{kX}$, $\alpha=89^{\circ} 58.5^{\prime}, \beta=101^{\circ} 8^{\prime}, \gamma=105^{\circ} 57^{\prime}$. Crystals $\{100\}$ tablets elongated along $c$. Perfect $\{100\}$ and good $\{010\}$ cleavages; $\{001\}$ parting. Multiple twinning common. Hardness varies: on $\{100\}$ it is $4-5$ parallel to $c$ and 6-7 parallel to $b$; on $\{010\}$ it is 6 parallel to $c$ and 7 normal to $c$; on $\{001\}$ it is 5.5 parallel to $b$ and 6.5 parallel to $a$; on $\{1 \overline{1} 0\}$ it is 7.5 . G. $3.6 c a$. Changes to mullite and glass at about $1300^{\circ}$ C., more easily than andalusite. X nearly normal to $\{100\}$; extinction on (100), $\mathrm{Z}^{\prime} \wedge c=27^{\circ}-32^{\circ}$; on ( 010 ), $Z^{\prime} \wedge c=5^{\circ}-8^{\circ}$; on (001), $\mathrm{X}^{\prime} \wedge a=0^{\circ}-2.5^{\circ}$. It may contain a little $\mathrm{Fe}_{2} \mathrm{O}_{3}$, $\mathrm{Na}_{2} \mathrm{O}, \mathrm{K}_{2} \mathrm{O}, \mathrm{H}_{2} \mathrm{O}$ which modify the properties as follows:

| $\mathrm{Fe}_{2} \mathrm{O}_{3}$ | $(\mathrm{Na}, \mathrm{K})_{2} \mathrm{O}$ | $\mathrm{H}_{2} \mathrm{O}$ | $(-) 2 \mathrm{~V}$ | $n_{\mathrm{X}}$ | $n_{\mathrm{Y}}$ | $n_{\mathrm{Z}}$ | G | Authority |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :--- |
| 0.30 | $?$ | 0.03 | $82^{\circ} 15^{\prime}$ | 1.7131 | 1.7219 | 1.7285 | 3.65 | Baric $^{62}$ |
| 0.33 | 1.10 | 0.83 | $?$ | 1.7171 | 1.722 | 1.7290 | 3.53 | Gubelin $^{63}$ |
| 0.34 | $?$ | $?$ | $82^{\circ}$ | 1.718 |  | 1.734 | $?$ | Ozerov $^{64}$ |

Color blue (whence the name), white, rarely gray, green or black. Colorless in thin section. In thick sections it may be pleochroic with X colorless, Y violet blue, Z dark cobalt blue. The color may disappear on heating. PD 1.38, 3.20, 1.93; 3-1164*.
$\mathrm{CaTiOSiO}_{4}$ (Titanite or Sphene) is monoclinic with $a=6.55, b=$ 8.70, $c=7.43 \AA, \beta=119^{\circ} 43^{\prime}$. Crystals often wedge-shaped (whence the name sphene) with large $\{001\}$ and $\{111\}$ faces; varied. Distinct $\{110\}$ cleavage. H. 5-5.5. G. $3.4-3.6$. $\mathrm{Y}=b ; \mathrm{Z} \wedge c=47^{\circ}-52^{\circ}$ and nearly normal to $\{102\} .(+) 2 \mathrm{~V}=23^{\circ}-35^{\circ}, \mathrm{r}>\mathrm{v}$ extreme. Titanite may contain 1 to 20 per cent $\mathrm{R}_{2} \mathrm{O}_{3}$ perhaps as $\mathrm{R}_{2} \mathrm{SiO}_{5} ; \mathrm{R}$ may be $\mathrm{Fe}^{\prime \prime \prime}$, $\mathrm{Al}, \mathrm{Y}$,

[^197]$\mathrm{Ce}, \mathrm{Cb}$. One O atom may be replaced in part by OH and F . In general refractive indices decrease and the optic angle increases with decrease of Ti. Data follow:

| $\mathrm{TiO}_{2}$ | $\mathrm{Fe}_{2} \mathrm{O}_{3}$ | $\mathrm{Al}_{2} \mathrm{O}_{3}$ | $(\mathrm{Ce}, \mathrm{Y})_{2} \mathrm{O}_{3}$ | $(+) 2 \mathrm{~V}$ | $n_{\mathrm{x}}$ | $n_{\mathrm{Y}}$ | $n_{\mathrm{Z}}$ | $\mathrm{Z} \wedge c$ | Authority |
| :--- | :---: | :---: | :---: | :--- | :---: | :---: | :---: | :---: | :---: |
| 40.89 | 0.00 | 0.00 | Trace | $23^{\circ} c a$. | 1.901 | $?$ | 2.093 | $51^{\circ}$ | Sahama $^{65}$ |
| 40.10 | 0.40 | 0.27 | $?$ | $20^{\circ}$ ca. | 1.950 | 1.970 | 2.092 |  | Bohnstedt $^{66}$ |
| 35.26 | 1.34 | 1.02 | 4.51 | $33^{\circ}$ calc. | 1.90 |  | 2.04 | $36^{\circ}$ | Morgante $^{67}$ |
| 30.65 | 6.17 | 7.32 | 3.58 | $35^{\circ}-40^{\circ}$ | 1.843 | 1.870 | 1.943 |  | Young $^{68}$ |

Color brown, gray, yellow, green, rose-red, black, often varying in a single crystal. Pleochroism often weak or absent in thin section; in thick sections:

| X | Greenish yellow | Pale brownish yellow | Nearly colorless |
| :--- | :--- | :--- | :--- |
| Y | Greenish pink | Pale brownish yellow | Greenish yellow |
| Z | Salmon pink | Pale yellow | Orange to brownish |
|  |  |  | red |

PD 3.20, 2.59, 2.98; 2-0521. Made by fusing a mixture of $\mathrm{SiO}_{2}, \mathrm{TiO}_{2}$ and $\mathrm{CaCl}_{2}{ }^{69}$
$\mathrm{Pb}_{2} \mathrm{UO}_{2} \mathrm{SiO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ (Kasolite) is monoclinic with $a=13.28, b=7.01$, $c=6.71, \beta=103^{\circ} 42^{\prime}$. Crystals minute prisms (along b) with perfect $\{001\}$ and poor $\{100\}$ and $\{010\}$ cleavages. H. 4-5. G. 6.46. $\mathrm{X}=b ; \mathrm{Z} \wedge c=$ $1^{\circ} c a .(+) 2 \mathrm{~V}=42^{\circ} 58^{\prime} \mathrm{Li}, 43^{\circ} 18^{\prime} \mathrm{Na} . n_{\mathrm{X}}=1.80$ calc., $n_{\mathrm{Y}}=1.90, n_{\mathrm{Z}}=$ 1.967 calc., $n_{\mathrm{Z}}-n_{\mathrm{X}}=0.077$ calc. Color yellow to brown. Made from solution ${ }^{55 a}$ at $180^{\circ} \mathrm{C}$. and higher. PD 3.26, 2.93, 4.18; 8-297.
$\mathbf{C a}_{5} \mathbf{C O}_{3}\left(\mathbf{S i O}_{4}\right)_{2}$ has two crystal phases. The high temperature $\alpha$-phase is stable above $1200^{\circ} \mathrm{C}$. under a pressure of 90 atmospheres. It is orthorhombic with good $\{001\}$ and $\{010\}$ cleavages. $\mathrm{Y}=a .2 \mathrm{~V}=$ large. $n_{\mathrm{x}}=$ 1.665, $n_{\mathrm{Y}}=$ ?, $n_{\mathrm{Z}}=1.680, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.015$. Colorless. The $\beta$-phase (spurrite) is monoclinic(?) with ${ }^{70}$ distinct $\{001\}$ and poor $\{100\}$ cleavages at $79^{\circ}$. Multiple twinning. H. 5. G. 3. F. 7. $\mathrm{X}=b ; \mathrm{Z} \wedge a=$ nearly $0^{\circ}$, distinct crossed dispersion. ( - ) $2 \mathrm{~V}=39.5^{\circ}, \mathrm{r}>\mathrm{v}$ weak. $n_{\mathrm{x}}=1.640$, $n_{\mathrm{Y}}=1.674, n_{\mathrm{Z}}=1.679, n_{\mathrm{Z}}-n_{\mathrm{X}}=0.039$. According to Tilley ${ }^{11}$ the dis-

[^198]

Fig. 11-1. Composition of borosilicate crown glasses ( - ), crown (crown glasses of this type have less than 20 percent BaO .), and barium crown glasses ( 0 ), flint glasses (x), and barium flint glasses (+). Modified, after F. E. Wright: J. Amer. Ceramic Soc. III, p. 785 (1920).

The diagram (Fig. 11-1) gives a summary of the composition of commercial glasses, but dees not express all the facts. If the percentage of silica exceeds 75 per cent, the melt is too viscous to be satisfactory in the furnace; if the alkalies exceed 20 per cent, the glass produced is soft, hygroscopic and chemically unstable, being more or less soluble in water. Accordingly, a minimum of about 5 per cent of lime (or RO) is needed to give a satisfactory melt and durable glass; other things being equal glass with both alkalies is more durable than glass with either alkali alone; if the lime exceeds 13 per cent the mixture fuses with difficulty and the resultant glass crystallizes very easily; lead oxide may be used up to 80 per cent, but as the percentage of lead oxide increases, so also does the danger of crystallization on cooling, the danger of attack on the melting pot, the softness of the resultant glass, and the depth of its (yellow) color. In some types of glass barium oxide may be used up to about 50 per cent, but with important percentages of BaO it is desirable to use increasing amounts of $\mathrm{B}_{2} \mathrm{O}_{3}$ and $\mathrm{Al}_{2} \mathrm{O}_{3}$; mixtures high in BaO attack the crucible seriously, espe-
cially if any free silica is present in the clay. Boron oxide may be used up to about 20 per cent, but it is not desirable in lead glasses. Zinc oxide in excess of about 12 per cent is apt to induce crystallization, though small amounts may aid in preventing crystallization. More than 5 per cent of alumina tends ${ }^{1}$ to make most glass melts exceedingly viscous, but alumina decreases the danger of crystallization and renders the glass tough and resistant; in dense barium glasses alumina even up to 10 per cent aids in preventing crystallization of barium disilicate and improves the working qualities of the melt and the glass.
Various types of manufactured glass are, in general, so complicated in composition that it is very difficult to draw accurate conclusions regarding the relations between composition and physical properties from analyses of such types accompanied by measures of physical data. Peddle ${ }^{2}$ adopted a different method of determining these relationships. He made many kinds of glass of varying, but simple, composition; in any one series the composition was varied as to only one component: by measuring the indices of refraction and densities of the glasses thus made, he was able to reach important conclusions. He began with the simplest case: glasses of the composition $100 \mathrm{SiO}_{2} \cdot x \mathrm{Na}_{2} \mathrm{O}, x$ varying from 20 to 100 molecules. He tested next the corresponding case: $100 \mathrm{SiO}_{2} \cdot x \mathrm{~K}_{2} \mathrm{O}, x$ again varying from 20 to 100 molecules; in this case no large pieces of glass could be obtained and all the glasses were highly soluble in water-physical data could not be measured on them, but were obtained in two cases by extrapolation from other series. The next test was on a series: $100 \mathrm{SiO}_{2} \cdot \frac{1}{2} x \mathrm{Na}_{2} \mathrm{O}$. $\frac{1}{2} x \mathrm{~K}_{2} \mathrm{O}, x$ varying as before; these glasses were intermediate in character between those of the $\mathrm{Na}_{2} \mathrm{O}$ and the $\mathrm{K}_{2} \mathrm{O}$ series, but not suitable for measurements of physical data. Peddle next considered glasses having only two silica-alkali ratios, $100 \mathrm{SiO}_{2}+$ either 40 or $20 \mathrm{~K}_{2} \mathrm{O}$ or $\mathrm{Na}_{2} \mathrm{O}$, and studied alkali-calcium series obtained by adding various amounts of CaO to each of these. He studied also similar series of alkali-lead, and of alkali-barium glasses.

Some of his results may be tabulated as follows: ${ }^{3}$

| $\boldsymbol{c}$ |  |  |  |  |  |  |  |
| ---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $x$ | $\mathrm{SiO}_{2}$ | $\mathrm{Na}_{2} \mathrm{O}$ | $\mathrm{Al}_{2} \mathrm{O}_{2}+\mathrm{Fe}_{2} \mathrm{O}_{2}$ | $n(\mathrm{D})$ | $n(\mathrm{~F})-n(\mathrm{C})$ | $\frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}$ | G |
|  |  |  |  |  |  |  |  |
| 20 | 83.00 | 16.58 | 0.42 | 1.4851 | 0.00790 | 61.4 | 2.353 |
| 30 | 76.64 | 22.98 | 0.38 | 1.4952 | 0.00835 | 59.3 | 2.413 |
| 40 | 71.20 | 28.44 | 0.36 | 1.5015 | 0.00875 | 57.3 | 2.457 |
| 70 | 58.68 | 41.03 | 0.29 | 1.5118 | 0.00962 | 53.2 | 2.535 |
| 100 | 49.91 | 49.84 | 0.25 | 1.5168 | 0.01017 | 50.8 | 2.560 |

[^199]

Fig. 11-2. Relations between refractive index and density, etc., in some artificial and natural glasses. Modified from Bannister: Mineral. Mag. XXII, p. 136 (1929).
glass, provided that $0<x<75 \%$, and $0<y<20 \%$, by the following regression equation: ${ }^{4 \mathrm{~b}}$

$$
n \text { (glass) }=1.5766+0.00057 \mathrm{x}+0.00066 \mathrm{y} \pm .0010
$$

where the last term (.0010) is the standard error of the regression.
As silica seems to be the characteristic constituent of nearly all glasses Bannister ${ }^{5}$ devised a method of distinguishing between the various kinds of glass which is based on the way in which they differ from silica in their physical characters. The index of refraction of $\mathrm{SiO}_{2}$ glass is taken as 1.46 and its density as 2.21 . The chief types of commercial glasses may be identified by their position on a diagram which has the index of refraction as one coordinate and the ratio ( $n-1.46$ )/(G-2.21) as the other coordinate. A modification of Bannister's diagram is shown in Fig. 11-2. The separation of lead and calcium glasses is very distinct, but calcium glasses grade into borosilicate glasses and barium glasses overlap lead glasses considerably. These conditions are natural since there are so many variables in glass. Opal glasses are quite distinct. Natural glasses composing obsidians and basalt glasses are also shown. The data include several glasses used as imitation gem stones.

## Data for Figs. 11-2 and 11-3

## Borosolicate Glasses:

1. Imitation gem stone, Bannister's No. 14 in Min. Mag., XXII, p. 136 (1929). No analysis. $n(\mathrm{D})=1.500$, G. 2.36.
2. Borosilicate crown glass, Wright's No. 12 in J. Am. Ceram. Soc., III, p. 783 (1920). $\mathrm{SiO}_{2}=72.0, \mathrm{~B}_{2} \mathrm{O}_{3}=12.0, \mathrm{Na}_{2} \mathrm{O}=11.0, \mathrm{Al}_{2} \mathrm{O}_{3}=5.0 . n(\mathrm{D})=1.4997 ; \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=$ 64.7; G. 2.37.
3. Borosilicate crown glass, Morey's No. 5 in Intern. Crit. Tables, II, p. 87 (1927). $\mathrm{SiO}_{2}=59.5, \mathrm{~B}_{2} \mathrm{O}_{3}=21.5, \mathrm{~K}_{2} \mathrm{O}=14.4, \mathrm{CaO}=0.3, \mathrm{Al}_{2} \mathrm{O}_{3}=1.9, \mathrm{ZnO}=2.3$, $\mathrm{As}_{2} \mathrm{O}_{5}=0.1 . n(\mathrm{C})=1.49573, n(\mathrm{D})=1.4980, n(\mathrm{~F})=1.50336, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=$ 65.3, G. 2.40.
4. Borosilicate crown glass, Wright's No. 15, op. cit. $\mathrm{SiO}_{2}=70.6, \mathrm{~B}_{2} \mathrm{O}_{3}=6.0$, $\mathrm{Al}_{2} \mathrm{O}_{3}=1.0, \quad \mathrm{As}_{2} \mathrm{O}_{3}=0.3, \quad \mathrm{Mn}_{2} \mathrm{O}_{3}=0.1, \quad \mathrm{~K}_{2} \mathrm{O}=10.5, \quad \mathrm{Na}_{2} \mathrm{O}=11.5 . \quad n(\mathrm{C})=$ 1.50446, $n(\mathrm{D})=1.5069, n(\mathrm{~F})=1.51259, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=62.3$, G. 2.48.

## Calcium Glasses:

5. Hard crown glass, Morey's No. 27, op. cit. $\mathrm{SiO}_{2}=69.6, \mathrm{CaO}=11.5, \mathrm{~K}_{2} \mathrm{O}=18.4$, $\mathrm{Al}_{2} \mathrm{O}_{3}=0.3, \quad \mathrm{As}_{2} \mathrm{O}_{3}=0.2 . \quad n(\mathrm{C})=1.51496, \quad n(\mathrm{D})=1.5175, \quad n(\mathrm{~F})=1.52352$, $\frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=60.5, \mathrm{G} .2 .49$.
${ }^{4 b}$ Regression formula based on the data of DeVries and Osborn (ref. 4a), calc. by HW.
${ }^{5}$ Min. Mag. XXII, p. 136 (1929).
6. Imitation gem stone, Bannister's No. 10, op. cit. No analysis. $n(D)=1.538$. G. 2.57.
7. Imitation gem stone, Bannister's No. 8, op. cit. No analysis. $n(\mathrm{D})=1.532$, G. 2.56 .
8. Imitation gem stone, Bannister's No. 12, op. cit. No analysis. $n(\mathrm{D})=1.532$. G. 2.60.
9. Ordinary crown glass, Wright's No. 1, op. cit. $\mathrm{SiO}_{2}=74.6, \mathrm{As}_{2} \mathrm{O}_{3}=0.3, \mathrm{Mn}_{2} \mathrm{O}_{3}=$ $0.1, \mathrm{CaO}=5.0, \mathrm{~K}_{2} \mathrm{O}=11.0, \mathrm{Na}_{2} \mathrm{O}=9.0 . n(\mathrm{D})=1.5055, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=60.2$, G.2.5.

## Intermediate and Special Types:

10. Beryllium glass, Lai and Silverman's No. $\mathrm{B}_{3}$, in J. Am. Ceram. Soc., XI, p. 535 (1928): $\mathrm{SiO}_{2}=73.39, \mathrm{BeO}=7.64, \mathrm{Na}_{2} \mathrm{O}=18.96 .\left(\mathrm{Na}_{2} \mathrm{O} \cdot \mathrm{BeO} \cdot 4 \mathrm{SiO}_{2}\right) \cdot n(\mathrm{D})=$ 1.5193, G. 2.45.
11. Imitation gemstone, Bannister's No. 18, op. cit. No analysis, but considered to be an iron calcium glass. $n(\mathrm{D})=1.577$. G. 2.68.
12. Imitation gem stone, opal white, Bannister's No. 24 , op. cit. No analysis. $n(\mathrm{D})=$ 1.450. G. 2.15.
13. Barium borosilicate crown glass, Morey's No. 18, op. cit. $\mathrm{SiO}_{2}=67.1, \mathrm{~B}_{2} \mathrm{O}_{3}=7.2$, $\mathrm{Al}_{2} \mathrm{O}_{3}=0.3, \mathrm{As}_{2} \mathrm{O}_{5}=0.1, \mathrm{CaO}=2.0, \mathrm{BaO}=7.2, \mathrm{~K}_{2} \mathrm{O}=16.2 . n(\mathrm{C})=1.51358$, $n(\mathrm{D})=1.5160, n(\mathrm{~F})=1.52167, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=63.8, \mathrm{G} .=2.54$.
14. Zinc crown glass, Morey's No. 16, op. cit. $\mathrm{SiO}_{2}=69.7, \mathrm{Al}_{2} \mathrm{O}_{3}=0.3, \mathrm{As}_{2} \mathrm{O}_{5}=0.4$, $\mathrm{CaO}=0.4, \quad \mathrm{ZnO}=16.5, \quad \mathrm{~K}_{2} \mathrm{O}=1.7, \quad \mathrm{Na}_{2} \mathrm{O}=11.0 . \quad n(\mathrm{C})=1.51225, \quad n(\mathrm{D})=$ 1.5149, $n(\mathrm{~F})=1.52115, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=57.9$, G. 2.62 .
15. Imitation gem stone, opal white, Bannister's No. 26, op. cit. No analysis. $n(\mathrm{D})=$ 1.457, G. 2.17.
16. Imitation gem stone, dark, brown, Bannister's No. 22, op. cit. No analysis, but considered to be colored by iron and titanium. $n(\mathrm{D})=1.488, \mathrm{G} .2 .52$.

## Lead Glasses:

17. Flint glass, Wright's No. 47, op. cit. $\mathrm{SiO}_{2}=68.7, \mathrm{Mn}_{2} \mathrm{O}_{3}=0.1, \mathrm{As}_{2} \mathrm{O}_{3}=0.2$, $\mathrm{PbO}=13.3, \mathrm{ZnO}=2.0, \mathrm{Na}_{2} \mathrm{O}=15.7 . n(\mathrm{C})=1.51721, n(\mathrm{D})=1.5202, n(\mathrm{~F})=$ 1.52747, $\frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=50.7, \mathrm{G} .2 .7$.
18. Flint glass, Wright's No. 53 , op. cit. $\mathrm{SiO}_{2}=59.3, \mathrm{As}_{2} \mathrm{O}_{3}=0.2, \mathrm{PbO}=27.5$, $\mathrm{K}_{2} \mathrm{O}=8.0, \quad \mathrm{Na}_{2} \mathrm{O}=5.0 . \quad n(\mathrm{C})=1.55024, \quad n(\mathrm{D})=1.5537, \quad n(\mathrm{~F})=1.56217$, $\frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=46.4$, G. 2.9.
19. Flint glass, Morey's No. 48, op. cit. $\mathrm{SiO}_{2}=60.6, \mathrm{Al}_{2} \mathrm{O}_{3}=0.3$. $\mathrm{As}_{2} \mathrm{O}_{5}=0.1$, $\mathrm{CaO}=0.3, \quad \mathrm{BaO}=2.5, \quad \mathrm{PbO}=22.5, \quad \mathrm{~K}_{2} \mathrm{O}=13.9 . \quad n(\mathrm{C})=1.54562, \quad n(\mathrm{D})=$ 1.5491, $n(\mathrm{~F})=1.55768, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=45.5, \mathrm{G} .2 .95$.
20. Flint glass, Morey's No. 55, op. cit. $\mathrm{SiO}_{2}=55.9, \mathrm{Al}_{2} \mathrm{O}_{3}=0.2, \mathrm{As}_{2} \mathrm{O}_{5}=0.1$, $\mathrm{CaO}=0.3, \mathrm{PbO}=32.9, \mathrm{~K}_{2} \mathrm{O}=11.1 . n(\mathrm{C})=1.55945, n(\mathrm{D})=1.5632, n(\mathrm{~F})=$ 1.57257, $\frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=42.9, \mathrm{G} .3 .07$.
21. Flint glass, Wright's No. 56, op. cit. $\mathrm{SiO}_{2}=53.7, \mathrm{Mn}_{2} \mathrm{O}_{3}=0.1, \mathrm{As}_{2} \mathrm{O}_{3}=0.3$
$\mathrm{PbO}=36.6, \mathrm{Na}_{2} \mathrm{O}=1.0, \mathrm{~K}_{2} \mathrm{O}=8.3 . n(\mathrm{C})=1.57122, n(\mathrm{D})=1.5752, n(\mathrm{~F})=$ 1.58507, $\frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=41.0$, G. 3.22 .
22. Imitation gem stone, red. Bannister's No. 7, op. cit. No analysis. $n(\mathrm{D})=1.585$, G. 3.18.
23. Imitation gem stone, green. Bannister's No. 6, op. cit. $n(\mathrm{D})=1.606$, G. 3.42 .
24. Flint glass, Morey's No. 92, op. cit. $\mathrm{SiO}_{2}=48.0, \mathrm{Al}_{2} \mathrm{O}_{3}=0.2, \mathrm{As}_{2} \mathrm{O}_{5}=0.1$, $\mathrm{PbO}=45.1, \quad \mathrm{CaO}=0.3, \quad \mathrm{Na}_{2} \mathrm{O}=5.2, \quad \mathrm{~K}_{2} \mathrm{O}=1.2 . \quad n(\mathrm{C})=1.60867, \quad n(\mathrm{D})=$ 1.6134, $n(\mathrm{~F})=1.62529, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=36.9$, G. 3.55 .
25. Imitation gem stone, yellow, Bannister's No. 5, op. cit. No analysis. $n(\mathrm{D})=1.630$, G. 3.53.
26. Imitation gem stone, yellow, Bannister's No. 4, op. cit. No analysis. $n(\mathrm{D})=1.640$, G. 3.70.
27. Flint glass, Morey's No. 101, op. cit. $\mathrm{SiO}_{2}=40.6, \mathrm{Al}_{2} \mathrm{O}_{3}=0.2, \mathrm{As}_{2} \mathrm{O}_{5}=0.1$, $\mathrm{CaO}=0.2, \mathrm{PbO}=51.5, \mathrm{~K}_{2} \mathrm{O}=7.5 . n(\mathrm{C})=1.64149, n(\mathrm{D})=1.6469, n(\mathrm{~F})=$ 1.66066, $\frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=33.7$, G. 3.87 .
28. Imitation gem stone, purple. Bannister's No. 3. op.cit. No analysis. $n(\mathrm{D})=1.654$, G. 3.79.
29. Imitation gem stone, yellow, Bannister's No. 2, op. cit. No analysis. $n(\mathrm{D})=1.662$, G. 3.97.
30. Flint glass, Wright's No. 78, op. cit. $\mathrm{SiO}_{2}=38.0$. $\mathrm{As}_{2} \mathrm{O}_{3}=0.2, \mathrm{PbO}=56.8$. $\mathrm{K}_{2} \mathrm{O}=5.0 . n(\mathrm{C})=1.67413, n(\mathrm{D})=1.6801, n(\mathrm{~F})=1.69517, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=$ 32.3, G. 4.1.
31. Flint glass, Wright's No. 80, op. cit. $\mathrm{SiO}_{2}=33.7, \mathrm{As}_{2} \mathrm{O}_{3}=0.3, \mathrm{PbO}=62.0$, $\mathrm{K}_{2} \mathrm{O}=4.0, n(\mathrm{C})=1.71055, n(\mathrm{D})=1.7174, n(\mathrm{~F})=1.73489, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=$ 29.5, G. 4.49.
32. Flint glass, Wright's No. 82 , op. cit. $\mathrm{SiO}_{2}=28.4, \mathrm{As}_{2} \mathrm{O}_{3}=0.1, \mathrm{PbO}=69.0$ $\mathrm{K}_{2} \mathrm{O}=2.5 . n(\mathrm{C})=1.74641, n(\mathrm{D})=1.7541, n(\mathrm{~F})=1.77384, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=$ 27.5, G. 4.78.
33. Flint glass, Wright's No. 83, op. cit. $\mathrm{SiO}_{2}=27.3, \mathrm{As}_{2} \mathrm{O}_{3}=0.1, \mathrm{PbO}=71.0$, $\mathrm{K}_{2} \mathrm{O}=1.5 . n(\mathrm{C})=1.76999, n(\mathrm{D})=1.7782, n(\mathrm{~F})=1.79940, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=$ 26.5, G. 4.99.

33a. Flint glass, Wright's No. 84 , op. cit. $\mathrm{SiO}_{2}=22.0, \mathrm{PbO}=78.0 . n(\mathrm{C})=1.87938$, $n(\mathrm{D})=1.8904, n(\mathrm{~F})=1.91935, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=22.3$, G. 5.83.
33b. Flint glass, Wright's No. 87 , op. cit. $\mathrm{SiO}_{2}=18.0, \mathrm{As}_{2} \mathrm{O}_{3}=0.1, \mathrm{PbO}=82.0$. $n(\mathrm{C})=1.94925, n(\mathrm{D})=1.9626, n(\mathrm{~F})=1.99807, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=19.7$, G. 6.33 .

## Barium Glasses:

34. Barium crown glass, Morey's No. 43, op. cit. $\mathrm{SiO}_{2}=57.1, \mathrm{~B}_{2} \mathrm{O}_{3}=1.8, \mathrm{Al}_{2} \mathrm{O}_{3}=$ $0.2, \mathrm{As}_{2} \mathrm{O}_{5}=0.1, \mathrm{CaO}=0.3, \mathrm{BaO}=26.9, \mathrm{~K}_{2} \mathrm{O}=13.7 . n(\mathrm{C})=1.53802, n(\mathrm{D})=$ 1.5407, $n(\mathrm{~F})=1.54712, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=59.4, \mathrm{G} .2 .90$.
35. Barium flint glass, Wright's No. 89, op. cit. $\mathrm{SiO}_{2}=56.2, \mathrm{As}_{2} \mathrm{O}_{3}=0.3, \mathrm{PbO}=7.0$, $\mathrm{ZnO}=9.0, \mathrm{BaO}=15.0, \mathrm{~K}_{2} \mathrm{O}=11.0, \mathrm{Na}_{2} \mathrm{O}=1.5 . n(\mathrm{C})=1.54694, n(\mathrm{D})=$ 1.5500, $n(\mathrm{~F})=1.55736, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=52.8, \mathrm{G} .3 .0$.
36. Barium flint glass, Wright's No. 95, op. cit. $\mathrm{SiO}_{2}=51.2, \mathrm{As}_{2} \mathrm{O}_{3}=0.3, \mathrm{PbO}=4.0$, $\mathrm{ZnO}=14.0, \mathrm{BaO}=20.0, \mathrm{~K}_{2} \mathrm{O}=5.0, \mathrm{Na}_{2} \mathrm{O}=5.5, n(\mathrm{C})=1.56607, n(\mathrm{D})=$ 1.5692, $n(\mathrm{~F})=1.57679, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=53.1, \mathrm{G} .3 .12$.
37. Barium crown glass, Wright's No. 40, op. cit. $\mathrm{SiO}_{2}=37.5, \mathrm{~B}_{2} \mathrm{O}_{3}=15.0, \mathrm{Al}_{2} \mathrm{O}_{3}=$ $5.0, \mathrm{As}_{2} \mathrm{O}_{3}=1.5, \mathrm{BaO}=41.0 . n(\mathrm{C})=1.58703, n(\mathrm{D})=1.5899, n(\mathrm{~F})=1.59673$, $\frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=60.8, \mathrm{G} .3 .32$.
38. Barium crown glass, Wright's No. 45, op. cit. $\mathrm{SiO}_{2}=31.0, \mathrm{~B}_{2} \mathrm{O}_{3}=12.0, \mathrm{Al}_{2} \mathrm{O}_{3}=$ $8.0, \mathrm{As}_{2} \mathrm{O}_{3}=1.0, \mathrm{BaO}=48.0 . n(\mathrm{C})=1.60673, n(\mathrm{D})=1.6098, n(\mathrm{~F})=1.61710$, $\frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=58.8$, G. 3.54.
39. Barium flint glass, Wright's No. 102, op. cit. $\mathrm{SiO}_{2}=42.8, \mathrm{As}_{2} \mathrm{O}_{3}=0.5, \mathrm{PbO}=$ $32.6, \mathrm{ZnO}=5.1, \mathrm{BaO}=10.8, \mathrm{~K}_{2} \mathrm{O}=7.5, \mathrm{Na}_{2} \mathrm{O}=0.7 . n(\mathrm{C})=1.62233, n(\mathrm{D})=$ 1.6269, $n(\mathrm{~F})=1.63832, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=34.8$, G. 3.70.
40. Barium flint glass, Morey's No. 104, op. cit. $\mathrm{SiO}_{2}=36.6, \mathrm{Al}_{2} \mathrm{O}_{3}=0.2, \mathrm{Sb}_{2} \mathrm{O}_{3}=$ $0.6, \mathrm{As}_{2} \mathrm{O}_{5}=0.2, \mathrm{~K}_{2} \mathrm{O}=4.9, \mathrm{CaO}=0.2, \mathrm{BaO}=13.6, \mathrm{ZnO}=4.7, \mathrm{PbO}=39.2$. $n(\mathrm{C})=1.66297, n(\mathrm{D})=1.6683, n(\mathrm{~F})=1.68173, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=35.6, \mathrm{G} .3 .98$.

## Thallium Glasses:

41. Thallium glass, Bannister's No. 3, op. cit. p. 152. $\mathrm{SiO}_{2}=36.99, \mathrm{PbO}=18.06$, $\mathrm{K}_{2} \mathrm{O}=37.49, \quad \mathrm{Tl}_{2} \mathrm{O}=7.46 . \quad n(\mathrm{C})=1.581, \quad n(\mathrm{D})=1.586, \quad n(\mathrm{~F})=1.599$, $\frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=32.5, \mathrm{G} .3 .12$.
42. Thallium glass, Bannister's No. 2, op. cit. p. 152. $\mathrm{SiO}_{2}=38.45, \mathrm{PbO}=18.81$, $\mathrm{K}_{2} \mathrm{O}=12.63, \quad \mathrm{Tl}_{2} \mathrm{O}=29.38 . \quad n(\mathrm{C})=1.650, n(\mathrm{D})=1.657, \quad n(\mathrm{~F})=1.673$, $\frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=28.6$, G. 3.75.
43. Thallium glass, Bannister's No. 1. op. cit. p. 152. $\mathrm{SiO}_{2}=27.17, \mathrm{PbO}=23.98$, $\mathrm{K}_{2} \mathrm{O}=12.07, \mathrm{Tl}_{2} \mathrm{O}=36.36 . \quad n(\mathrm{C})=1.736, \quad n(\mathrm{D})=1.744, \quad n(\mathrm{~F})=1.766$, $\frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=24.8$, G. 4.42 .
44. Thallium glass, Bannister's No. 4, op. cit. p. 152. $\mathrm{SiO}_{2}=20.83, \mathrm{PbO}=24.82$, $\mathrm{K}_{2} \mathrm{O}=0.00, \quad \mathrm{Tl}_{2} \mathrm{O}=55.01 . \quad n(\mathrm{C})=1.9276, \quad n(\mathrm{D})=1.9431, \quad n(\mathrm{~F})=1.9808$, $\frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=17.7$, G. 6.03.

## Natural Rock Glasses:

A. Rhyolite obsidian, Yellowstone Park, C. E. Tilley: Min. Mag. XIX, p. 275 (1922). $n(\mathrm{D})=1.482, \mathrm{G} .2 .353$.
B. Rhyolite obsidian, Clifton, Ariz., B. Ježek and Woldfrich: Zeit. Krist. LIII, p. 82 (1913). $n(\mathrm{C})=1.4850, n(\mathrm{D})=1.4871, n(\mathrm{~F})=1.4956, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=46.0$, G. 2.355: $n(\mathrm{C})$ and $n(\mathrm{~F})$ by graphic solution from $n$ for $\mathrm{Li}, \mathrm{Na}$ and Tl .
C. Rhyolite obsidian, Easter Island, Pacific, C. E. Tilley, op. cit. $n(\mathrm{D})=1.490$, G. 2.400 .
D. Rhyolite obsidian, Greenland, B. Ježek, op. cit. $n(\mathrm{C})=1.4939, n(\mathrm{D})=1.4956$, $n(\mathrm{~F})=1.5002, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=78.7$, G. 2.413 .
E. Rhyolite obsidian, Real del Monte, Mexico, B. Ježek. op. cit. $n(\mathrm{C})=1.4889$, $n(\mathrm{D})=1.4912, n(\mathrm{~F})=1.4970, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=60.6, \mathrm{G} .2 .394$.
F. Rhyolite obsidian, Papayan, Colombia, B. Ježek, op. cit. $n(\mathrm{C})=1.4830, n(\mathrm{D})=$ 1.4852, $n(\mathrm{~F})=1.4925, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=51.1, \mathrm{G} .2 .352$.
G. Rhyolite obsidian, Lipari Island, C. E. Tilley, op. cit. $n(\mathrm{D})=1.490$, G. 2.363 .
H. Rhyolite obsidian, Guamani, Ecuador, B. Ježek, op. cit. $n(\mathrm{C})=1.4840, n(\mathrm{D})=$ 1.4863, $n(\mathrm{~F})=1.4941, \frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}=48.1, \mathrm{G} .2 .336$.
J. Trachyte obsidian, Pantelleria, C. E. Tilley, op. cit. $n(\mathrm{D})=1.508$, G. 2.454 .
K. Trachyte obsidian, Ascension, C. E. Tilley, op. cit. $n(\mathrm{D})=1.506$, G. 2.435 .
L. Trachyte obsidian, Teneriffe, C. E. Tilley, op. cit. $n(\mathrm{D})=1.512$, G. 2.467 .
M. Basalt glass, Gallanach, Island of Muck, C. E. Tilley, op. cit. $n(\mathrm{D})=1.583$, G. 2.704.
N. Basalt glass, Portree, Skye, C. E. Tilley, op. cit. $n(\mathrm{D})=1.576$, G. 2.716 .
P. Basalt glass, Vesuvius (1805), C. E. Tilley, op. cit. $n(\mathrm{D})=1.586$, G. 2.769 .
R. Basalt glass, Kau desert, Kilauea, C. E. Tilley, op. cit. $n(\mathrm{D})=1.603$, G. 2.841 .
S. Basalt glass, Caisteal, Island of Muck, C. E. Tilley, op. cit. $n(\mathrm{D})=1.598$, G. 2.773.
T. Basalt glass, Reunion Isl., C. E. Tilley, op. cit. $n(\mathrm{D})=1.608, \mathrm{G} .2 .825$.
V. Basalt glass, Kildonan, Island of Eigg, C. E. Tilley, op. cit. $n(\mathrm{D})=1.649$, G. 3.003.

Wright ${ }^{6}$ has shown that glasses are well characterized by their refractive index and dispersion. They are equally well characterized by the refractive index and the reciprocal of the dispersion, which is called $\nu$ and equals $\frac{n(\mathrm{D})-1}{n(\mathrm{~F})-n(\mathrm{C})}$. These values are the coordinates used in Fig. 11-3, which shows that the lead glasses fall along a remarkably smooth curve, the calcium glasses fall close together and the borosilicate glasses form another small group, while the barium glasses scatter over a large area; the thallium glasses of Bannister ${ }^{5}$ fall along a curve nearly parallel with that of the lead glasses. Natural acid volcanic glasses or obsidians vary in dispersion much more than in refractive index, which is low. Basalt glasses have a refractive index ranging from about 1.58 to about 1.67 , but their dispersion is apparently unknown. It should be understood that there are all gradations between the various artificial types of glass, and also between obsidians and basalt glasses. Wright and Peddle both worked out diagrams and tables from which the batch composition necessary to give certain physical

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Fig. 11-3. Relations between refractive index and dispersion as measured by $\nu=\frac{\mathrm{N}_{\mathrm{D}}-1}{\mathrm{~N}_{\mathrm{F}}-\mathrm{N}_{\mathrm{C}}}$ in some artificial glasses and obsidians.
properties of glass may be derived. Data of Morey and Merwin ${ }^{7}$ are summarized in Fig. 11-4.

Glass has been made from feldspar; ${ }^{8}$ such glass is said to be tough; high purity of the crude feldspar is said to be unnecessary. If pure plagioclase

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Fig. 11-4. Refractive index, $\mathrm{N}_{\mathrm{D}}$, dispersion, $\mathrm{N}_{\mathrm{F}}-\mathrm{N}_{\mathrm{C}}$ and density of glasses in part of the ternary system, $\mathrm{SiO}_{2}-\mathrm{Na}_{2} \mathrm{O}-\mathrm{CaO}-(M o r e y ~ a n d ~ M e r w i n, ~ J . ~ O p t . ~ S o c . ~ A m e r . ~$ XXII, p. 632, 1932).
feldspar were used the glass would have the following optical properties: ${ }^{9}$

| Per Cent | Per Cent <br> Anorthite | $n(\mathrm{C})$ | $n(\mathrm{D})$ | $n(\mathrm{~F})$ | $\nu$ | G |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Albite |  |  |  |  |  |  |$\quad$| 100.0 | 0.0 |
| :---: | :---: |

Silica is the chief component of nearly all commercial glass, usually being 60 to 80 per cent of the whole. Some glass is pure silica, but its melting point ( $1710^{\circ} \mathrm{C}$.) is so high that it is expensive to make. However, " $96 \%$
${ }^{9}$ Larsen: Am. J. Sci., XXVIII, p. 263 (1909). $n(\mathrm{C}), n(\mathrm{~F})$ (and $\nu$ ) by graphic solution from indices for $\mathrm{Li}, \mathrm{Na}$, and Tl light given by Larsen.
silica" glass ( $4 \%$ is chiefly $\mathrm{B}_{2} \mathrm{O}_{3}$ ) introduced by Corning Glass Works in 1939, has some remarkable properties which have made it important. Its low coefficient of expansion makes it extremely resistant to thermal shock. It has very high chemical durability and electrical resistance. One variety of this glass has very high transmission for ultra violet light.

## Part Two

## Determinative Tables and Charts

## Introduction

Separate tables, for isotropic and for anisotropic substances, respectively, are provided. The first table lists substances (other than the glasses covered in Chapter XI, p. 313) arranged by the refractive index $n$. Each entry shows the formula (or name, or both), the refractive index $n$, and the page reference in this book.

The tables of anisotropic substances are arranged by birefringence within groups determined by the refractive index $n_{\mathrm{Y}}$, and each group is keyed by a number in the first column, to a graphical display showing in polar coordinates the values of birefringence $n_{\mathrm{z}}-n_{\mathrm{X}}$ and optic axial angle $2 V$. It will be noted that uniaxial substances fall along the left boundary of each semicircular chart, biaxial ones elsewhere as determined by their properties. Each chart corresponds to one of the groups determined by ranges of $n_{\mathrm{Y}}$; these ranges are broad enough to cover the uncertainty of an ordinary microscopical measurement of index by the immersion method with white light. Extreme values of $n_{\mathrm{Y}}$ are so rare that two or more such groups have been combined so that no chart will have less than about 15 items.

The use of these tables and charts depends not so much upon knowledge of the exact values of principal refractive indices, which might be considered the fundamental optical constants, as upon values that can be obtained routinely either by examination of grains in immersion oils or by study of thin sections. The value of 2 V and the optic character ("sign" of 2 V ) can be obtained in several well-known ways, including examination of an interference figure of a grain (whether in immersion or in thin section) that shows practically no interference effects between crossed nicols, and therefore is oriented to give an approximately centered optic-axis interference figure. The same grain may also be used to determine $n_{\mathrm{Y}}$, and by the interference color at the margin of the field of the interference figure, it may furthermore be used to estimate the value of the birefringence, $n_{\mathbf{Z}}-n_{\mathbf{X}}$. If a substance is too fine-grained to permit such detailed observations, its mean index, $n$, may nevertheless be obtained in most cases, and is usually fairly close to $n_{\mathrm{Y}}$. The birefringence in such a case cannot be estimated accurately, but its order of magnitude may be determined in many instances. At the worst, no more than two or three entire groups from this list may have to be considered. In such instances, other methods will normally be used.
In preparing these tables it was unfortunately necessary in many cases to estimate values of birefringence or of $2 V$, or both, from qualitative de-
scriptions such as "birefringence moderate," " $2 V$ rather large," etc. This has been done somewhat arbitrarily using the following lists, but modifying the numbers if other evidence was available.

| Birefringence scale |  |  | Optic axial angle scale |  |
| :--- | :---: | :--- | :--- | :---: |
| Description | Assumed value |  |  |  |
|  |  |  | Description | Assumed value <br> $n_{\mathrm{z}}-n_{\mathbf{X}}$ |
|  | 0.002 |  | Very small | $10^{\circ}$ (or $15^{\circ}$ ) |
| Very weak | 0.006 |  | Small | $25^{\circ}$ |
| Low or Weak | 0.014 |  | Medium small | $40^{\circ}$ |
| Moderate | 0.023 |  | Moderate | $50^{\circ}$ |
| Rather strong | 0.032 |  | Medium large | $60^{\circ}$ |
| Strong | 0.045 |  | Large | $70^{\circ}$ (or $75^{\circ}$ ) |
| Very strong | $>0.05$ |  | Very large | $85^{\circ}$ (or $80^{\circ}$ ) |
| Extreme |  |  |  |  |

Another source of difficulty lies in ambiguous expressions giving ranges to express uncertainty, rather than probable values with standard errors. The center of a range was generally taken as the most probable value unless the ranges of properties were due to varying composition. Thus " $n_{\mathrm{Y}}=$ $1.698-1.721$ " would be taken in most cases as " $n_{\mathrm{Y}} \doteq 1.71$," dropping the last figure after the decimal point, but for a known isomorphous series with substantial variation of optical properties, entries are made in several of the $n_{\mathrm{Y}}$-groups. A similar remark may be made for birefringence and 2 V as shown on the charts, though for the most part it is assumed that the user of these charts will probably realize the necessity for a sufficient (and variable!) tolerance in his determinations of optical properties.
A very serious source of difficulty in compiling these tables and charts arises from incomplete data. If, for example, two unidentified refractive indices $n_{1}$ and $n_{2}$, have been published, with or without additional data on birefringence and $2 V$, it is always possible to state that $n_{1} \leq n_{\mathrm{Y}} \leq n_{2}$, and that $n_{\mathrm{Z}}-n_{\mathrm{X}} \geq n_{2}-n_{1}$. Such data permit assigning substances to the correct $n_{\mathrm{Y}}$ group in many cases, but the estimation of birefringence and $2 V$ is usually very uncertain. If for any reason the birefringence can be assumed to be small, it may be reasonable to show the substance at or near the origin in the semicircular diagram without serious risk of misleading the user.

In some instances it is possible to list a substance in one of the $n_{\mathrm{Y}}$-groups, but quite impossible to show its position in the diagram. Such limitations of the available data are minimized as much as possible, but must be kept in mind when using the charts. The observed optic angle, $2 V$, is too frequently omitted from optical descriptions; if the three principal indices
are given, 2 V can be calculated, and this has been done in preparing the charts, but calculated values of 2 V seldom agree with observed values, for the calculations are sensitive to very small errors in the refractive indices, especially if the birefringence is small. The equation may be stated in several forms, of which the following is convenient:

$$
\tan ^{2} V_{\mathrm{Z}}=\left(\frac{1}{n_{\mathrm{X}^{2}}}-\frac{1}{n \mathrm{Y}^{2}}\right) /\left(\frac{1}{n_{\mathrm{Y}}{ }^{2}}-\frac{1}{n_{\mathrm{Z}}{ }^{2}}\right)
$$

A convenient chart giving the solutions to this equation for the most frequently met combinations of optical data was published by J. B. Mertie. ${ }^{1}$ Mertie's chart not only indicates the solution quickly, but also furnishes evidence as to the precision thereof. A somewhat more detailed discussion of the use of tables and charts of this type is given in the author's book on "Optical Properties of Minerals." ${ }^{2}$
${ }^{1}$ Am. Min. XXVII, p. 538 (1942).
${ }^{2}$ H. Winchell, "Optical Properties of Minerals." Academic Press, New York. In press.

## DETERMINATIVE TABLES

I. Isotropic Crystalline Solids
(Glasses described in chapter XI, p. 313f, are excluded)
Arranged in order of increasing refractive index, $n$.

| Substance | $n$ | Page |
| :---: | :---: | :---: |
| NaF | 1.3258 | 16 |
| $\mathrm{K}_{2} \mathrm{SiF}_{6}$, Hieratite | 1.339 | 46 |
| $\mathrm{Li}_{3} \mathrm{Na}_{3} \mathrm{Al}_{2} \mathrm{~F}_{12}$, Cryolithionite | 1.3395 | 42 |
| $\mathrm{K}_{2} \mathrm{SiF}_{6}$, Hieratite | 1.347 | 46 |
| KF | 1.352 | 17 |
| KF | 1.3629 | 17 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SiF}_{6}$, Cryptohalite | 1.3696 | 46 |
| $\mathrm{K}_{2} \mathrm{NaAlF}_{6}$, Elpasolite | 1.376 | 43 |
| Lif | 1.3921 | 17 |
| RbF | 1.396 | 17 |
| $\mathrm{K}_{3} \mathrm{HfF}_{7}$ | 1,403 | 47 |
| $\mathrm{K}_{3} \mathrm{ZrF}_{7}$ | 1.408 | 47 |
| KCN | 1.410 | 22 |
| $\mathrm{K}_{2} \mathrm{Zn}(\mathrm{CN})_{4}-\mathrm{K}_{2} \mathrm{Cd}(\mathrm{CN})_{4}$ - Series | 1.413 | 38 |
| $\mathrm{Li}_{3} \mathrm{FeF}_{6}$ | 1.42 | 42 |
| $\left(\mathrm{NH}_{4}\right)_{3} \mathrm{HfF}_{7}$ | 1.426 | 47 |
| $\mathrm{Co}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{NH}_{3}$ | 1.430 | 112 |
| $\left(\mathrm{NH}_{4}\right)_{3} \mathrm{ZrF}_{7}$ | 1.433 | 47 |
| $\mathrm{CaF}_{2}$, Fluorite | 1.4338 | 23 |
| $\mathrm{K}_{2}(\mathrm{Cd}, \mathrm{Hg})(\mathrm{CN})_{4}$ | 1.435 | 38 |
| $61 \mathrm{~K}_{2} \mathrm{Cd}(\mathrm{CN})_{4} \cdot 39 \mathrm{~K}_{2} \mathrm{Hg}(\mathrm{CN})_{4}$ | 1.435 | 38 |
| $\mathrm{Ni}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{NH}_{3}$ | 1.437 | 112 |
| $\mathrm{SrF}_{2}$ | 1.438 | 23 |
| $\mathrm{NaAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$, Soda Alum | 1.4388 | 158 |
| $\mathrm{Sr}\left(\mathrm{BF}_{4}\right)_{2}$ | 1.44 | 48 |
| $\mathrm{K}_{2} \mathrm{Cd}(\mathrm{CN})_{4}-\mathrm{K}_{2} \mathrm{Hg}(\mathrm{CN})_{4}$ - Series | 1.441 | 38 |
| $\mathrm{K}_{2} \mathrm{Zn}(\mathrm{CN})_{4}-\mathrm{K}_{2} \mathrm{Hg}(\mathrm{CN})_{4}$ - Series | 1.443 | 38 |
| $\mathrm{Na}_{7}\left(\mathrm{PO}_{4}\right)_{2} \mathrm{~F} \cdot 19 \mathrm{H}_{2} \mathrm{O}$ | 1.4519 | 205 |
| Na (CN) | 1.452 | 22 |
| $\mathrm{NH}_{2}\left(\mathrm{CH}_{3}\right)_{2} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4525 | 159 |
| KH | 1.453 | 22 |
| $\mathrm{NH}_{3} \mathrm{CH}_{3} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$, | 1.4531 | 159 |
| $\mathrm{KAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$, Potash Alum | 1.4565 | 158 |
| $\mathrm{RbAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4566 | 159 |


| Substance | $n$ | Page |
| :---: | :---: | :---: |
| $\mathrm{B}_{2} \mathrm{O}_{3}$ | 1.458 | 59 |
| $\mathrm{K}_{2} \mathrm{Hg}(\mathrm{CN})_{4}$ | 1.458 | 38 |
| $\mathrm{CsAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4586 | 159 |
| $\mathrm{SiO}_{2}$, Lechatelierite | 1.4588 | 65 |
| $\mathrm{NH}_{3} \mathrm{C}_{2} \mathrm{H}_{5} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.459 | 159 |
| $\mathrm{NH}_{4}\left(\mathrm{NO}_{3}\right)$ | 1.459 | 101 |
| $\mathrm{N}\left(\mathrm{CH}_{3}\right)_{4} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4592 | 159 |
| $\mathrm{NH}_{2}\left(\mathrm{C}_{2} \mathrm{H}_{5}\right)_{2} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4592 | 159 |
| $\mathrm{NH}_{4} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$, Ammonia Alum | 1.4594 | 158 |
| $\mathrm{NH}\left(\mathrm{C}_{2} \mathrm{H}_{5}\right)_{3} \mathrm{AlSO}_{4} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4594 | 159 |
| $\mathrm{N}\left(\mathrm{C}_{2} \mathrm{H}_{5}\right)_{4} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4595 | 159 |
| $\mathrm{NH}_{3} \mathrm{C}_{4} \mathrm{H}_{9} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4598 | 159 |
| $\mathrm{NH}_{3} \mathrm{C}_{3} \mathrm{H}_{7} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4602 | 159 |
| $\mathrm{NH}_{3} \mathrm{C}_{5} \mathrm{H}_{11} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4602 | 159 |
| $\mathrm{RbIn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4638 | 159 |
| $\mathrm{B}_{2} \mathrm{O}_{3}$ | 1.464 | 59 |
| $\mathrm{NH}_{2}(\mathrm{OH}) \mathrm{HAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4642 | 159 |
| $\mathrm{NaK}(\mathrm{CN})_{2}$ | 1.465 | 22 |
| $\mathrm{RbTi}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.465 | 159 |
| $\mathrm{CsGa}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4650 | 159 |
| $\mathrm{CsIn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4652 | 159 |
| $\mathrm{KGa}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4653 | 159 |
| $\mathrm{RbGa}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4658 | 159 |
| $\mathrm{NH}_{4} \mathrm{In}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4664 | 159 |
| $\mathrm{NH}_{4} \mathrm{Ga}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4684 | 159 |
| $\mathrm{RbV}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.469 | 159 |
| $\mathrm{Na}_{7}\left(\mathrm{AsO}_{4}\right)_{2} \mathrm{~F} \cdot 19 \mathrm{H}_{2} \mathrm{O}$ | 1.4693 | 205 |
| $\mathrm{Al}(\mathrm{OH})_{2} \mathrm{SiAlO}_{4}$ | 1.47 | 251 |
| NaH | 1.470 | 21 |
| $\mathrm{CsTi}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4736 | 159 |
| $\mathrm{BaF}_{2}$ | 1.4741 | 25 |
| $\mathrm{NH}_{3} \mathrm{CH}_{3} \mathrm{Cr}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4745 | 160 |
| $\mathrm{NH}_{4} \mathrm{~V}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.475 | 159 |
| $\mathrm{CsV}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.478 | 159 |
| CsF | 1.478 | 18 |
| $\mathrm{NH}_{3} \mathrm{CH}_{3} \mathrm{Al}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4780 | 160 |
| $\mathrm{Na}_{2} \mathrm{CaSi}_{10} \mathrm{Al}_{4} \mathrm{O}_{28} \cdot 20 \mathrm{H}_{2} \mathrm{O}$, Faujasite | 1.48 | 239 |
| $\mathrm{Li}_{2} \mathrm{Si}_{8} \mathrm{Al}_{2} \mathrm{O}_{20} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 1.480 | 240 |
| $\mathrm{KAl}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4801 | 160 |
| $\mathrm{CsCr}\left(\mathrm{SO}_{4}\right)_{2} \times 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4810 | 159 |
| $\mathrm{RbAl}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4810 | 160 |


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| $\mathrm{KCr}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4814 | 159 |
| $\mathrm{RbCr}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4815 | 159 |
| $\mathrm{KFe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4817 | 159 |
| $\mathrm{RbFe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4825 | 159 |
| $\mathrm{CsMn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.483 | 159 |
| $\mathrm{Na}_{4} \mathrm{ClSi}_{3} \mathrm{Al}_{3} \mathrm{O}_{12}$, Sodalite | 1.4837 | 251 |
| $\mathrm{CsFe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4838 | 159 |
| CsF | 1.484 | 18 |
| $\mathrm{NH}_{4} \mathrm{Cr}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4842 | 159 |
| $\mathrm{NaPO}_{3}$ | 1.4847 | 212 |
| $\mathrm{NH}_{4} \mathrm{Fe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4848 | 159 |
| $\mathrm{NH}_{4} \mathrm{Al}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4856 | 160 |
| $\mathrm{NaSi}_{2} \mathrm{AlO}_{6} \cdot \mathrm{H}_{2} \mathrm{O}$, Analcite | 1.486 | 239 |
| $\mathrm{Na}_{8} \mathrm{SO}_{4} \mathrm{Si}_{6} \mathrm{Al}_{6} \mathrm{O}_{24}$, Noselite | 1.486 | 252 |
| $\mathrm{SiO}_{2}$, Cristobalite | 1.486 | 63 |
| $\mathrm{NH}_{3}(\mathrm{OH}) \mathrm{Cr}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4863 | 160 |
| $\mathrm{CsAl}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4864 | 160 |
| $\mathrm{NaSi}_{3} \mathrm{AlO}_{8}$ | 1.4891 | 235 |
| $\mathrm{Na}_{8}(\mathrm{WO})_{4} \mathrm{Si}_{6} \mathrm{Al}_{6} \mathrm{O}_{24}$, Noselite $\mathrm{WO}_{4}$ | 1.490 | 252 |
| $\mathrm{KSi}_{2} \mathrm{AlO}_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.490 | 239 |
| KCl , Sylvite | 1.4904 | 15 |
| RbCl | 1.4936 | 17 |
| $\mathrm{Na}_{8} \mathrm{SO}_{4} \mathrm{Si}_{6} \mathrm{Al}_{6} \mathrm{O}_{24}$ | 1.494 | 252 |
| $\mathrm{KSi}_{2} \mathrm{AlO}_{6}$, Leucite | 1.495 | 226 |
| $\mathrm{Na}_{4} \mathrm{OHSi}_{3} \mathrm{Al}_{3} \mathrm{O}_{12}$, Sodalite, OH | 1.495 | 252 |
| $\mathrm{LiSi}_{4} \mathrm{AlO}_{10}$ | 1.495 | 228 |
| $\mathrm{K}_{2} \mathrm{Mg}\left(\mathrm{CO}_{3}\right)_{2}$ | 1.496 | 96 |
| $\mathrm{Na}_{3} \mathrm{CaSO}_{4} \mathrm{Si}_{3} \mathrm{Al}_{3} \mathrm{O}_{12}$, Hauynite | 1.4961 | 252 |
| $\mathrm{TlAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4975 | 159 |
| $\mathrm{K}_{2} \mathrm{MgSi}_{5} \mathrm{O}_{12}$ | 1.498 | 254 |
| $\mathrm{Na}_{4} \mathrm{SSi}_{3} \mathrm{Al}_{3} \mathrm{O}_{12}$, Lazurite | 1.500 | 252 |
| $2 \mathrm{NaCl} \cdot 7 \mathrm{KCl}$ | 1.500 | 16 |
| $\mathrm{K}_{2} \mathrm{MgSi}_{5} \mathrm{O}_{12}$ | 1.501 | 254 |
| $\mathrm{RbRh}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.501 | 159 |
| $2 \mathrm{NaCl} \cdot 5 \mathrm{KCl}$ | 1.503 | 16 |
| $\mathrm{Na}_{2} \mathrm{Si}_{2} \mathrm{O}_{5}$ | 1.504 | 255 |
| $\mathrm{TlGa}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.5067 | 159 |
| $\mathrm{RbFe}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.5070 | 160 |
| $\mathrm{CsRh}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.5077 | 159 |
| $\mathrm{KSiAlO}_{4}$ | 1.508 | 226 |
| $2 \mathrm{NaCl} \cdot 3 \mathrm{KCl}$ | 1.5085 | 16 |


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| $\mathrm{NaSiAlO}_{4}$ | 1.51 | 224 |
| $\mathrm{Na}_{6} \mathrm{Mg}_{2} \mathrm{SO}_{4}\left(\mathrm{CO}_{3}\right)_{4}$, Tychite | 1.510 | 100 |
| $\mathrm{NaSiAlO}_{4}$ | 1.510 | 224 |
| $\mathrm{NH}_{4} \mathrm{Rh}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.5103 | 159 |
| $\mathrm{CsFe}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.5116 | 160 |
| $\mathrm{Mg}\left(\mathrm{BrO}_{3}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5139 | 109 |
| $1 \mathrm{NaCl} \cdot 1 \mathrm{KCl}$ | 1.514 | 16 |
| $\mathrm{TlV}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.514 | 159 |
| $\mathrm{Na}_{3} \mathrm{MgCl}\left(\mathrm{CO}_{3}\right)_{2}$, Northupite | 1.5144 | 98 |
| $\mathrm{Na}_{2} \mathrm{~B}_{4} \mathrm{O}_{7}$, Borax Glass | 1.5147 | 116 |
| $\mathrm{Na}_{3} \mathrm{MgBr}\left(\mathrm{CO}_{3}\right)_{2}$, | 1.515 | 99 |
| $\mathrm{NaClO}_{3}$ | 1.5151 | 108 |
| $4 \mathrm{NaCl} \cdot 3 \mathrm{KCl}$ | 1.518 | 16 |
| $3 \mathrm{NaCl} \cdot 2 \mathrm{KCl}$ | 1.519 | 16 |
| $\mathrm{NaSi}_{3} \mathrm{GaO}_{8}$ | 1.519 | 232 |
| $\mathrm{KSi}_{3} \mathrm{GaO}_{8}$ | 1.519 | 232 |
| $\mathrm{TlAl}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.522 | 160 |
| $\mathrm{TlCr}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.5228 | 159 |
| $\mathrm{CsSi}_{2} \mathrm{AlO}_{6}$ | 1.523 | 226 |
| $\mathrm{K}_{4} \mathrm{Be}_{3} \mathrm{Si}_{4} \mathrm{O}_{12}$ | 1.523 | 267 |
| $2 \mathrm{NaCl} \cdot 1 \mathrm{KCl}$ | 1.523 | 16 |
| $\mathrm{Na}_{2} \mathrm{MgSiO}_{4}$ | 1.523 | 299 |
| $\mathrm{Na}_{7}\left(\mathrm{VO}_{4}\right)_{2} \mathrm{~F} \cdot 19 \mathrm{H}_{2} \mathrm{O}$ | 1.5230 | 205 |
| $\mathrm{TlFe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.5237 | 159 |
| $\mathrm{Be}_{3} \mathrm{Al}_{2} \mathrm{Si}_{6} \mathrm{O}_{18}$ | 1.526 | 288 |
| $3 \mathrm{NaCl} \cdot 1 \mathrm{KCl}$ | 1.528 | 16 |
| $\mathrm{NH}_{4}\left(\mathrm{NO}_{3}\right)$ | 1.530 | 101 |
| $\mathrm{RbSiAlO}_{4}$ | 1.531 | 227 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Ca}_{2}\left(\mathrm{SO}_{4}\right)_{3}$ | 1.532 | 132 |
| $\mathrm{K}_{2} \mathrm{Mg}_{2}\left(\mathrm{SO}_{4}\right)_{3}$ | 1.539 | 132 |
| $5 \mathrm{NaCl} \cdot 1 \mathrm{KCl}$ | 1.533 | 16 |
| CsCl | 1.534 | 18 |
| $\mathrm{K}_{2} \mathrm{Mg}_{2}\left(\mathrm{SO}_{4}\right)_{3}$, Langbeinite | 1.5347 | 132 |
| $7 \mathrm{NaCl} \cdot 1 \mathrm{KCl}$. | 1.536 | 16 |
| $\mathrm{Li}_{4} \mathrm{~K} \cdot 10 \mathrm{Si}_{7} \mathrm{O}_{21}$ | 1.540 | 267 |
| $\mathrm{Na}_{6} \mathrm{Zn}_{8}\left(\mathrm{CO}_{3}\right)_{11} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.540 | 96 |
| $\mathrm{K}_{2} \mathrm{SiAl}_{2} \mathrm{O}_{6}$ | 1.540 | 226 |
| $\mathrm{LiSiAlO}_{4}$ | 1.541 | 227 |
| $\mathrm{CaP}_{2} \mathrm{O}_{6}$ | 1.542 | 211 |
| NaCl , Halite | 1.5443 | 15 |
| $\mathrm{Zn}\left(\mathrm{BrO}_{3}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5452 | 109 |


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| $\mathrm{TlRh}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.548 | 159 |
| RbBr | 1.5528 | 17 |
| $\mathrm{Na}_{6} \mathrm{Mg}_{2}\left(\mathrm{CrO}_{4}\right)\left(\mathrm{CO}_{3}\right)_{4}$ | 1.555 | 100 |
| KBr | 1.5595 | 17 |
| $\mathrm{AgSi}_{2} \mathrm{AlO}_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.56 | 239 |
| $\mathrm{CdF}_{2}$ | 1.56 | 24 |
| $\mathrm{Cr}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 18 \mathrm{H}_{2} \mathrm{O}$ | 1.564 | 171 |
| $\mathrm{AlO}(\mathrm{OH})$ | 1.565 | 70 |
| $\mathrm{Co}\left(\mathrm{ClO}_{4}\right)_{3} 6 \mathrm{NH}_{3}$ | 1.570 | 112 |
| $\mathrm{Na}_{4} \mathrm{CaSi}_{3} \mathrm{O}_{9}$ | 1.571 | 267 |
| $\mathrm{Ba}\left(\mathrm{NO}_{3}\right)_{2}$, Nitrobarite | 1.5711 | 103 |
| $\mathrm{K}_{2} \mathrm{Mn}_{2}\left(\mathrm{SO}_{4}\right)_{3}$, Manganolangbeinite | 1.572 | 132 |
| $\mathrm{K}_{4} \mathrm{CaSi}_{3} \mathrm{O}_{9}$ | 1.572 | 267 |
| $\mathrm{NaSiBO}_{4}$ | 1.572 | 226 |
| $\mathrm{CsSiAlO}_{4}$ | 1.574 | 228 |
| $\mathrm{NaSiAlO} 4 \cdot \mathrm{CaAl}_{2} \mathrm{O}_{4}$ | 1.577 | 225 |
| CsF | 1.578 | 18 |
| $\mathrm{KGe}_{3} \mathrm{AlO}_{8}$ | 1.578 | 232 |
| $\mathrm{Ni}_{3}(\mathrm{OH})_{4} \mathrm{CO}_{3} \cdot 4 \mathrm{H}_{2} \mathrm{O}$, Zaratite | 1.58 | 98 |
| CsBr | 1.582 | 18 |
| $\mathrm{Na}_{10} \mathrm{Fe}_{2} \mathrm{Si}_{8} \mathrm{O}_{24}$ | 1.583 | 267 |
| $\mathrm{KSi}_{3} \mathrm{FeO}_{8}$ | 1.586 | 232 |
| $\mathrm{Sr}\left(\mathrm{NO}_{3}\right)_{2}$ | 1.5878 | 103 |
| $\mathrm{Sr}\left(\mathrm{NO}_{2}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.589 | 106 |
| $\mathrm{Ca}_{2} \mathrm{Si}_{4} \mathrm{Al}_{3} \mathrm{GaO}_{16}$ | 1.591 | 232 |
| $\mathrm{NaGe}_{3} \mathrm{AlO}_{8}$ | 1.592 | 232 |
| $\mathrm{Ca}_{5} \mathrm{Al}_{6} \mathrm{O}_{14}$ | 1.593 | 77 |
| $\mathrm{Sb}_{3} \mathrm{O}_{6}(\mathrm{OH})$ or $\mathrm{Sb}_{2} \mathrm{O}_{4} \cdot \mathrm{nH}_{2} \mathrm{O}$, Stibiconite | 1.6 | 66 |
| $\mathrm{Na}_{2} \mathrm{CaSiO}_{4}$ | 1.60 | 299 |
| $\mathrm{Ni}_{3}(\mathrm{OH})_{4} \mathrm{CO}_{3} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 1.60 | 98 |
| $\mathrm{KAlO}_{2}$ | 1.603 | 72 |
| $\mathrm{Ca}_{3} \mathrm{Al}_{2}(\mathrm{OH})_{12}$, Hydrogrossularite | 1.604 | 72 |
| $\mathrm{Ca}_{3} \mathrm{Al}_{2} \mathrm{O}_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.604 | 83 |
| $\mathrm{Ca}_{3} \mathrm{Al}_{2} \mathrm{O}_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.605 | 299 |
| $\mathrm{CaMgSi}_{2} \mathrm{O}_{6}$ | 1.6071 | 274 |
| KFe " $\mathrm{Fe}^{\text {"' }}\left(\mathrm{SO}_{4}\right)_{3} \cdot 4 \mathrm{H}_{2} \mathrm{O}$, Voltaite | 1.608 | 157 |
| $\mathrm{Ca}_{5} \mathrm{Al}_{6} \mathrm{O}_{14}$ | 1.608 | 77 |
| $\mathrm{CaSi}_{2} \mathrm{AlGaO}_{8}$ | 1.608 | 232 |
| $\mathrm{BaSi}_{2} \mathrm{O}_{5}$ | 1.6085 | 258 |
| $\mathrm{LiNH}_{2}$ | 1.610 | 22 |


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| $\mathrm{CaSiGeAl} \mathrm{O}_{2} \mathrm{O}_{8}$ | 1.611 | 232 |
| $\mathrm{NaBrO}{ }_{3}$ | 1.617 | 108 |
| $\mathrm{KGe}_{3} \mathrm{GaO}_{8}$ | 1.617 | 232 |
| $\mathrm{BO}(\mathrm{OH})$ | 1.619 | 69 |
| $\mathrm{K}_{2} \mathrm{ZnSiO}_{4}$ | 1.622 | 299 |
| $\mathrm{GeBr}_{4}$ | 1.6269 | 35 |
| $\mathrm{Ca}_{3} \mathrm{Si}_{3} \mathrm{O}_{9}$ | 1.628 | 292 |
| $\mathrm{Sr}_{3} \mathrm{Si}_{3} \mathrm{O}_{9}$ | 1.632 | 288 |
| $\mathrm{CaSi}_{2} \mathrm{Ga}_{2} \mathrm{O}_{8}$ | 1.633 | 232 |
| $\mathrm{NaGe} \mathrm{CGOO}_{8}$ | 1.636 | 232 |
| $\mathrm{TlSi}_{2} \mathrm{AlO}_{6}$ | 1.637 | 226 |
| $\mathrm{Ca}_{2} \mathrm{AlSiAlO}_{7}$ | 1.638 | 295 |
| $5\left(\mathrm{Ca}_{2} \mathrm{MgSi}_{2} \mathrm{O}_{7}\right) \cdot 5\left(\mathrm{Ca}_{2} \mathrm{AlSiAlO}_{7}\right)$ | 1.638 | 294 |
| $\mathrm{Ca}_{2} \mathrm{MgSi}_{2} \mathrm{O}_{7}$ | 1.641 | 294 |
| NaBr | 1.6412 | 17 |
| CsCl | 1.6418 | 17 |
| $\mathrm{NH}_{4} \mathrm{Cl}$, Salammoniac | 1.6426 | 21 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{FeCl}_{4}$ | 1.6439 | 36 |
| $\mathrm{Li}_{2} \mathrm{O}$ | 1.644 | 56 |
| $\mathrm{BaAl}_{2} \mathrm{O}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.644 | 83 |
| RbI | 1.6474 | 17 |
| $\mathrm{SrCl}_{2}$ | 1.6499 | 26 |
| $\mathrm{Mn}_{3} \mathrm{Al}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$ | 1.655 | 298 |
| $\mathrm{K}_{2} \mathrm{SnCl}_{6}$ | 1.6574 | 47 |
| $\mathrm{CaGe}_{2} \mathrm{Al}_{2} \mathrm{O}_{8}$ | 1.658 | 232 |
| Csl | 1.661 | 18 |
| LiCl | 1.662 | 17 |
| KI | 1.6670 | 17 |
| $\mathrm{Fe}_{9}^{\prime \prime} \mathrm{Fe}_{2}^{\prime \prime \prime}(\mathrm{OH})_{16} \mathrm{Si}_{18} \mathrm{O}_{20}$, Greenalite | 1.674 | 260 |
| $\mathrm{Cs}_{2} \mathrm{GeCl}_{6}$ | 1.68 | 47 |
| $\mathrm{BaAl}_{2} \mathrm{O}_{4}$ | 1.683 | 77 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SnCl}_{6}$ | 1.690 | 47 |
| $\mathrm{Al}_{2} \mathrm{O}_{3}$ | 1.696 | 60 |
| CsBr | 1.6984 | 18 |
| $\mathrm{Sb}_{3} \mathrm{O}_{6}(\mathrm{OH})$ or $\mathrm{Sb}_{2} \mathrm{O}_{4} \cdot \mathrm{nH}_{2} \mathrm{O}$, Stibiconite | 1.7 | 66 |
| $\mathrm{CaMn}_{4} \mathrm{Si}_{5} \mathrm{O}_{15}$ | 1.700 | 292 |
| $\mathrm{NH}_{4} \mathrm{I}$ | 1.7031 | 17 |
| $\mathrm{Mg}_{3} \mathrm{Al}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$, Pyrope | 1.705 | 297 |
| $\mathrm{CaGe}_{2} \mathrm{Ga}_{2} \mathrm{O}_{8}$ | 1.705 | 232 |
| $\mathrm{AlVO}_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$, Steigerite | 1.710 | 201 |


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| $\mathrm{Ca}_{3} \mathrm{Al}_{2} \mathrm{O}_{6}$ | 1.710 | 77 |
| $\mathrm{Ca}_{3} \mathrm{Fe}_{2} \mathrm{O}_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.710 | 83 |
| $\mathrm{NH}_{4} \mathrm{Br}$ | 1.7108 | 21 |
| $\mathrm{NH}_{4} \mathrm{Br}$ | 1.7124 | 21 |
| $\mathrm{MgAl}_{2} \mathrm{O}_{4}$, Spinel | 1.7190 | 74 |
| $\mathrm{Sr}_{3} \mathrm{Al}_{2} \mathrm{O}_{6}$ | 1.728 | 77 |
| Fe | 1.73 | 3 |
| $\mathrm{LiAl}_{5} \mathrm{O}_{8}$ | 1.735 | 74 |
| $\mathrm{Ca}_{3} \mathrm{Al}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$, Grossularite | 1.735 | 298 |
| MgO, Periclase | 1.7366 | 57 |
| $\mathrm{NH}_{4} \mathrm{CH}_{3} \mathrm{PtCl}_{6}$ | 1.74 | 47 |
| $\mathrm{ZnGa} 2 \mathrm{O}_{4}$ | 1.74 | 76 |
| $\mathrm{As}_{2} \mathrm{O}_{3}$, Arsenolite | 1.755 | 61 |
| Nal | 1.7745 | 17 |
| $\mathrm{K}_{2} \mathrm{~Pb}_{2} \mathrm{Si}_{2} \mathrm{O}_{7}$ | 1.775 | 295 |
| $\mathrm{CsHgCl}_{3}$ | 1.779 | 37 |
| $\mathrm{CoAl} \mathrm{O}_{4}$ | 1.78 | 76 |
| $\mathrm{Pb}\left(\mathrm{NO}_{3}\right)_{2}$ | 1.7815 | 10.3 |
| $\mathrm{ZnAl}_{2} \mathrm{O}_{4}$ | 1.782 | 76 |
| LiBr | 1.784 | 17 |
| Csl | 1.7876 | 18 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{PtCl}_{6}$ | 1.8 | 47 |
| $\mathrm{Sb}_{3} \mathrm{O}_{6}(\mathrm{OH})$, or $\mathrm{Sb}_{2} \mathrm{O}_{4} \cdot \mathrm{nH}_{2} \mathrm{O}$, Stibiconite | 1.8 | 66 |
| $\mathrm{Mn}_{3} \mathrm{Al}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$, Spessartite | 1.80 | 298 |
| $\mathrm{K}_{2} \mathrm{PbCu}\left(\mathrm{NO}_{2}\right)_{6}$ | 1.80 | 105 |
| $\mathrm{ZaAl}_{2} \mathrm{O}_{4}$, Gahnite | 1.805 | 76 |
| $\mathrm{SeCl}_{4}$ | 1.807 | 35 |
| $\mathrm{Y}_{3} \mathrm{Al}_{2} \mathrm{Al}_{3} \mathrm{O}_{12}$, Ytrogarnet | 1.823 | 298 |
| $\mathrm{K}_{2} \mathrm{PtCl}_{6}$ | 1.827 | 47 |
| $\mathrm{FeAl}_{2} \mathrm{O}_{4}$, Hercynite | 1.83 | 75 |
| $\mathrm{Fe}_{3} \mathrm{Al}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$, Almandite | 1.830 | 298 |
| CaO , Lime | 1.837 | 57 |
| $\mathrm{Na}_{2} \mathrm{U}_{2} \mathrm{O}_{7} \cdot \mathrm{nH}_{2} \mathrm{O}$ | 1.84 | 84 |
| $\mathrm{MnAl}_{2} \mathrm{O}_{4}$, Galaxite | 1.848 | 76 |
| $\mathrm{Ca}_{3} \mathrm{Cr}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$, Uvarovite | 1.86 | 298 |
| SrO | 1.870 | 58 |
| $\mathrm{Ca}_{3} \mathrm{Fe}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$, Andradite | 1.895 | 299 |
| $\mathrm{Sb}_{3} \mathrm{O}_{6}(\mathrm{OH})$ or $\mathrm{Sb}_{2} \mathrm{O}_{4} \cdot \mathrm{nH}_{2} \mathrm{O}$, Stibiconite | 1.9 | 66 |
| $\mathrm{MgCr}_{2} \mathrm{O}_{4}$, Magnesiochromite | 1.90 | 75 |
| $\mathrm{Y}_{2} \mathrm{O}_{3}$ | 1.910 | 59 |


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| $\mathrm{MnAl} 2_{2} \mathrm{O}_{4}$ | 1.923 | 76 |
| $\mathrm{Pb}_{2} \mathrm{SO}_{4}(\mathrm{OH})_{2}$ | 1.93 | 173 |
| CuCl | 1.930 | 19 |
| $\mathrm{Mg}_{2} \mathrm{FeO}_{3}$ | 1.95 | 57 |
| LiI | 1.955 | 17 |
| $\mathrm{Mg}_{2} \mathrm{TiO}_{4}$ | 1.959 | 77 |
| $\mathrm{NaCaCb} \mathrm{O}_{6} \mathrm{~F}$, Pyrochlore | 1.96 | 85 |
| CuCl , Nantokite | 1.973 | 19 |
| BaO | 1.980 | 58 |
| S (Liquid) | 1.998 | 4 |
| $\mathrm{Sb}_{3} \mathrm{O}_{6}(\mathrm{OH})$ or $\mathrm{Sb}_{2} \mathrm{O}_{4} \cdot \mathrm{nH}_{2} \mathrm{O}$, Stibiconite | 2.0 | 66 |
| $\mathrm{Hg}_{3} \mathrm{OCl}_{4}$ | 2.001 | 51 |
| $\mathrm{S}_{9} \mathrm{Se}$ (Liquid) | 2.025 | 4 |
| $\mathrm{MgCr}_{2} \mathrm{O}_{4}$ | 2.035 | 75 |
| $\mathrm{PbCu}(\mathrm{OH})_{2} \mathrm{Cl}_{2}$, Percylite | 2.05 | 31 |
| ( $\mathrm{Na}, \mathrm{Ca})_{2} \mathrm{Ta}_{2} \mathrm{O}_{6}(\mathrm{O}, \mathrm{OH}, \mathrm{F})$, Microlite | 2.055 | 85 |
| $\mathrm{S}_{8} \mathrm{Se}_{2}$ (Liquid) | 2.06 | 4 |
| AgCl , Chlorargyrite | 2.071 | 17 |
| $\mathrm{Li}_{2} \mathrm{TiO}_{3}$ | 2.087 | 72 |
| $\mathrm{Sb}_{2} \mathrm{O}_{3}$, Senarmonite | 2.087 | 61 |
| $\mathrm{S}_{7} \mathrm{Se}_{3}$ (Liquid) | 2.10 | 4 |
| $\mathrm{Snl}_{4}$ | 2.106 | 35 |
| SrS | 2.107 | 9 |
| CuBr | 2.116 | 19 |
| P | 2.117 | 5 |
| $\mathrm{MgFe} \mathrm{2}^{\mathrm{O}}{ }_{3}$ | 2.12 | 57 |
| FeCri $\mathrm{O}_{4}$, Chromite | 2.12 | 76 |
| CaS, Oldhamite | 2.137 | 9 |
| $\mathrm{S}_{6} \mathrm{Se}_{4}$ (Liquid) | 2.15 | 4 |
| BaS | 2.155 | 9 |
| MnO , Manganosite | 2.19 | 57 |
| ThO 2 , Thorianite | 2.2 | 62 |
| Agl, Miersite | 2.20 | 20 |
| $\mathrm{Se}_{5} \mathrm{~S}_{5}$ (Liquid) | 2.20 | 4 |
| SrSe | 2.220 | 11 |
| MnO | 2.23 | 57 |
| TlCl | 2.247 | 18 |
| AgBr, Bromargyrite | 2.252 | 17 |
| BaSe | 2.268 | 11 |
| NiO, Bunsenite | 2.27 | 58 |


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| $\mathrm{Se}_{6} \mathrm{~S}_{4}$ (Liquid) | 2.27 | 4 |
| MgS | 2.271 | 9 |
| CaSe | 2.274 | 11 |
| $2 \mathrm{AgBr} \cdot 1 \mathrm{AgI}$ | 2.299 | 17 |
| FeO , Wustitie | 2.32 | 57 |
| Cul, Marshite | 2.345 | 19 |
| Fe | 2.36 | 3 |
| ZnFe ${ }_{2} \mathrm{O}_{4}$, Franklinite | 2.36 | 76 |
| $1 \mathrm{AgBr} \cdot 2 \mathrm{Agl}$ | 2.36 | 17 |
| ZnS | 2.368 | 10 |
| $\mathrm{Se}_{7} \mathrm{~S}_{3}$ (Liquid) | 2.37 | 4 |
| CaTiO ${ }_{3}$, Perovskite | 2.38 | 81 |
| $\mathrm{MgFe} \mathrm{O} \mathrm{O}_{4}$, Magnesioferrite | 2.39 | 76 |
| $\mathrm{CdFe}_{2} \mathrm{O}_{4}$ | 2.39 | 76 |
| $\mathrm{BaTiO}_{3}$ | 2.40 | 81 |
| LiFeO 2 | 2.40 | 72 |
| SrTe | 2.408 | 12 |
| $\mathrm{SrTiO}_{3}$ | 2.409 | 79 |
| TlBr | 2.418 | 19 |
| C, Diamond | 2.4195 | 5 |
| $\mathrm{Fe}^{\prime \prime} \mathrm{Fe}_{2}^{\text {II' }} \mathrm{O}_{4}$, Magnetite | 2.42 | 76 |
| $\mathrm{Bi}_{2} \mathrm{O}_{3}$, Sillenite | 2.42 | 61 |
| BaTe | 2.440 | 12 |
| $4 \mathrm{TlBr} \cdot 1 \mathrm{Tli}$ | 2.468 | 19 |
| ZnS | 2.47 | 10 |
| MgSe | 2.48 | 11 |
| CdO | 2.49 | 58 |
| $\mathrm{Se}_{8} \mathrm{~S}_{2}$ (Liquid) | 2.49 | 4 |
| CdS, Hawleyite | 2.5 | 10 |
| $1 \mathrm{TlBr} \cdot 1 \mathrm{TlI}$ | 2.567 | 19 |
| $\mathrm{Fe}_{2} \mathrm{O}_{3}$, Maghemite, Oxymagnite | 2.6 | 76 |
| CaTe | 2.605 | 12 |
| SiC | 2.65 | 6 |
| $1 \mathrm{TIBr} \cdot 3 \mathrm{TH}$ | 2.662 | 19 |
| $\mathrm{Se}_{9} \mathrm{~S}$ (Liquid) | 2.67 | 4 |
| $M \mathrm{~S} \mathrm{~S}_{2}$, Hauerite | 2.69 | 12 |
| MnS, Alabandite | 2.70 | 11 |
| $\mathrm{Cu}_{2} \mathrm{O}$, Cuprite | 2.705 | 57 |
| THI | 2.78 | 19 |
| ZnSe | 2.89 | 12 |


| Substance | $n$ | Page |
| :--- | :--- | :---: |
| $(\mathrm{Cu}, \mathrm{Fe})_{12} \mathrm{As}_{4} \mathrm{~S}_{13}$, Tennantite | 2.914 |  |
| $\mathrm{Se} \mathrm{(Liquid)}$ | 2.92 | 13 |
| P (Amorphous) | 3.0 | 4 |
| $(\mathrm{Cu}, \mathrm{Fe})_{12} \mathrm{Sb}_{4} \mathrm{~S}_{13}$, Tetrahedrite | 3.128 | 5 |
| $\mathrm{PbS}, \mathrm{Galena}^{\mathrm{PbS}}$ | 3.912 | 13 |
| $\mathrm{FeS}_{2}, \mathrm{Pyrite}$ | 4.71 | 11 |

Table II

## DETERMINATIVE TABLES

II. Anisotropic Crystalline Solids

Arranged by birefringence, $n_{z}-n_{x}$, within groups based on $n_{y}$ (or $n_{o}$ )

| No. on Chart | Substance | $n_{x}$ | $n_{y}$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | $\mathrm{LiBeF}_{3}$ |  | 1.33 |  |  |  | 35 |
| 1 | $\mathrm{LiNaB}_{2} \mathrm{~F}_{6}$ |  | 1.33 |  |  |  | 35 |
| 1 | $\mathrm{Li}_{2} \mathrm{BeF}_{4}$ |  | 1.34 |  |  |  | 35 |
| 1 | $\mathrm{CaBeF}_{4}$ |  | 1.355 |  |  | 00 | 25 |
| 1 | $\mathrm{CsBF}_{4}$ |  | 1.36 |  |  |  | 43 |
| 1 | $\mathrm{KBF}_{4}$, Avogadrite | 1.3239 | 1.3245 | 1.3247 | 0.0008 | -75 | 43 |
| 2 | $\mathrm{K}_{2} \mathrm{LiAlF}_{6}$ | 1.390 | 1.391 |  | 0.001 | -00 | 43 |
| 3 | $\mathrm{Na}_{3} \mathrm{AlF}_{6}$, Cryolite | 1.3376 | 1.3377 | 1.3387 | 0.0011 | +43 | 42 |
| 4 | $\mathrm{NH}_{4} \mathrm{~F}$ |  | 1.3147 | 1.3160 | 0.0013 | +00 | 21 |
| 4 | $\mathrm{H}_{2} \mathrm{O}$, Ice |  | 1.3091 | 1.3104 | 0.0014 | +00 | 57 |
| 5 | $\mathrm{Ca}\left(\mathrm{BF}_{4}\right)_{2}$ |  | 1.36 |  | 0.002 | -15 | 49 |
| 2 | $\mathrm{K}_{2} \mathrm{MgF}_{4}$ | 1.377 | 1.379 |  | 0.002 | -00 | 36 |
| . 2 | $\mathrm{K}_{2} \mathrm{GeF}_{6}$ | 1.381 | 1.383 |  | 0.002 | -00 | 47 |
| 3 | $\mathrm{NH}_{4} \mathrm{LiSO}_{4}$ |  | 1.437 |  | 0.002 | +40 | 126 |
| 6 | $\mathrm{Na}_{2} \mathrm{GeF}_{6}$ | 1.324 | 1.327 |  | 0.003 | -00 | 46 |
| 6 | $\left(\mathrm{NH}_{4}\right)_{\mathbf{G e F}}^{6}$ | 1.425 | 1.428 |  | 0.003 | -00 | 47 |
| 7 | $\mathrm{Na}_{3} \mathrm{SO}_{4} \mathrm{~F}$, Schairerite |  | 1.436 | 1.439 | 0.003 | +00 | 173 |
| 6 | $\mathrm{Na}_{2} \mathrm{SiF}_{6}$, Malladrite | 1.3089 | 1.3125 |  | 0.0036 | -00 | 46 |
| 8 | $\mathbf{L i}_{2} \mathrm{SiF}_{6} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.296 | 1.298 | 1.300 | 0.004 | -90 | 46 |
| 8 | $\mathrm{K}_{2} \mathrm{TaF}_{7}$ | 1.414 | 1.417 | 1.418 | 0.004 | -75 | 48 |
| 8 | $\mathrm{Na}_{2} \mathrm{HPO}_{4} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.4321 | 1.4361 | 1.4373 | 0.0052 | -57 | 192 |
| 9 | $\mathrm{CoSiF}_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ |  | 1.3817 | 1.3872 | 0.0055 | +00 | 50 |
| 10 | $\mathrm{NaBF}_{4}$, Ferruccite | 1.301 | 1.3012 | 1.3068 | 0.0058 | +11 | 43 |
| 11 | $\mathrm{Na}_{5} \mathrm{Al}_{3} \mathrm{~F}_{14}$, Chiolite | 1.3424 | 1.3486 |  | 0.0062 | -00 | 43 |
| 12 | $\mathrm{Na}_{2} \mathrm{TiF}_{6}$ | 1.412 | 1.419 |  | 0.007 | -00 | 47 |
| 13 | $\underset{\mathrm{NaCaAlF}}{\mathrm{NH}_{4} \mathrm{HF}_{2}} \cdot \mathrm{H}_{2} \mathrm{O}$, Thomsenolite | 1.4072 1.385 | 1.4136 1.390 | 1.4150 1.394 | 0.0078 0.009 | -50 .10 | 48 |
| 15 | $\mathrm{NaPO}_{3} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ |  | 1.400 |  | 0.009 | +70 | 212 |
| 15 | $\mathrm{NaCaAlF}_{6} \cdot \mathrm{H}_{2} \mathrm{O}$, Pachnolite | 1.411 | 1.413 | 1.420 | 0.009 | +76 | 48 |
| 16 | $\mathrm{NaHF}_{2}$ |  | 1.32 | 1.33 | 0.01 | +00 | 21 |
| 16 | $\mathrm{MgZnF}{ }_{4}$ |  | 1.40 | 1.41 | 0.01 | +00 | 25 |
|  | $\mathrm{Zn}\left(\mathrm{BF}_{4}\right)_{2}$ |  | 1.36 |  | 0.011 |  | 48 |
| 17 | $\mathrm{KHF}_{2}$ | 1.342 | 1.354 |  | 0.012 | -00 | 21 |
| 18 | $\mathrm{MgF}_{2}$, Sellaite |  | 1.378 | 1.390 | 0.012 | +00 | 23 |
|  | $\mathrm{Mn}\left(\mathrm{BF}_{4}\right)_{2}$ | 1.346 | 1.35 | 1.359 | 0.013 | 30 | 49 |
| 19 | $\mathrm{ZnSiF} \mathrm{F}_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ |  | 1.3824 | 1.3956 | 0.0132 | +00 | 50 |
|  | $\mathrm{Mg}\left(\mathrm{BF}_{4}\right)_{2}$ |  | 1.36 |  | 0.014 | 00 | 49 |
|  | $\mathrm{Co}\left(\mathrm{BF}_{4}\right)_{2}$ |  | 1.40 |  | 0.014 | 00 | 49 |
| 20 | $\mathrm{CoF}_{2} \cdot 5 \mathrm{HF} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ |  | 1.384 | 1.399 | 0.015 | +00 | 54 |
| 2.1 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SiF}_{6}$, Bararite | 1.391 | 1.406 |  | 0.015 | -00 | 46 |
| 20 | $\mathrm{NiSiF} \mathrm{F}_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ |  | 1.3910 | 1.4066 | 0.0156 | +00 | 50 |
| 22 | $\mathrm{NiF} \mathrm{F}_{2} \cdot 5 \mathrm{HF} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ |  | 1.392 | 1.408 | 0.016 | +00 | 54 |
| 22 | $\mathrm{MgSiF} \mathrm{F}_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ |  | 1.3439 | 1.3602 | 0.0163 | +00 | 50 |
| 23 | $\mathrm{MnSiF} \mathrm{F}_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ |  | 1.3570 | 1.3742 | 0.0172 | +00 | 50 |
| 24 | $\mathrm{KF} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.345 | 1.352 | 1.363 | 0.018 | +85 | 23 |
| 25 | $\mathrm{NH}_{4} \mathrm{HF}_{2}$ | 1.368 | 1.385 | 1.387 | 0.019 | -40 | 21 |
| 26 | FeSiF ${ }_{5} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ |  | 1.3638 | 1.3848 | 0.0210 | +00 | 50 |
| 27 | $\mathrm{Na}_{2} \mathrm{SO}_{4} \cdot 10 \mathrm{H}_{2} \mathrm{O}$, Mirabilite | 1.396 | 1.4103 | 1.419 | 0.023 | -76 | 136 |
| 28 | $\mathrm{CaCl}_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.393 | 1.417 |  | 0.024 | -00 | 28 |
| 29 | $\mathrm{NH}_{3} \mathrm{BF}_{3}$ | 1.335 | 1.345 | 1.36 | 0.025 | 90 | 54 |
| 30 | $\left(\mathrm{NH}_{2} \mathrm{OH}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{GeF}_{6} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.418 | 1.438 | 1.443 | 0.025 | -60 | 54 |
| 31 | $2 \mathrm{NaH}_{2} \mathrm{PO}_{3} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 1.4193 | 1.4309 | 1.4493 | 0.0300 | -78 | 211 |
| 32 | $\mathrm{Na}_{2} \mathrm{CO}_{3} \cdot 10 \mathrm{H}_{2} \mathrm{O}$, Natron | 1.405 | 1.425 | 1.440 | 0.035 | -71 | 91 |
| 33 | $\mathrm{KB}_{5} \mathrm{O}_{3} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 1.422 | 1.436 | 1.480 | 0.058 | +70 | 116 |
| 34 | $\mathrm{NH}_{4} \mathrm{~B}_{5} \mathrm{O}_{8} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 1.427 | 1. 431 | 1.486 | 0.059 | +30 | 117 |
| 35 | $\mathrm{NaNO}_{2}$ | 1.340 | 1.425 | 1.655 | 0.315 | +15 | 106 |



A
${ }^{n} y=1.440$ to 1.4599

| No. <br> on <br> Chart | Substance |  |  |  |  |  |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |


$n_{y}=1.460$ to 1.479

| .No. on Chart | Substance | $n^{\boldsymbol{x}}$ | $n_{y}$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | RbHSO4 |  | 1.473 |  |  | - 56 | 123 |
| 1 | I.iKSO4 | 1.4717 | 1.4723 |  | 0.0006 | - 00 | 124 |
| 2 | $\mathrm{P}_{2} \mathrm{O}_{5}$ |  | 1.469 | 1.471 | 0.002 | +00 | 66 |
| 3 | $\mathrm{Ca}_{6} \mathrm{Al}_{2}\left(\mathrm{IO}_{3}\right)_{2}(\mathrm{OH})_{19} \cdot 24 \mathrm{H}_{2} \mathrm{O}$ | 1.471 | 1.471 |  | 0.002 | -00 | 112 |
|  | $\mathrm{Ca}_{6} \mathrm{Al}_{2} \mathrm{O}_{9}\left(\mathrm{IO}_{3}\right)_{2} \cdot 33 \mathrm{H}_{2} \mathrm{O}$ |  | 1.471 |  | 0.002 |  | 86 |
| 4 | $\mathrm{KClO}_{4}$ | 1.4731 | 1.4737 | 1.1769 | 0.0038 | +50 | 110 |
| 4 | $\mathrm{RbClO}_{4}$ | 1.4692 | 1.4701 | 1.4731 | 0.0039 | +55 | 111 |
| 4 | $\mathrm{SiO}_{2}$, Tridymite | 1.469 | 1.469 | 1.473 | 0.004 | +35 | 64 |
| 5 | $\mathrm{NaSi}_{2} \mathrm{AlO}_{6} \cdot 3 \mathrm{H}_{2} \mathrm{O}$, Gmelinite | 1.46 | 1.46 | 1.46 | 0.005 | - 15 | 240 |
| 6 | $\left(\mathrm{NH}_{4}\right)_{3} \mathrm{ScFF}_{6}$ |  | 1.47 |  | 0.005 | -00 | 44 |
| 7 | $\mathrm{K}_{2} \mathrm{Si}_{4} \mathrm{O}_{\text {, }}$ | 1.477 | 1.479 | 1.482 | 0.005 | $+60$ | 286 |
| 8 | $\mathrm{Na}_{2} \mathrm{H}_{2} \mathrm{P}_{2} \mathrm{O}_{7} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4599 | 1.4615 | 1.4649 | 0.0050 | - 32 | 214 |
| 9 | $\mathrm{CsClO}_{4}$ | 1.4752 | 1.4788 | 1.4804 | 0.0052 | -62 | 111 |
| 10 | $\mathrm{Ca}_{6} \mathrm{Al}_{2}\left(\mathrm{SO}_{4}\right)_{3}(\mathrm{OH})_{\mathbf{1 2}} \cdot 26 \mathrm{HH}_{2} \mathrm{O}$, Etringite | 1.158 | 1.464 |  | 0.006 | - 00 | 176 |
| 11 | $\mathrm{Na}_{2} \mathrm{CaSi}_{20} \mathrm{Al}_{4} \mathrm{O}_{44} \cdot 1 \mathrm{HH}_{2} \mathrm{O}$, Mordenite | 1.474 | 1.477 | 1.480 | 0.006 | - 70 | 245 |
| 12 | $\mathrm{NaPO}_{3}$ | 1.474 | 1.478 | 1.480 | 0.006 | -80 | 212 |
| 13 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Mg}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$, Boussingaultite | 1.4716 | 1.4730 | 1.4786 | 0.0070 | +51 | 142 |
| 14 | $\mathrm{Na}_{2} \mathrm{SiO}_{3} \cdot \mathbf{8 H}_{2} \mathbf{O}$ | 1.457 | 1.463 | 1.465 | 0.008 | -63 | 282 |
| 15 | $\mathrm{Mg}_{3}\left(\mathrm{PO}_{4}\right)_{2} \cdot 22 \mathrm{H}_{2} \mathrm{O}$ | 1.461 | 1.465 | 1.469 | 0.008 | - 90 | 198 |
| 16 | $\mathrm{Al}_{4} \mathrm{SO}_{4}(\mathrm{OH})_{10} \cdot 10 \mathrm{H}_{2} \mathrm{O}$, Parluminite | 1.463 | 1.471 | 1.471 | 0.008 | - 25 | 175 |
| 17 | $\mathrm{Ca}_{6} \mathrm{Al}_{2} \mathrm{O}_{9}-33 \mathrm{H}_{2} \mathrm{O}$ | 1.466 | 1:475 |  | 0.009 | - 00 | 82 |
| 18 | $\mathrm{ZnF}_{3} \cdot \mathbf{4 \mathrm { H } _ { 2 } \mathrm { O }}$ | 1.16 | 1.468 | 1.47 | 0.01 | - 50 | 30 |
| 19 | $\mathrm{Lic}_{2} \mathrm{SO}_{4}$ |  | 1.465 |  | 0.01 | - 72 | 129 |
| 20 | $\mathrm{Al}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 15 \mathrm{H}_{2} \mathrm{O}$, Alunogen | 1.460 | 1.461 | 1.470 | 0.010 | +31 | 172 |
| 21 | $\mathrm{CaZnF}{ }_{4}$ | 1.455 | 1.465 |  | 0.010 | -00 | 25 |
| 22 | $\mathrm{Rb}_{2} \mathrm{Mg}_{\mathrm{g}}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4672 | 1.4689 | 1.4779 | 0.0107 | +49 | 112 |
| 23 | $\mathrm{NH}_{4} \mathrm{ZnF}_{3}$ |  | 1.47 | 1.481 | 0.011 | +00 | 37 |
|  | $\mathrm{K}_{2} \mathrm{HfF} \mathrm{F}_{6}$ | 1.419 | 1.461 |  | 0.012 |  | 17 |
| 24 | $\left(\mathrm{N}_{2} \mathrm{H}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{GeFF}_{6}$ | 1.152 | 1.160 | 1.461 | 0.012 | -85 | 54 |
| 25 | $\mathrm{Li}(\mathrm{OH})$ | 1.452 | 1.464 |  | 0.012 | -00 | 68 |
| 26 | $\mathrm{NaClO}_{4}$ | 1.4606 | 1.4617 | 1.1730 | 0.0124 | +25 | 110 |
| 27 | $\mathrm{Na}_{2} \mathrm{~B}_{4} \mathrm{O}_{7} \cdot 5 \mathrm{H}_{2} \mathrm{O}$, Tincalconite |  | 1.461 | 1.474 | 0.013 | +00 +58 | 115 |
| 28 | $\mathrm{Na}_{3} \mathrm{PO}_{4} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.458 | 1.468 | 1.471 | 0.013 | -58 | 197 |
| 29 | $\mathrm{Na}_{2} \mathrm{SO}_{4}$, Thenardite | 1.471 | 1.477 | 1.484 | 0.013 | +84 | 125 |
| 30 | $\mathrm{NaAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.449 | 1.461 | 1.463 | 0.014 | -56 | 158 |
| 31 | $\mathrm{Na}_{2} \mathrm{Si}_{3} \mathrm{Al}_{2} \mathrm{O}_{10} \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Natrolite | 1.475 | 1.179 | 1.489 | 0.014 | +62 | 245 |
| 32 | $\mathrm{NH}_{4} \mathrm{NaHAsO} \mathbf{4}_{4} \cdot \mathbf{4} \mathrm{H}_{2} \mathrm{O}$ | 1.4649 | 1.4663 | 1.4791 | 0.0142 | +38 | 192 |
| 33 | $\mathrm{FeSO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$, Melanterite | 1.4713 | 1.4782 | 1.4856 | 0.0143 | +85 | 167 |
| 34 | $\mathrm{K}_{2} \mathrm{Mg}_{\mathrm{g}}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$, Picromerite | 1.4607 | 1.4629 1.470 | 1.4755 | 0.0148 0.015 | +48 +50 | 142 |
| 35 | $\mathrm{Na}(\mathrm{OH})$ | 1.457 | 1.470 | 1.472 | 0.015 | - 50 | 68 197 |
| 36 37 | $\mathrm{Na}_{3}\left(\mathrm{PO}_{4}\right) \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.462 | 1.473 1.4658 | 1.477 1.4782 | 0.015 | -60 +57 | 197 |
| 37 | $\mathrm{Na}_{2} \mathrm{HAsO}_{4} \cdot \mathbf{7 H}_{2} \mathrm{O}$ | 1.4622 | 1.4658 | 1.4782 | 0.016 | +57 +85 | 192 |
| 38 | $\mathrm{Na}_{3} \mathrm{PO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 1.462 | 1.470 1.465 | 1.478 1.483 | 0.016 0.018 | +85 +00 | 197 |
| 39 | $\mathrm{KPO}_{3}$ | 1.4653 | 1.465 1.4738 | 1.483 1.4804 | 0.018 0.0182 | +80 -82 | 211 |
| 41 | $\mathrm{Na}_{2} \mathrm{SiO}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.465 | 1.473 | 1.485 | 0.020 | +70 | 282 |
| 42 | $\mathrm{Na}_{4} \mathrm{P}_{2} \mathrm{O}_{7}$ | 1.475 | 1.477 | 1.496 | 0.021 | +40 | 214 |
| 43 | $\mathrm{Na}_{2} \mathrm{~B}_{4} \mathrm{O}_{7} \cdot 10 \mathrm{H}_{2} \mathrm{O}$, Borax | 1.4467 | 1.4694 | 1.4724 | 0.0257 | +39 +80 | 116 |
| 44 | $\mathrm{Na}_{2} \mathrm{HPO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.450 | 1.461 | 1.477 | 0.027 | +80 | 192 |
| 45 | $\mathrm{Na}_{5} \mathrm{P}_{3} \mathrm{O}_{4} 0$ | 1.477 | 1.478 | 1.504 | 0.027 | +21 +70 | 214 |
| 46 | $\mathrm{KMRCl}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$, Carnallite | 1.4665 | 1.4753 | 1.4937 | 0.0272 | +70 | 39 |
| 47 | $\mathrm{Li}_{2} \mathrm{SO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.459 | 1.477 | 1.488 | 0.029 | -78 | 136 |
| 48 | $\mathrm{Na}_{2} \mathrm{~B}_{4} \mathrm{O}_{7} \cdot 4 \mathrm{H}_{2} \mathrm{O}$, Kernite | 1.455 | 1.472 | 1.487 | 0.032 0.0325 | -80 -00 | 115 160 |
| 49 | $\mathrm{BeSO}_{4} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 1.4395 | 1.4720 |  | 0.0325 | -00 -00 | 160 |
| 50 | $\mathrm{Be}_{2}\left(\mathrm{C}_{2} \mathrm{H}_{5}\right)_{2}\left(\mathrm{SO}_{4}\right)_{2} \mathrm{O} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 1.435 | 1.473 |  | 0.038 0.04 | -00 -50 | 177 136 |
| 51 | $\mathrm{NaHSO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.43 | 1.46 | 1.47 | 0.04 | -50 -45 | 136 68 |
| 52 | $\mathrm{Na}(\mathrm{OH}) \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.435 | 1.470 | 1.475 1.4815 | 0.040 0.0414 | -45 -83 | 68 193 |
| 53 | $\mathrm{NaH}_{2} \mathrm{PO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.4401 1.454 | 1.4629 1.465 | 1.4815 1.498 | 0.0414 0.044 | -83 +60 | 193 47 |
| 54 55 | $\mathrm{K}_{2} \mathrm{ZrF}_{6}$ $\mathrm{CaCl}_{2} \cdot \mathbf{4} \mathrm{H}_{2} \mathrm{O}$ | 1.454 1.447 | 1.465 1.477 | 1.498 1.491 | 0.044 0.044 | +60 -68 | 47 27 |
| 56 | ${ }^{\mathrm{NaBO}} \cdot 2 \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.439 | 1.473 | 1.484 | 0.045 | - 58 | 115 |
| 57 | $\mathrm{KHSO}_{4}$, Mercallite | 1.445 | 1.460 | 1.491 | 0.046 | $+56$ | 123 |
| 58 | $\mathrm{NH}_{4} \mathrm{HSO}_{4}$ | 1.463 | 1.473 | 1.510 | 0.047 | +60 | 123 |
| 59 | $\mathrm{Rb}_{2} \mathrm{~S}_{2} \mathrm{O}_{3}$ |  | 1.46 | 1.51 | 0.0504 | +00 | 120 94 |
| 60 | $\mathrm{MgCO}_{3} \cdot 5 \mathrm{H}_{2} \mathrm{O}$, L, ansfordite | 1.456 | 1.469 | 1.508 | 0.052 0.1048 | +60 +30 | 94 122 |
| 61 | $\mathrm{K}_{2} \mathrm{~S}_{2} \mathrm{O}_{0}$ | 1.4609 | 1.4669 | 1.5657 | 0.1048 | + 30 | 122 |
| 62 | $\mathrm{B}(\mathrm{OH})_{3}$, Sassolite | 1.337 | 1.461 | 1.462 | 0.125 | -10 +75 | 71 |
| 63 | $\mathrm{NaNO}_{2}$ | 1.354 | 1.460 | 1.648 | 0294 | +75 | 106 |



C
$n_{y}=1.480$ to 1.4899

| No. on Chart | Substance | $n^{\boldsymbol{x}}$ | $n^{\prime}$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\mathrm{RbSi}_{2} \mathrm{AlO}_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ |  | 1.481 |  |  | 00 | 227 |
|  | $\mathrm{CaAl}_{2} \mathrm{O}_{4} \cdot 10 \mathrm{H}_{2} \mathrm{O}$ |  | 1.48 |  |  | + 00 | 83 |
| 1 | $\mathrm{SiO}_{2}$, Cristobalite | 1.484 | 1.487 |  | 0.003 | -00 | 63 |
| 2 | $\mathrm{Na}_{6} \mathrm{Mg}\left(\mathrm{SO}_{4}\right)_{4}$, Vanthoffite | 1.4855 | 1.4876 | 1.4893 | 0.0038 | - 84 | 132 |
| 3 | $\mathrm{Na}_{2} \mathrm{Mg}_{8}\left(\mathrm{SO}_{4}\right)_{2} \cdot 4 \mathrm{H}_{2} \mathrm{O}$, Bloedite | 1.4826 | 1.4855 | 1.4869 | 0.0041 | - 71 | 138 |
| 4 | $\mathrm{NaSi} \mathrm{C}^{\text {AlO }}$ 6 $\cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.48 | 1.48 | 1.48 | 0.005 | - 15 | 240 |
|  | $\mathrm{Na}_{2} \mathrm{SO}_{4}$ | 1.480 | 1.48 | 1.485 | 0.005 | 90 | 125 |
| 6 | $\mathrm{K}_{2} \mathrm{Si}_{6} \mathrm{Al}_{2} \mathrm{O}_{\mathbf{1 6}} \cdot 7 \mathrm{H}_{\mathbf{2}} \mathrm{O}($ ? ), Stilbite, Potassium | 1.478 | 1.481 | 1.483 | 0.005 | - 70 | 249 |
| 7 | $\mathrm{Na}_{8} \mathrm{~K}_{2}\left(\mathrm{SO}_{4}\right)_{5}$ |  | 1.485 | 1.490 | 0.005 | +00 | 124 |
| 8 | $\mathrm{MgSeO}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4856 | 1.4892 | 1.4911 | 0.0055 | - 28 | 166 |
| 9 | $\mathrm{Cs}_{2} \mathrm{Mg}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4857 | 1.4858 | 1.4916 | 0.0059 | +18 | 143 |
|  | $\mathrm{CaSi}_{4} \mathrm{Al}_{2} \mathrm{O}_{12} \cdot 6 \mathrm{H}_{2} \mathrm{O}$, Chabazite | 1.48 |  | 1.48 | 0.006 | 15 | 240 |
| 10 | $\mathrm{Ca}_{6} \mathrm{Fe}_{2}\left(\mathrm{SO}_{4}\right)_{3}(\mathrm{OH})_{12} \cdot 26 \mathrm{H}_{2} \mathrm{O}$ |  | 1.486 | 1.492 | 0.006 | +00 | 176 |
| 11 | $\mathrm{NH}_{4} \mathrm{ClO}_{4}$ | 1.4818 | 1.4833 | 1.4881 | 0.00630.007 | + 70 | 110 |
| 12 | $\mathrm{Ca}_{5} \mathrm{Al}_{2} \mathrm{O}_{8} \cdot 34 \mathrm{H}_{2} \mathrm{O}$ | 1.480 | 1.487 |  |  | - 00 | 83 |
| 13 | $\mathrm{MgAl}_{2}\left(\mathrm{SO}_{4}\right)_{4} \cdot 22 \mathrm{H}_{2} \mathrm{O}$, Pickeringite | 1.476 | 1.480 | 1.483 | 0.008 | -60 | 170 |
| 14 | $\mathrm{K}_{2} \mathrm{Mg}_{2}\left(\mathrm{SO}_{4}\right)_{2} \cdot \mathbf{4 H _ { 2 } \mathrm { O }}$, Leonite | 1.479 | 1.482 | 1.487 | 0.008 | +70 | 139 |
| 14 | ( $\mathrm{Fe}, \mathrm{Zn}, \mathrm{Cu}$ ) $\mathrm{SO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 1.479 | 1.483 | 1.488 | 0.009 | +70 | 167 |
| 15 | $\mathrm{Sr}_{3} \mathrm{Fe}_{2} \mathrm{~F}_{12} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.473 | 1.480 | 1.482 | 0.009 | - 55 | 49 |
| 16 | $\mathrm{MgHPO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$, Phosphorroesslerite | 1.477 | 1.485 | 1.486 | 0.009 | - 38 | 194 |
| 17 | $\mathrm{Cd}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.480 | 1.489 |  | 0.009 | - 00 | 112 |
| 18 | $\mathrm{FeAl}_{2}\left(\mathrm{SO}_{4}\right)_{4} \cdot 22 \mathrm{H}_{2} \mathrm{O}$, Halotrichite | 1.480 | 1.486 | 1.490 | 0.010 | - 35 | 170 |
| 19 | $\mathrm{K}_{2} \mathrm{H}_{2} \mathrm{P}_{2} \mathrm{O}_{6} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.4768 | 1.4843 | 1.4870 | 0.0102 | -62 | 212 |
| 20 | $\mathrm{CsSO}_{3} \mathrm{~F}$ | 1.4645 | 1.4755 |  | 0.011 | -00 | 172 |
| 21 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Mn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4801 | 1.4840 | 1.4913 | 0.0112 | +70 +73 | 145 |
| 21 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Cd}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4847 | 1.4887 | 1.4959 | 0.0112 | +73 | 144 |
| 22 | $\mathrm{K}_{6} \mathrm{H}_{6}\left(\mathrm{SO}_{4}\right)_{7}$, Mis isenite | 1.475 | 1.480 | 1.487 | 0.012 | +70 +74 | 123 |
| 22 | $\mathrm{Rb}_{2} \mathrm{Zn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{CH}_{2} \mathrm{O}$ $\left(\mathrm{Zn}, \mathrm{Fe}, \mathrm{Mn} \mathrm{Al}_{2}\left(\mathrm{SO}_{4}\right)_{4} \cdot 22 \mathrm{H}_{2} \mathrm{O}\right.$, Dietrichite | 1.4833 | 1.4884 1.480 | 1.4975 1.488 | 0.0124 0.013 | +74 +70 | 144 |
| 23 | $\mathrm{Al}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 12 \mathrm{H}_{2} \mathrm{O}{ }^{\text {a }}$ | 1.483 | 1.484 | 1.496 | 0.013 | + 30 | 172 |
| 24 | Bieberite | 1.474 | 1.4820 | 1.4885 | 0.0137 | - 88 | 168 |
| 24 | $\mathrm{CoSO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 1.4748 | 1.4820 | 1.4885 | 0.0137 | -88 | 168 |
| 25 | $\mathrm{Rb}_{2} \mathrm{Mn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4767 | 1.4807 | 1.4907 | 0.0140 | $+67$ | 145 |
| 26 | $\mathrm{Rb}_{2} \mathrm{Cd}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4798 | 1.4848 | 1.4948 | 0.0150 | +72 | 145 |
| 27 | $\mathrm{Ca}_{3} \mathrm{Al}_{2} \mathrm{O}_{6} \cdot 18 \mathrm{H}_{2} \mathrm{O}$ | 1.479 | 1.489 | 1.495 | 0.016 | -75 | 83 |
| 28 | $\mathrm{Rb}_{2} \mathrm{Fe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4815 | 1.4874 | 1.4977 | 0.0162 | +73 | 146 |
| 29 | $\mathrm{CaAl}_{2} \mathrm{O}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ |  | 1.489 | 1.507 | 0.018 | +00 | 83 |
| 30 | $\mathrm{K}_{2} \mathrm{Cu}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$, Cyanochroite | 1.4836 | 1.4864 | 1.5020 | 0.0184 | +47 | 148 |
| 31 | $\mathrm{Na}_{2} \mathrm{H}_{2} \mathrm{P}_{2} \mathrm{O}_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4855 | 1.4897 | 1.5041 | 0.0186 | $+57$ | 213 |
| 32 | $\mathrm{K}_{2} \mathrm{Zn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4775 | 1.4833 | 1.4969 | 0.0194 | +68 | 143 |
| 32 | $\mathrm{K}_{2} \mathrm{Co}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4807 | 1.4865 | 1.5004 | 0.0197 | +69 | 146 |
| 33 | $\mathrm{CuSO}_{4} \cdot \mathrm{TH}_{2} \mathrm{O}$, Boothite | 1.47 | 1.48 | 1.49 | 0.02 | - 80 | 167 |
| 34 | $\mathrm{Na}_{22} \mathrm{~K}\left(\mathrm{CO}_{3}\right)_{2}\left(\mathrm{SO}_{4}\right)_{9} \mathrm{Cl}$, Hanksite | 1.461 | 1.481 |  | 0.020 | - 00 | 178 |
| 35 | $\mathrm{K}_{2} \mathrm{Fe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4759 | 1.4821 | 1.4969 | 0.021 | $+67$ | 146 |
| 36 | $\mathrm{NiSO}_{4} \cdot \mathbf{7 H}_{2} \mathrm{O}$, Morenosite | 1.4693 | 1.4893 | 1.4923 | 0.023 | - 42 | 163 |
| 37 | $\mathrm{Mg}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.458 | 1.482 |  | 0.024 | - 00 | 111 |
| 38 | $\mathrm{Na}_{4} \mathrm{P}_{2} \mathrm{O}_{7} \cdot 1 \mathbf{1 0 H}_{2} \mathrm{O}$ | 1.4777 | 1.4822 | 1.5036 | 0.0259 | +49 | 213 |
| 39 | $\mathrm{ZnSO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$, Goslarite | 1.4568 | 1.4801 | 1.4836 | 0.0268 | - 46 | 163 |
| 40 | $\mathrm{ZnSO}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$, Bianchite | 1.462 | '1.4895 | 1.490 | 0.028 | -15 | 166 |
| 41 | $\mathrm{Ni}\left(\mathrm{BF}_{4}\right)_{2}$ | 1.47 | 1.45 | 1.50 | 0.03 | $+05$ | 49 |
| 42 | $\mathrm{MnZnF}_{4}$ |  | 1.487 | 1.517 | 0.030 | +00 | 25 |
| 43 | $\mathrm{NaHPO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.4557 | 1.4852 | 1.4873 | 0.0316 | - 29 | 193 |
| 44 | $\mathrm{LiClO}_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.448 | 1.483 |  | 0.035 | - 00 | 110 |
| 45 | $\mathrm{K}_{4}\left(\mathrm{CO}_{3}\right)_{2} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.474 | 1.483 | 1.510 | 0.036 | $+66$ | 91 |
| 46 | $\mathrm{MgB4}_{4} \mathrm{O}_{7} \cdot 9 \mathrm{H}_{2} \mathrm{O}$ | 1.442 | 1.485 |  | 0.043 | - 00 | 116 |
| 47 | $\mathrm{K}_{3} \mathrm{H}\left(\mathrm{SO}_{4}\right)_{2}$ | 1.4793 | 1.4899 | 1.5259 | 0.0466 | - 61 | 123 |
| 48 | $\mathrm{K}_{2} \mathrm{Mg}^{\left(\mathrm{CO}_{3}\right)_{2} \cdot 4 \mathrm{H}_{2} \mathrm{O}}$ | 1.465 | 1.485 | 1.535 | 0.070 | +65 | 96 |
|  | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{~B}_{10} \mathrm{O}_{16} \cdot 5 \mathrm{H}_{2} \mathrm{O}$, Ammonioborite | 1.470 | 1.487 | 1.540 | 0.070 | +60 | 117 |
| 49 | $\mathrm{Rb}_{2} \mathrm{~S}_{2} \mathrm{O}_{3}$ | 1.4812 | 1.4888 | 1.5719 | 0.0907 | +35 | 122 |
| 50 | $\mathrm{Na}_{3} \mathrm{SO}_{4}\left(\mathrm{NO}_{3}\right) \cdot \mathrm{H}_{2} \mathrm{O}$, Darapskite | 1.391 | 1.481 | 1.486 | 0.095 | - 27 | 105 |
| 51 | $\mathrm{KHCO}_{3}$, Kalicinite | 1.380 | 1.482 | 1.573 | 0.193 | -82 | 89 |
| 52 | $\mathrm{Ca}\left[\mathrm{N}(\mathrm{CN})_{2}\right]_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.405 | 1.480 | 1.82 | 0.415 | +50 | 32 |

$1.48<n_{y}<1.49$

$n_{y}=1.490$ to 1.4999

| $\begin{gathered} \text { No. } \\ \text { on } \\ \text { Chart } \end{gathered}$ | Substance | $n_{x}$ | $n_{y}$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\mathrm{MgSO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ |  | 1.493 |  |  |  | 164 |
| 1 | $\mathrm{K}_{2} \mathrm{SO}_{4}$, Arcanite | 1.4935 | 1.4947 | 1.4973 | 0.0038 | $+67$ | 125 |
| 2 | $\mathrm{LiNaSO}_{4}$ |  | 1.490 | 1.495 | 0.005 | + 00 | 124 |
| 2 | $\mathrm{Na}_{3} \mathrm{~K}_{3}\left(\mathrm{SO}_{4}\right)_{3}$ |  | 1.490 | 1.495 | 0.005 | +00 | 124 |
| 2 | $\mathrm{NaK}_{3}\left(\mathrm{SO}_{4}\right)_{2}$ |  | 1.493 | 1.498 | 0.005 | +00 | 124 |
| 3 | $\left(\mathrm{NH}_{4}\right)_{3} \mathrm{UO}_{2} \mathrm{~F}_{3}$ | 1.49 | 1.495 |  | 0.005 | - 00 | 37 |
| 3 | $\mathrm{CaSi} \mathrm{Al}_{2} \mathrm{O}_{10} \cdot 5 \mathrm{H}_{2} \mathrm{O}$, Levynite | 1.491 | 1.496 |  | 0.005 | -00 | 241 |
| 2 | $\mathrm{Na}_{2} \mathrm{~K}_{4}\left(\mathrm{SO}_{4}\right)_{3}$ |  | 1.491 | 1.4965 | 0.0055 | +00 | 124 |
|  | $\mathrm{NaSi} \mathrm{S}^{1} \mathrm{IO}_{8} \cdot \mathrm{H}_{2} \mathrm{O}$ |  | 1.49 |  | 0.006 |  | 245 |
| 4 | $\mathrm{CaSi}_{6} \mathrm{Al}_{2} \mathrm{O}_{16} \cdot 5 \mathrm{H}_{2} \mathrm{O}$, Heulandite | 1.497 | 1.498 | 1.503 | 0.006 | +32 | 249 |
| 5 | $\mathrm{Na}_{2} \mathrm{~K}_{8}\left(\mathrm{SO}_{4}\right)_{5}$ |  | 1.4935 | 1.500 | 0.0065 | + 0 ס | 124282 |
|  | $\mathrm{Na}_{2} \mathrm{SiO}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.488 |  | 1.495 | 0.007 |  |  |
| 6 | $\mathrm{MgSO}_{4} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 1.490 | 1.491 | 1.497 | 0.007 | + 50 | 166 |
| 7 | $\mathrm{K}_{4} \mathrm{P}_{2} \mathrm{O}_{7}$ |  | 1.495 | 1.502 | 0.007 | +00 | 213 |
| 8 | $\mathrm{Ca}_{4} \mathrm{Si}_{8} \mathrm{O}_{32} \cdot 12 \mathrm{H}_{2} \mathrm{O}$, Phillipsite | 1.493 | 1.497 | 1.500 | 0.007 | - 70 | 247 |
| 9 | $\mathrm{NaNH}_{2} \mathrm{SO}_{3}$ | 1.494 | 1.498 | 1.501 | 0.007 | - 83 | 121 |
| 10 | $\mathrm{Cs}_{2} \mathrm{Mn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4946 | 1.4966 | 1.5025 | 0.0079 | $+60$ | 145 |
| 7 | $(\mathrm{K}, \mathrm{Na})_{3} \mathrm{Na}\left(\mathrm{SO}_{4}\right)_{2}$, Aphthitalite |  | 1.491 | 1.499 | 0.008 | +00 | 124 |
| 11 | $\mathrm{NH}_{4} \mathrm{Mg}\left(\mathrm{PO}_{4}\right) \cdot 6 \mathrm{H}_{2} \mathrm{O}$, Struvite | 1.495 | 1.496 | 1.504 | 0.009 | $+37$ | 197 |
| 12 | $\mathrm{CaSi}_{6} \mathrm{Al}_{2} \mathrm{O}_{16} \cdot 7 \mathrm{H}_{2} \mathrm{O}$, Stilbite | 1.49 | 1.49 | 1.50 | 0.01 | -40 | 248 |
| 13 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Zn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4888 | 1.4930 | 1.4994 | 0.0106 | +79 | 143 |
| 14 | $\mathrm{MgSO}_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$, Pentahydrite | 1.482 | 1.492 | 1.493 | 0.011 | $\therefore .45$ | 168 |
| 15 | KOH | 1.486 | 1.492 | 1.497 | 0.011 | $+70$ | 68 |
| 16 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Fe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4870 | 1.4915 | 1.4989 | 0.0119 | +76 | 146 |
| 17 | $\mathrm{NaAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$, Tamarugite | 1.488 | 1.491 | 1.500 | 0.013 | $+60$ | 160 |
| 18 | $\mathrm{Ca}_{4}\left(\mathrm{ClO}_{4}\right)_{2}(\mathrm{OH})_{6} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.490 | 1.499 | 1.503 | 0.013 | -66 | 113 |
| 19 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Co}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4902 | 1.4953 | 1.5032 | 0.0130 | +82 | 146 |
| 20 | $\mathrm{NH}_{4} \mathrm{PO}_{3}$ | 1.490 |  | 1.505 | 0.015 | +70 | 211 |
| 21 | $\mathrm{Fe}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.478 | 1.493 |  | 0.015 | -00 | 111 |
| 22 | $\mathrm{Na}_{3} \mathrm{PO}_{4}$ | 1.493 | 1.499 | 1.508 | 0.015 | +76 | 189 |
| 23 | $\mathrm{Rb}_{2} \mathrm{Cu}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4886 | 1.4906 | 1.5036 | 0.0150 | +45 | 149 |
| 22 | $\mathrm{Rb}_{2} \mathrm{Co}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4859 | 1.4916 | 1.5014 | 0.0155 | +75 | 147 |
| 24 | $\mathrm{Rb}_{2} \mathrm{Ni}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4895 | 1.4961 | 1.5052 | 0.0157 | $+82$ | 148 |
| 25 | $\mathrm{Mn}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.475 | 1.492 |  | 0.017 | - 00 | 111 |
| 26 | $\mathrm{AlF}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.489 | 1.495 | 1.506 | 0.017 | +76 | 33 |
| 27 | $\mathrm{K}_{2} \mathrm{Mg}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4969 | 1.4991 | 1.5139 | 0.0170 | $+40$ | 149 |
| 28 | $\mathrm{Na}_{4} \mathrm{Mg}_{2}\left(\mathrm{SO}_{4}\right)_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$, Loeweite | 1.471 | 1.490 |  | 0.019 | -00 | 137 |
| 29 | $\mathrm{K}_{2} \mathrm{Ni}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4836 | 1.4916 | 1.5051 | 0.0215 | +75 | 147 |
|  | $\mathrm{Na}_{56} \mathrm{Si}_{42} \mathrm{Al}_{38} \mathrm{O}_{169} \cdot 24 \mathrm{H}_{2} \mathrm{O}$ |  | 1.498 |  | 0.022 | 00 | 240 |
| 30 | $\mathrm{Sr}(\mathrm{OH})_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.476 | 1.499 |  | 0.023 | - 00 | 68 |
| 31 | $\mathrm{Na}_{3} \mathrm{PO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ |  | 1.497 | 1.522 | 0.025 | +00 | 197 |
| 32 | $\mathrm{Na}_{6}\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ |  | 1.499 | 1.525 | 0.026 | +00 | 197 |
| 33 | $\mathrm{KNH}_{2} \mathrm{SO}_{3}$ | 1.487 | 1.490 | 1.515 | 0.028 | +26 | 121 |
| 34 | $\mathrm{CaP}_{4} \mathrm{O}_{11}$ | 1.470 | 1.497 | 1.499 | 0.029 | -15 | 215 |
| 35 | $\mathrm{H}_{6}\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.485 | 1,492 | 1.519 | 0.034 | + 56 | 197 |
| 36 | $\mathrm{CoSO}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.460 | 1.495 |  | 0.035 | -00 | 161 |
| 37 | $\mathrm{Na}_{2} \mathrm{~S}_{2} \mathrm{O}_{6} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.4820 | 1.4953 | 1.5185 | 0.0365 | $+75$ | 134 |
| 38 | AlF ${ }_{3} \cdot \mathrm{H}_{2} \mathrm{O}$, Fluellite | 1.473 | 1.490 | 1.511 | 0.038 | $+80$ | 33 |
| 39 | $\mathrm{Ca}\left(\mathrm{NO}_{3}\right)_{2} \cdot 4 \mathrm{H}_{2} \mathrm{O}$, Nitrocalcite | 1.465 | 1.498 | 1.504 | 0.039 | - 50 | 103 |
|  | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{MnF}_{3}$ | 1.46 |  | 1.50 | 0.04 |  | 44 |
| 40 | $\mathrm{Na}_{6} \mathrm{CO}_{3}\left(\mathrm{SO}_{4}\right)_{2}$, Burkeite | 1.450 | 1.490 | 1.492 | 0.042 | - 34 | 178 |
| 41 | $\mathrm{Na}_{2} \mathrm{HPO}_{4}$ | 1.483 | 1:499 | 1.525 | 0.042 | +78 | 187 |
| 42 | $\mathrm{Mg}_{2} \mathrm{UO}_{2}\left(\mathrm{CO}_{3}\right)_{3} \cdot 18 \mathrm{H}_{2} \mathrm{O}$, Bayleyite | 1.455 | 1.490 | 1.500 | 0.045 | - 30 | 99 |
| 43 | $\mathrm{UO}_{2}\left(\mathrm{NO}_{3}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.482 | 1.494 | 1.572 | 0.090 | - 46 | 105 |
| 44 | $\mathrm{Na}_{4}\left(\mathrm{CO}_{3}\right)_{2} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 1.435 | 1.492 | 1.547 | 0.112 | -70 -72 | 91 89 |
| 45 | $\mathrm{Na}_{3} \mathrm{H}\left(\mathrm{CO}_{3}\right)_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Trona | 1.412 | 1.492 | 1.540 | 0.128 | - 72 | 89 |
| 46 | $\mathrm{NH}_{4}\left(\mathrm{NO}_{3}\right)$ |  | 1.493 | 1.623 | 0.130 | +00 | 101 |
| 47 | $\mathrm{Li}\left(\mathrm{NO}_{3}\right) \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.365 | 1.490 | 1.523 | 0.158 | - 55 | 102 |


$n_{y}=1.500$ to 1.5099

| No. on Chart | Substance | $n_{x}$ | $n y$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\mathrm{Cu}\left(\mathrm{BF}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ |  | 1.50 |  |  | - 70 | 49 |
|  | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{ZnCl}_{4}$ |  | 1.5055 |  |  | + 54 | 37 |
|  | $\mathrm{Ce}_{2}\left(\mathrm{~S}_{2} \mathrm{O}_{6}\right)_{3} \cdot 15 \mathrm{H}_{2} \mathrm{O}$ |  | 1.507 |  |  | -89 | 135 |
| 1 | $\mathrm{Na}_{2} \mathrm{Ca}_{2} \mathrm{Si}_{9} \mathrm{Al}_{6} \mathrm{O}_{30} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.5073 | 1.5074 | 1.5075 | 0.0002 | - 85 | 246 |
| 1 | $\mathrm{Na}_{2} \mathrm{Ca}_{2} \mathrm{Si}_{9} \mathrm{Al}_{6} \mathrm{O}_{30} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Mesolite | 1.5048 | 1.5050 | 1.5053 | 0.0005 | - 85 | 246 |
| 2 | $\mathrm{KSi}_{2} \mathrm{AlO}_{6}$ |  | 1.508 | 1.509 | 0.001 | $+00$ | 227 |
| 2 | $\mathrm{K}_{2} \mathrm{Mg}_{8} \mathrm{Si}_{5} \mathrm{O}_{12}$ |  | 1.505 |  | 0.002 |  | 254 |
| 3 | $\mathrm{Ba}_{2} \mathrm{Si}_{11} \mathrm{Al}_{4} \mathrm{O}_{38} \cdot 10 \mathrm{H}_{2} \mathrm{O}$, Harmotome | 1.503 | 1.505 | 1.508 | 0.005 | +79 | 248 |
| 4 | $2 \mathrm{NaSiAlO} \mathrm{C}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.503 | 1.506 | 1.508 | 0.005 | - 70 | 242 |
| 5 | $\mathrm{Na}_{26} \mathrm{Si}_{22} \mathrm{Al}_{18} \mathrm{O}_{34} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.495 | 1.502 |  | 0.007 | - 00 | 240 |
| 6 | $\mathrm{LiNH}_{2} \mathrm{SO}_{3}$ |  | 1.507 |  | 0.007 | - 48 | 121 |
| 7 | $\mathrm{Cs}_{2} \mathrm{Zn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5022 | 1.5048 | 1.5093 | 0.0071 | +74 | 144 |
| 7 | $\mathrm{Cs}_{2} \mathrm{Co}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5057 | 1.5085 | 1.5132 | 0.0075 | +82 | 147 |
| 8 | $\mathrm{Cs}_{2} \mathrm{Cd}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4975 | 1.5000 | 1.5062 | 0.0087 | +68 | 145 |
| 9 | $\mathrm{Cs}_{2} \mathrm{Fe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5003 | 1.5035 | 1.5094 | 0.0091 | +75 | 146 |
| 10 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Mg}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5070 | 1.5093 | 1.5169 | 0.0099 | + 55 | 149 |
| 11 | $\mathrm{Na}_{2} \mathrm{Fe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 1.493 | 1.500 | 1.503 | 0.010 | - 60 | 138 |
| 12 | $\mathrm{K}_{2} \mathrm{Al}_{6} \mathrm{H}_{10}\left(\mathrm{PO}_{4}\right)_{10} \cdot 15 \mathrm{H}_{2} \mathrm{O}$ | 1.495 | 1.504 | 1.505 | 0.010 | - 25 | 196 |
| 11 | $\mathrm{K}_{2} \mathrm{Si}_{2} \mathrm{O}_{5}$ | 1.503 | 1.509 | 1.513 | 0.010 | - 60 | 256 |
| 10 | $\mathrm{Cs}_{2} \mathrm{Cu}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5048 | 1.5061 | 1.5153 | 0.0105 | + 43 | 149 |
| 13 | $\mathrm{BaFeF}_{5} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.502 | 1.503 | 1.513 | 0.011 | +20 | 49 |
| 14 | $\mathrm{Na}_{2} \mathrm{Si}_{2} \mathrm{O}_{5}$ | 1.497 | 1.505 | 1.508 | 0.011 | - 52 | 255 |
| 15 | $\mathrm{Rb}_{2} \mathrm{Mg}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5011 | 1.5031 | 1.5135 | 0.0124 | +47 | 149 |
| 16 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Ni}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4949 | 1.5007 | 1.5081 | 0.0132 | +87 | 148 |
| 17 | $\mathrm{Na}_{3}\left(\mathrm{VO}_{4}\right) \cdot 12 \mathrm{H}_{2} \mathrm{O}$ |  | 1.5095 | 1.5232 | 0.0137 | +00 | 196 |
| 18 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Cu}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4910 | 1.5007 | 1.5054 | 0.0144 | - 69 | 148 |
| 19 | $\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{O}_{7} \cdot \mathrm{SO}_{3} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.488 | 1.504 |  | 0.016 | - 00 | 86 |
| 19 | $\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{SO}_{4}(\mathrm{OH})_{12} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.488 | 1.504 |  | 0.016 | - 00 | 175 |
| 20 | $\mathrm{MnSO}_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 1.495 | 1.508 | 1.514 | 0.019 | - 60 | 170 |
| 21 | $\mathrm{Na}_{3} \mathrm{~K}\left(\mathrm{PO}_{3}\right)_{4}$ | 1.493 | 1.500 | 1.514 | 0.021 | - 40 | 211 |
| 22 | $\mathrm{Zn}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.487 | 1.508 |  | 0.021 | - 00 | 112 |
| 23 | $\mathrm{KMgSO}_{4} \mathrm{Cl} \cdot 3 \mathrm{H}_{2} \mathrm{O}$, Kainite | 1.494 | 1.505 | 1.516 | 0.022 | - 85 | 176 |
| 24 | $\mathrm{Al}(\mathrm{OH}) \mathrm{Si}_{2} \mathrm{O}_{5} \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Leverrierite | 1.485 | 1.509 | 1.510 | 0.025 | - 10 | 265 |
| 25 | $\mathrm{NaCaB}_{5} \mathrm{O}_{9} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Ulexite | 1.493 | 1.505 | 1.519 | 0.026 | +73 | 116 |
| 26 | $\mathrm{Cu}\left(\mathrm{ClO}_{4} \mathrm{O}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.495 | 1.505 | 1.522 | 0.027 | +54 | 112 |
| 27 | $\mathrm{Mgr}_{3} \mathrm{O}_{4}(\mathrm{OH})_{3} \cdot 15 \mathrm{H}_{2} \mathrm{O}$, Inderite | 1.488 | 1.508 | 1.515 | 0.027 | - 63 | 118 |
| 28 | $\mathrm{Ca}\left(\mathrm{NH}_{2} \mathrm{SO}_{3}\right)_{2} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.488 | 1.508 | 1.512 | 0.029 | - 48 | 134 |
| 29 | $\mathrm{K}_{2} \mathrm{Si}_{2} \mathrm{O}_{5} \cdot \mathrm{H}_{2} \mathrm{O}$ |  | 1.50 |  | 0.03 | +10 | 259 |
| 30 | $\mathrm{K}_{2} \mathrm{SiO}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ |  | 1.50 |  | 0.03 | +25 | 282 |
| 31 | $\mathrm{K}_{4} \mathrm{Si}_{2} \mathrm{O}_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ |  | 1.50 |  | 0.03 | $+85$ | 281 |
| 32 | $\mathrm{Ca}_{4} \mathrm{Al}_{2}\left(\mathrm{NO}_{3}\right)_{2}(\mathrm{OH})_{12} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ |  | 1.502 | 1.532 | 0.030 | +00 | 104 |
| 32 | $\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{O}_{6}\left(\mathrm{NO}_{3}\right)_{2} \cdot 10 \mathrm{H}_{2} \mathrm{O}$ |  | 1.502 | 1.532 | 0.030 | +00 | 86 |
| 33 | $\mathrm{Ba}(\mathrm{OH})_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.471 | 1.5017 | 1.502 | 0.031 | - 09 | 69 |
| 34 | $\mathrm{MgCl}_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$, Bischofite | 1.495 | 1.507 | 1.528 | 0.033 | +79 | 27 |
| 35 | $\mathrm{NaH}_{2} \mathrm{PO}_{4}$ | 1.481 | 1.507 | 1.517 | 0.036 | - 64 | 187 |
| 36 | $\mathrm{BeSeO}_{4} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 1.4664 | 1.5007 | 1.5027 | 0.0363 | - 26 | 161 |
| 37 | $\mathrm{KHSi}_{2} \mathrm{O}_{5}$ | 1.495 | 1.501 | 1.535 | 0.040 | + 40 | 258 |
| 38. | $\mathrm{KH}_{2} \mathrm{PO}_{4}$ | 1.4684 | 1.5095 |  | 0.0411 | - 00. | 187 |
| $39^{\circ}$ | $\mathrm{CaSO}_{4}$ |  | 1.505 | 1.548 | 0.043 | +00 | 129 |
| 40 | $2 \mathrm{MgB}_{6} \mathrm{O}_{10} \cdot 15 \mathrm{H}_{2} \mathrm{O}$ | 1.463 | 1.5081 |  | 0.045 | +00 +89 | 117 |
| 41 | $\mathrm{NaH}_{2} \mathrm{AsO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.4794 | 1.5021 | 1.5265 | 0.0471 | +89 | 193 |
| 42 | $\mathrm{Na}_{2} \mathrm{~S}_{2} \mathrm{O}_{3} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 1.4886 | 1.5079 | 1.5360 | 0.0474 | +81 | 135 |
| 41 | $\mathrm{NaAsO}_{3}$ | 1.479 | 1.502 | 1.5265 | 0.0475 | +88 | 211 |
| 43 | $\mathrm{H}_{3} \mathrm{PO}_{4}$ | 1.455 | 1.504 | 1.505 | 0.050 | - 12 | 189 |
|  | $\mathrm{CaSO}_{4}$ | 1.50 |  | 1.56 | 0.06 |  | 129 |
| 44 | $\mathrm{Na}_{2} \mathrm{Ca}\left(\mathrm{CO}_{3}\right)_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Pirssonite | 1.5043 | 1.5095 | 1.5751 | 0.0694 | +31 | 96 |
| 45 | $\mathrm{NH}_{4}\left(\mathrm{NO}_{3}\right)$ |  | 1.509 | 1.585 |  | +00 | 101 |
| 46 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{~S}_{2} \mathrm{O}_{8}$ | 1.4981 | 1.5016 | 1.5866 | 0.0885 | +24 | 122 |
| 47 | $\mathrm{Na}_{2} \mathrm{CO}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.420 | 1.506 | 1.524 | 0.104 | - 48 | 90 |
| 48 | $\mathrm{MgCO}_{3} \cdot 3 \mathrm{H}_{2} \mathrm{O}$, Nesquehonite | 1.417 | 1.503 | 1.527 | 0.110 | - 53 | 94 |
| 49 | $\mathrm{Bo}(\mathrm{OH})$ | 1.378 | 1.503 | 1.507 | 0.129 | - 23 | 69 |
| 50 | $\mathrm{K}\left(\mathrm{NO}_{3}\right)$, Niter | 1.3346 | 1.5056 | 1.5064 | 0.1718 | - 07 | 101 |
| 51 | NaHCO 3 , Nahcolite | 1.380 | 1.500 | 1.586 | 0.206 | - 75 | 89 |
| 52 | $\mathrm{Mg}\left(\mathrm{NO}_{3}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$, Nitromagnesite | 1.34 | 1.506 | 1.506 | 0.266 | - 05 | 103 |

$1.50<n_{y}<1.51$


| No. on Chart | Substance | $n_{x}$ | $n_{y}$ | $n_{z}$ | $n_{z} \boldsymbol{n}_{\boldsymbol{x}}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\mathrm{K}_{4} \mathrm{Cd}_{2}\left(\mathrm{SO}_{4}\right)_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ |  | 1.51 |  |  | -64 | 138 |
|  | $\mathrm{K}_{4} \mathrm{Mn}_{2}\left(\mathrm{SO}_{4}\right)_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ |  | 1.512 |  |  | +61 | 138 |
|  | $\mathrm{Rb}_{2} \mathrm{SO}_{4}$ | 1.5131 | 1.5133 | 1.5144 | 0.0013 | +42 | 127 |
| 2 | $\mathrm{Hg}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.509 | 1.511 |  | 0.002 | - 00 | 112 |
| 3 | $\mathrm{Th}\left(\mathrm{SO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ |  | 1.5168 |  | 0.002 | +76 | 17.2 |
| 4 | $\mathrm{K}_{2} \mathrm{Al}_{3} \mathrm{H}_{4}\left(\mathrm{PO}_{4}\right)_{5} \cdot 11 \mathrm{H}_{2} \mathrm{O}$ | 1.510 | 1.51 | 1.515 | 0.005 | +25 | 195 |
| 5 | $\mathrm{Li}_{2} \mathrm{~K}_{4} \mathrm{Si}_{6} \mathrm{O}_{15}$ | 1.510 | 1.5125 | 1.515 | 0.005 | -87 | 256 |
| 6 | $\mathrm{NaSiAlO}_{4}$ | 1.509 | 1.514 | 1.514 | 0.005 | - 12 | 224 |
| 7 | $\mathrm{LiAlSi} \mathrm{C}_{6}$ |  | 1.519 | 1.524 | 0.005 | +00 | 280 |
| 4 | $\left.\mathrm{Cs}_{2} \mathrm{Mg}^{\left(S e O_{4}\right.}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5178 | 1.5179 | 1.5236 | 0.0058 | +19 | 150 |
|  | $\mathrm{Na}_{2} \mathrm{H}_{2} \mathrm{P}_{2} \mathrm{O}{ }_{7}$ | 1.51 |  | 1.517 | 0.007 |  | 214 |
| 8 | $\mathrm{NaCa}_{2} \mathrm{Si}_{5} \mathrm{Al}_{5} \mathrm{O}_{20} \cdot 6 \mathrm{H}_{2} \mathrm{O}$, Thomsonite | 1.511 | 1.513 | 1.518 | 0.007 | +75 | 243 |
| 9 | $\mathrm{Cs}_{2} \mathrm{Ni}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5087 | 1.5129 | 1.5162 | 0.0075 | -87 | 148 |
| 10 | $\mathrm{CaSi}_{3} \mathrm{Al}_{2} \mathrm{O}_{10} \cdot 3 \mathrm{H}_{2} \mathrm{O}$, Scolecite | 1.5122 | 1.5187 | 1.5194 | 0.0083 | - 36 | 246 |
| 11 | $\mathrm{CaH}_{2} \mathrm{O}_{4} \cdot 6 \mathbf{H}_{2} \mathrm{O}$ | 1.505 | 1.511 | 1.515 | 0.010 | - 77 | 116 |
| 12 | $\mathrm{CaSi}_{4} \mathrm{Al}_{2} \mathrm{O}_{12} \cdot 4 \mathrm{H}_{2} \mathrm{O}$, Leonhardite | 1.505 | 1.514 | 1.516 | 0.011 | - 27 | 247 |
| 13 | $\mathrm{LiSi}_{4} \mathrm{AlO}_{10}$, Petalite | 1.504 | 1.510 | 1.516 | 0.012 | $+84$ | 228 |
| 14 | $\mathrm{CaSi}_{4} \mathrm{Al}_{2} \mathrm{O}_{12} \cdot 4 \mathrm{H}_{2} \mathrm{O}$, Laumontite | 1.509 | 1.518 | 1.521 | 0.012 | - 40 | 247 |
| 15 | $\mathbf{N a B r} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.5128 | 1.5192 | 1.5252 | 0.0124 | -85 | 23 |
| 16 | $\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{O}_{7} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.506 | 1.519 |  | 0.013 | - 00 | 82 |
| 16 | $\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{SO}_{4}(\mathrm{OH})_{12} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ (?) | 1.506 | 1.519 |  | 0.013 | - 00 | 175 |
| 16 | $\mathrm{Ca}_{2} \mathrm{Al}_{2} \mathrm{O}_{5} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.506 | 1.519 |  | 0.013 | -00 | 83 |
| 17 | CaSis $\mathrm{Al}_{2} \mathrm{O}_{14} \cdot 4 \mathrm{H}_{2} \mathrm{O}$, Epistilbite | 1.505 | 1.515 | 1.519 | 0.014 | +44 | 251 |
| 18 | $\mathrm{MnSO}_{4} \cdot \mathbf{4 \mathrm { H } _ { 2 } \mathrm { O }}$ | 1.508 | 1.518 | 1.522 | 0.014 | -63 | 166 |
| 19 | $\mathrm{Na}_{2} \mathrm{Si}_{2} \mathrm{O}_{5}$ | 1.500 | 1.510 | 1.515 | 0.015 | - 48 | 255 |
| 20 | $\mathrm{ZnF}_{2}$ |  | 1.510 | 1.526 | 0.016 | $+00$ | 23 |
| 21 | $\mathrm{Mg}_{6} \mathrm{Al}_{2}(\mathrm{OH})_{16} \mathrm{CO}_{3} \cdot 4 \mathrm{H}_{2} \mathrm{O}$, Hydrotalcite | 1.495 | 1.511 |  | 0.016 | - 00 | 85 |
| 22 | $\mathrm{Rb}_{2} \mathrm{Mn}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5094 | 1.5140 | 1.5258 | 0.0164 | +66 +53 | 151 |
| 23 | $\mathrm{Rb}_{2} \mathrm{Cu}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5153 | 1.5183 | 1.5318 | 0.0165 | +53 | 154 |
| 24 | $\mathrm{K}_{2} \mathrm{Ca}\left(\mathrm{SO}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$, Syngenite | 1.5010 | 1.5166 | 1.5176 | 0.0166 | - 28 | 138 |
| 25 | $\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{SO}_{4}(\mathrm{OH})_{12} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.499 | 1.517 |  | 0.018 | - 00 | 175 |
| 26 | $\mathrm{MgHPO}_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$, Newberyite | 1.514 | 1.517 | 1.533 | 0.019 | +45 | 193 |
| 27 | $\mathrm{Co}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.490 | 1.510 |  | 0.020 | - 00 | 111 |
| 28 | $\mathrm{Na}_{6} \mathrm{Si}_{2} \mathrm{O}_{7} \cdot 11 \mathrm{H}_{2} \mathrm{O}$ | 1.504 | 1.510 | 1.524 | 0.020 | +65 | 296 |
| 29 | $\mathrm{Ni}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.498 | 1.518 |  | 0.020 | - 00 | 111 |
| 29 | $\mathrm{K}_{2} \mathrm{Zn}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5121 | 1.5181 | 1.5335 | 0.0214 | +66 | 150 |
| 30 | $\mathrm{NiSO}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$, Retgersite | 1.4873 | 1.5109 |  | 0.0236 | - 00 | 160 |
| 31 | $\left(\mathrm{NH}_{4}\right)_{3} \mathrm{H}\left(\mathrm{SO}_{4}\right)_{2}$, Letovicite | 1.501 | 1.516 | 1.526 | 0.024 | - 75 | 123 |
| 32 | $\mathrm{CaB}_{3} \mathrm{O}_{4}(\mathrm{OH})_{3} \cdot 5 \mathrm{H}_{2} \mathrm{O}$, Inyoite | 1.495 | 1.51 | 1.520 | 0.025 | - 70 | 118 |
| 33 | $\mathrm{Mg}\left(\mathrm{NH}_{2} \mathrm{SO}_{3}\right)_{2}$ | 1.510 | 1.517 | 1.535 | 0.025 | +68 | 122 |
| 34 | $\mathrm{K}_{2} \mathrm{Fe}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5095 | 1.5182 | 1.5345 | 0.0250 | +64 | 152 |
| 35 | $\mathrm{NaPO}_{3}$ | 1.498 | 1.510 | 1.529 | 0.031 | +78 | 212 |
| 36 | $\mathrm{Ca}\left(\mathrm{NH}_{3}\right)_{4}\left(\mathrm{NO}_{3}\right)_{2}$ | 1.475 |  | 1.510 | 0.035 | - 45 | 105 |
| 37 | $\mathrm{Ca}_{2} \mathrm{P}_{6} \mathrm{O}_{17}$ | 1.477 | 1.511 | 1.513 | 0.036 | - 23 | 215 |
| 38 | $\mathrm{CaH}_{4}\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.4932 | 1.5176 | 1.5292 | 0.0360 | - 70 | 196 |
| 39 | $\mathrm{PNO}_{4} \mathrm{H}_{6}$ | 1.477 | 1.515 |  | 0.038 | - 00 | 8 |
| 40 | $\mathrm{MgSO}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.464 | 1.511 |  | 0.047 | - 00 | 133 |
| 41 | $\mathrm{CaMgB}_{6} \mathrm{O}_{8}(\mathrm{OH})_{6} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Inderborite | 1.483 | 1.512 | 1.530 | 0.047 | - 77 | 118 |
| 42 | $\mathrm{Ca}_{3}\left(\mathrm{ClO}_{2}\right)_{2}(\mathrm{OH})_{4}$ |  | 1.51 | 1.585 | 0.075 | +00 | 108 |
| 43 | $\mathrm{CaMgUO}_{2}\left(\mathrm{CO}_{3}\right)_{3} \cdot 12 \mathrm{H}_{2} \mathrm{O}$, Swartzite | 1.465 | 1.51 | 1.540 | 0.075 | -40 | 99 |
| 44 | $\mathrm{Na}_{2} \mathrm{Ca}\left(\mathrm{CO}_{3}\right)_{2} \cdot 5 \mathrm{H}_{2} \mathrm{O}$, Gaylussite | 1.4435 | 1.5156 | 1.5233 | 0.0798 | - 34 | 96 |
| 45 | $\mathrm{MgKH}\left(\mathrm{CO}_{3}\right)_{2} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 1.430 | 1.51 | 1.542 | 0.112 | -65 | 90 |
| 46 | $\mathrm{KClO}_{3}$ | 1.4099 | 1.5174 | 1.5241 | 0.1142 | - 27 | 108 |
| 47 | $\mathrm{Bo}(\mathrm{OH})$ | 1.376 | 1.514 | 1.521 | 0.145 | - 23 | 69 |


$n_{y}=1.520$ to 1.5299

| $\begin{gathered} \text { No. } \\ \text { on } \\ \text { Chart } \end{gathered}$ | Substance | $n^{\prime}$ | $n^{\prime}$ | $n_{z}{ }^{*}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\mathrm{RbSi} \mathrm{AlO}_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ |  | 1.521 |  |  | - 00 | 227 |
| 1 | $\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{O}_{6} \cdot\left(\mathrm{ClO}_{3}\right)_{2} \cdot 10 \mathrm{H}_{2} \mathrm{O}$ | - | 1.520 | 1.521 | 0.001 | +00 | 86 |
| 2 | $\mathrm{K}_{3} \mathrm{Cu}(\mathrm{CN})_{4}$ | 1.519 | 1.5215 |  | 0.002 | - 00 | 22 |
| 2 | KSiAlO ${ }_{4} \cdot \mathbf{n H}_{\mathbf{2}} \mathrm{O}$ | 1.523 | 1.5256 |  | 0.002 | - 00 | 239 |
| 2 | $\mathrm{Ca}_{4} \mathrm{Al}_{2}\left(\mathrm{ClO}_{3}\right)_{2}(\mathrm{OH})_{12} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 1.521 | 1.521 |  | 0.002 | - 00 | 112 |
| 3 | $\mathrm{SrS}_{2} \mathrm{O}_{6} \cdot \mathbf{4 H 2} \mathbf{}$ | 1.5262 | 1.5297 |  | 0.0035 | - 00 | 133 |
| 3 | $\mathrm{K}_{5} \mathrm{P}_{3} \mathrm{O}_{10}{ }^{\text {a }}$ | 1.516 | 1.520 |  | 0.004 | - 00 | 213 |
| 3 | $\mathrm{NaSiAlO}_{4}$ | 1.522 | 1.526 |  | 0.004 | - 00 | 224 |
| 3 | $\mathrm{Mg}_{2} \mathrm{Al}_{3} \mathrm{Si}_{5} \mathrm{AlO}_{18}$, Indialite | 1.524 | 1.528 |  | 0.004 | - 00 | 290 |
| 4 | $\mathrm{LiSiAlO}_{4}$ | 1.5195 | 1.524 |  | 0.0045 | - 00 | 227 |
|  | $\mathrm{LiK}_{5} \mathrm{Si}_{2} \mathrm{O}_{7}$ | 1.515 |  | 1.520 | 0.005 |  | 296 |
|  | $\mathrm{Na}_{6} \mathrm{OSiO}_{4}$ | 1.524 |  | 1.529 | 0.005 | + | 308 |
|  | $\mathrm{Na}_{6} \mathrm{Si}_{2} \mathrm{O}_{7}$ | 1.524 |  | 1.529 | 0.005 | + | 296 |
|  | $\mathrm{RbSi}_{3} \mathrm{AlO}_{4}$ | 1.524 |  | 1.529 | 0.005 |  | 232 |
| 5 | AlPO ${ }_{4}$, Berlinite |  | 1.5235 | 1.529 | 0.0055 | +00 | 190 |
| 6 | $\mathrm{KSi}_{3} \mathrm{AlO}_{3}$, Adularia | 1.52 | 1.525 | 1.53 | 0.006 | $+60$ | 230 |
| 7 | $\mathrm{KSi}_{3} \mathrm{AlO}_{\mathbf{g}}$, Sanidine | 1.520 | 1.525 | 1.53 | 0.006 | - 10 | 229 |
| 8 | $\mathrm{NaSi}_{3} \mathrm{AlO}_{4}$ | 1.523 | 1.528 | 1.529 | 0.006 | - 42 | 233 |
| 9 | $\mathrm{KSi}_{3} \mathrm{AlO}_{3}$, Microcline | 1.518 | 1.522 | 1.525 | 0.007 | - 83 | 231 |
| 10 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Ca}\left(\mathrm{SO}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$, Koktaite | 1.521 | 1.527 | 1.529 | 0.007 | - 50 | 138 |
| 11 | $\mathrm{Mg}_{3} \mathrm{La}_{2}\left(\mathrm{NO}_{3}\right)_{12} \cdot 24 \mathrm{H}_{2} \mathrm{O}$ | 1.5150 | 1.5220 |  | 0.0070 | - 00 | 104 |
| 11 | $\mathrm{Mg}_{3} \mathrm{Ce}_{2}\left(\mathrm{NO}_{3}\right)_{12} \cdot 24 \mathrm{H}_{2} \mathrm{O}$ | 1.5176 | 1.5249 |  | 0.0073 | - 00 | 104 |
| 11 | $\mathrm{Mg}_{3} \mathrm{Pr}_{2}\left(\mathrm{NO}_{3}\right)_{12} \cdot \mathbf{2 4 H 2} \mathbf{O}$ | 1.5182 | 1.5255 |  | 0.0073 | - 00 | 104 |
| 11 | $\mathrm{Mg}_{3} \mathrm{Nd}_{2}\left(\mathrm{NO}_{3}\right)_{12} \cdot 24 \mathrm{H}_{2} \mathrm{O}$ | 1.5192 | 1.5266 |  | 0.0074 | - 00 | 104 |
| 12 | $\mathrm{NaSi}_{3} \mathrm{AlO}_{6}$ | 1.5198 | 1.5242 | 1.5276 | 0.0078 | - 60 | 233 |
| 13 | CaM $\mathrm{B}_{2} \mathrm{Cl}_{6} \cdot 12 \mathrm{H}_{2} \mathrm{O}$, Tachyhydrite | 1.512 | 1.520 |  | 0.008 | - 00 | 28 |
| 14 | $\mathrm{K}_{2} \mathrm{SiO}_{3} \mathrm{SeO}_{4} \mathrm{CH}^{\text {O }}$ | 1.520 | 1.521 | 1.528 | 0.008 | +35 | 268 |
| 15 | $\mathrm{Cs}_{2} \mathrm{Mn}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5250 | 1.5279 | 1.5338 | 0.0088 | +68 | 151 |
| 16 | $\mathrm{SiO}_{2}$, Keatite | 1.513 | 1.522 |  | 0.009 | - 00 | 64 |
| 16 | $\mathrm{Mg}_{3} \mathrm{Si}_{4} \mathrm{O}_{11} \cdot \mathrm{nH}_{2} \mathrm{O}$, Sepiolite | 1.515 | 1.525 | 1.525 | 0.009 | - 05 | 260 |
| 17 | $\mathrm{CaSO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Gypsum | 1.5205 | 1.5226 | 1.5296 | 0.0091 | $+58$ | 164 |
| 18 | $\mathrm{M}_{\mathrm{B}_{2}} \mathrm{Al}_{3} \mathrm{Si}_{5} \mathrm{AlO}_{10}$, Cordierite | 1.52 | 1.525 | 1.53 | 0.01 | - 60 | 290 |
|  | $\mathrm{KCaCl}_{3}, \mathrm{Chlor}^{2}$ ocalcite |  | 1.52 |  | 0.010 |  | $36$ |
| 19 | $\mathrm{Cs}_{2} \mathrm{Cu}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5282 | 1.5298 | 1.5394 | 0.0112 | +48 | 154 |
| 20 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Mn}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5160 | 1.5202 | 1.5288 | 0.0128 | + 70 | 151 |
| 21 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SO}_{4}$, Mascagnite | 1.5209 | 1.5230 | 1.5330 | 0.0128 | +52 | 126 |
| 22 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Cd}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5206 | 1.5260 | 1.5352 | 0.0146 | +77 | 151 |
| 23 | $\mathrm{Na}_{2} \mathrm{SiO}_{3}$ | 1.513 | 1.520 | 1.528 | 0.015 | - 80 | 268 |
| 24 | $\mathrm{K}, \mathrm{Cr}(\mathrm{CN})_{6}$ | 1.5221 | 1.5244 | 1.5373 | 0.0152 | $+46$ | 44 |
| 25 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Fe}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5216 | 1.5280 | 1.5381 | 0.0165 | + 78 | 152 |
| 25 | $\mathrm{Rb}_{2} \mathrm{Zn}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5162 | 1.5222 | 1.5331 | 0.0169 | +75 | 150 |
| 25 | $\mathrm{Rb}_{2} \mathrm{Co}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5199 | 1.5256 | 1.5369 | 0.0170 | +74 | 153 |
| 26 | $\mathrm{Na}_{2} \mathrm{BO}_{2} \mathrm{Cl} \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Teepleite | 1.503 | 1.521 |  | 0.018 | - 00 | 117 |
| 26 | $\mathrm{ZnSeO}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5039 | 1.5291 |  | 0.0183 | - 00 | 161 |
| 27 | $\mathrm{CaHAsO}_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.513 | 1.524 | 1.532 | 0.019 | - 70 | 194 |
| 28 | $\mathrm{Rb}_{2} \mathrm{Ni}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5189 | 1.5291 | 1.5390 | 0.0192 | $+82$ | 153 |
| 29 | $\mathrm{Rb}_{2} \mathrm{Fe}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5133 | 1.5200 | 1.5328 | 0.0195 | $+74$ | 152 |
| 30 | $\mathrm{Na}_{2} \mathrm{CaUO}_{2}\left(\mathrm{CO}_{3}\right)_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$, Andersonite |  | 1.520 | 1.540 | 0.020 | +00 | 99 |
| 31 | $\mathrm{Ca}_{2} \mathrm{Al}_{2} \mathrm{O}_{5} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.502 | 1.522 |  | 0.020 | - 00 | 83 |
| 32 | $\mathrm{K}_{2} \mathrm{Ca}_{2} \mathrm{Si}_{9} \mathrm{O}_{21}$ | 1.515 | 1.526 | 1.535 | 0.020 | - 70 | 258 |
| 30 | $\mathrm{Cs}_{2} \mathrm{~S}_{2} \mathrm{O}_{6}$ |  | 1.5230 | 1.5438 | 0.0208 | + 00 | 121 |
| 33 | $\mathrm{Mg}_{4}(\mathrm{OH})_{2}\left(\mathrm{CO}_{3}\right)_{3} \cdot 3 \mathrm{H}_{2} \mathrm{O}$, Hydromagnesite | 1.523 | 1.527 | 1.545 | 0.022 | + 50 | 98 |
| 34 | $\mathrm{K}_{2} \mathrm{Co}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5158 | 1.5218 | 1.5380 | 0.0222 | +62 | 152 |
| 35 | $\mathrm{Na}_{4} \mathrm{Fe}(\mathrm{CN})_{6} \cdot 10 \mathrm{H}_{2} \mathrm{O}$ | 1.5193 | 1.5295 | 1.5436 | 0.0243 | +81 | 40 |
| 36 37 | $\mathrm{K}_{2} \mathrm{Ni}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5181 | 1.5272 | 1.5427 | 0.0246 | +73 | 153 |
| 37 | $\mathrm{K}_{2} \mathrm{Cu}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5101 | 1.5228 | 1.5349 | 0.02.48 | - 88 | 154 |
| 38 | $\mathrm{Ca}_{5} \mathrm{Al}_{2}\left(\mathrm{IO}_{3}\right)_{2}(\mathrm{OH})_{15} \cdot 14 \mathrm{H}_{2} \mathrm{O}$ | 1.496 | 1.521 |  | 0.025 | - 00 | 112 |
| 38 | $\mathrm{Ca}_{5} \mathrm{Al}_{2} \mathrm{O}_{5}\left(\mathrm{IO}_{3}\right)_{2} \cdot 22 \mathrm{H}_{2} \mathrm{O}$ | 1.496 | 1.521 |  | 0.025 | -00 +73 | 86 |
| 39 | $\mathrm{NaCaB}, \mathrm{O}_{9} \cdot \mathrm{SH}_{2} \mathrm{O}$, Probertite | 1.514 | 1.524 | 1.543 | 0.029 | +73 | 116 |
| 40 | $\mathrm{Mg}_{3}\left(\mathrm{PO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Bobierrite | 1.5,10 | 1.520 | 1.543 | 0.033 | +71 | 197 |
| 41 | $\mathrm{PNO}_{2} \mathrm{H}_{2}$ | 1.479 | 1.522 |  | 0.043 | - 00 | 8 |
| 42 | $\mathrm{CaMg} \mathrm{Br}_{6} \mathrm{O}_{6}(\mathrm{OH})_{6} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Inder borite | 1.496 | 1.521 | 1.54 | 0.044 | -80 | 118 |
| 43 | $\mathrm{NH}_{4} \mathrm{H}_{2}\left(\mathrm{PO}_{4}\right)$ | 1.4792 | 1.5246 |  | 0.0454 | - 00 | 187 |
| 43 | $\mathrm{PNO}_{4} \mathrm{H}_{6}$ | 1.4792 | 1.5246 |  | 0.0454 | - 00 | 8 |
| 44 | $\mathrm{CoSeO}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.47 | 1.5225 | 1.5227 | 0.05 | -07 | 167 |
| 45 | $\mathrm{K}_{2}\left(\mathrm{UO}_{2}\right)\left(\mathrm{SO}_{4}\right)_{2} \cdot \mathbf{2 H} \mathbf{2} \mathbf{O}$ | 1.5144 | 1.5266 | 1.5705 | 0.0561 | $+60$ | 176 |
| 46 | $\mathrm{NaNH}_{2}$ | 1.500 | 1.527 | 1.562 | 0.062 | +50 +57 | 22 |
| 47 | $\mathrm{MgSO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$, Kieserite | 1.523 | 1.525 | 1.596 | 0.063 | $+57$ | 163 |
| 48 | $\mathrm{Na}_{2} \mathrm{Fe}\left(\mathrm{SO}_{4}\right)_{2}(\mathrm{OH}) \cdot 3 \mathrm{H}_{2} \mathrm{O}$, Sideronatrite | 1.508 | 1.525 | 1.586 | 0.078 | $+58$ | 176 |
| 49 | $\mathrm{NaHSO}_{3}$ | 1.474 | 1.526 | 1.685 | 0.211 | +65 | 120 |



| No. on Chart | Substance | $n_{x}$ | $n_{y}$ | $n_{z}$ | $n_{z}-n_{x}$ | 2 V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $4 \mathrm{MgSO}_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 1.512 | 1.530 |  |  |  | 164 |
|  | $\left(\mathrm{NH}_{4}\right)_{3} \mathrm{ZnCl}_{5}$ |  | 1.538 |  |  | + 46 | 37 |
| 1 | $\mathrm{Ba}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.5323 | 1.5330 |  | 0.0007 | - 00 | 112 |
| 2 | $\mathrm{Na}_{4} \mathrm{ClSi}_{9} \mathrm{Al}_{3} \mathrm{O}_{24}$, Marialite |  | 1.532 | 1.534 | 0.002 | +00 | 253 |
| 2 | $\mathrm{KCa}_{4} \mathrm{FSi}_{8} \mathrm{O}_{20} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Apophyllite |  | 1.535 | 1.537 | 0.002 | +00 | 264 |
|  | $\mathrm{Ca}_{2}\left(\mathrm{ClO}_{4}\right)_{2}(\mathrm{OH})_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.532 | 1.535 |  | 0.003 | - | 113 |
| 3 | $\mathrm{RbSiAlO}{ }_{4}$ | 1.526 | 1.530 |  | 0.004 | - 00 | 227 |
| 4 | $\mathrm{Fe}\left(\mathrm{SO}_{4}\right) \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 1.533 | 1.535 | 1.537 | 0.004 | - 85 | 166 |
| 3 | $\mathrm{KSiAlO}_{4}$, Kaliophilite | 1.533 | 1.537 |  | 0.004 | - 00 | 226 |
| 3 | $\mathrm{NaSiAlO}_{4}$, Nepheline | 1.533 | 1.537 |  | 0.004 | - 00 | 224 |
| 5 | K Al ${ }_{2}\left(\mathrm{PO}_{4}\right)_{2} \mathrm{~F} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 1.528 | 1.530 | 1.533 | 0.005 | $+85$ | 210 |
| 5 | $\mathrm{BaAl}_{2} \mathrm{O}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.535 |  | 1.540 | 0.005 | $+$ | 83 |
| 6 | $\mathrm{K}_{2} \mathrm{MgSi}_{3} \mathrm{O}_{8}$ | 1.524 | 1.530 |  | 0.006 | - 00 | 255 |
|  | $\mathrm{Mg}_{3}\left(\mathrm{PO}_{4}\right)_{2} \cdot 3+\mathrm{H}_{2} \mathrm{O}$ |  | 1.535 |  | 0.006 |  | 198 |
| 7 | $\mathrm{KAl}_{2}\left(\mathrm{PO}_{4}\right)_{2}(\mathrm{OH}) \cdot 4 \mathrm{H}_{2} \mathrm{O}$, Minyulite | 1.531 | 1.534 | 1.538 | 0.007 | +70 | 209 |
| 8 | $\mathrm{SiO}_{2}$, Chalcedony | 1.530 | 1.537 |  | 0.007 | - 00 | 65 |
| 9 | $\mathrm{NaSi}_{3} \mathrm{AlO}_{8}$. Albite | 1.533 | 1.539 | 1.542 | 0.007 | - 50 | 235 |
| 10 | $\mathrm{Na}_{3}\left(\mathrm{VO}_{4}\right) \cdot 10 \mathrm{H}_{2} \mathrm{O}$ |  | 1.5398 | 1.5475 | 0.0077 | +00 | 196 |
| 11 | $\mathrm{Cs}_{2} \mathrm{Zn}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5326 | 1.5362 | 1.5412 | 0.0086 | $+83$ | 150 |
| 12 | $\mathrm{KSiAlO}_{4}$ | 1.528 | 1.536 | 1.537 | 0.009 | - 40 | 226 |
| 13 | $\mathrm{Zn}\left(\mathrm{NH}_{3}\right)_{6} \mathrm{Cl}_{2}$ | 1.530 | 1.539 |  | 0.009 | - 00 | 53 |
| 14 | $\mathrm{K}_{2} \mathrm{SeO}_{4}$ | 1.5352 | 1.5390 | 1.5446 | 0.0094 | +77 | 128 |
| 15 | $\mathrm{Cs}_{2} \mathrm{Co}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5354 | 1.5399 | 1.5453 | 0.0099 | +87 | 153 |
|  | $\mathrm{Na}_{4} \mathrm{SiO}_{4}$ |  | 1.536 |  | 0.01 | - 90 | 304 |
| 15 | $\mathrm{LiSiAlO} \mathbf{4}^{-2 \mathrm{H}_{2} \mathrm{O}}$ | 1.525 | 1.53 | 1.535 | 0.010 | 90 ? | 242 |
| 16 | $\mathrm{NaSi}_{3} \mathrm{AlO}_{8}$ | 1.5274 | 1.5314 | 1.5379 | 0.0105 | +65 | 235 |
| 17 | $\mathrm{Cs}_{2} \mathrm{Fe}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5306 | 1.5352 | 1.5414 | 0.0108 | +83 | 152 |
| 18 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Ca}\left(\mathrm{SO}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$, Koktaite | 1.524 | 1.532 | 1.536 | 0.012 | - 72 | 138 |
| 19 | $\mathrm{NH}_{4} \mathrm{NH}_{2} \mathrm{SO}_{3}$ | 1.526 | 1.532 | 1.538 | 0.012 | -84 | 121 |
| 19 | $\mathrm{Na}_{4} \mathrm{SiO}_{4}$ | 1.524 |  | 1.537 | 0.013 | 90? | 304 |
| 20 | $\mathrm{Na}_{6} \mathrm{Be}_{6} \mathrm{Si}_{14} \mathrm{O}_{37}$ | 1.532 | 1.533 | 1.545 | 0.013 | + 38 | 258 |
| 21 | $\mathrm{Fe}\left(\mathrm{SO}_{4}\right) \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 1.525 |  | 1.539 | 0.014 | 90? | 167 |
| 21 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Zn}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5240 | 1.5300 | 1.5385 | 0.0145 | $+82$ | 150 |
| 22 | $\left(\mathrm{NH}_{4}\right)_{4}\left(\mathrm{NO}_{3}\right)_{2}\left(\mathrm{SO}_{4}\right)$ | 1.521 | 1.531 | 1.536 | 0.015 | -64 | 179 |
| 23 | $\mathrm{NaCa}_{2} \mathrm{Si}_{5} \mathrm{Al}_{5} \mathrm{O}_{20} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.530 | 1.532 | 1.545 | 0.015 | + 50 | 243 |
| 22 | $\mathrm{RbNH}_{2} \mathrm{SO}_{3}$ |  | 1.537 |  | 0.015 | -65 | 122 |
| 24 | $\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{O}_{7} \cdot \mathrm{SiO}_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.523 | 1.538 |  | 0.015 | -00 | 86 153 |
| 21 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Co}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5261 | 1.5327 | 1.5417 | 0.0156 | +82 | 153 |
| 25 | $\mathrm{Na}_{2} \mathrm{~S} \cdot 9 \mathrm{H}_{2} \mathrm{O}$ |  | 1.534 | 1.550 | 0.016 | +00 | 9 |
| 26 | $\mathrm{Fe}\left(\mathrm{SO}_{4}\right) \cdot 5 \mathrm{H}_{2} \mathrm{O}$, Siderotil | 1.526 | 1.536 | 1.542 | 0.016 | - 50 | 168 |
| 27 | K $\mathrm{AlH}_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.522 | 1.536 | 1.539 | 0.017 | - 50 | 195 |
| 28 | $\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{O}_{7} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.520 | 1.537 | 1.537 | 0.017 | - 10 | 82 |
| 29 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Ni}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5285 | 1.5370 | 1.5460 | 0.0185 | +86 | 153 |
| 30 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Cu}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5201 | 1.5344 | 1.5387 | 0.0186 | - 55 | 154 |
| 31 | $\mathrm{Mg}_{2} \mathrm{PO}_{4}(\mathrm{OH})$ | 1.533 | 1.533 | 1.552 | 0.019 | + 25 | 201 |
| 32 | $\mathrm{K}_{2} \mathrm{Ca}_{2}\left(\mathrm{Si}_{3} \mathrm{O}_{7}\right)_{3}$ | 1.515 | 1.53 | 1.535 | 0.020 | - 70 | 267 |
|  | $\mathrm{Li}_{2} \mathrm{Si}_{2} \mathrm{O}_{5}$ | 1.525 |  | 1.545 | 0.020 |  | 256 |
| 33 | $\mathrm{Ca}_{3} \mathrm{Al}_{2} \mathrm{O}_{6} \cdot 11 \mathrm{H}_{2} \mathrm{O}$ | 1.510 | 1.530 |  | 0.020 | - 00 | 84 |
| 34 | $\mathrm{Ca}_{5} \mathrm{O}_{4} \mathrm{Cl}_{2} \cdot 14 \mathrm{H}_{2} \mathrm{O}$ | 1.517 1.515 | 1.532 | 1.537 | 0.020 | - 45 | 51 132 |
| 35 | $\mathrm{Na}_{2} \mathrm{Ca}\left(\mathrm{SO}_{4}\right)_{2}$, Glauberite | 1.515 | 1.535 | 1.536 | 0.021 | - 07 | 132 |
| 36 | $\mathrm{CaCl}_{2} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 1.506 | 1.530 | 1.530 | 0.024 | -05 | 27 |
| 37 | $\mathrm{MgH}\left(\mathrm{AsO}_{4}\right) \cdot 7 \mathrm{H}_{2} \mathrm{O}$, Roesslerite | 1.525 | 1.53 | 1.550 | 0.025 | + 25 | 194 |
| 38 | $\mathrm{NiSeO} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5125 | 1.5393 |  | 0.0268 | - 00 | 161 |
| 39 | $(\mathrm{Zn}, \mathrm{Cu}) \mathrm{SO}_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 1.513 | 1.533 | 1.540 | 0.027 | - 50 | 170 |
| 40 | $\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{O}_{7} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.506 | 1.533 | 1.534 | 0.028 | - 14 | 82 |
| 41 | $\mathrm{Cu}\left(\mathrm{SO}_{4}\right) \cdot 5 \mathrm{H}_{2} \mathrm{O}$, Chalcanthite | 1.5411 | 1.5368 | 1.5435 | 0.0294 | -56 +88 | 169 |
| 42 | $\mathrm{BaS}_{2} \mathrm{O}_{6} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ |  | 1.532 |  | 0.03 | +88 | 135 |
| 43 | $\mathrm{Fe}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 9 \mathrm{H}_{2} \mathrm{O}$, Coquimbite |  | 1.536 | 1.572 | 0.036 | +00 | 171 |
| 44 | $\mathrm{CaMgB}_{6} \mathrm{O}_{8}(\mathrm{OH})_{6} \cdot 3 \mathrm{H}_{2} \mathrm{O}$, Hydroboracite | 1.522 | 1.534 | 1.570 | 0.048 | +63 | 118 |
| 45 | $\mathrm{K}_{2} \mathrm{H}_{2} \mathrm{P}_{2} \mathrm{O}_{6} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.4893 | 1.5314 | 1.5363 | 0.0490 | - 36 | 213 |
| 46 | $\mathrm{SrCl}_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4866 | 1.5364 |  | 0.0498 | - 00 | 28 |
| 46 | $\mathrm{SrCl}_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.4857 | 1.5356 |  | 0.0499 | - 00 | 30 |
| 46 | $\mathrm{K}_{2} \mathrm{Ca}\left(\mathrm{CO}_{3}\right)_{2}$, Fairchildite | 1.48 | 1.530 |  | 0.05 | -00 | 96 |
| 47 | $\mathrm{KMgBr}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ |  | 1.535 |  | 0.05 | +87 | 39 |
| 48 | $\mathrm{CaB}_{3} \mathrm{O}_{4}(\mathrm{OH})_{3} \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Meyerhofferite | 1.500 | 1.535 | 1.560 | 0.060 | - 78 | 118 |
| 49 | $\mathrm{Ca}_{4} \mathrm{O}_{3} \mathrm{Cl}_{2} \cdot 15 \mathrm{H}_{2} \mathrm{O}$ | 1.481 | 1.536 | 1.543 | 0.062 | -44 +50 | 51 178 |
| 50 | $\mathrm{MgFe}_{4}\left(\mathrm{SO}_{4}\right)_{6}(\mathrm{OH})_{2} \cdot 20 \mathrm{H}_{2} \mathrm{O}$, Magnesiocopiapite | 1.510 | 1.535 | 1.575 | 0.065 | + 50 | 178 |
| 51 | $\mathrm{Cd}_{2} \mathrm{MgCl}_{6} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.49 | 1.5331 | 1.5769 | 0.08 | -85 | 30 |
| 52 | $\mathrm{CaCO}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.460 | 1.535 | 1.545 | 0.085 | - 38 | 95 |
| 53 | $\mathrm{Na}_{2} \mathrm{Cu}\left(\mathrm{CO}_{3}\right)_{2} \cdot 3 \mathrm{H}_{2} \mathrm{O}$, Chalconatrite | 1.483 | 1.530 | 1.576 | 0.093 | +70 +00 | 97 51 |
| 54 | $\mathrm{Ca}_{2} \mathrm{OCl}_{2} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ |  | 1.535 | 1.63 | 0.095 | +00 | 51 |
| 54 | $\mathrm{Ca}\left(\mathrm{ClO}_{2}\right)_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ |  | 1.53 | 1.63 | 0.10 | +00 | 108 |
| 55 | $\mathrm{K}_{2} \mathrm{CO}_{3}$ | 1.426 | 1.531 | 1.5411 | 0.115 | - 35 | 90 |
| 56 | $\mathrm{NaAlCO}_{3}(\mathrm{OH})_{2}$ | 1.462 | 1.537 | 1.589 | 0.127 | -67 | 99 |
| 57 | $\mathrm{Na}_{2} \mathrm{CO}_{3}$ | 1.415 | 1.535 | 1.546 | 0.131 | - 34 | 90 |
| 58 | $\mathrm{NH}_{4} \mathrm{HCO}_{3}$, Teschemacherite | 1.4227 | 1.5358 | 1.5545 | 0.1318 | - 42 | 87 |
| 59 | $\mathrm{LiNaCO}_{3}$ | 1.406 | 1.538 |  | 0.132 | - 00 | 90 |



| No. on Chart | Substance | $n_{x}$ | $n_{y}$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | KCa44 $\mathrm{FSi}_{8} \mathrm{O}_{20} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Apophyllite |  | 1.5418 | 1.5418 | 0.000 | 00 | 264 |
| 1 | $\mathrm{KCa}_{4} \mathrm{FSi}_{8} \mathrm{O}_{20} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Apophyllite | 1.5429 | 1.5433 |  | 0.0004 | - 00 | 264 |
| 2 | $\mathrm{NaBe}(\mathrm{OH}) \mathrm{Si}_{3} \mathrm{O}_{7}$, Epididymite | 1.5440 | 1.5441 | 1.5464 | 0.0024 | + 31 | 266 |
| 2 | $\mathrm{LiKSi}_{2} \mathrm{O}_{5}$ | 1.536 | 1.54 | 1.540 | 0.004 | 53 | 256 |
| 3 | $\mathrm{Mg}_{2} \mathrm{Al}_{3} \mathrm{Si}_{5} \mathrm{AlO}_{18}$, Indialite | 1.537 | 1.541 |  | 0.004 | - 00 | 290 |
| 3 | $\mathrm{BaZnF}_{4}$ |  | 1.544 |  | 0.004 | - 00 | 25 |
| 4 | KSiAlO ${ }_{4}$, Kalsilite | 1.537 | 1.542 |  | 0.005 | - 00 | 226 |
| 4 | $\mathrm{KSi}_{3} \mathrm{GaO}_{3}$ | 1.533 |  | 1.539 | 0.006 | -10? | 232 |
| 5 | $\mathrm{Na}_{2} \mathrm{Mg}_{2} \mathrm{Si}_{6} \mathrm{O}_{15}$ | 1.540 | 1.5425 | 1.546 | 0.006 | +70 | 258 |
| 6 | $\mathrm{LiSiAlO}_{4}$, Eucryptite | 1.54 | 1.545 |  | 0.006 | - 00 | 227 |
| 7 | $\mathrm{NaBe}(\mathrm{OH}) \mathrm{Si}_{3} \mathrm{O}_{7}$, Eudidymite | 1.545 | 1.546 | 1.551 | 0.006 | + 30 | 267 |
| 8 | Oligoclase (High-Temp) | 1.540 | 1.544 | 1.547 | 0.007 | - 75 | 235 |
| 9 | $\mathrm{BaSiO}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.542 | 1.548 | 1.549 | 0.007 | - 40 | 281 |
|  | $\mathrm{K}_{2} \mathrm{UO}_{2}\left(\mathrm{NO}_{3}\right)_{4}$ | 1.535 |  | 1.542 | 0.007 |  | 105 |
| 10 | $\mathrm{K}_{4} \mathrm{CaSi}_{6} \mathrm{O}_{15}$ | 1.535 | 1.541 | 1.543 | 0.008 | - 60 | 258 |
| 11 | $\mathrm{K}_{2} \mathrm{Mg}_{5} \mathrm{Si}_{12} \mathrm{O}_{30}$ |  | 1.543 | 1.550 | 0.008 | +00 | 255 |
| 12 | Oligoclase (Low-Temp) | 1.540 | 1.544 | 1.548 | 0.008 | -89 | 235 |
| 13 | $\mathrm{SiO}_{2}$, Quartz |  | 1.5442 | 1.5533 | 0.0091 | +00 | 63 |
| 14 | $\mathrm{Cs}_{2} \mathrm{Ni}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5395 | 1.5450 | 1.5489 | 0.0094 | -83 | 154 |
| 14 | $\mathrm{Mg}_{2} \mathrm{Al}_{3} \mathrm{Si}_{5} \mathrm{AlO}_{18}$, Cordierite | 1.54 | 1.545 | 1.55 | 0.01 | -85 | 290 |
|  | Reaumurite | 1.540 |  | 1.55 | 0.01 |  | 257 |
| 15 | $\mathrm{Ca}_{4}(\mathrm{OH})_{2} \mathrm{Si}_{6} \mathrm{O}_{15} \cdot 3 \mathrm{H}_{2} \mathrm{O}$, Gyrolite | 1.535 | 1.545 |  | 0.010 | -00 | 265 |
| 16 | KAl $\left.\mathbf{2}^{( } \mathrm{PO}_{4}\right)_{2} \mathrm{OH} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.536 | 1.541 | 1.547 | 0.011 | +85 | 210 |
| 17 | $\mathrm{CaCl}_{2}$ | 1.531 | 1.542 |  | 0.011 | - 00 | 26 |
| 17 | $\mathrm{K}_{8} \mathrm{CaSi}_{10} \mathrm{O}_{25}$ | 1.537 | 1.548 |  | 0.011 | - 00 | 255 |
| 17 | $\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{O}_{7} \cdot\left(\mathrm{CH}_{3} \cdot \mathrm{CO}_{2}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.538 | 1.549 |  | 0.011 | -00 | 86 |
| 18 | $\mathrm{CaH}\left(\mathrm{PO}_{4}\right) \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Brushite | 1.539 | 1.545 | 1.551 | 0.012 | +86 | 194 |
| 17 | $\mathrm{K}_{2} \mathrm{Al}_{2}\left(\mathrm{SO}_{4}\right)_{4}$ | 1.533 | 1.545 |  | 0.012 | -00 | 132 |
| 19 | $\mathrm{Mg}_{6}(\mathrm{OH})_{3} \mathrm{Si}_{4} \mathrm{O}_{10}$, Chrysotile | 1.542 | 1.543 | 1.555 | 0.013 | $+32$ | 260 |
| 20 | $\mathrm{Na}_{4} \mathrm{Si}_{4} \mathrm{Al}_{4} \mathrm{O}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.534 | 1.546 | 1.548 | 0.014 | - 50 | 242 |
| 21 | $\mathrm{CaSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8} \cdot 4 \mathrm{H}_{2} \mathrm{O}$, Gismondite | 1.5308 | 1.5402 | 1.5484 | 0.0176 | -84 -00 | 242 82 |
| 22 | Ca4 ${ }^{\text {a }}{ }_{2} \mathrm{O}_{7} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ $(\mathrm{Mg}, \mathrm{Fe})_{3}\left(\mathrm{OH} \mathrm{Si}_{3} \mathrm{AlO}_{10} \cdot 4 \mathrm{H}_{2} \mathrm{O}\right.$, Vermiculite | 1.53 1.525 | 1.549 1.545 |  | 0.02 0.020 | -00 | 82 265 |
| 23 24 | (Mg, Fe$)_{3}\left(\mathrm{OH}_{2} \mathrm{Si}_{3} \mathrm{AO}_{10} \cdot 4 \mathrm{H}_{2} \mathrm{O}\right.$, Vermiculite $\mathrm{CoSO}_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 1.525 1.530 | 1.545 1.548 | 1.545 1.550 | 0.020 0.020 | -04 | 170 |
| 25 | $\mathrm{Pr}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.5392 | 1.5479 | 1.5592 | 0.0200 | +84 | 171 |
| 25 | $\mathrm{Pr}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.5399 | 1.5494 | 1.5607 | 0.0208 | $+85$ | 171 |
| 26 | $\mathrm{Mg}_{3} \mathrm{~B}_{2}(\mathrm{OH})_{6}\left(\mathrm{PO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$, Lueneburgite | 1.520 | 1.54 | 1.545 | 0.025 | - 62 | 215 |
| 27 | $\mathrm{KMg}_{3} \mathrm{~F}_{2} \mathrm{Si}_{3} \mathrm{AlO}_{10}$, Phlogopite, Fluorine | 1.519 | 1.545 | 1.547 | 0.028 | - 10 | 262 |
| 28 | $\mathrm{Na}_{3} \mathrm{Fe}(\mathrm{CN})_{6} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.531 | 1.549 | 1.560 | 0.029 | - 77 | 46 |
| 29 | $\mathrm{Y}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.5433 | 1.549 | 1.5755 | 0.0322 | +51 | 171 |
| 30 | $\mathrm{Na}_{2} \mathrm{Ca}\left(\mathrm{CO}_{3}\right)_{2}$ | 1.504 | 1.547 |  | 0.043 | - 00 | 96 |
| 31 | $\begin{gathered} \mathrm{NaCa}_{3}\left(\mathrm{UO}_{2}\right)\left(\mathrm{CO}_{3}\right)_{3}\left(\mathrm{SO}_{4}\right) \mathrm{F} \cdot 10 \mathrm{H}_{2} \mathrm{O}, \\ \text { Schroeckingerite } \end{gathered}$ | 1.495 | 1.543 | 1.544 | 0.049 | - 16 | 179 |
| 32 | $\mathrm{NaCa}\left(\mathrm{UO}_{2}\right)\left(\mathrm{CO}_{3}\right)_{3}\left(\mathrm{SO}_{4}\right) \mathrm{F} \cdot 10 \mathrm{H}_{2} \mathrm{O}$ | 1.489 | 1.542 | 1.542 | 0.053 | -05 | 179 |
| 33 | $\left(\mathrm{NH}_{4}\right)_{5}\left(\mathrm{NO}_{3}\right)_{3}\left(\mathrm{SO}_{4}\right)$ | 1.488 | 1.540 1.546 | 1.552 | 0.064 | -50 +52 | 179 |
| 34 | $\mathrm{Fe}^{\prime \prime} \mathrm{Fe}_{4}^{\prime \prime}\left(\mathrm{SO}_{4}\right)_{6}(\mathrm{OH})_{2} \cdot 20 \mathrm{H}_{2} \mathrm{O}$, Copiapite | 1.531 | 1.546 | 1.597 | 0.066 0.130 | +52 +77 | 178 99 |
| 35 | $\mathrm{NaAlCO}_{3}(\mathrm{OH})_{2}$, Dawsonite | 1.466 | 1.542 1.543 | 1.596 | 0.130 0.137 | -77 .80 | 99 101 |
| 36 | $\mathrm{NH}_{4}\left(\mathrm{NO}_{3}\right)$ | 1.463 | 1.543 | 1.600 | 0.137 0.140 | -80 +32 | 101 |
| 37 | $\mathrm{CaS}_{4} \mathrm{O}_{6}$ | 1.535 | 1.540 | 1.675 | 0.140 | + 32 | 123 |


$n_{y}=1.550$ to 1.5599

| $\begin{aligned} & \text { No. } \\ & \text { on } \\ & \text { Chart } \end{aligned}$ | Substance | $n_{x}$ | $n_{y}$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | CaSiO ${ }_{3} \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Plombierite |  | 1.550 |  |  |  | 281 |
| 1 | ( $\mathrm{s}\left(\mathrm{NO}_{3}\right.$ ) | 1.560 | 1.558 |  | 0.002 | - 00 | 101 |
| 1 | $\mathrm{Al}(\mathrm{OH})_{3}$, Bayerite |  | 1.55 |  | 0.005 |  | 71 |
|  | I. $\mathrm{i}_{2} \mathrm{~K}_{10} \mathrm{Si}_{7} \mathrm{O}_{20}$ | 1.550 |  | 1.555 | 0.005 | 13 | 270 |
| 2 | $\mathrm{Rb}_{2} \mathrm{SeO}_{4}$ | 1.5515 | 1.5537 | 1.5582 | 0.0067 | $+67$ | 128 |
| 3 | Andesine (High-Temp) | 1.550 | 1.553. | 1.557 | 0.007 | -90 | 235 |
| 3 | Andesine (Low-Temp) | 1.551 | 1.554 | 1.558 | 0.007 | $+88$ | 235 |
| 2 | $\mathrm{Ca}_{4} \mathrm{O}_{3} \mathrm{Br}_{2} \cdot 15 \mathrm{H}_{2} \mathrm{O}$ | 1.552 | 1.555 | 1.559 | 0.007 | $+70$ | 51 |
| 4 | $\mathrm{NaBe}\left(\mathrm{PO}_{4}\right)$, Beryllonite | 1.5520 | 1.5579 | 1.561 | 0.009 | -68 | 191 |
| 5 | $\mathrm{Nd}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.5413 | 1.5505 | 1.5621 | 0.0092 | $+84$ | 172 |
| 6 | $\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{O}_{6} \mathrm{Br}_{2} \cdot 10 \mathrm{H}_{2} \mathrm{O}$ | 1.546 | 1.556 |  | 0.010 | - 00 | 85 |
| 6 | $\mathrm{CaS}_{2} \mathrm{O}_{6} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 1.5414 | 1.5516 |  | 0.0102 | - 00 | 133 |
| 7 | $\mathrm{Li}_{2} \mathrm{Si}_{2} \mathrm{O}_{5}$ | 1.547 | 1.550 | 1.558 | 0.011 | +55 | 256 |
| 8 | $\mathrm{ZrOCl}_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ |  | 1.552 | 1.563 | 0.011 | +00 | 52 |
|  | $\mathrm{Na}_{2} \mathrm{Ca}_{5}\left(\mathrm{SO}_{4}\right)_{6} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.5557 |  | 1.567 | 0.0113 |  | 157 |
| 9 | $\mathrm{K}_{5} \mathrm{CaSi}_{10} \mathrm{O}_{25}$ | 1.539 | 1.551 |  | 0.012 | - 00 | 255 |
| 10 | $\mathrm{K}_{3} \mathrm{Rh}(\mathrm{CN})_{6}$ | 1.5498 | 1.5513 | 1.5634 | 0.0136 | + 39 | 44 |
| 11 | $\mathrm{HfOCl}_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.543 | 1.557 |  | 0.014 | - 00 | 52 |
| 12 | $\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{O}_{6} \mathrm{Cl}_{2} \cdot 10 \mathrm{H}_{2} \mathrm{O}$ | 1.535 | 1.550 |  | 0.015 | - 00 | 85 |
| 13 | $\mathrm{BaSi}_{3} \mathrm{Al}_{2} \mathrm{O}_{\mathbf{2 0}} \cdot \mathbf{4 \mathrm { H } _ { 2 } \mathrm { O }}$, Edingtonite | 1.541 | 1.553 | 1.557 | 0.016 | - 54 | 242 |
| 14 | $\mathrm{Na}_{2} \mathrm{WO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.5526 | 1.5533 | 1.5695 | 0.0169 | +25 | 183 |
| 15 | $\mathrm{K}_{3} \mathrm{Mn}(\mathrm{CN})_{6}$ | 1.5527 | 1.5547 | 1.5710 | 0.0183 | $+43$ | 44 |
| 16 | $\mathrm{LiNaSiO}_{3}$ | 1.552 | 1.557 | 1.571 | 0.019 | +70 | 268 |
| 17 | $\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{O}_{6} \cdot \mathrm{CO}_{2} \cdot 11 \mathrm{H}_{2} \mathrm{O}$ | 1.532 | 1.552 |  | 0.020 | - 00 | 86 |
| 18 | $\mathrm{Sm}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.5427 | 1.5519 | 1.5629 | 0.0202 | +70 | 172 |
| 19 | $\mathrm{Mn}_{2} \mathrm{Al}_{3} \mathrm{Si}_{5} \mathrm{AlO}_{18}$, Cordierite, Mn | 1.537 | 1.558 | 1.558 | 0.021 | - 25 | 291 |
| 20 | $\left.\mathrm{Mg}_{( } \mathrm{OH}\right)_{2}$, Brucite |  | 1.559 | 1.580 | 0.021 | +00 | 68 307 |
| 21 | $\mathrm{Mg}_{3} \mathrm{~F}_{2} \mathrm{SiO}_{4}$ | 1.548 | 1.552 | 1.570 | 0.022 | + 33 | 307 |
| 22 | $\mathrm{Ca}_{4} \mathrm{Al}_{2}(\mathrm{OH})_{14} \cdot 6 \mathrm{H}_{2} \mathrm{O}$, Hydrocalumite | 1.535 1.535 | 1.553 1.557 | 1.557 | 0.022 | - 24 | 82 |
| 23 | $\mathrm{SrBr}_{2}-6 \mathrm{H}_{2} \mathrm{O}$ | 1.535 | 1.557 |  | 0.022 | - 00 | 29 |
| 24 | $\mathrm{NaH}_{2} \mathrm{AsO} \mathrm{C}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.5382 | 1.5535 | 1.5607 | 0.0225 | -68 | 193 |
| 25 | $2 \mathrm{CaSO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.559 | 1.5595 | 1.5736 | 0.0246 | $+14$ | 161 |
| 26 | $2 \mathrm{CaSO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$, Bassanite |  | 1.558 | 1.586 | 0.028 | +00 | 161 |
| 27 | $\mathrm{Na}_{3} \mathrm{CaCO}_{3}(\mathrm{OH})_{2} \mathrm{Si}_{3} \mathrm{Al}_{3} \mathrm{O}_{22}$, Cancrinite | 1.519 | 1.550 |  | 0.031 | -00 +50 | 254 |
| 28 | $\mathrm{Al}\left(\mathrm{PO}_{4}\right)$ | 1.546 | 1.556 | 1.578 | 0.032 | +50 +57 | 190 |
| 29 | $\mathrm{Mg}_{5} \mathrm{Fe}\left(\mathrm{PO}_{4}\right)_{4} \cdot 16 \mathrm{H}_{2} \mathrm{O}$ | 1.5468 | 1.5533 | 1.5820 | 0.0352 | +57 | 198 |
| 30 | $\mathrm{NiSO}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.509 | 1.552 |  | 0.043 | - 00 | 133 |
|  | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{UO}_{2}\left(\mathrm{SO}_{4}\right)_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ |  | 1.555 | 1.600 | 0.045 |  | 177 |
| 31 | $\mathrm{MgCrO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 1.5211 | 1.5500 | 1.5680 | 0.0469 | - 75 | 163 |
| 32 | $\mathrm{CoSO}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.506 | 1.553 |  | 0.047 | - 00 | 133 |
| 33 | $\mathrm{Na}_{3} \mathrm{Fe}\left(\mathrm{SO}_{4}\right)_{3} \cdot 3 \mathrm{H}_{2} \mathrm{O}$, Ferrinatrite |  | 1.558 | 1.614 | 0.055 | +00 | 157 |
| 34 35 | $\mathrm{CaCl}_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ $\mathrm{Na} 2 \mathrm{Co}(\mathrm{CNS})_{4} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Julienite | 1.4949 | 1.5504 |  | 0.0555 | -00 +00 | 28 |
| 35 35 | $\mathrm{Na}_{2} \mathrm{Co}(\mathrm{CNS})_{4} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Julienite <br> CaCO |  | 1.556 1.550 | 1.645 1.645 | 0.089 0.095 | +00 +00 | 42 |
| 36 | $\mathrm{Rb}_{2} \mathrm{~S}_{3} \mathrm{O}_{6}$ | 1.4874 | 1.5580 | 1.5867 | 0.0993 | -63 | 121 |
| 37 | $\mathrm{FeH}\left(\mathrm{SO}_{4}\right)_{2} \cdot 4 \mathrm{H}_{2} \mathrm{O}$, Rhomboclase | 1.533 | 1.550 | 1.635 | 0.102 | +27 | 136 |
| 38 | KCNO | 1.377 | 1.552 |  | 0.173 | - 00 | 22 |

$1.55<n_{y}<1.56$

$n_{y}=1.560$ to 1.5699

| $\begin{gathered} \text { No. } \\ \text { on } \\ \text { Chart } \end{gathered}$ | Substance | $n_{x}$ | $n_{y}$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $3 \mathrm{CdSO}_{4} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ |  | 1.565 |  |  | - 88 | 165 |
| 1 | $\mathrm{Be}_{3} \mathrm{Al}_{2} \mathrm{Si}_{6} \mathrm{O}_{18}$, Beryl | 1.564 | 1.568 |  | 0.004 | - 00 | 288 |
| 2 | $\mathrm{La}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 9 \mathrm{H}_{2} \mathrm{O}$ |  | 1.564 | 1.569 | 0.005 | +00 | 171 |
|  | $\mathrm{CuSeO}_{4} \cdot \mathrm{SH}_{2} \mathrm{O}$ |  | 1.56 | 1.565 |  |  | 170 |
| 3 | Rivaite |  | 1.56 |  | 0.006 | - 25 | 257 |
| 3 | $\mathrm{NaSi}_{3} \mathrm{GaO}_{8}$ | 1.552 |  | 1.558 | 0.006 | - ? | 232 |
| 4 | $\mathrm{Al}_{4}(\mathrm{OH})_{8} \mathrm{Si}_{4} \mathrm{O}_{10}$, Dickite | 1.560 | 1.562 | 1.566 | 0.006 | +75 | 264 |
| 5 | $\mathrm{Al}_{4}(\mathrm{OH})_{8} \mathrm{Si}_{4} \mathrm{O}_{10}$, Nacrite | 1.557 | 1.562 | 1.563 | 0.006 | +90 | 264 |
| 4 | $\mathrm{KAl}_{2}\left(\mathrm{PO}_{4}\right)_{2}(\mathrm{OH}) \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.562 | 1.564 | 1.568 | 0.006 | +71 | 210 |
| 3 | $\mathrm{Al}_{4}(\mathrm{OH})_{8} \mathrm{Si}_{4} \mathrm{O}_{10}$, Kaolinite | 1.561 | 1.565 | 1.566 | 0.006 | - 30 | 263 |
| 6 | $\mathrm{FeCl}_{2}$, Lawrencite | 1.566 | 1.567 |  | 0.006 | - 00 | 26 |
| 7 | $\mathrm{Cs}_{2}\left(\mathrm{SO}_{4}\right)$ | 1.5598 | 1.5644 | 1.5662 | 0.0064 | - 65 | 127 |
| 8 | $\mathrm{Mg}_{3}(\mathrm{OH})_{4} \mathrm{Si}_{2} \mathrm{O}_{5}$, Antigorite | 1.55 | 1.56 | 1.57 | 0.007 | - 50 | 261 |
| 9 | Labradorite | 1.559 | 1.562 | 1.567 | 0.008 | +82 | 235 |
| 10 | $\mathrm{NH}_{4} \mathrm{Al}_{2}\left(\mathrm{PO}_{4}\right)_{2}(\mathrm{OH}) \cdot 2.5 \mathrm{H}_{2} \mathrm{O}$ | 1.564 | 1.566 | 1.572 | 0.008 | +60 | 210 |
| 11 | $\mathrm{SmCl}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.564 | 1.569 | 1.573 | 0.009 | - 70 | 34 |
| 11 | $\mathrm{K}_{2} \mathrm{Ca}_{3} \mathrm{Si}_{6} \mathrm{O}_{16}$ | 1.56 |  | 1.57 | 0.01 | - | 257 |
| 12 | $\mathrm{MgB}_{2} \mathrm{O}_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$, Pinnoite |  | 1.565 | 1.575 | 0.010 | +00 | 115 |
| 13 | $\mathrm{CaSO}_{4}$ | 1.562 | 1.562 | 1.595 | 0.013 | + 30 | 129 |
| 14 | $\mathrm{Na}_{2} \mathrm{Sn}(\mathrm{OH})_{6}$ |  | 1.568 | 1.582 | 0.014 | +00 | 72 |
| 15 | $\mathrm{Be}\left(\mathrm{NH}_{2} \mathrm{SO}_{3}\right)_{2}$ | 1.552 | 1.563 | 1.567 | 0.015 | - 60 | 122 |
| 16 | $\mathrm{HNH}_{2} \mathrm{SO}_{3}$ | 1.553 | 1.563 | 1.568 | 0.015 | - 63 | 121 |
| 17 | $\mathrm{K}_{3} \mathrm{Fe}(\mathrm{CN})_{6}$ | 1.5660 | 1.5689 | 1.5831 | 0.0171 | + 49 | 44 |
| 18 | $\mathrm{Mg}(\mathrm{OH})_{2}$ |  | 1.5662 | 1.5853 | 0.0191 | +00 | 68 |
| 19 | $\mathrm{K}_{2} \mathrm{Ca}_{2} \mathrm{Mg}_{2}\left(\mathrm{SO}_{4}\right)_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Polyhalite | 1.547 | 1.560 | 1.567 | 0.020 | -62 | 157 |
| 20 | $\mathrm{Al}\left(\mathrm{PO}_{4}\right) \cdot 2 \mathrm{H}_{2} \mathrm{O}$, | 1.550 | 1.565 | 1.570 | 0.020 | - 55 | 200 |
| 21 | $\mathrm{Al}(\mathrm{OH})_{3}$, Gibbsite | 1.566 | 1.566 | 1.587 | 0.021 | +05 | 71 |
| 22 | $\mathrm{Al}(\mathrm{OH}) \mathrm{Si}_{2} \mathrm{O}_{5} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.543 | 1.565 | 1.565 | 0.022 | - 20 | 265 |
| 23 | $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.55 | 1.567 | 1.572 | 0.022 | - 62 | 207 |
| 24 | $\mathrm{Fe}_{2} \mathrm{Al}_{3} \mathrm{Si}_{5} \mathrm{AlO}_{18}$, Cordierite, Fe | 1.551 | 1.564 | 1.574 | 0.023 | - 70 | 290 |
| 25 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SeO}_{4}$ | 1.5607 | 1.5630 | 1.5846 | 0.0239 | +38 | 128 |
| 26 | $\mathrm{Li}_{2} \mathrm{~S}_{2} \mathrm{O}_{6} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.5487 | 1.5602 | 1.5788 | 0.0301 | +78 | 134 |
| 27 | $\mathrm{K}_{2} \mathrm{Ca}_{5}\left(\mathrm{SO}_{4}\right)_{6} \cdot \mathrm{H}_{2} \mathrm{O}$, Görgeyite | 1.550 | 1.565 | 1.583 | 0.033 | +85 | 157 |
| 28 | $\mathrm{CaCl}_{2} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 1.532 | 1.560 | 1.571 | 0.039 | -63 | 27 |
|  | $\mathrm{HfF}_{4}$ |  | 1.56 |  | 0.04 |  | 35 |
| 29 | $\mathrm{KH}_{2} \mathrm{AsO}_{4}$ | 1.5179 | 1.5674 |  | 0.0495 | - 00 | 187 |
| 29 | $\mathrm{Na}_{2} \mathrm{SO}_{3}$ | 1.515 | 1.565 |  | 0.050 | -00 | 120 |
| 30 | $\mathrm{K}_{2} \mathrm{Cd}\left(\mathrm{NO}_{2}\right)_{4}$ | 1.556 | 1.565 | 1.608 | 0.052 | $+48$ | 106 |
| 31 | $\mathrm{AlCl}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$, Chloraluminite | 1.507 | 1.560 |  | 0.053 | - 00 | 34 |
| 32 | $\mathrm{CaS}_{2} \mathrm{O}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.545 | 1.560 | 1.605 | 0.060 | +60 | 135 |
| 33 | $\mathrm{Na}_{4} \mathrm{Ca}\left(\mathrm{PO}_{4}\right)_{6}$ | 1.518 | 1.564 | 1.581 | 0.063 | -80 | 212 |
| 34 | $\mathrm{K}_{2} \mathrm{~S}_{3} \mathrm{O}_{6}$ | 1.4934 | 1.5641 | 1.602 | 0.1086 | - 72 | 121 |
| 35 | $\mathrm{Ca}(\mathrm{OH}) \mathrm{VO}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.447 | 1.564 | 1.583 | 0.136 | - 44 | 104 |
| 36 | $\mathrm{KAuCl}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.55 | 1.56 | 1.69 | 0.14 | +25 | 45 |
| 37 | $\mathrm{Li}_{2} \mathrm{CO}_{3}$ | 1.428 | 1.567 | 1.572 | 0.144 | -15 | 90 |
| 38 | $\mathbf{M g P t}(\mathrm{CN})_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ |  | 1.5608 | 1.91 | 0.35 | +00 | 31 |



L

| $\begin{gathered} \text { No. } \\ \text { on } \\ \text { Chart } \end{gathered}$ | Substance | $n_{x}$ | $n_{y}$ | $n_{z}$ | $n_{z}{ }^{-n_{x}}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\mathrm{K}_{4} \mathrm{Fe}(\mathrm{CN})_{5} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ |  | 1.5772 |  |  | - 78 | 41 |
| 1 | $\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{O}_{6} \mathrm{I}_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.572 | 1.575 |  | 0.003 | - 00 | 86 |
| 2 | $\mathrm{BaSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{6}$ |  | 1.57 | 1.5712 | 0.004 | +00 | 237 |
| 3 | $\mathrm{Na}_{2} \mathrm{Al}_{2} \mathrm{Si}_{2} \mathrm{O}_{8} \cdot \mathrm{H}_{2} \mathrm{O}$, Lembergite | 1.569 | 1.570 | 1.573 | 0.004 | $+67$ | 259 |
| 4 | $\mathrm{Ca}_{2} \mathrm{Si}_{2} \mathrm{O}_{6} \cdot \mathrm{H}_{2} \mathrm{O}$, Tobermorite | 1.570 | 1. 571 | 1.575 | 0.005 | + 25 | 281 |
| 5 | $\mathrm{Be}_{3} \mathrm{Al}_{2} \mathrm{Si}_{6} \mathrm{O}_{18}$, Emerald | 1.573 | 1.578 |  | 0.005 | - 00 | 288 |
| 6 | $\mathrm{Mg}_{5} \mathrm{Al}(\mathrm{OH})_{8} \mathrm{Si}_{3} \mathrm{AlO}_{10}$, Clinochlore | 1.57 | 1.57 | 1.58 | 0.006 | + 20 | 260 |
|  | $\mathrm{Ca}_{5} \mathrm{H}_{2}\left(\mathrm{AsO}_{4}\right)_{4} \cdot 9 \mathrm{H}_{2} \mathrm{O}$ | 1.568 | 1.57 | 1.577 | 0.009 |  | 195 |
| 7 | $\mathrm{KAl}_{2}\left(\mathrm{PO}_{4}\right)_{2}(\mathrm{OH}) \cdot 0.5 \mathrm{H}_{2} \mathrm{O}$ | 1.565 | 1.571 | 1.574 | 0.009 | - 71 | 210 |
| 8 | $\mathrm{Zn}(\mathrm{OH})_{2}$ | 1.5705 | 1. 5777 | 1.5796 | 0.0091 | - 51 | 69 |
| 9 | $\mathrm{K}_{2} \mathrm{Ca}_{3} \mathrm{Si}_{6} \mathrm{O}_{16}$ | 1.56 |  | 1.57 | 0.01 | - | 266 |
| 9 | $\mathrm{GdCl}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.565 | 1.570 | 1.575 | 0.010 | - 75 | 34 |
| 10 | Bytownite | 1.567 | 1.571 | 1.577 | 0.010 | -84 | 236 |
| 11 | $\mathrm{LiSiAlO}_{4}$ |  | 1.573 | 1.583 | 0.010 | +00 | 227 |
| 12 | $\mathrm{LiSiAlO}_{4}$ | 1.575 | 1.578 | 1.586 | 0.011 | +70 | 227 |
| 13 | $\mathrm{H}_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Hydrogen-Autunite | 1.568 | 1.579 |  | 0.011 | - 00 | 205 |
| 14 | $\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{O}_{6} \mathrm{Br}_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.558 | 1.570 |  | 0.012 | - 00 | 85 |
| 15 | $\mathrm{NaAlO}_{2}$ | 1.566 | 1.575 | 1.580 | 0.014 | - 30 | 73 |
| 16 | $\mathrm{Mg}_{2} \mathrm{PO}_{4} \mathrm{~F}$, Wagnerite | 1.5678 | 1.5719 | 1.5824 | 0.0146 | +28 | 202 |
| 17 | $\mathrm{Na}_{2} \mathrm{Ca}_{3} \mathrm{Si}_{6} \mathrm{O}_{16}$, Devitrite | 1.564 | 1.570 | 1.579 | 0.015 | +75 | 256 |
| 18 | $\mathrm{Mg}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}, \mathrm{Mg}$-Autunite | 1.559 | 1.574 |  | 0.016 | - 00 | 208 |
| 19 | Thomsonite, thallian | 1.568 | 1.574 | 1.585 | 0.017 | $+50$ | 244 |
| 20 | $\mathrm{Al}(\mathrm{OH})_{3}$ | 1.577 | 1.577 | 1.595 | 0.018 | +05 | 71 |
|  | $\mathrm{Ca}_{4} \mathrm{O}_{3} \mathrm{I}_{2} \cdot 15 \mathrm{H}_{2} \mathrm{O}$ |  | 1.575 | 1.595 | 0.02 | $+$ | 51 173 |
| 21 | $\mathrm{KAl}_{3}\left(\mathrm{SO}_{4}\right)_{2}(\mathrm{OH})_{6}$, Alunite |  | 1.572 | 1.592 | 0.020 | +00 | 173 |
| 22 | $\mathrm{Na}_{4} \mathrm{Ca}_{4} \mathrm{ClCO}_{3} \mathrm{Si}_{1} \mathrm{Al}_{9} \mathrm{O}_{48}$ | 1.550 | 1.571 |  | 0.021 | - 00 | 253 |
| 23 | $\mathrm{K}_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathrm{nH}_{2} \mathrm{O}$ | 1.553 | 1.575 | 1.575 | 0.022 | -05 | 206 |
| 24 | $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.555 | 1.575 | 1.578 | 0.023 | - 20 | 207 |
| 25 | $\mathrm{Na} \mathrm{Ir}\left(\mathrm{SO}_{3}\right)_{3}\left(\mathrm{NH}_{3}\right)_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.546 | 1.570 |  | 0.024 | -00 | 133 |
| 26 | $1 \mathrm{Mg}(\mathrm{F}, \mathrm{OH})_{2} \cdot 1 \mathrm{Mg}_{2} \mathrm{SiO}_{4}$, Norbergite | 1.563 | 1.570 | 1.590 | 0.027 | +45 | 307 |
| 27 | $\mathrm{Ca}(\mathrm{OH})_{2}$, Portlandite | 1.545 | 1.574 |  | 0.029 | - 00 | 69 |
| 28 | $\mathrm{NH}_{4} \mathrm{Mg}_{3} \mathrm{~F}_{2} \mathrm{Si}_{3} \mathrm{AlO}_{4}$, Phlogopite, $\mathrm{NH}_{4}$ | 1.54 | 1.57 | 1.57 | 0.03 | - 10 | 262 |
| 28 | $\mathrm{KFe}_{2}^{\prime \prime}\left(\mathrm{Fe}^{\prime \prime \prime}, \mathrm{Mg}, \mathrm{Al}_{5} \mathrm{~S}_{5} \mathrm{Si}_{8} \mathrm{O}_{20} \cdot 4 \mathrm{H}_{2} \mathrm{O}\right.$, Stilpnomelane | 1.546 | 1.576 | 1.576 1.573 | 0.030 | - 10 | 265 |
| 29 | $(\mathrm{Mg}, \mathrm{Fe})_{3}(\mathrm{OH})_{2} \mathrm{Si}_{3} \mathrm{AlO}_{10} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 1.542 | 1.573 | 1.573 | 0.031 | - 04 | 265 |
| 30 | $\mathrm{Mg}_{3}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Hoernesite | 1.563 | 1.571 | 1.596 | 0.033 | +60 | 198 |
| 31 | $\mathrm{Mg}_{3}(\mathrm{OH})_{2} \mathrm{Si}_{4} \mathrm{O}_{10}$, Talc | 1.540 | 1.575 | 1.575 | 0.035 | - 15 | 259 |
| 32 | $\mathrm{K}_{2} \mathrm{Mg}_{5} \mathrm{Al}(\mathrm{OH})_{4} \mathrm{Si}_{5} \mathrm{Al}_{3} \mathrm{O}_{20}$, Eastonite | 1.542 | 1.577 | 1.578 | 0.036 | -10 +43 | 262 |
| 33 | $\mathrm{Ca}\left(\mathrm{SO}_{4}\right)$, Anhydrite | 1.5698 | 1.5754 | 1.6136 | 0.0438 | $+43$ | 129 |
| 34 | $\mathrm{KPtCl}_{3} \cdot \mathrm{NH}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.5438 | 1.5754 | 1.588 | 0.044 | -64 | 53 |
| 34 | $\mathrm{P}_{2} \mathrm{O}_{5}$ | 1.545 | 1.578 | 1.589 | 0.044 | +65 +78 | 66 |
| 35 | $\mathrm{MnCl}_{2} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 1.555 | 1.575 | 1.607 | 0.052 | +78 | 29 |
| 36 | $\mathrm{CaH}_{4}\left(\mathrm{PO}_{4}\right)_{2}$ | 1.548 | 1.572 | 1.602 | 0.054 | +85 | 188 |
| 37 | $\mathrm{NH}_{4} \mathrm{H}_{2}\left(\mathrm{AsO}_{4}\right)$ | 1.5217 | 1.5766 |  | 0.0549 | -00 | 187 |
| 38 | $\mathrm{Na}_{2} \mathrm{Cu}\left(\mathrm{SO}_{4}\right)_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Kroehnkite | 1.544 | 1.578 | 1.601 | 0.057 | - 79 | 138 |
| 39 | $\mathrm{CaH}_{2} \mathrm{P}_{2} \mathrm{O}_{7}$ | 1.518 | 1.578 |  | 0.060 | - 00 | 214 |
| 40 | $\mathrm{CuFe}_{4}\left(\mathrm{SO}_{4}\right)_{6}(\mathrm{OH})_{2} \cdot 2 \mathrm{2OH}_{2} \mathrm{O}$, Cuprocopiapite | 1.558 | 1.575 | 1.620 | 0.062 | +63 +75 | 178 |
| 41 | $\mathrm{CuSO}_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.554 | 1.577 | 1.618 | 0.064 | +75 | 166 |
| 42 | $\mathrm{Ba}\left(\mathrm{ClO}_{3}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.562 | 1.577 | 1.635 | 0.073 | +56 +85 | 109 |
| 43 | $\mathrm{NiCl}_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.535 | 1.57 | 1.61 | 0.075 | +85 | 29 |
| 44 | $\mathrm{Na}_{4} \mathrm{Fe}_{2}\left(\mathrm{SO}_{4}\right)_{4}(\mathrm{OH})_{2} \cdot 3 \mathrm{H}_{2} \mathrm{O}$, Metasideronatrite | 1.543 | 1.575 | 1.634 | 0.091 | +60 | 176 |
| 45 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{H}\left(\mathrm{PO}_{4}\right)$ | 1.468 | 1.570 | 1.582 1.579 | 0.114 | - 28 | 187 |
| 46 | $\mathrm{Bo}(\mathrm{OH})$ | 1.450 | 1.574 | 1.579 | 0.129 | - 22 | 69 |
| 47 | $\mathrm{Bo}(\mathrm{OH})$ | 1.434 | 1.570 | 1.588 | 0.154 | - 35 | 69 |


${ }^{n_{y}}=1.580$ to 1.5899

| $\begin{aligned} & \text { No. } \\ & \text { on } \\ & \text { Chart } \end{aligned}$ | Substance | $n_{x}$ | $n_{y}$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\mathrm{K}_{4} \mathrm{Ru}(\mathrm{CN})_{6} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ |  | 1.5837 |  |  | - 54 | 42 |
|  | $\mathrm{MgPt}(\mathrm{CN})_{4} \cdot \mathrm{C}_{3} \mathrm{H}_{8} \mathrm{O}_{3} \cdot 5^{\mathrm{H}} \mathrm{C}^{\mathrm{O}}$ |  | 1.584 |  |  | - 18 | 31 |
| 1 | $\mathrm{NaK}_{3} \mathrm{FeCl}_{6}$, Rinneite |  | 1.5886 | 1.5894 | 0.0008 | +00 | 35 |
| 2 | $\mathrm{Ca}_{3}\left(\mathrm{PO}_{4}\right)_{2}$ | 1.588 | 1.5891 | 1.591 | 0.003 | $+75$ | 189 |
| 3 | $\mathrm{NaCaAlSi} \mathrm{O}_{7}$ | 1.575 | 1.580 |  | 0.005 | - 00 | 295 |
|  | $\mathrm{Al}(\mathrm{OH})_{3}$, Bayerite |  | 1.583 |  | 0.005 |  | 71 |
| 4 | $\mathrm{CaSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8}$ |  | 1.585 | 1.590 | 0.005 | +00 | 236 |
| 5 | $\mathrm{NaSiAlO}_{4} \cdot \mathrm{CaAl}_{2} \mathrm{O}_{4}$ | 1.588 | 1.582 |  | 0.006 | - 00 | 225 |
| 5 | $\mathrm{K}_{2} \mathrm{NaFe}(\mathrm{CN})_{6}$ | 1.581 | 1.585 | 1.590 | 0.0075 | $+80$ | 45 |
| 6 | $7 \mathrm{n}_{3}\left(\mathrm{PO}_{4}\right)_{2} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 1.574 | 1.582. | 1.582 | 0.008 | - 20 | 197 |
| 7 | $\mathrm{MgSnCl} 6_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ |  | 1.5885 | 1.597 | 0.0085 | +00 | 50 |
| 8 | $\mathrm{NaH}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 1.57 | 1.580 |  | 0.01 | - 00 | 206 |
| 9 | $\mathrm{Ca}_{3} \mathrm{Si}_{3} \mathrm{O}_{9} \cdot \mathrm{H}_{2} \mathrm{O}$, Xonotlite | 1.583 | 1.583 | 1.593 | 0.010 | $+10$ | 291 |
| 10 | $\mathrm{NH}_{4} \mathrm{Fe}_{3} \mathrm{H}_{8}\left(\mathrm{PO}_{4}\right)_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ |  | 1.580 | 1.591 | 0.011 | $+00$ | 195 |
| 11 | $\mathrm{K}_{2} \mathrm{NaFe}(\mathrm{CN})_{6}$ | 1.580 | 1.581 | 1.591 | 0.011 | +31 | 45 |
| 12 | $\mathrm{CaH}\left(\mathrm{AsO}_{4}\right) \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Pharmacolite | 1.583 | 1.589 | 1.594 | 0.011 | - 79 | 194 |
| 13 | $\mathrm{CaSi} \mathrm{Cl}_{2} \mathrm{O}_{8}$, Anorthice | 1.574 | 1.581 | 1.586 | 0.012 | - 77 | 236 |
| 14 | $\mathrm{SrSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8}$ | 1.574 | 1.582 | 1.586 | 0.012 | - 70 | 237 |
| 15 | $\mathrm{Li}_{2} \mathrm{SiO}_{3}$ |  | 1.587 | 1.599 | 0.012 | +00 | 267 |
| 16 | $\mathrm{Cu}_{4}(\mathrm{OH})_{2} \mathrm{Si}_{2} \mathrm{O}_{7}$, Custerite | 1.586 | 1.589 | 1.598 | 0.012 | $+60$ | 297 |
| 17 | $\mathrm{CaSi} \mathrm{Al}_{2} \mathrm{O}_{8}$ | 1.5755 | 1.5832 | 1.5885 | 0.0130 | - 77 | 236 |
| 17 | $\left(\mathrm{aSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8}\right.$ | 1.5768 | 1.5846 | 1.5903 | 0.0135 | - 72 | 236 |
| 18 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{NaFe}(\mathrm{CN})_{6}$ | 1.584 | 1.587 | 1.598 | 0.014 | $+10$ | 45 |
| 19 | $\mathrm{K}_{2} \mathrm{Ca}_{3} \mathrm{Si}_{6} \mathrm{O}_{16}$ | 1.575 | 1.582 | 1.590 | 0.015 | $+70$ | 266 |
| 19 | $\mathrm{K}_{2} \mathrm{Ca}_{2} \mathrm{Si}_{6} \mathrm{O}_{15}$ | 1.575 | 1.58 | 1.59 | 0.015 | $+70$ | 257 |
| 20 | $\mathrm{L} . \mathrm{i} \mathrm{AlO}_{2}$ | 1.570 | 1.586 |  | 0.016 | - 00 | 73 |
| 21 | $\mathrm{BaSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8}$, Paracelsian | 1.5702 | 1.5824 | 1.5869 | 0.0167 | - 52 | 237 |
| 22 | Thomsonite, argentian | 1.582 | 1.588 | 1.600 | 0.018 | +60 | 244 |
| 23 | $\mathrm{UO}_{2} \mathrm{SO}_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.574 | 1.589 | 1.593 | 0.019 | - 54 | 177 |
| 24 | $\mathrm{Na}_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.562 | 1.582 |  | 0.020 | - 00 | 206 |
| 25 | $\mathrm{CaP}_{2} \mathrm{O}_{6}$ | 1.573 | 1.587 | 1.596 | 0.023 | - 80 | 211 |
| 26 | $\mathrm{Tl}_{2} \mathrm{Mg}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5705 | 1.5884 | 1.5949 | 0.0244 | - 75 | 143 |
| 27 | $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, U'ranospinite | 1.56 | 1.586 |  | 0.026 | - 00 | 207 |
| 28 | $\mathrm{Ca}_{2} \mathrm{Fe}(\mathrm{CN})_{6} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 1.5700 | 1.5818 | 1.5961 | 0.0261 | $+85$ | 32 |
| 29 | $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.560 | 1.582 | 1.587 | 0.027 | - 46 | 207 |
| 30 | $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2}+\mathrm{H}_{2} \mathrm{O}$ | 1.562 | 1.589 |  | 0.027 | - 00 | 207 |
| 31 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Ca}_{5}\left(\mathrm{SO}_{4}\right)_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.567 | 1. 580 | 1.595 | 0.028 | +86 | 157 |
| 32 | $\mathrm{Al}\left(\mathrm{PO}_{4}\right) \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Variscite | 1.565 | 1.588 | 1.593 | 0.028 | - 50 | 200 |
| 33 | $\mathrm{Al}(\mathrm{OH}) \mathrm{Si}_{2} \mathrm{O}_{5} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.559 | 1.588 | 1.588 | 0.029 | - 30 | 265 |
| 34 | $\mathrm{KLiFeAl}(\mathrm{OH})_{2} \mathrm{Si}_{3} \mathrm{AlO}_{10}$, Zinnwaldite | 1.55 | 1.58 | 1.58 | 0.03 | - 30 | 263 |
| 35 | $\mathrm{H}_{2} \mathrm{UO}_{2}\left(\mathrm{SO}_{4}\right)_{2} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 1.555 | 1.586 | 1.586 | 0.031 | - 10 | 177 |
| 36 | $\left(\mathrm{UO}_{2}\right)_{2} \mathrm{H}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 1.555 | 1.586 | 1.586 | 0.031 | - 05 | 136 |
| 37 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Al}_{2} \mathrm{H}_{4}\left(\mathrm{PO}_{4}\right)_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.565 | 1.586 | 1.597 | 0.032 | - 72 | 195 |
| 38 | $\mathrm{KAl}_{2}(\mathrm{OH})_{2} \mathrm{Si}_{3} \mathrm{AlO}_{10}$, Muscovite | 1.552 | 1.582 | 1.588 | 0.036 | - 45 | 263 |
| 39 | $2 \mathrm{Ca}_{4} \mathrm{O}_{3}\left(\mathrm{CNS}\right.$ ) $\cdot \mathbf{2 5 \mathrm { H } _ { 2 } \mathrm { O }}$ | 1.586 | 1.587 | 1.622 | 0.036 | $+12$ | 51 |
| 40 | $\mathrm{KMg}_{3}(\mathrm{OH})_{2} \mathrm{Si}_{3} \mathrm{AlO}_{10}$, Phlogopite | 1.548 | 1.588 | 1.588 | 0.040 | - 10 | 261 |
| 41 | AlOHSi ${ }_{2} \mathrm{O}_{5}$, Pyrophyllite | 1.552 | 1.588 | 1.600 | 0.048 | - 57 | 261 |
| 42 | $\mathrm{NaCa} 3\left(\mathrm{UO}_{2}\right)\left(\mathrm{CO}_{3}\right)_{3} \mathrm{SO}_{4} \mathrm{~F} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 1.532 | 1.581 |  | 0.049 | - 00 | 179 |
| 43 | $\mathrm{Fe}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 7 \mathrm{H}_{2} \mathrm{O}$, Kornelite | 1.572 | 1.586 | 1.640 | 0.068 | +55 | 171 |
| 44 | $(\mathrm{La}, \mathrm{Ce})_{2}\left(\mathrm{CO}_{3}\right)_{3} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Lanthanite | 1.53 | 1.587 | 1.613 | 0.083 | - 63 | 95 |
| 45 | $4 \mathrm{Co}\left(\mathrm{NH}_{2}\right)_{2} \cdot \mathrm{CaSO}_{4}$ | 1.523 | 1.583 | 1.615 | 0.092 | - 70 | 179 |
| 46 | $\mathrm{Na}\left(\mathrm{NO}_{3}\right)$, Soda-Niter | 1.3361 | 1.5874 |  | 0.2513 | - 00 | 101 |


$n_{y}=1.590$ to 1.5999

| No. <br> on <br> Onart |  |  |  |  |  |  |  |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |


$n_{y}=1.600$ to 1.6199

| $\begin{gathered} \text { No. } \\ \text { on } \\ \text { Chart } \end{gathered}$ | Substance | ${ }^{n} \boldsymbol{x}$ | $n_{y}$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\mathrm{Cu}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 16 \mathrm{H}_{2} \mathrm{O}$, Zeunerite |  | 1.602 |  |  | - 00 | 209 |
|  | $\mathrm{K}_{4} \mathrm{Os}(\mathrm{CN})_{6} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ |  | 1.6071 |  |  | - 47 | 42 |
|  | $\mathrm{Cu}_{2}\left(\mathrm{UO}_{2}\right)_{2} \cdot\left(\mathrm{AsO}_{4}\right)_{2} \cdot 10 \mathrm{H}_{2} \mathrm{O}$ |  | 1.610 |  |  | - 00 | 209 |
|  | $\mathrm{Zn}\left(\mathrm{NH}_{3}\right)_{2} \mathrm{Cl}_{2}$ |  | 1.618 |  |  | - 75 | 53 |
| 1 | $\mathrm{Ca}_{5} \mathrm{H}_{2}\left(\mathrm{AsO}_{4}\right)_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 1.613 |  | 1.615 | 0.002 |  | 195 |
| 1 | $\mathrm{Cu}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ |  | 1.61 | 1.61 | 0.002 | +00 | 208 |
| 2 | $\mathrm{Ca}_{3}\left(\mathrm{PO}_{4}\right)_{2}$ |  | 1.607 | 1.604 | 0.003 | - 00 | 189 |
| 1 | $\mathrm{BaAl}_{2} \mathrm{O}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.610 | 1.611 | 1.613 | 0.003 | + | 83 |
| 3 | $\mathrm{K}_{2} \mathrm{CaSiO}_{4}$ |  | 1.600 | 1.605 | 0.005 | +00 | 300 |
| 4 | $\mathrm{Ca}_{2} \mathrm{Si}_{2} \mathrm{O}_{6} \cdot \mathrm{H}_{2} \mathrm{O}$, Riversideite | 1.600 | 1.601 | 1.605 | 0.005 | +50 | 281 |
| 5 | $\mathrm{Ca}_{10}\left(\mathrm{PO}_{4}\right)_{6} \mathrm{CO}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.598 | 1.603 |  | 0.005 | - 00 | 204 |
| 6 | $\mathrm{Ca}_{2} \mathrm{SiO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$, Hillebrandite | 1.605 | 1.61 | 1.612 | 0.007 | - 42 | 305 |
| $6{ }^{\prime}$ | $\mathrm{CaSi}_{2} \mathrm{AlGaO}_{8}$ | 1.604 |  | 1.611 | 0.007 | 90? | 232 |
| $6^{\prime}$ | $\mathrm{CaSiGeAl} \mathrm{O}_{8}$ | 1.608 |  | 1.615 | 0.007 | 90? | 232 |
| $6 "$ | $\mathrm{CaSi}_{2} \mathrm{AlGaO}_{3}$ | 2.604 |  | 1.611 | 0.007 | 90? | 232 |
| $6^{\prime}$ | $\mathrm{KSi}_{3} \mathrm{FeO}_{8}$ | 1.601 |  | 1.609 | 0.008 | 90? | 232 |
| 7 | $\mathrm{Ba}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$, Uranocircite | 1.604 | 1.613 |  | 0.009 | - 00 | 209 |
| 8 | $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 10 \mathrm{H}_{2} \mathrm{O}$, Autunite | 1.59 | 1.60 |  | 0.01 | - 00 | 207 |
| 8 | $\mathrm{Mn}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 8 \cdot \mathrm{H}_{2} \mathrm{O}, \mathrm{Mn}$-Autunite | 1.59 | 1.60 |  | 0.01 | - 00 | 208 |
| $8{ }^{\prime}$ | $\mathrm{Al}_{4} \mathrm{OSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{12}, \mathrm{Mullite}$ | 1.600 |  | 1.610 | 0.010 |  | 268 |
| 8 | $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 8-\mathrm{H}_{2} \mathrm{O}$, Meta-Autunite-I | 1.590 | 1.600 |  | 0.010 | - 00 | 208 |
| 8 | $\mathrm{CoCl}\left(\mathrm{ClO}_{4}\right)_{2} 6 \mathrm{NH}_{3}$ | 1.600 | 1.610 |  | 0.010 | - 00 | 112 |
| 8 | $\left(\mathrm{NH}_{4}\right)_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.601 | 1.611 |  | 0.010 | - 00 | 206 |
| 9 | $\mathrm{Al}_{2} \mathrm{~F}_{2} \mathrm{SiO}_{4}$, Topaz | 1.6072 | 1.6104 | 1.6176 | 0.0104 | +67 | 306 |
| 10 | $\mathrm{Mg}_{2} \mathrm{P}_{2} \mathrm{O}_{7}$ | 1.602 | 1.604 | 1.615 | 0.013 | +21 | 214 |
| 11 | $\mathrm{CaCl}_{2}$, Hydrophilite | 1.600 | 1.605 | 1.613 | 0.013 | +50 | 26 |
|  | $\mathrm{NaGe} \mathrm{AlO}_{3}$ | 1.606 | 1.61 | 1.619 | 0.013 |  | 232 |
| 12 | $\mathrm{SiO}_{2}$ | 1.599 | 1.60 | 1.604 | 0.014 | +54 | 64 |
| 13 | $\mathrm{Ca}_{2} \mathrm{Si}_{2} \mathrm{O}_{6} \cdot 3 \mathrm{H}_{2} \mathrm{O}$, Crestmoreite | 1.593 | 1.603 | 1.607 | 0.014 | - 70 | 282 |
| 14 | $\mathrm{Na}_{10} \mathrm{Fe}_{2} \mathrm{Si}_{8} \mathrm{O}_{24}$ |  | 1.609 | 1.625 | 0.016 | +00 | 267 |
|  | $\mathrm{SrH}\left(\mathrm{PO}_{4}\right)$ | 1.608 |  | 1.625 | 0.017 |  | 187 |
| 15 | $\mathrm{Mg}_{5} \mathrm{Fe}_{2} \mathrm{Si}_{8} \mathrm{O}_{22} \mathrm{~F}_{2}$ | 1.604 | 1.613 | 1.623 | 0.019 | +88 | 284 |
| 16 | $\mathrm{Na}_{2} \mathrm{CaMg}_{5} \mathrm{Si}_{4} \mathrm{O}_{22} \mathrm{~F}_{2}$ | 1.603 | 1.614 | 1.622 | 0.019 | - 72 | 285 |
| 17 | $\mathrm{NaCa}_{2} \mathrm{Mg}_{5} \mathrm{Si}_{7} \mathrm{AlO}_{22} \mathrm{~F}_{2}$ | 1.605 | 1.617 | 1.624 | 0.019 | -69 | 286 |
| 18 | $\mathrm{Tl}_{2} \mathrm{Cu}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5996 | 1.6096 | 1.6190 | 0.0194 | -85 | 149 |
| 19 | $\mathrm{NaCa}_{2} \mathrm{Mg}_{5} \mathrm{Si}_{7} \mathrm{AlO}_{22}(\mathrm{OH})_{2}$, Edenite | 1.61 | 1.613 | 1.63 | 0.02 | + 50 | 286 |
| 20 | $\mathrm{Li}_{4} \mathrm{SiO}_{4}$ | 1.594 | 1.60 | 1.614 | 0.020 | +25 | 304 |
| 21 | $\mathrm{Tl}_{2} \mathrm{Ni}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.6024 | 1.6183 | 1.6224 | 0.0200 | -62 | 148 |
| 18 | $\mathrm{Fe}(\mathrm{OH}) \mathrm{Si}_{2} \mathrm{O}_{5} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.589 | 1.600 | 1.610 | 0.021 | - 86? | 266 |
| 22 | $\mathrm{Zn}_{4}(\mathrm{OH})_{2} \mathrm{Si}_{2} \mathrm{O}_{7} \cdot \mathrm{H}_{2} \mathrm{O}$, Hemimorphite | 1.614 | 1.617 | 1.636 | 0.022 | +46 | 296 |
| 23 | $\mathrm{Tl}_{2} \mathrm{Co}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.6009 | 1.6176 | 1.6238 | 0.0229 | -67 | 147 |
| 23 | $\mathrm{Tl}_{2} \mathrm{Fe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5929 | 1.6093 | 1.6162 | 0.0233 | -69 | 146 |
| 23 | $\mathrm{Tl}_{2} \mathrm{Zn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.5931 | 1.6093 | 1.6168 | 0.0237 | -69 | 144 |
| 24 | $\mathrm{BaSi}_{2} \mathrm{O}_{5}$, Sanbornite | 1.597 | 1.612 | 1.621 | 0.024 | - 75 | 258 |
|  | $\left(\mathrm{NH}_{4}\right)_{4}\left(\mathrm{UO}_{2}\right)\left(\mathrm{CO}_{3}\right)_{3}$ | 1.60 | 1.6 | 1.625 | 0.025 | - | 99 |
| 25 | $\mathrm{Ca}_{2} \mathrm{Mg}_{5} \mathrm{Si}_{8} \mathrm{O}_{32}(\mathrm{OH})_{2}$, Tremolite | 1.599 | 1.613 | 1.625 | 0.026 | - 88 | 285 |
| 26 | $\mathrm{NH}_{4} \mathrm{Fe}(\mathrm{CN})_{6} \cdot 2 \mathrm{NH}_{4} \mathrm{Cl} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.5922 | 1.6198 |  | 0.0276 | - 00 | 42 |
| 26 | Hydrogen-Uranospinite | 1.584 | 1.612 |  | 0.028 | - 00 | 205 |
| 26 | $\mathrm{H}_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{4} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.584 | 1.612 |  | 0.028 | - 00 | 205 |
| 27 | $\mathrm{Mg}_{9} \mathrm{~F}_{2} \mathrm{Si}_{4} \mathrm{O}_{6}$ | 1.608 | 1.618 | 1.636 | 0.028 | +76 | 308 |
| 28 | $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2} \cdot \mathrm{nH}_{2} \mathrm{O}$, Air dried | 1.591 | 1.619 | 1.621 | 0.030 | - 30 | 207 |
| 29 | $\mathrm{Na}_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.586 | 1.617 |  | 0.031 | -00 | 206 |
| 30 | $\mathrm{Mg}_{7} \mathrm{~F}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$ | 1.598 | 1.606 | 1.630 | 0.032 | +59 | 307 |
| 31 | $\mathrm{Fe}_{3}(\mathrm{OH})_{2} \mathrm{Si}_{4} \mathrm{O}_{10}$, Minnesotaite | 1.586 | 1.618 | 1.618 | 0.032 | -04 | 259 |
| 32 | $\mathrm{CaAl}_{4} \mathrm{O}_{7}$ | 1.617 | 1.617 | 1.651 | 0.035 | +05 | 79 |
| 33 | $\mathrm{Al}_{3} \mathrm{BO}_{6}$ | 1.586 | 1.603 | 1.623 | 0.037 | +87 | 114 |
| 34 | $\mathrm{HNaCa}_{2} \mathrm{Si}_{3} \mathrm{O}_{9}$, Pectolite | 1.595 | 1.604 | 1.632 | 0.037 | +60 | 293 |
| 35 | $\mathrm{KFeH}_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.592 | 1.614 | 1.630 | 0.038 | -79 | 195 |
| 36 | $\mathrm{Li}_{2} \mathrm{~K}_{2} \mathrm{Fe}(\mathrm{CN})_{6} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.5883 | 1.6007 | 1.6316 | 0.0433 | $+66$ | 40 |
| 37 | $\mathrm{Ca}_{3} \mathrm{Si}_{3} \mathrm{O}_{9}$, Pseudowollastonite | 1.610 | 1.611 | 1.654 | 0.044 | +10 | 291 |
| 38 | $\mathrm{Y}\left(\mathrm{PO}_{4}\right) \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Weinschenkite | 1.600 | 1.608 | 1.645 | 0.045 | + 30 | 200 |
| 39 | $\mathrm{Ca}_{4}\left(\mathrm{CO}_{3}\right) \mathrm{Si}_{6} \mathrm{Al}_{6} \mathrm{O}_{24}$, Meionite | 1.565 | 1.610 |  | 0.045 | - 00 | 253 |
| 40 | $\mathrm{CaH}\left(\mathrm{AsO}_{4}\right) \cdot \mathrm{H}_{2} \mathrm{O}$, Haidingerite | 1.590 | 1.602 | 1.638 | 0.048 | +58 | 194 |
| 41 | $\mathrm{AlBr}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.555 | 1.605 |  | 0.050 | - 00 | 34 |
| 42 | $\mathrm{Fe}_{3}\left(\mathrm{PO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Vivianite | 1.5788 | 1.6024 | 1.6294 | 0.0506 | +84 | 198 |
| 43 | $\mathrm{CaH}\left(\mathrm{PO}_{4}\right)$, Monetite | 1.587 | 1.615 | 1.640 | 0.053 | - 70 | 188 |
| 44 | $\mathrm{K}_{2} \mathrm{~S}_{4} \mathrm{O}_{6}$ | 1.5896 | 1.6057 | 1.6435 | 0.0539 | +67 | 122 |
| 45 | $\mathrm{Gd}\left(\mathrm{BrO}_{3}\right)_{3} \cdot 9 \mathrm{H}_{2} \mathrm{O}$ | 1.551 | 1.605 |  | 0.054 | - 00 | 110 |
| 45 | $\mathrm{Sm}\left(\mathrm{BrO}_{3}\right)_{3} \cdot 9 \mathrm{H}_{2} \mathrm{O}$ | 1.551 | 1.605 |  | 0.054 | -00 | 110 |
| 46 | $\mathrm{Sr}\left(\mathrm{ClO}_{3}\right)_{2}$ | 1.5670 | 1.6047 | 1.6257 | 0.0587 | -72 | 109 |
| 47 | $\mathrm{K}_{2} \mathrm{PbSi}_{4} \mathrm{O}_{10}$ | 1.590 | 1.612 | 1.650 | 0.060 | +75 | 257 |
| 48 | $\mathrm{Na}_{2} \mathrm{Pt}(\mathrm{CN})_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.541 | 1.608 | 1.611 | 0.070 | - 24 | 41 |
| 49 | $\mathrm{MnCl}_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.584 | 1.611 | 1.666 | 0.082 | +7- | 28 |
| 50 | $\mathrm{SrPt}(\mathrm{CN})_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 1.547 | 1.613 | 1.637 | 0.090 | - 52 | 33 |
| 51 | $\mathrm{CaNi}(\mathrm{CN})_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 1.5405 | 1.617 | 1.638 | 0.0975 | - 40 | 32 |
| 52 | $\mathrm{CaPd}(\mathrm{CN})_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 1.539 | . 1.602 | 1.639 | 0.100 | -68 | 32 |
| 51 | $\mathrm{SrPd}(\mathrm{CN})_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 1.495 | 1.6025 | 1.612 | 0.117 | -40 | 32 |
| 53 | $\mathrm{Ca}\left(\mathrm{N}_{3}\right)_{2} \cdot 2\left(\mathrm{~N}_{2} \mathrm{H}_{4}\right)$ | 1.583 | 1.610 | 1.70 | 0.117 | $+80$ | 8 |
| 54 | $\left(\mathrm{NH}_{4}\right)_{2}\left(\mathrm{UO}_{2}\right)\left(\mathrm{NO}_{3}\right)_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.508 | 1.619 | 1.639 | 0.131 | - 45 | 105 |
| 55 | $\mathrm{SrNi}(\mathrm{CN})_{4} \cdot \mathrm{SH}_{2} \mathrm{O}$ | 1.492 | 1.612 | 1.6235 | 0.1315 | - 30 | 32 |
| 56 | $\mathrm{NH}_{4}\left(\mathrm{NO}_{3}\right)$, Ammonia-Niter | 1.413 | 1.611 | 1.637 | 0.224 | - 35 | 101 |
| 57 | $\mathrm{NaKPt}(\mathrm{CN})_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.6088 | 1.61 | 1.90 | 0.29 | $+10$ | 40 |
| 58 | $\mathrm{Ca}(\mathrm{CN})_{2}$ |  | 1.60 |  | 0.35 | +00 | 8 |


${ }^{n} y=1.620$ to 1.6399

| No. on Chart | Substance | ${ }^{n} \boldsymbol{x}$ | $n_{y}$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\mathrm{Pb}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ |  | 1.626 |  |  | - 00 | 209 |
| 1 | $\mathrm{Cu}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Metatorbernite |  | 1.62 | 1.62 | 0.002 | +00 | 208 |
| 1 | $\mathrm{Na}_{8} \mathrm{Ca}_{3} \mathrm{Si}_{5} \mathrm{O}_{17}$ |  | 1.620 |  | 0.002 |  | 270 |
| 2 | $\mathrm{FeBaSi} \mathrm{O}_{10}$, Gillespite | 1.619 | 1.621 |  | 0.002 | - 00 | 254 |
| 2 | $\mathrm{Sr}_{5}\left(\mathrm{PO}_{4}\right)_{3} \mathrm{~F}$ | 1.619 | 1.621 |  | 0.002 | - 00 | 204 |
| 2 | $\mathrm{Ca}_{5}\left(\mathrm{PO}_{4}\right)_{3} \mathrm{~F}$, Fluorapatite | 1.630 | 1.6325 |  | 0.0025 | - 00 | 203 |
| 3 | $\mathrm{Ca}_{3}\left(\mathrm{PO}_{4}\right)_{2}$, Whitlockite | 1.626 | 1.629 |  | 0.003 | - 00 | 189 |
| 4 | $\mathrm{Ca}_{2} \mathrm{P}_{2} \mathrm{O}_{7}$ |  | 1.624 | 1.628 | 0.004 | +00 | 213 |
| $4{ }^{\prime}$ | $\mathrm{CaSi}_{2} \mathrm{Ga}_{2} \mathrm{O}_{8}$ | 1.625 |  | 1.631 | 0.004 | - 75? | 232 |
| 3 | $\mathrm{Ca}_{2} \mathrm{OCl}_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.634 | 1.638 |  | 0.004 | - 00 | 51 |
| 5 | $\mathrm{KAg}(\mathrm{CN})_{2}$ |  | 1.625 | 1.623 | 0.005 | +00 | 22 |
| 6 | $\mathrm{Ca}_{2} \mathrm{OCl}_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.623 | 1.628 |  | 0.005 | - 00 | 51 |
| 7 | $\mathrm{K}_{2} \mathrm{Pt}(\mathrm{CN})_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.615 | 1.62 | 1.62 | 0.005 | + 40 | 42 |
| 7 | $\mathrm{CaAs}_{2} \mathrm{O}_{6}$ | 1.629 |  | 1.635 | 0.006 | +? | 212 |
| 8 | $\mathrm{Ca}_{8} \mathrm{Si}_{3} \mathrm{O}_{24} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.630 |  | 1.636 | 0.006 | +10 | 281 |
| 7 | $\underset{(\mathrm{Ca}, \mathrm{Sr}) \mathrm{SiO}_{3}}{\mathrm{ZnSiO}_{3}}$ | 1.616 | 1.623 | 1.623 1.630 | 0.007 0.007 | $+?$ +00 | 268 |
| 9 | $\mathrm{Ca}_{2} \mathrm{MgSi}_{2} \mathrm{O}_{7}$, Akermanite |  | 1.632 | 1.639 | 0.007 | +00 | 294 |
| 10 | ( $\mathrm{Ni}, \mathrm{Mg})_{6}(\mathrm{OH})_{6} \mathrm{Si}_{4} \mathrm{O}_{11} \cdot \mathrm{H}_{2} \mathrm{O}$, Garnierite | 1.622 | 1.62 | 1.630 | 0.008 | +05 | 260 |
| 11 | $\mathrm{Ca}_{5}\left(\mathrm{PO}_{4}\right)_{2} \mathrm{SiO}_{4}$, Silicocarnotite | 1.632 | 1.636 | 1.640 | 0.008 | - 70 | 215 |
| 12 | $\mathrm{Ca}_{10}\left(\mathrm{PO}_{4}\right)_{6}\left(\mathrm{CO}_{3}\right) \cdot \mathrm{H}_{2} \mathrm{O}$, Carbonate-Apatite | 1.619 | 1.628 |  | 0.009 | - 00 | 204 |
| 13 | $\mathrm{Ca}_{2} \mathrm{P}_{2} \mathrm{O}_{7}$ |  | 1.630 | 1.639 | 0.009 | +00 | 213 |
| 14 | $\mathrm{Al}_{2}(\mathrm{~F}, \mathrm{OH})_{2} \mathrm{SiO}_{4}$ | 1.629 | 1.631 | 1.638 | 0.009 | +48 | 306 |
| 14 | $\mathrm{Sr}\left(\mathrm{SO}_{4}\right)$, Celestite | 1.6215 | 1.6232 | 1.6305 | 0.0092 | + 50 | 131 |
| 15 | $\left(\mathrm{UO}_{2}\right)_{6}(\mathrm{OH})_{10}\left(\mathrm{SO}_{4}\right) \cdot 12 \mathrm{H}_{2} \mathrm{O}$, Uranopilite | 1.620 | 1.624 | 1.630 | 0.010 | +50 | 177 |
| 16 | $\mathrm{Al}_{2} \mathrm{OSiO}_{4}$, Andalusite | 1.634 | 1.639 | 1.645 | 0.011 | -86 | 309 |
| 17 | $\left(\mathrm{Ca}, \mathrm{Sr}^{(2)} \mathrm{SiO}_{3}\right.$ |  | 1.639 | 1.650 | 0.011 | +00 | 280 |
| 18 | $\mathrm{BaSO}_{4}$, Barite | 1.6363 | 1.6373 | 1.6484 | 0.0121 | +37 | 130 |
| 19 | $\mathrm{KGe}_{3} \mathrm{GaO}_{8}$ | 1.615 |  | 1.628 | 0.013 |  | 232 |
| 19 | $\mathrm{Ca}_{5} \mathrm{Mg}_{2} \mathrm{Si}_{6} \mathrm{O}_{19}$ | 1.621 | 1.627 | 1.635 | 0.014 | +80 | 291 |
| 19' | $\mathrm{Ba}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.607 | 1.621 |  | 0.014 | - 00 | 209 |
| 20 | $\mathrm{Ca}_{3} \mathrm{Si}_{3} \mathrm{O}_{9}$, Wolla sionite | 1.620 | 1.632 | 1.634 | 0.014 | - 39 | 291 |
| 21 | $\mathrm{Tl}_{2} \mathrm{Mg}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.6250 | 1.6337 | 1.6404 | 0.0154 | -78 | 150 |
| 22 | $\mathrm{Ca}_{3} \mathrm{Si}_{2} \mathrm{O}_{7} \cdot 3 \mathrm{H}_{2} \mathrm{O}$, Afwillite | 1.6169 | 1.6204 | 1.6336 | 0.0167 | +55 | 297 |
| 23 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Mg}\left(\mathrm{CrO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.6363 | 1.6371 | 1.6531 | 0.0168 | +27 | 155 |
| 24 | $\mathrm{Ca}_{3} \mathrm{Si}_{3} \mathrm{O}_{9}$, Parawollastonite | 1.614 | 1.629 | 1.631 | 0.017 | -. 35 | 291 |
| 25 | $\mathrm{Ca}_{10} \mathrm{Si}_{5} \mathrm{O}_{20} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.614 | 1.620 | 1.623 | 0.019 | +50 | 306 |
| 26 | $\mathrm{Ca}_{2} \mathrm{SiO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.614 | 1.620 | 1.633 | 0.019 | +68 | 305 |
| 27 | $\mathrm{PbS}_{2} \mathrm{O}_{6} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ |  | 1.6366 | 1.6557 | 0.0191 | +00 | 133 |
| 28 | $\mathrm{Mg}(\mathrm{F}, \mathrm{OH})_{2} \cdot 2 \mathrm{Mg}_{2} \mathrm{SiO}_{4}$, Chondrodite | 1.613 | 1.623 | 1.643 | 0.02 | +71 | 307 |
| 29 | $\mathrm{NaCa}_{2} \mathrm{Mg}_{4} \mathrm{AlSi}_{6} \mathrm{Al}_{2} \mathrm{O}_{22}(\mathrm{OH})_{2}$, Hastingsite | 1.62 | 1.63 | 1.64 | 0.02 | +85 | 286 |
|  | - $\mathrm{Ca}_{2} \mathrm{OBr}_{2} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ |  | 1.623 | 1.645 | 0.02 | $+$ | 51 |
| 30 | $\mathrm{Al}\left(\mathrm{AsO}_{4}\right) \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Mansfieldite | 1.622 | 1.624 | 1.642 | 0.020 | +30 | 200 |
| 29 | $\mathrm{Mg}_{3} \mathrm{Fe}_{4} \mathrm{Si}_{8} \mathrm{O}_{22} \mathrm{~F}_{2}$ | 1.625 | 1.634 | 1.645 | 0.020 | +86 | 284 |
| 31 | $\mathrm{Zn}_{2} \mathrm{PO}_{4}(\mathrm{OH})$ | 1.608 | 1.624 | 1.629 | 0.021 | - 70 | 201 |
| 32 | $\mathrm{K}_{2} \mathrm{CuCl}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.6148 | 1.6365 |  | 0.0217 | -00 -87 | 39 156 |
| 33 | $\mathrm{Rb}_{2} \mathrm{Mg}\left(\mathrm{CrO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.6217 | 1.6330 | 1.6435 | 0.0218 | - 87 | 156 |
| 32 | $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ Heated $110^{\circ}$ | 1.615 | 1.637 |  | 0.022 | - 00 | 207 |
| 34 | $\mathrm{Zn}_{3}\left(\mathrm{PO}_{4}\right)_{2} \cdot 4 \mathrm{H}_{2} \mathrm{O}$, Parahopeite | 1.614 | 1.625 | 1.637 | 0.023 | +85 | 199 |
| 35 | $\mathrm{Fe}(\mathrm{OH}) \mathrm{Si}_{2} \mathrm{O}_{5} \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Nontronite | 1.617 | 1.637 | 1.640 | 0.023 | -40 | 266 |
| 36 | $\mathrm{Ba}_{2} \mathrm{Si}_{3} \mathrm{O}_{8}$ | 1.620 | 1.625 | 1.645 | 0.025 | + 54 | 256 |
| 37 | $\mathrm{Ba}_{2} \mathrm{Si}_{3} \mathrm{O}_{8}$ | 1.620 | 1.625 | 1.645 | 0.025 | +58 | 268 |
| 38 | $\mathrm{BaAl}_{2} \mathrm{O}_{4} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 1.625 | 1.628 | 1.650 | 0.025 | +40 | 83 |
| 39 | $\mathrm{SrAl}_{4} \mathrm{O}_{7}$ | 1.614 | 1.623 | 1.640 | 0.026 | + 75 | 79 |
| 40 | $\mathrm{KIO}_{4}$ |  | 1.6205 | 1.6479 | 0.0274 | +00 | 110 |
| 41 | $\mathrm{HNa}(\mathrm{Ca}, \mathrm{Mn})_{2} \mathrm{Si}_{3} \mathrm{O}_{9}$, Schizolite | 1.631 | 1.636 | 1.660 | 0.029 | +48 | 293 |
| 42 | $\mathrm{H}_{8} \mathrm{Na}_{6}\left(\mathrm{MoO}_{4}\right)_{7} \cdot 18 \mathrm{H}_{2} \mathrm{O}$ |  | 1.627 |  | 0.03 | -84 | 183 |
| 43 | $\mathrm{CaCuSi}_{4} \mathrm{O}_{10}$ | 1.6053 | 1.6354 |  | 0.0301 | - 00 | 254 |
| 44 | $1 \mathrm{Mg}(\mathrm{F}, \mathrm{OH})_{2} \cdot 3 \mathrm{Mg}_{2} \mathrm{SiO}_{4}$, Humite | 1.623 | 1.634 | 1.655 | 0.032 | +69 | 307 |
| 45 | $\mathrm{Ce}\left(\mathrm{PO}_{4}\right) \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Churchite | 1.620 1.595 | 1.620 | 1.654 | 0.034 0.037 | +10 -24 | 200 |
| 46 | $\mathrm{CoCO}_{3} \mathrm{SO}_{4} \cdot 4 \mathrm{NH}_{3} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.595 | 1.631 | 1.632 | 0.037 | - 24 | 179 |
| 47 | $\mathrm{CuAl}_{6}\left(\mathrm{PO}_{4}\right)_{4}(\mathrm{OH})_{8} \cdot 4 \mathrm{H}_{2} \mathrm{O}$, Turquois | 1.61 | 1.62 | 1.65 | 0.04 | +40 | 207 |
| 48 | $\mathrm{Zn}_{3}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Koettigite | 1.622 | 1.638 | 1.671 | 0.049 | -74 -70 | 199 |
| 49 | $\mathrm{Fe}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$, Lausenite | 1.605 | 1.635 | 1.657 | 0.052 | -70 | 171 |
| 50 | $\mathrm{H}_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Troegerite | 1.585 | 1.630 |  | 0.055 | -00 | 206 |
| 51 | $\mathrm{Pd}\left(\mathrm{NH}_{3}\right)_{4} \mathrm{Cl}_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.557 | 1.620 |  | 0.063 0.071 | -00 -25 | 53 40 |
| 52 | $\left(\mathrm{NH}_{4}\right)_{2}\left(\mathrm{UO}_{2}\right) \mathrm{Cl}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.566 | 1.633 | 1.637 | 0.071 | -25 +80 | 40 163 |
| 53 | $\mathrm{FeSO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$, Szomolnokite | 1.591 | 1.623 | 1.663 | 0.072 | +80 | 163 |
| 54 | $\mathrm{CoSO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.603 | 1.639 | 1.683 | 0.080 | -85 | 164 |
| 55 | $\mathrm{Rb}_{2} \mathrm{Pt}(\mathrm{CN})_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.6111 | 1.62 | 1.696 | 0.085 | +60 | 42 134 |
| 56 | $3 \mathrm{~K}_{2} \mathrm{~S}_{5} \mathrm{O}_{6} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.570 | 1.63 | 1.658 1.695 | 0.088 0.150 | -65 -82 | 134 22 |
| 57 | NaCNS | 1.545 | 1.625 1.6233 | 1.695 1.9310 | 0.150 0.3106 | -82 +13 | 22 |
| 58 | $\underline{\mathrm{LiRbPt}}(\mathrm{CN})_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.6204 | 1.6233 | 1.9310 | 0.3106 | +13 | 40 |
| 59 | $\mathrm{CsICl}_{2}$ |  | 1.637 1.6278 | 2.15 | 0.513 0.6679 | +00 +19 | 21 40 |
| 60 | $\underline{\mathrm{LiKPt}}(\mathrm{CN})_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.6237 | 1.6278 | 2.2916 | 0.6679 | +19 | 40 |



|  | Substance | $n_{x}$ | $n y$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | $\mathrm{Ca}_{5}\left(\mathrm{PO}_{4}\right)_{3} \mathrm{Cl}$, Chlorapatite | 1.6675 | 1.6684 |  | 0.0009 | - 00 | 203 |
| 2 | $\mathrm{Na}_{2} \mathrm{Ca}_{2} \mathrm{Si}_{2} \mathrm{O}_{7}$ | 1.665 | 1.665 | 1.665 | 0.003 | 70 | 296 |
| 3 | $\mathrm{Ba}_{5}\left(\mathrm{PO}_{4}\right)_{3} \mathrm{~F}$ | 1.665 | 1.669 |  | 0.004 | - 00 | 204 |
| 4 | $\mathrm{Ca}_{2} \mathrm{FeSiAlO}_{7}$, Ferrigehlenite | 1.661 | 1.666 |  | 0.005 | -00 | 295 |
| 5 | $\mathrm{BaSiO}_{3}$ | 1.673 | 1.674 | 1.678 | 0.005 | + 29 | 268 |
| 6 | $\mathrm{Ca}_{2} \mathrm{ZnSi}_{2} \mathrm{O}_{7}$, Hardystonite | 1.6624 | 1.6718 |  | 0.0094 | - 00 | 295 |
|  | $\mathrm{NH}_{4} \mathrm{FeH}_{2}\left(\mathrm{PO}_{4}\right)_{2}$ |  | 1.66 |  | 0.01 |  | 189 |
| 7 | $\mathrm{Ca}_{3}\left(\mathrm{PO}_{4}\right)_{2} \cdot 2 \mathrm{Ca}_{2} \mathrm{SiO}_{4}$, Nagelschmidtite | 1.67 | 1.675 | 1.68 | 0.01 | + 20 | 215 |
| 6 | $\mathrm{Ca}_{12}\left(\mathrm{PO}_{4}\right)_{6} \mathrm{SiO}_{5}$, Steadite |  | 1.66 |  | 0.01 | - 00 | 215 |
| 8 |  | 1.658 | 1.662 | 1.668 | 0.010 | +82 | 117 |
| 9 | LiMnPO4, Lithiophilite | 1.663 | 1.666 | 1.673 | 0.010 | +65 | 191 |
| 10 | $\mathrm{Ca}_{3} \mathrm{AlSiAlO}_{4}$ | 1.675 | 1.679 | 1.685 | 0.010 | +60 | 305 |
| 11 | $\mathrm{Mg}_{3} \mathrm{~B}_{7} \mathrm{O}_{13} \mathrm{Cl}$ | 1.6622 | 1.6670 | 1.6730 | 0.0108 | +80 | 117 |
| 12 | $\mathrm{Ca}_{2} \mathrm{AlSiAlO}_{7}$, Gehlenite | 1.658 | 1.669 |  | 0.011 | - 00 | 295 |
| 13 | $\mathrm{ZnSO}_{4}$, Zinkosite | 1.658 | 1.669 | 1.670 | 0.012 | - 25 | 130 |
| 14 | 2( $\left.\mathrm{Ca}_{2} \mathrm{MgSi}_{2} \mathrm{O}_{7}\right) \cdot 8\left(\mathrm{Ca}_{2} \mathrm{FeSi}_{2} \mathrm{O}_{7}\right)$, Melilite | 1.658 | 1.670 |  | 0.012 | - 00 | 294 |
| 15 | $\mathrm{CaAl}_{4} \mathrm{O}_{7}$ | 1.662 | 1.671 | 1.674 | 0.012 | - 35 | 79 |
| 14 | Justite | 1.657 | 1.670 |  | 0.013 | - 00 | 295 |
| 16 | $\mathrm{Ca}_{6} \mathrm{Si}_{3} \mathrm{O}_{12} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.650 | 1.661 | 1.664 | 0.014 | - 25 | 281 |
| 17 | $\mathrm{CaMnSi} \mathrm{O}_{6}$, Bustamite | 1.662 | 1.674 | 1.676 | 0.014 | - 44 | 293 |
| 18 | $\mathrm{LiAlSi} \mathrm{O}_{6}$, Spodumene | 1.661 | 1.666 | 1.676 | 0.015 | +75 | 280 |
|  | $\mathrm{SrH}\left(\mathrm{AsO}_{4}\right)$ | 1.65 |  | 1.67 | 0.02 |  | 188 |
| 19 | $\mathrm{Ca}_{2}\left(\mathrm{PO}_{4}\right) \mathrm{Cl}$, Chlor-spodiosite | 1.649 | 1.665 | 1.670 | 0.021 | - 70 | 201 |
| 20 | $\mathrm{Ag}_{2} \mathrm{CO}_{3} \cdot 4 \mathrm{NH}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.66 | 1.66 | 1.68 | 0.023 | + 10 | 100 |
| 21 | $\mathrm{Al}_{2} \mathrm{OSiO}_{4}$, Sillimanite | 1.661 | 1.670 | 1.684 | 0.023 | + 28 | 309 |
| 22 | $\mathrm{Ca}_{2} \mathrm{Mg}_{4} \mathrm{FeSi}_{8} \mathrm{O}_{22} \mathrm{~F}_{2}$, Actinolite | 1.655 | 1.665 | 1.68 | 0.025 | - 80 | 285 |
| 23 | $\mathrm{Fe}_{7} \mathrm{Si}_{8} \mathrm{O}_{22} \mathrm{~F}_{2}$ | 1.665 | 1.676 | 1.690 | 0.025 | +85 | 284 |
| 24 | $\mathrm{K}_{2} \mathrm{Al}_{12} \mathrm{O}_{19}$ | 1.64 | 1.668 |  | 0.028 | 00 | 80 |
| 25 | $\mathrm{CaMgSi}_{2} \mathrm{O}_{6}$, Diopside | 1.6658 | 1.6720 | 1.6946 | 0.0288 | + 58 | 274 |
| 26 | $\mathrm{NaFe}_{3} \mathrm{Al}_{6}(\mathrm{OH})_{4} \mathrm{~B}_{3} \mathrm{O}_{9} \mathrm{Si}_{6} \mathrm{O}_{18}$, Schorlite | 1.639 | 1.668 |  | 0.029 | - 00 | 289 |
| $26^{\prime}$ | Andalusite | 1.662 | 1.671 | 1.691 | 0.029 | - 71 | 309 |
| 27 | $\mathrm{Ce}_{2} \mathrm{Pt}_{3}(\mathrm{CN})_{12} \cdot 18 \mathrm{H}_{2} \mathrm{O}$ | 1.65 | 1.66 | 1.68 | 0.03 | +70 | 49 |
| 28 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{CuCl}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.641 | 1.671 |  | 0.030 | - 00 | 40 |
| 29 | $\mathrm{Co}\left(\mathrm{NH}_{3}\right)_{6} \cdot \mathrm{Fe}(\mathrm{CN})_{6}$ |  | 1.662 | 1.695 | 0.033 | + 00 | 53 |
| 30 | $\mathbf{A g}_{2} \mathrm{~S}_{2} \mathrm{O}_{6} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.631 | 1.662 | 1.665 | 0.034 | - 30 | 134 |
| 31 | $\mathrm{Mg}_{7} \mathrm{Fe}_{2} \mathrm{Si}_{4} \mathrm{O}_{16} \mathrm{~F}_{2}$, Clinohumite | 1.664 | 1.673 | 1.698 | 0.034 | +62 | 308 |
| 32 | $\mathrm{Na}_{2} \mathrm{Al}_{12} \mathrm{O}_{19}$ | 1.633 | 1.670 |  | 0.037 | - 00 | 80 |
| 33 | $\mathrm{Y}(\mathrm{OH})_{3}$ |  | 1.676 | 1.714 | 0.038 | +00 | 72 |
| 34 | $\mathrm{Ca}_{5} \mathrm{CO}_{3}\left(\mathrm{SiO}_{4}\right)_{2}$, Spurrite | 1.640 | 1.674 | 1.679 | 0.039 | - 39 | 311 |
| 35 | $\left(\mathrm{NH}_{4}\right)_{9} \mathrm{Ag}_{\mathbf{(}}\left(\mathrm{S}_{2} \mathrm{O}_{3}\right)_{4} \mathrm{Br}$ | 1.6294 | 1.6769 |  | 0.0475 | - 00 | 121 |
| 36 | $\mathrm{KFeH}_{2}\left(\mathrm{PO}_{4}\right)_{2}$ | 1.631 | 1.665 | 1.680 | 0.049 | - 66 | 188 |
| 37 | $\mathrm{NaAlAsO} \mathrm{O}_{4} \mathrm{~F}$, Durangite | 1.634 | 1.673 | 1.685 | 0.051 | - 45 | 202 |
| 38 | $\mathrm{K}_{2} \mathrm{HgCl}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.648 | 1.678 | 1.699 | 0.051 | - 78 | 39 199 |
| 39 | $\mathrm{Fe}_{3}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Symplesite | 1.635 | 1.668 | 1.702 | 0.067 | -86 +90 | 199 |
| 40 | $\mathrm{Co}_{3}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Erythrite | 1.626 | 1.661 | 1.699 | 0.073 0.073 | +90 | 198 |
| 41 | $\mathrm{Cu}\left(\mathrm{SO}_{4}\right) \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.626 | 1.671 1.662 | 1.699 | 0.073 0.082 | -75 | 164 |
| 42 | $\mathrm{Ca}_{2} \mathrm{~B}_{2} \mathrm{O}_{5}$ | 1.585 | 1.662 | 1.667 | 0.082 0.085 | - 25 | 114 |
| 43 | $\mathrm{MgCl}_{2}$, Chloromagnesite | 1.59 | 1.675 1.662 | 1.721 | 0.085 0.095 | -00 +78 | 28 |
| 44 45 | $\mathrm{CoCl}_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ $\mathrm{K}_{2} \mathrm{Pt}\left(\mathrm{NO}_{2}\right)_{4}$ | 1.626 1.590 | 1.662 | 1.721 | 0.095 0.095 | +5 | 106 |
| 46 | $\mathrm{Na}_{6} \mathrm{Te}\left(\mathrm{MoO}_{4}\right)_{6} \cdot 22 \mathrm{H}_{2} \mathrm{O}$ | 1.577 | 1.662 | 1.683 | 0.106 | - 51 | 184 |
| 47 | $\mathrm{K}_{2} \mathrm{PtBr}_{2}\left(\mathrm{NO}_{2}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.626 | 1.6684 | 1.757 | 0.131 | +72 | 106 |
| 48 | $\mathrm{CaBa}\left(\mathrm{CO}_{3}\right)_{2}$, Alstonite | 1.525 | 1.673 | 1.673 | 0.148 | - 07 | 95 |
| 49 | $\mathrm{BaCO}_{3}$, Witherite | 1.529 | 1.676 | 1.677 | 0.148 | - 16 | 94 |
| 48 | $\mathrm{SrCO}_{3}$, Strontianite | 1.5199 | 1.6666 | 1.6685 | 0.1486 | - 07 | 93 |
| 50 | $\mathrm{FeSO}_{4}(\mathrm{OH}) \cdot \mathbf{2 \mathrm { H } _ { 2 } \mathrm { O }}$, Butlerite | 1.588 | 1.678 | 1.749 | 0.161 | - 70 | 177 |
| 51 | $\mathrm{CaMg}\left(\mathrm{CO}_{3}\right)_{2}$, Dolomite | 1.502 | 1.679 |  | 0.177 | - 00 | 95 |
| 52 | KCNS | 1.532 | 1.660 | 1.730 | 0.198 | - 68 | 22 |
| 53 | $\mathrm{BaPt}(\mathrm{CN})_{4} \cdot \mathbf{4 H 2} \mathbf{~}$ | 1.666 | 1.6745 | 1.919 | 0.253 | +25 | 33 |


$n_{y}=1.680$ to 1.6999

| $\begin{aligned} & \text { No. } \\ & \text { on } \\ & \text { Chart } \end{aligned}$ | Substance | $n^{\prime}$ | $n^{\prime}$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | $\mathrm{Na}_{3} \mathrm{AsS}_{4} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ |  | 1.6802 |  | 0.006 | - 88 | 14 |
| 2 | $\mathrm{Ba}_{10}\left(\mathrm{PO}_{4}\right)_{6}\left(\mathrm{CO}_{3}\right)$ | 1.683 | 1.691 |  | 0.008 | - 00 | 204 |
| 3 | $\mathrm{K}_{2} \mathrm{Ca}_{23} \mathrm{Si}_{12} \mathrm{O}_{48}$ |  | 1.695 | 1.703 | 0.008 | +00 | 300 |
| 4 | $\mathrm{BAsO}_{4}$ |  | 1.681 | 1.690 | 0.009 | +00 | 190 |
| 5 | $\mathrm{Ca}_{2} \mathrm{BaSi}_{3} \mathrm{O}_{9}$ | 1.668 | 1.681 |  | 0.013 | -00 | 288 |
| 6 | $\mathrm{Ca}_{2} \mathrm{FeSi}_{2} \mathrm{O}_{7}$, Ferroakermanite | 1.673 | 1.690 |  | 0.017 | - 00 | 295 |
| 7 | $\mathrm{Zn}_{2} \mathrm{SiO}_{4}$, Willemite |  | 1.695 | 1.715 | 0.020 | +00 | 300 |
| 8 | $\mathrm{Ca}_{5}\left(\mathrm{BO}_{3}\right)_{2} \mathrm{SiO}_{4}$ | 1.666 | 1.682 | 1.690 | 0.024 | - 50 | 119 |
| 9 | $\mathrm{ZnCl}_{2}$ |  | 1.687 | 1.713 | 0.026 | +00 | 26 |
| 10 | Augite | 1.687 | 1.694 | 1.713 | 0.026 | +59 | 278 |
| 11 | $\mathrm{Na}_{2} \mathrm{Al}_{12} \mathrm{O}_{19}$ | 1.650 | 1.686 |  | 0.036 | - 00 | 80 |
| 11 | $\mathrm{K}_{2} \mathrm{Al}_{12} \mathrm{O}_{19}$, Alumina, Gamma | 1.660 | 1.696 |  | 0.036 | -00 | 80 |
| $11^{\prime}$ | $\mathrm{Mg}_{16} \mathrm{Fe}_{4}\left(\mathrm{SiO}_{4}\right)_{10}$, Olivine | 1.674 | 1.692 | 1.712 | 0.038 | -87 | 303 |
| 12 | $\mathrm{GeO}_{2}$ |  | 1.695 | 1.735 | 0.040 | +00 | 63 |
| 13 | $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{4}\left(\mathrm{PO}_{4}\right)_{2}(\mathrm{OH})_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 1.658 | 1.699 | 1.699 | 0.041 | - 25 | 210 |
| $13^{\prime}$ | $\left(\mathrm{UO}_{2}\right)_{2} \mathrm{SiO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Soddyite | 1.65 | 1.68 | 1.71 | 0.06 | -85? | 308 |
| 14 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Fe}_{2} \mathrm{H}_{4}\left(\mathrm{PO}_{4}\right)_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.655 | 1.680 | 1.715 | 0.060 | +57 | 195 |
| 15 | $\mathrm{Na}_{2} \mathrm{Cr}_{2} \mathrm{O}_{7} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.6610 | 1.6994 | 1.7510 | 0.090 | $+84$ | 135 |
| 16 | $\mathrm{CuCl}_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Eriochalcite | 1.644 | 1.684 | 1.742 | 0.098 | +81 | 29 |
| 17 | $\mathrm{K}_{2} \mathrm{Rh}_{2}\left(\mathrm{NH}_{3}\right)_{4}\left(\mathrm{NO}_{2}\right)_{8} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.612 | 1.690 | 1.716 | 0.104 | - 62 | 107 |
| 18 | $\mathrm{K}_{2} \mathrm{PtCl}_{4}$ | 1.553 | 1.683 |  | 0.130 | - 00 | 36 |
| 18 | $\mathrm{K}_{2} \mathrm{PtCl}_{4}$ | 1.557 | 1.690 |  | 0.133 | - 00 | 36 |
| 18 | $\mathrm{KBrO}_{3}$ | 1.54 | 1.68 |  | 0.14 | - 00 | 108 |
| 18 | $\mathrm{K}_{2} \mathrm{PtCl}_{4}$ | 1.548 | 1.693 |  | 0.145 | - 00 | 36 |
| 19 | $\mathrm{NH}_{4} \mathrm{CNS}$ | 1.546 | 1.685 | 1.692 | 0.146 | - 23 | 22 |
| 20 | $\mathrm{CaCO}_{3}$, Aragonite | 1.5300 | 1.6810 | 1.6854 | 0.1554 | -18 | 93 |
| 21 | AgCN |  | 1.685 | 1.94 | 0.255 | +00 | 22 |


${ }^{n_{y}}=1.700$ to 1.7199

| $\begin{gathered} \text { No. } \\ \text { on } \\ \text { Chart } \end{gathered}$ | Substance | $n_{x}$ | $n_{y}$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\mathrm{BaN}_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ |  | 1.7 |  |  |  | 8 |
|  | $\mathrm{BaCdBr}_{4} \cdot \mathbf{4 H _ { 2 } \mathrm { O }}$ |  | 1.702 |  |  | - 70 | 30 |
| 1 | $\mathrm{Ba}_{5}\left(\mathrm{PO}_{4}\right)_{3} \mathrm{Cl}$ | 1.699 | 1.701 |  | 0.002 | - 00 | 204 |
| 2 | $\mathrm{K}_{2} \mathrm{~Pb}\left(\mathrm{SO}_{4}\right)_{2}$, Palmierite | 1.68 | 1.712 |  | 0.03 | - 00 | 132 |
| 3 | $\mathrm{Pt}\left(\mathrm{NH}_{3}\right)_{5} \mathrm{Cl}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ |  | 1.718 | 1.722 | 0.004 | +00 | 53 |
| 4 | $\mathrm{Mg}_{4} \mathrm{Al}_{10} \mathrm{Si}_{2} \mathrm{O}_{23}$, Sapphirine | 1.7055 | 1.7088 | 1.7112 | 0.0057 | -69 | 86 |
| 4 | LiFePO4, Triphylite | 1.696 | 1.700 | 1.702 | 0.006 | -65 | 191 |
|  | $\mathrm{Co}\left(\mathrm{NH}_{3}\right)_{6} \mathrm{Cl}_{3}$ |  | 1.706 |  | 0.006 |  | 54 |
| 5 | $\mathrm{Mg}_{4} \mathrm{Al}_{10} \mathrm{Si}_{2} \mathrm{O}_{23}$ | 1.714 | 1.719 | 1.720 | 0.006 | - 50 | 86 |
| 6 | $\mathrm{CaGe}_{2} \mathrm{Ga}_{2} \mathrm{O}_{5}$ | 1.705 | 1.71 | 1.711 | 0.006 | 90? | 232 |
| 6 | $\mathrm{Rh}\left(\mathrm{NH}_{3}\right)_{5} \mathrm{Cl}_{2}$ | 1.700 | 1.703 | 1.707 | 0.007 | +85 | 53 |
| 7 | $\mathrm{SrAl}_{12} \mathrm{O}_{19}$ | 1.694 | 1.702 |  | 0.008 | - 00 | 80 |
| 7 | $\mathrm{BaAl}_{12} \mathrm{O}_{19}$ | 1.694 | 1.702 |  | 0.008 | - 00 | 80 |
| 8 | $\mathrm{NaCa}_{4} \mathrm{Al}_{3} \mathrm{O}$, | 1.702 | 1.708 | 1.710 | 0.008 | - 50 | 73 |
| 8 | $\mathrm{Zn}_{2} \mathrm{SiO}_{4}$ |  | 1.700 |  | 0.009 | - 49 | 300 |
| 9 | ZnClF |  | 1.70 |  | 0.009 | +70 | 25 |
| 10 | $\left(\mathrm{NH}_{4}\right)_{3} \mathrm{IrCl}_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.706 | 1.714 | 1.718 | 0.012 | - 66 | 46 |
| 11 | $\mathrm{Ca}_{2} \mathrm{SiO}_{4}$, Bredigite | 1.712 | 1.716 | 1.725 | 0.013 | + 30 | 301 |
| 12 | BeO , Bromellite |  | 1.719 | 1.733 | 0.014 | +00 | 58 |
| 13 | $\mathrm{Mn}_{2} \mathrm{P}_{2} \mathrm{O}_{7}$ | 1.695 | 1.704 | 1.710 | 0.015 | +85 | 214 |
| 14 | $\mathrm{Ca}_{2} \mathrm{FeMn}_{3} \mathrm{Si}_{6} \mathrm{O}_{18}$ | 1.692 | 1.705 | 1.707 | 0.015 | - 35 | 293 |
| 15 | $\mathrm{Zn}_{2} \mathrm{SiO}_{4}$ | 1.685 | 1.700 | 1.703 | 0.018 | - 40 | 300 |
| 16 | $\mathrm{Ca}(\mathrm{Fe}, \mathrm{Mn}, \mathrm{Mg})_{2} \mathrm{Si}_{3} \mathrm{O}_{9}$, Vogtite | 1.685 | 1.701 | 1.703 | 0.018 | - 66 | 292 |
| 17 | $\mathrm{Ca}_{3} \mathrm{Mg}\left(\mathrm{SiO}_{4}\right)_{2}$, Merwinite | 1.706 | 1.712 | 1.724 | 0.018 | +66 | 305 |
| 18 | $\mathrm{Cu}(\mathrm{OH})_{3} \mathrm{NO}_{3}$, Gerhardtite | 1.703 | 1.713 | 1.722 | 0.019 | +85 | 104 |
| 19 | $\mathrm{Rb}_{2} \mathrm{CrO}_{4}$ |  | 1.71 | 1.72 | 0.02 | -60 | 128 |
| 20 | $\mathrm{Ca}_{2} \mathrm{SiO}_{4}$, Larnite | 1.707 | 1.715 | 1.730 | 0.023 | $+50$ | 301 |
| 21 | $\mathrm{Na}_{4} \mathrm{Zr}_{2}\left(\mathrm{SiO}_{4}\right)_{3}$ | 1.692 | 1.715 |  | 0.023 | - 00 | 300 |
| 22 | $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{4}\left(\mathrm{PO}_{4}\right)_{2}(\mathrm{OH})_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Phosphuranylite | 1.682 | 1.706 | 1.708 | 0.026 | - 30 | 210 |
| 23 | $\mathrm{CaMnSi} \mathrm{O}_{6}$, Johannsenite | 1.710 | 1.719 | 1.738 | 0.028 | + 70 | 279 |
| 24 | $\mathrm{FeMgSi}_{2} \mathrm{O}_{6}$ | 1.7079 | 1.7089 | 1.7370 | 0.0291 | +20 | 273 |
| $24^{\prime}$ | $\left(\mathrm{NH}_{4}\right)_{3} \mathrm{H}_{6} \mathrm{Al}\left(\mathrm{MoO}_{4}\right)_{6} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 1.700 | 1.700 | 1.741 | 0.041 | $+10$ | 183 |
| 25 | $\mathrm{MgFe}_{6} \mathrm{Si}_{8} \mathrm{O}_{22}(\mathrm{OH})_{2}$, Grunertite | 1.686 | 1.709 | 1.729 | 0.043 | - 86 | 284 |
| 26 | $\left(\mathrm{UO}_{3}\right)_{4} \cdot 9 \mathrm{H}_{2} \mathrm{O}$, Schoepite | 1.690 | 1.714 | 1.733 | 0.045 | -89 | 67 |
| 27 | $\mathrm{NaAgS} \mathrm{O}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.69 | 1.715 | 1.74 | 0.05 | +90 +55 | 134 |
| 28 | $\mathrm{KCo}\left(\mathrm{NH}_{3}\right)_{2}\left(\mathrm{NO}_{2}\right)_{4}$ | 1.702 | 1.713 | 1.760 | 0.058 | +55 | 107 |
| 29 | $\mathrm{Cu}_{4} \mathrm{SO}_{4}(\mathrm{OH})_{6} \cdot \mathrm{H}_{2} \mathrm{O}$, Langite | 1.654 | 1.713 | 1.722 | 0.068 | - 37 | 175 |
| 30 | $\mathrm{Cs}_{6} \mathrm{Te}\left(\mathrm{MoO}_{4}\right)_{6} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 1.709 | 1.716 | 1.797 | 0.088 | +34 | 184 |
| 31 | $\mathrm{Li}_{6} \mathrm{Te}\left(\mathrm{MoO}_{4}\right)_{6} \cdot 13 \mathrm{H}_{2} \mathrm{O}$ | 1.612 | 1.703 |  | 0.091 | - 00 | 183 |
| 32 | $\mathrm{SrCr}_{2} \mathrm{O}_{7} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 1.7146 | 1.7174 | 1.812 | 0.0954 | $+20$ | 135 |
| 33 | $\mathrm{K}_{6} \mathrm{Te}\left(\mathrm{MoO}_{4}\right)_{6} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 1.66 | 1.70 | 1.76 | 0.10 0.110 | +81 .83 | 183 |
| 34 | $\left(\mathrm{UO}_{2}\right)_{3}\left(\mathrm{SO}_{4}\right)_{2}(\mathrm{OH})_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Zippeite | 1.655 | 1.717 | 1.765 | 0.110 | -83 | 177 37 |
| 35 | ${ }_{\left(\mathrm{NH}_{4}\right)_{2} \mathrm{PrCl}_{4}}$ | 1.574 1.537 | 1.706 1.715 |  | 0.132 0.178 | -00 -00 | 37 36 |
| 36 36 | $\mathrm{K}_{2} \mathrm{PdCl}_{4} \mathrm{Rb}_{2} \mathrm{PdCl}_{4}$ | 1.537 1.533 | 1.715 1.715 |  | 0.178 0.182 | -00 | 36 37 |
| 36 | $\mathrm{K}_{2} \mathrm{PdCl}_{4}$ | 1.523 | 1.710 |  | 0.187 | - 00 | 36 |
| 37 | $\mathrm{MgCO}_{3}$, Magnesite | 1.509 | 1.700 |  | 0.191 | - 00 | 91 |

$1.70<n_{y}<1.72$

$n_{y}=1.720$ to !.7499

|  | Substance | $n^{\boldsymbol{x}}$ | $n_{y}$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\mathrm{H}_{4} \mathrm{Mg}\left(\mathrm{WO}_{4}\right)_{4} \cdot \mathrm{SH}_{2} \mathrm{O}$ |  | 1.74 |  |  | +78 | 183 |
| 1 | $\mathrm{M}_{8_{4} \mathrm{Al}_{10} \mathrm{Si}_{2} \mathrm{O}_{23}}$ | 1.729 | 1.734 | 1.734 | 0.005 | - 60 | 86 |
| 2 | $\mathrm{Ca}_{3} \mathrm{OSiO}_{4}$ | 1.716 | 1.722 |  | 0.006 | - 00 | 308 |
| 3 | $\mathrm{MgBeAl}_{4} \mathrm{O}_{4}$ | 1.717 | 1.724 |  | 0.007 | - 00 | 78 |
| 4 | $\mathrm{NaK}_{3} \mathrm{Cr}_{2} \mathrm{O}_{6}$ |  | 1.7278 | 1.7361 | 0.0083 | +00 | 125 |
| 5 | $\mathrm{BeAl}_{2} \mathrm{O}_{4}$, Chrysoberyl | 1.732 | 1.734 | 1.741 | 0.009 | +70 | 78 |
|  | $\mathrm{Ba}_{3} \mathrm{Al}_{2} \mathrm{O}_{6}$ |  | 1.735 |  | 0.009 |  | 77 |
| 6 | $\mathrm{CaMn}_{4} \mathrm{Si}_{5} \mathrm{O}_{15}$, Rhodonite | 1.729 | 1.731 | 1.739 | 0.010 | $+60$ | 292 |
| 6 | $\mathrm{BeAl}_{2} \mathrm{O}_{4}$ | 1.746 | 1.748 | 1.756 | 0.010 | +60 | 78 |
| 7 | $\mathrm{BaCl}_{2}$ | 1.7302 | 1.7361 | 1.7420 | 0.0117 | $+85$ | 26 |
| 8 | $\mathrm{Ca}_{2} \mathrm{SiO}_{4}$ |  | 1.724 | 1.738 | 0.014 | +00 | 301 |
|  | $\mathrm{Cd}_{2} \mathrm{SiO}_{4}$ |  | 1.74 |  | 0.014 |  | 304 |
| 9 | $\mathrm{Ca}_{2} \mathrm{SiO}_{4}$ | 1.725 | 1.728 | 1.740 | 0.015 | $+33$ | $\begin{array}{r} 301 \\ 79 \end{array}$ |
|  | $\mathrm{Ca}_{2} \mathrm{GeO}_{4}$ | 1.724 |  | 1.739 | 0.015 |  |  |
| 10 | $\mathrm{CuSO}_{4}$, Chalcocyanite | 1.724 | 1.733 | 1.739 | 0.015 | - 70 | 130 |
| 11 | $\mathrm{MgFeSi}_{2} \mathrm{O}_{6}$ | 1.7117 | 1.724 | 1.7268 | 0.0151 | - 47 | 272 |
| 12 | $\mathrm{Al}_{2} \mathrm{OSiO}_{4}$, Kyanite | 1.7131 | 1.7219 | 1.7285 | 0.0154 | - 82 | 310 |
| 13 | $\mathrm{Ca}_{3} \mathrm{Fe}_{2} \mathrm{O}_{6}$ | 1.73 |  |  | 0.017 |  | 79 |
| 13 | $\mathrm{CaFe}_{2} \mathrm{Si}_{3} \mathrm{O}_{4}$ | 1.716 | 1.725 | 1.734 | 0.018 | - 85 | 292 |
| 14 | $\mathrm{Pb}\left(\mathrm{UO}_{2}\right)_{4}\left(\mathrm{PO}_{4}\right)_{2}(\mathrm{OH})_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$, Renardite | 1.715 | 1.736 | 1.739 | 0.018 | - 41 | 210 |
| 15 | $\mathrm{NaCa}_{2} \mathrm{Fe}_{5} \mathrm{Si}_{3} \mathrm{AlO}_{22}(\mathrm{OH})_{2}$, Ferroednite | 1.71 |  | 1.73 | 0.02 | - 20 | 286 |
| 16 | $\mathrm{NaCa}_{2} \mathrm{Fe}_{4}^{\prime \prime} \mathrm{Fe}^{\mathrm{W}} \mathrm{Si}_{6} \mathrm{Al}_{2} \mathrm{O}_{22}(\mathrm{OH})_{2}$, Ferrohastingsite | 1.72 |  | 1.74 | 0.02 | - 35 | 286 |
| 17 | $\mathrm{CuSeO}_{3} \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Chalcomenite | 1.710 | 1.731 | 1.732 | 0.022 | - 34 | 134 |
| 18 | $\mathrm{Sr}_{2} \mathrm{SiW}_{12} \mathrm{O}_{40} \cdot 16 \mathrm{H}_{2} \mathrm{O}$ |  | 1.749 |  | 0.023 | +87 | 184 |
| 19 | $\mathrm{Ca}_{2} \mathrm{Fe}_{5} \mathrm{Si}_{4} \mathrm{O}_{22}(\mathrm{OH})_{2}$, Ferrotremolite | 1.710 |  | 1.735 | 0.025 | - 75 | 286 |
| 20 | Augite | 1.726 | 1.732 | 1.753 | 0.027 | +49 | 278 |
| 21 | $\mathrm{La}(\mathrm{OH})_{3}$ |  | 1.740 | 1.768 | 0.028 | +00 | 71 |
| 21 | $\mathrm{Nd}(\mathrm{OH})_{3}$ |  | 1.740 | 1.768 | 0.028 | +00 | 71 |
| 21 | $\mathrm{Sm}(\mathrm{OH})_{3}$ |  | 1.740 | 1.768 | 0.028 | +00 | 72 |
| 22 | $\mathrm{Sr}_{2} \mathrm{SiO}_{4}$ | 1.7275 | 1.732 | 1.756 | 0.0285 | +32 | 305 |
| 23 | $\mathrm{CaFeSi} \mathrm{O}_{6}$, Hedenbergite | 1.7260 | 1.7318 | 1.7551 | 0.0291 | +60 | 274 |
| 24 | $\mathrm{Ca}_{2} \mathrm{Fe}_{3}^{\prime \prime} \mathrm{Fe}_{2}^{\text {m/ }} \mathrm{Si}_{8} \mathrm{Nl}_{2} \mathrm{O}_{2 \mathrm{l}}(\mathrm{OH})_{2}$, Ferrot schermalkite | 1.72 |  | 1.75 | 0.03 | -70 | 286 |
| 25 | $\mathrm{NH}_{4} \mathrm{Co}\left(\mathrm{NH}_{3}\right)_{2}\left(\mathrm{NO}_{2}\right)_{4}$ | 1.73 | 1.73 | 1.76 | 0.03 | +35 | 107 |
| 26 | $\mathrm{BaBr}_{2} \cdot \mathbf{2 H}_{2} \mathrm{O}$ | 1.7129 | 1.7266 | 1.7441 | 0.0312 | +84 | 29 |
| 27 | $\mathrm{FePO}_{4} \cdot \mathbf{2 \mathrm { H } _ { 2 } \mathrm { O }}$, Strengite | 1.730 | 1.732 | 1.762 | 0.032 | +25 | 200 |
| 28 | $\mathrm{HCa}_{2} \mathrm{Fe}^{\prime \prime} \mathrm{Fe}^{\text {"'Sis }} \mathrm{O}_{15}$ | 1.713 | 1.726 | 1.746 | 0.033 | +62 | 294 |
| 29 | $\mathrm{HCa}_{2} \mathrm{Fe}^{\prime \prime} \mathrm{Fe}^{\prime \prime \prime} \mathrm{Si}_{5} \mathrm{O}_{15}$, Babingtonite | 1.720 | 1.731 | 1.753 | 0.033 | +76 | 294 |
| 30 | $\mathrm{KFe}_{2}\left(\mathrm{PO}_{4}\right)_{2}(\mathrm{OH}) \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.706 | 1.720 | 1.741 | 0.035 | +81 | 210 |
| 31 | $\mathrm{Zn}_{2} \mathrm{AsO}_{4}(\mathrm{OH})$, Adamite | 1.722 | 1.742 | 1.761 | 0.039 | +88 | 202 |
| 32 | $\mathrm{KAuBr}_{4}$ | 1.74 | 1.74 |  | 0.04 | - 10 | 43 |
| 33 | $\mathrm{Mg}_{12} \mathrm{Fe}_{\mathbf{8}}\left(\mathrm{SiO}_{4}\right)_{10}$, Olivine | 1.712 | 1.735 | 1.753 | 0.041 | - 78 | 303 |
|  | $\left(\mathrm{NH}_{4}\right)_{3} \mathrm{H}_{6} \mathrm{Al}\left(\mathrm{MoO}_{4}\right)_{6} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 1.700 | 1.741 |  | 0.041 |  | 183 |
| 34 | $\mathrm{Mn}(\mathrm{OH})_{2}$, Pyrochroite | 1.681 | 1.723 |  | 0.042 | - 00 | 69 |
| 35 | $\mathrm{K}_{2} \mathrm{CrO}_{4}$, Tarapacaite | 1.687 | 1.722 | 1.731 | 0.044 | - 52 | 127 |
| 36 | $\mathrm{CaFeSiO}_{4}$ | 1.696 | 1.734 | 1.743 | 0.047 | - 49 | 303 |
| 37 | $\mathrm{HAlO}_{2}$, Diaspore | 1.702 | 1.722 | 1.750 | 0.048 | +84 | 73 |
|  | $\mathrm{SbBr}_{3}$ |  | 1.74 |  | 0.05 |  | 34 |
| 38 | $\mathrm{Zn}_{2} \mathrm{AsO}_{4}(\mathrm{OH})$ | 1.708 | 1.734 | 1.758 | 0.050 | -87 | 202 |
| 39 | $\mathrm{CaMnSiO}_{4}$, Glaucochroite | 1.685 | 1.723 | 1.736 | 0.051 | -61 | 304 |
| 40 | $\mathrm{Cu}_{3} \mathrm{SO}_{4}(\mathrm{OH})_{4}$, Antlerite | 1.726 | 1.738 | 1.789 | 0.051 | + 53 | 173 |
| 41 | $\left(\mathrm{NH}_{4}\right)_{6} \mathrm{Te}_{2}(\mathrm{OH})_{6}\left(\mathrm{MoO}_{4}\right)_{6} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 1.684 | 1.727 | 1.741 | 0.057 | - 58 | 184 |
| 42 | $\mathrm{AgNO}_{3}$ | 1.729 | 1.744 | 1.788 | 0.059 | +62 | 102 |
| 43 | $\mathrm{Pt}\left(\mathrm{NH}_{3}\right)_{2} \mathrm{O}_{2}(\mathrm{OH})_{2} \mathrm{Cl}_{2}$ | 1.690 | 1.730 | 1.756 | 0.066 | - 75 | 53 |
| 44 | $\mathrm{PtCONH}_{3} \mathrm{Cl}_{2}$ | 1.722 | 1.745 | 1.790 | 0.068 | +74 | 54 |
| 45 | $\mathrm{Cs}_{6} \mathrm{Te}\left(\mathrm{MoO}_{4}\right)_{6} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 1.669 | 1.734 | 1.738 | 0.069 | - 30 | 184 |
| 46 | $\mathrm{Pt}\left(\mathrm{NH}_{3}\right)_{2}\left(\mathrm{NO}_{2}\right)_{2}$ | 1.711 | 1.742 | 1.790 | 0.079 | $+80$ | 107 |
| 47 | $\mathrm{Rh}\left(\mathrm{NH}_{3}\right)_{2}\left(\mathrm{NO}_{2}\right)_{3}$ | 1.700 | 1.720 | 1.780 | 0.080 | +69 | 107 |
| 48 | $\mathrm{UO}_{2} \mathrm{CO}_{3}$, Rutherfordine | 1.715 | 1.730 | 1.795 | 0.080 | +53 | 98 |
| 49 | $\mathrm{Cu}_{2} \mathrm{PO}_{4}(\mathrm{OH})$, Libethenite | 1.701 | 1.743 | 1.787 | 0.086 | - 85 | 201 |
| 50 | $\mathrm{CaI}_{2}$ | 1.652 | 1.743 |  | 0.091 | - 00 | 27 |
| 51 | $\mathrm{YPO}_{4}$, Xe notime |  | 1.7207 | 1.8155 | 0.0948 | +00 | 190 |
| 52 | $\mathrm{K}_{2} \mathrm{Cr}_{2} \mathrm{O}_{7}$, Lopezite | 1.7202 | 1.7380 | 1.8197 | 0.0995 | + 52 | 122 |
| 53 | $\mathrm{KFe}{ }_{2}^{\prime \prime}\left(\mathrm{Fe}^{\prime \prime}, \mathrm{Mg}_{\mathrm{g}}, \mathrm{Al}\right)_{5} \mathrm{Si}_{8} \mathrm{O}_{\mathbf{2 0}} \cdot \mathbf{4 \mathrm { H } _ { 2 } \mathrm { O }}$ | 1.625 | 1.735 | 1.735 | 0.110 | - 10 | 265 |
| 54 | $\mathrm{Zn}_{5}(\mathrm{OH})_{6}\left(\mathrm{CO}_{3}\right)_{2}$, Hydrozincite | 1.640 | 1.736 | 1.750 | 0.110 | - 40 | 98 |
| 55 | $\mathrm{NH}_{4} \mathrm{SH}$ | 1.74 | 1.74 |  | 0.14 | - 00 | 9 |
| 56 | $\mathrm{MN}_{3} \mathrm{~B}_{4} \mathrm{O}$, | 1.617 | 1.738 | 1.776 | 0.159 | - 56 | 115 |
| 57 | $\mathrm{Cs}_{2} \mathrm{PdCl}_{4}$ | 1.560 | 1.720 |  | 0.160 | - 00 | 37 |
| 58 | $\mathrm{NiCl}_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.620 | 1.723 | 1.783 | 0.163 | - 72 | 28 |
| 57 | $\left.\left(\mathrm{NH}_{4}\right)_{2} \mathrm{PdCl}\right]_{4}$ | 1.553 | 1.723 |  | 0.170 | - 00 | 37 |
| 59. | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{PdCl}_{4}$ | 1.544 | 1.736 |  | 0.192 | - 00 | 37 |
| $59^{\prime}$ | $\mathrm{Fe}_{2}\left(\mathrm{MoO}_{4}\right)_{3} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Ferrimolybdite | 1.720 | 1.733 | 1.935 | 0.215 | +10 ? | 183 |
| 60 | $\mathrm{H}_{\mathrm{g}_{2}}(\mathrm{OH})_{2}\left(\mathrm{NO}_{3}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.69 | 1.72 | 1.92 | 0.23 | +70 | 104 |
| 61 | $\mathrm{LiNO}_{3}$ | 1.435 | 1.735 |  | 0.300 | - 00 | 100 |

$1.72<n_{y}<1.75$

$n_{y}=1.750$ to 1.7999

| $\begin{aligned} & \text { No. } \\ & \text { on } \\ & \text { Chart } \end{aligned}$ | Substance | $n^{\prime}$ | $n_{y}$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\mathrm{Fe}\left(\mathrm{AsO}_{4}\right)$ |  | 1.78 |  |  |  | 190 |
| 1 | $\mathrm{ZrSiO}_{4}$, Malacon |  | 1.76 | 1.76 | 0.00 | +00 | 299 |
| 2 | $\mathrm{Na}_{4} \mathrm{Sn}_{5} \mathrm{O}_{2} \mathrm{~S}_{10} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ |  | 1.79 |  | 0.0019 | - 25 | 14 |
| 1 | $\mathrm{CsHgCl}_{3}$ |  | 1.779 |  | 0.002 |  | 37107 |
| 2 | $\mathrm{Pt}\left(\mathrm{NH}_{3}\right)_{2} \mathrm{BrNO}_{2}$ | 1.778 | 1.78 | 1.78 | 0.002 |  |  |
|  | $\mathrm{LaO}(\mathrm{OH})$ |  | 1.798 |  | 0.006 |  | 70 |
| 3 | $\mathrm{CaAl}_{12} \mathrm{O}_{19}$ | 1.750 | 1.757 |  | 0.007 | - 00 | 80 |
| 4 | $\mathrm{Al}_{2} \mathrm{O}_{3}$, Corundum | 1.7604 | 1.7686 |  | 0.0082 | - 00 | 60 |
| 5 | $\mathrm{Fe}_{2}\left(\mathrm{SO}_{4}\right)_{3}$ | 1.760 | 1.770 |  | 0.010 | - 00 | 131 |
| 5 | $\mathrm{Cs}_{3} \mathrm{Tl}_{2} \mathrm{Cl}_{9}$ | 1.774 | 1.784 |  | 0.010 | - 00 | 44 |
| 5 | $\mathrm{CaAl}_{12} \mathrm{O}_{19}$ | 1.780 | 1.790 |  | 0.010 | - 00 | 80 |
| 5 | $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2}$, Heated $1000^{\circ}$ | 1.765 | 1.778 |  | 0.013 | - 00 | 207 |
| 6 | $\mathrm{CuO} \cdot \mathrm{UO}_{3} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.765 | 1.792 | 1.82 | 0.015 | 90 | 84 |
| 7 | $\left(\mathrm{NH}_{4}\right)_{3} \mathrm{RhCl}_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.740 | 1.750 | 1.756 | 0.016 | - 70 | 45 |
| 8 | $4 \mathrm{Na}_{2} \mathrm{O} \cdot \mathrm{P}_{2} \mathrm{O}_{5} \cdot 24 \mathrm{WO} \mathrm{O}_{3} \cdot \mathrm{nH}_{2} \mathrm{O}$ | 1.766 | 1.776 | 1.789 | 0.023 | $+69$ | 185 |
|  | $\mathrm{Na}_{8} \mathrm{Sn}_{5} \mathrm{O}_{2} \mathrm{~S}_{12} \cdot 32 \mathrm{H}_{2} \mathrm{O}$ |  | 1.79 |  | 0.024 | - | 14 |
| 9 | $\mathrm{Pt}\left(\mathrm{NH}_{3}\right)_{2} \mathrm{ClNO}_{2}$ | 1.764 | 1.786 | 1.790 | 0.026 | -46 | 107 |
| 10 | $\mathrm{Ag}_{2} \mathrm{SO}_{4}$ | 1.7583 | 1.7748 | 1.7842 | 0.0269 | +73 | 127 |
| 11 | $\mathrm{Fe}{ }^{\text {F }} \mathrm{Fe}^{\text {" }} \mathrm{Si}_{2} \mathrm{O}_{6}$ | 1.7677 | 1.7691 | 1.7976 | 0.0299 | +25 | 273 |
| 12 | $\mathrm{CuO} \cdot \mathrm{UO}_{3} \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Vanden brandeite | 1.77 | 1.78 | 1.80 | 0.03 | - 70 | 84 |
| 13 | $\mathrm{SeO}_{2}$ |  | 1.76 |  | 0.03 | +00 | 63 |
| 14 | $\mathrm{Fe}\left(\mathrm{AsO}_{4}\right) \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Scorodite | 1.784 | 1.795 | 1.814 | 0.030 | +75 | 200 |
| 15 | $\mathrm{Zn}_{2}\left(\mathrm{AsO}_{4}\right)(\mathrm{OH})$ | 1.742 | 1.768 | 1.773 | 0.031 | - 23 | 202 |
| 16 | $\mathrm{Zn}_{2} \mathrm{GeO}_{4}$ |  | 1.769 | 1.802 | 0.033 | +00 | 300 |
| 17 | $6 \mathrm{Fe}_{2} \mathrm{SiO}_{4} \cdot 4 \mathrm{Mg}_{2} \mathrm{SiO}_{4}$ | 1.748 | 1.778 | 1.792 | 0.044 | -69 | 303 |
| 18 | $\mathrm{BaTiSi}_{3} \mathrm{O}_{9}$, Benitoite |  | 1.757 | 1.804 | 0.047 | +00 | 288 |
| 19 | $\mathrm{Na}_{2} \mathrm{ZrOSiO}_{4}$ | 1.741 | 1.790 | 1.790 | 0.049 | - 20 | 308 |
| 20 | $\mathrm{CaC}_{2}$ |  | 1.75 |  | 0.05 | + 15 | 5 |
| 21 | $(\mathrm{Ce}, \mathrm{La})\left(\mathrm{PO}_{4}\right)$ | 1.785 | 1.787 | 1.840 | 0.055 | +25 | 191 |
| 22 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{FeCl}_{5} \cdot \mathrm{H}_{2} \mathrm{O}$, Kremersite | 1.750 | 1.775 | 1.814 | 0.064 | +78 | 45 |
| 23 | $\mathrm{Fe}^{\prime \prime} \mathrm{Fe}_{2}^{\mathrm{\prime} \mathrm{\prime}}\left(\mathrm{PO}_{4}\right)_{2}(\mathrm{OH})_{2}$, Barbosalite | 1.77 | 1.79 | 1.835 | 0.065 | +70 | 203 |
| 24 | $\mathrm{Pt}\left(\mathrm{NH}_{3}\right)_{2} \mathrm{Cl}_{2}$ | 1.745 | 1.790 | 1.812 | 0.067 | -70 | 54 |
| 25 | $\mathrm{Cu}_{4} \mathrm{SO}_{4}(\mathrm{OH})_{6}$, Brochantite | 1.728 | 1.771 | 1.800 | 0.072 | - 77 | 17354 |
|  | $\mathrm{Pt}\left(\mathrm{NH}_{3}\right)_{2} \mathrm{Cl}_{2}$ | 1.706 | 1.778 | 1.790 | 0.084 |  |  |
| 26 | $\mathrm{K}_{2} \mathrm{FeCl}_{5} \cdot \mathrm{H}_{2} \mathrm{O}$, Erythrosiderite | 1.715 | 1.75 | 1.80 | 0.085 | +62 | 45 |
| 27 | $\mathrm{Cs}_{3} \mathrm{Ag}_{2} \mathrm{Ba}(\mathrm{CNS})_{7}$ | 1.6788 | 1.7761 |  | 0.0973 | - 00 | 38 |
| 28 | $\mathrm{Cu}_{3}(\mathrm{OH})_{2}\left(\mathrm{CO}_{3}\right)_{2}$, Azurite | 1.730 | 1.754 | 1.836 | 0.106 | +67 | 97 |
| 29 | $\mathrm{CaV}_{2} \mathrm{O}_{6} \cdot 4 \mathrm{H}_{2} \mathrm{O}$, Rossite | 1.710 | 1.770 | 1.840 | 0.130 | - 70 | 212 |
| 28 | $\mathrm{Pt}\left(\mathrm{NH}_{3}\right)_{2} \mathrm{Cl}\left(\mathrm{NO}_{2}\right)_{3}$ | 1.755 | 1.797 1.7909 | 1.89 | 0.135 0.1382 | +66 .00 | 107 |
| 30 | $\mathrm{K}_{2} \mathrm{PtI}_{2}\left(\mathrm{NO}_{2}\right)_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1.6527 | 1.7909 |  | 0.1382 | - 00 | 106 |
| 31 | $\mathrm{K}_{2} \mathrm{Cr}_{2} \mathrm{O}_{7}$ | 1.715 1.555 | 1.762 1.765 | 1.892 | 0.177 | +64 | 122 |
| 32 | $\mathrm{CaFe}\left(\mathrm{CO}_{3}\right)_{2}$, Ferrodolomite | 1.555 | 1.765 |  | 0.210 | -00 +25 | 95 183 |
| 33 | $\mathrm{Fe}_{2}\left(\mathrm{MoO}_{4}\right)_{3} \cdot 8 \mathrm{H}_{2} \mathrm{O}$, Ferrimolybdite | 1.78 | 1.79 | 2.04 | 0.26 | +25 | 183 |
| 34 | $\mathrm{Pt}\left(\mathrm{NH}_{3}\right)_{2}\left(\mathrm{NO}_{2}\right)_{2}$ | 1.531 | 1.779 | 1.80 | 0.269 | - 32 | 107 |


$n_{y}=1.800$ to 1.8499

| $\begin{aligned} & \text { No. } \\ & \text { on } \\ & \text { Chart } \end{aligned}$ | Substance | $n_{x}$ | $n y$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Lipscombite |  | 1.83 |  |  |  | 203 |
| 1 | $\mathrm{Na}_{4} \mathrm{Sn}_{5} \mathrm{O}_{2} \mathrm{~S}_{\mathbf{4 0}} \cdot 18 \mathrm{H}_{\mathbf{2}} \mathrm{O}$ |  |  |  | 0.0016 | - 60 | 14 |
| 2 | $\mathrm{Ag}_{2} \mathrm{HPO}_{4}$ | 1.7983 | 1.8036 |  | 0.0053 | - 00 | 187 |
| 3 | $\mathrm{Cu}_{2}(\mathrm{OH})_{3} \mathrm{Cl}$, Paratacamite |  | 1.842 | 1.848 | 0.006 | +00 | 31 |
|  | $\mathrm{YO}(\mathrm{OH})$ |  | 1.845 |  | 0.01 |  | 71 |
| 4 | $\mathrm{Fe}_{2}\left(\mathrm{SO}_{4}\right)_{3}$ | 1.802 | 1.814 | 1.818 | 0.016 | - 60 | 131 |
|  | $\mathrm{Ba}_{2} \mathrm{SiO}_{4}$ | 1.810 |  | 1.830 | 0.02 |  | 302 |
| 5 | $\mathrm{Be}_{2} \mathrm{Si}_{12} \mathrm{O}_{40} \cdot 16 \mathrm{H}_{2} \mathrm{O}$ |  | 1.816 |  | 0.023 | - 79 | 184 |
| 6 | $\mathrm{NaSiYO}_{4}$ | 1.804 | 1.832 |  | 0.028 | - 00 | 228 |
|  | $\mathrm{KFeSi}_{2} \mathrm{O}_{6}$ |  | 1.80 |  | 0.03 | - | 279 |
|  | $2 \mathrm{CrPO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ |  | 1.810 |  | 0.03 |  | 199 |
| 7 | $\mathrm{Mn}_{2} \mathrm{SiO}_{4}$, Tephroite | 1.78 | 1.805 | 1.82 | 0.04 | - 50 | 303 |
| 8 | $8 \mathrm{Fe}_{2} \mathrm{SiO}_{4} \cdot \mathbf{2 M g 2} \mathrm{SiO}_{4}$ | 1.786 | 1.821 | 1.834 | 0.048 | -62 | 303 |
| 9 | $(\mathrm{Ce}, \mathrm{La}) \mathrm{PO}_{4}$, Monazite | 1.800 | 1.801 | 1.849 | 0.049 | +13 | 191 |
| 10 | $\mathrm{NH}_{4} \mathrm{Fe}_{3}\left(\mathrm{SO}_{4}\right)_{2}(\mathrm{OH})_{6}$, Ammoniojarosite | 1.750 | 1.800 |  | 0.05 | -00 | 174 |
|  | $\mathrm{KMnO}_{4}$ | 1.80 |  | 1.85 | 0.05 |  | 82 |
| 11 | $\mathrm{CuPbSO}_{4}(\mathrm{OH})_{2}$, Linarite | 1.8090 | 1.8380 | 1.8593 | 0.0503 | - 80 | 175 |
| 13 | $\mathrm{NaFeSi}_{2} \mathrm{O}_{6}$, Acmite | 1.7710 | 1.8103 | 1.8271 | 0.0561 | - 60 | 279 |
| 14 | $\mathrm{AgBrO}_{3}$ |  | 1.8466 | 1.920 | 0.0734 | +00 | 108 |
|  | $\mathrm{Na}_{2} \mathrm{ZrO}_{3}$ | 1.720 |  | 1.80 | 0.08 | - | 73 |
|  | $\mathrm{PbH}_{4}\left(\mathrm{AsO}_{3}\right)_{2}$ | 1.74 | 1.82 |  | 0.08 | - | 188 |
| 15 | $\mathrm{RbFe}_{3}\left(\mathrm{SO}_{4}\right)_{2}(\mathrm{OH})_{6}$ | 1.720 | 1.805 |  | 0.085 | - 00 | 174 |
| 15 | $\mathrm{H}_{2} \mathrm{O} \cdot \mathrm{Fe}_{3}\left(\mathrm{SO}_{4}\right)_{4}(\mathrm{OH})_{5} \cdot \mathrm{H}_{2} \mathrm{O}$, Carphosiderite | 1.728 | 1.816 |  | 0.088 | - 00 | 174 |
| 16 | $\left(\mathrm{UO}_{3}\right)_{7} \cdot 11 \mathrm{H}_{2} \mathrm{O}$, Becquerelite | 1.735 | 1.820 | 1.830 | 0.095 | 31 | 67 |
| 17 | $\mathrm{Ca}\left(\mathrm{IO}_{3}\right)_{2}$, Lautarite | 1.792 | 1.840 | 1.888 | 0.096 | +85 | 109 |
| 18 | $\mathrm{KFe}_{3}\left(\mathrm{SO}_{4}\right)_{2}(\mathrm{OH})_{6}$, J arosite | 1.715 | 1.820 |  | 0.105 | - 00 | 174 |
| 18 | $\mathrm{Cs}_{3} \mathrm{Cu}_{2} \mathrm{Ba}(\mathrm{CNS})_{7}$ | 1.6882 | 1.8013 |  | 0.1131 | - 00 | 38 |
| 19 | $\mathrm{KIO}_{3}$ | 1.700 | 1.828 | 1.832 | 0.132 | - 25 | 108 |
| 20 | $(\mathrm{Mg}, \mathrm{Fe})_{2} \mathrm{FeBO}_{5}$, Ludwigite | 1.83 | 1.83 | 1.97 | 0.14 | +25 | 114 |
| 21 | $\mathrm{KHg}(\mathrm{CNS})_{3}$ | 1.735 | 1.82 | 1.88 | 0.150 | -65 | 38 |
| 22 | $\mathrm{Cu}_{2}\left(\mathrm{SO}_{4}\right) \mathrm{O}$, Dolerophanite | 1.715 | 1.820 | 1.880 | 0.165 | $+85$ | 175 |
| 22 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Cr}_{2} \mathrm{O}{ }_{7}$ | 1.725 | 1.80 | 1.905 | 0.180 | $+85$ | 122 |
| 23 | $\mathrm{MnCO}_{3}$, Rhodochrosite | 1.597 | 1.816 |  | 0.219 | - 00 | 92 |
| 23 | $\mathrm{ZnCO}_{3}$, Smith sonite | 1.621 | 1.848 |  | 0.227 | - 00 | 93 |
| 24 | $\mathrm{K}_{2} \mathrm{Hg}(\mathrm{CNS})_{4}$ | 1.645 | 1.80 | 1.9 | 0.255 | - 88 | 38 |

## $1.80<n_{y}<1.85$


${ }^{\prime} y=1.850$ to 1.8999

| No. on Chart | Substance | $n_{x}$ | $n_{y}$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | $\mathrm{CaSi}_{2} \mathrm{La}_{2} \mathrm{O}_{8}$ | 1.874 | 1.880 |  | 0.006 | - 00 | $\begin{array}{r} 228 \\ 70 \end{array}$ |
|  | $\mathrm{NdO}(\mathrm{OH})$ |  | 1.850 |  | 0.01 |  |  |
| 2 | $\mathrm{CaV}_{2} \mathrm{O}_{6} \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Metarossite | 1.840 | 1.85 | 1.85 | 0.01 | 70 | 212 |
|  | $\mathrm{SmO}(\mathrm{OH})$ |  | 1.860 |  | 0.01 |  | 71 |
|  | $\mathrm{Pb}_{2} \mathrm{UO}_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$, Parsonsite | 1.85 |  | 1.862 | 0.012 |  | 210 |
| 3 | $\mathrm{PbSO}_{4}$, Anglesite | 1.8781 | 1.8832 | 1.8947 | 0.0166 | $+68$ | 131 |
| 4 | $\mathrm{Tl}_{2} \mathrm{SO}_{4}$ | 1.8600 | 1.8671 | 1.8853 | 0.0253 | +68 | 127 |
| 5 | $\mathrm{KSiLaO}_{4}$ | 1.840 | 1.867 |  | 0.027 | - 00 | 228 |
| 5 | $\mathrm{NaSiLaO}_{4}$ | 1.840 | 1.867 |  | 0.027 | - 00 | 228 |
| 5 | $\mathrm{LiSiLaO}_{4}$ | 1.843 | 1.870 |  | 0.027 | - 00 | 228 |
| 6 | $\mathrm{NaSiNdO}_{4}$ | 1.861 | 1.889 |  | 0.028 | - 00 | 228 |
| 6 | $\mathrm{NaSiPrO}_{4}$ | 1.861 | 1.889 |  | 0.028 | - 00 | 228 |
| 7 | $\left(\mathrm{UO}_{2}\right)_{2} \cdot 7 \mathrm{H}_{2} \mathrm{O}$, Ianthinite |  | 1.88 | 1.91 | 0.03 | - 10 | 66 |
| 8 | $\mathrm{NaSiSmO}_{4}$ | 1.867 | 1.898 |  | 0.031 | - 00 | 228 |
| 9 | $\mathrm{Cu}_{2}(\mathrm{OH})_{3} \mathrm{Cl}$, Atacamite | 1.831 | 1.861 | 1.880 | 0.049 | - 75 | 30 |
| 10 | $\mathrm{Fe}_{2} \mathrm{SiO}_{4}$, Fayalite | 1.824 | 1.864 | 1.875 | 0.051 | - 47 | 303 |
| 11 | $\mathrm{Tl}\left(\mathrm{NO}_{3}\right)$ | 1.817 | 1.862 | 1.869 | 0.052 | - 53 | 102 |
| 12 | $\mathrm{K}_{2} \mathrm{Pt}(\mathrm{CN})_{6}$ | 1.820 | 1.890 |  | 0.070 | - 00 | 48 |
| 12 | $\mathrm{K}_{2} \mathrm{Pt}(\mathrm{CNS})_{6}$ | 1.820 | 1.890 |  | 0.070 | - 00 | 48 |
| 13 | $\mathrm{PbFe}_{6}\left(\mathrm{SO}_{4}\right)_{4}(\mathrm{OH})_{12}$, Plumbojarosite | 1.783 | 1.870 |  | 0.087 | - 00 | 174 |
| 14 | $\mathrm{AgFe}_{3}\left(\mathrm{SO}_{4}\right)_{2}(\mathrm{OH})_{6}$, Argentojarosite | 1.785 | 1.882 |  | 0.097 | - 00 | 174 |
| 15 | $\left(\mathrm{UO}_{3}\right)_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 1.79 | 1.89 | 1.91 | 0.12 | - 48 | 67 |
| 16 | $\mathrm{Cs}_{3} \mathrm{Cu}_{2} \mathrm{Sr}(\mathrm{CNS})_{7}$ | 1.6982 | 1.8535 |  | 0.1553 | - 00 | 38 |
| 17 | $(\mathrm{Mg}, \mathrm{Fe})_{2} \mathrm{FeBO}_{5}$ | 1.85 | 1.85 | 2.02 | 0.17 | +25 | 114 |
| 18 | $\mathrm{HgCl}_{2}$ | 1.725 | 1.859 | 1.965 | 0.240 | -85 | 26 |
| 19 | $\mathrm{FeCO}_{3}$, Siderite | 1.633 | 1.875 |  | 0.242 | -00 | 93 |
| 20 | $\mathrm{Cu}_{2}(\mathrm{OH})_{2} \mathrm{CO}_{3}$, Malachite | 1.655 | 1.875 | 1.909 | 0.254 | - 43 | 98 |
| 21 | $\mathrm{CoCO}_{3}$, Cobaltocalcite | 1.60 | 1.855 |  | 0.255 | - 00 | 93 |


$n_{y}=1.900$ to 1.9499

| No. on Chart | Substance | $n^{\prime}$ | $n_{y}$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | $\mathrm{SrMoO}_{4}$ |  | 1.9210 | 1.9258 | 0.0048 | +00 | 181 |
| 2 | $\mathrm{CaSi}_{2} \mathrm{Nd}_{2} \mathrm{O}_{3}$ | 1.898 | 1.903 |  | 0.005 | - 00 | 228 |
| 3 | $\mathrm{BiO}(\mathrm{OH}, \mathrm{Cl})$, Daubréeite | 1.90 | 1.91 |  | 0.01 | - 00 | 52 |
| 4 | $\mathrm{Y}_{3} \mathrm{Al}_{2} \mathrm{Al}_{3} \mathrm{O}_{12}$, Yttroalumite | 1.927 | 1.942 |  | 0.015 | - 00 | 298 |
| 5 | Cawor ${ }^{\text {, Scheelite }}$ |  | 1.9200 | 1.9365 | 0.0165 | +00 | 180 |
| 6 | $\mathrm{ZrSiO}_{4}$, Hyacinth |  | 1.90 | 1.92 | 0.02 | +00 | 299 |
| 7 | $\mathrm{PbAl}_{2} \mathrm{O}_{4}$ | 1.85 | 1.91 |  | 0.06 | - 00 | 78 |
| 8 | $\mathrm{Pb}_{2} \mathrm{UO}_{2} \mathrm{SiO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$, Kasolite | 1.80 | 1.90 | 1.967 | 0.077 | $+43$ | 311 |
| 9 | $\mathrm{PbHAsO}_{4}$, Schultenite | 1.8903 | 1.9097 | 1.9765 | 0.0862 | +66 | 187 |
| 10 | $\mathrm{PbO} \cdot \mathrm{UO}_{3} \cdot 5 \mathrm{H}_{2} \mathrm{O}$, Fourmarierite | 1.85 | 1.92 | 1.94 | 0.09 | - 70 | 84 |
| 11 | $3 \mathrm{Cu}\left(1 \mathrm{I}_{3}\right)_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Bellingerite | 1.890 | 1.90 | 1.99 | 0.10 | + 50 | 109 |
| 12 | $\mathrm{As}_{2} \mathrm{O}_{3}$, Claudetite | 1.87 | 1.92 | 2.01 | 0.14 | + 58 | 61 |
| 13 | $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{VO}_{4}\right)_{2} \cdot \mathrm{nH}_{2} \mathrm{O}$, Tyuyamunite | 1.76 | 1.93 | 1.96 | 0.17 | - 48 | 209 |
| 14 | $\mathrm{K}_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{VO}_{4}\right)_{2} \cdot 3 \mathrm{H}_{2} \mathrm{O}$, Carnotite | 1.750 | 1.925 | 1.950 | 0.200 | - 40 | 206 |
| 15 | $\mathrm{K}_{2} \mathrm{~Pb}_{2} \mathrm{Si}_{2} \mathrm{O}_{7}$ | 1.72 | 1.93 |  | 0.21 | - 00 | 295 |
| 16 | $\left(\mathrm{UO}_{2}\right)_{2} \cdot 7 \mathrm{H}_{2} \mathrm{O}$, Ianthinite | 1.674 | 1.90 | 1.92 | 0.246 | - 10 | 66 |

$1.90<n_{y}<1.95$

$n_{y}=1.950$ to 1.9999

| $\begin{gathered} \text { No. } \\ \text { on } \\ \text { Chart } \end{gathered}$ | Substance | $n_{x}$ | $n_{y}$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | $\mathrm{SrMoO}_{4} \cdot 39.7 \% \mathrm{Ce}_{2}\left(\mathrm{MoO}_{4}\right)_{3}$ |  | 1.952 | 1.956 | 0.004 | +00 | 181 |
| 2 | $\mathrm{CaMoO}_{4}=4.7 \% \mathrm{Y}_{2}\left(\mathrm{MoO}_{4}\right)_{3}$ |  | 1. 993 | 2.002 | 0.009 | +00 | 180 |
|  | $\mathrm{Na}_{12} \mathrm{Fe}_{8} \mathrm{O}_{8} \mathrm{Si}_{5} \mathrm{O}_{20}$ |  | 1.96 |  | 0.01 |  | 308 |
| 3 | $\mathrm{CaMoO}_{4}$, Powellite- |  | 1.974 | 1.984 | 0.010 | +00 | 180 |
| 4 | $\mathrm{Tl}_{2} \mathrm{SeO}_{4}$ | 1.9493 | 1.9592 | 1.9640 | 0.0147 | - 73 | 128 |
| 5 | $\mathrm{Pb}_{3} \mathrm{Si}_{3} \mathrm{O}_{9}$, Alamosite | 1.947 | 1.961 | 1.968 | 0.023 | - 65 | 291 |
| 6 | $\mathrm{Pb}_{3}\left(\mathrm{PO}_{4}\right)_{2}$ |  | 1.9702 | 1.9364 | 0.0338 | - 00 | 189 |
| 7 | $\mathrm{Pb}_{3}\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathrm{Ce}\left(\mathrm{PO}_{4}\right)$ | 1.9326 | 1.9697 |  | 0.0371 | - 00 | 189 |
| 8 | $\mathrm{Ni}_{2} \mathrm{SiO}_{4}$ | 1.976 | 1.987 | 2.019 | 0.043 | +60 | 304 |
| 9 | $\mathrm{Ca}_{6} \mathrm{Al}_{4} \mathrm{Fe}_{2} \mathrm{O}_{15}$ | 1.94 | 1.99 | 1.99 | 0.05 | - 25 | 79 |
| 10 | $\mathrm{ZrSiO}_{4}$, Zircon |  | 1.96 | 2.02 | 0.06 | +00 | 299 |
| 11 | $(\mathrm{Ca}, \mathrm{Mg}, \mathrm{Fe}, \mathrm{Fe}, \mathrm{Al})_{2}(\mathrm{Si}, \mathrm{Al})_{2} \mathrm{O}_{6}$, Mellorite | 1.92 | 1.95 | 2.00 | 0.08 | +75 | 272 |
| 12 | $\mathrm{GeO}_{2}$ |  | 1.99 | 2.08 | 0.09 | +00 | 63 |
| 13 | $\mathrm{CaTiOSiO}_{4}$, Sphene, Titanite | 1.950 | 1.970 | 2.092 | 0.142 | + 20 | 310 |
| 14 | WO ${ }_{3} \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Hydrotungstite | 1.70 | 1.95 | 2.04 | 0.34 | - 52 | 67 |
| 15 | HgCl , Calomel |  | 1.9733 | 2.6559 | 0.6826 | +00 | 20 |


$n_{y}=2.000$ to 2.099

| $\begin{aligned} & \text { No. } \\ & \text { on } \\ & \text { Chart } \end{aligned}$ | Substance | $n_{\boldsymbol{x}}$ | $n_{y}$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | C, Graphite |  | 2.0 |  |  | - 00 | 5 |
|  | $\left(\mathrm{Ca}, \mathrm{Na}_{2}\right) \mathrm{U}_{2} \mathrm{O}_{7} \cdot \mathrm{nH}_{2} \mathrm{O}$ |  | 2.00 |  |  | - | 84 |
|  | $\mathrm{Pb}_{\mathbf{2}} \mathrm{As}_{\mathbf{2}} \mathrm{O}_{7}$ |  | 2.03 |  |  |  | 214 |
| 1 | $(\mathrm{Nd}, \mathrm{Pr})_{2}\left(\mathrm{MoO}_{4}\right)_{3}$ | 2.02 | 2.026 |  | 0.00 | - 00 | 182 |
| 1 | $\mathrm{Y}_{2}\left(\mathrm{MoO}_{4}\right)_{3}$ |  | 2.03 | 2.031 | 0.001 | +00 | 182 |
| 1 | $\mathrm{Nd}_{2}\left(\mathrm{MoO}_{4}\right)_{3}$ | 2.0218 | 2.0239 |  | 0.0021 | - 00 | 182 |
| 2 | $\mathrm{Pr}_{2}\left(\mathrm{MoO}_{4}\right)_{3}$ | 2.007 | 2.01 |  | 0.003 | - 00 | 182 |
| 3 | S |  | 2.058 |  | 0.01 | - 58 | 4 |
| 4 | $\mathrm{Pb}_{5}\left(\mathrm{PO}_{4}\right)_{3} \mathrm{Cl}$, Pyromorphite | 2.048 | 2.058 |  | 0.011 | - 00 | 204 |
| 5 | $\mathrm{Ce}_{2}\left(\mathrm{MoO}_{4}\right)_{3}$ | 2.0277 | 2.0403 |  | 0.0126 | - 00 | 182 |
| 6 | ZnO , Zincite |  | 2.013 | 2.029 | 0.016 | +00 | 58 |
| 7 | $\mathrm{Pb}(\mathrm{Cu}, \mathrm{AR}) \mathrm{Cl}_{2}(\mathrm{OH})_{2} \cdot \mathrm{H}_{2} \mathrm{O}$, Boleite | 2.03 | 2.05 |  | 0.02 | - 00 | 31 |
|  | Rosickyite |  | 2.058 |  | 0.03 | - | 4 |
| 8 | $\mathrm{Na}_{2} \mathrm{SnS}_{3} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ |  | 2 |  | 0.06 | +00 | 14 |
| 9 | $\mathrm{PbO} \cdot 3 \mathrm{UO}_{3} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 2.05 | 2.08 | 2.12 | 0.07 | +50 | 84 |
| 10 | $\mathrm{Ca}_{4} \mathrm{Al}_{2} \mathrm{Fe}_{2} \mathrm{O}_{\mathbf{1}}$, Brownmillerite | 1.96 | 2.01 | 2.04 | 0.08 | - 75 | 78 |
| 11 | $\mathrm{SnO}_{2}$, Cassiterite |  | 2.0006 | 2.0972 | 0.0966 | +00 | 62 |
| 12 | $\mathrm{Pb}_{2}\left(\mathrm{SO}_{4}\right) \mathrm{O}$, Lanarkite | 1.928 | 2.007 | 2.036 | 0.108 | - 60 | 174 |
| 13 | Clarkeite ( $\sim \mathrm{CaU}_{\mathbf{2}} \mathrm{O}_{7} \cdot \mathbf{n H}_{\mathbf{2}} \mathrm{O}$ ) | 1.997 | 2.098 | 2.180 | 0.117 | - 40 | 84 |
| 13 | $\mathrm{Na}_{2} \mathrm{Ti}_{2} \mathrm{Si}_{2} \mathrm{O}_{9}$, Lorenzenite | 1.91 | 2.01 | 2.02 | 0.12 | - 39 | 268 |
| 14 | $\mathrm{Pb}_{4} \mathrm{SO}_{4}\left(\mathrm{CO}_{3}\right)_{2}(\mathrm{OH})_{2}$, Leadhillite | 1.87 | 2.00 | 2.01 | 0.14 | - 10 | 100 |
| 15 | $\mathrm{Pb}_{3}(\mathrm{OH})_{2}\left(\mathrm{CO}_{3}\right)_{2}$, Hydrocerussite | 1.94 | 2.09 |  | 0.15 | - 00 | 97 |
| 16 | $\mathrm{WO}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$, Tungstite | 1.82 | 2.03 | 2.04 | 0.22 | - 27 | 67 |
|  | $\mathrm{AgN}_{3}$ | 1.80 | 2.05 | 2.05 | 0.25 | - | 7 |
| 17 | $\mathrm{PbCO}_{3}$, Cerussite | 1.8037 | 2.0763 | 2.0780 | 0.2743 | - 09 | 94 |
| 18 | $\mathrm{Cu}(\mathrm{OH}) \mathrm{IO}_{3}$ | 1.775 | 2.046 | 2.052 | 0.277 | -15 | 109 |
| 19 | S, Sulfur | 1.9579 | 2.0377 | 2.2452 | 0.2875 | +68 | 4 |
| 20 | $\mathrm{Cu}(\mathrm{OH}) \mathrm{IO}_{3}$, Salesite | 1.786 | 2.070 | 2.075 | 0.289 | -05 | 109 |
| 21 | NiS | 1.908 | 2.046 | 3.22 | 1.212 | +70 | 11 |


${ }^{n} y=2.10$ to 2.299

| $\begin{aligned} & \text { No. } \\ & \text { on } \\ & \text { Chart } \end{aligned}$ | Substance | $n_{x}$ | $n v$ | $n_{z}$ | $n_{z} \cdot n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | AgI, Iodyrite |  | 2.218 | 2.229 | 0.011 | +00 | 20 |
| 1 | $(\mathrm{BiO})_{2} \mathrm{CO}_{3}, \mathrm{Bismutite}$ |  | 2.12 | 2.12 | 0.014 ? | +00 | 97 |
| 2 | $\mathrm{Pb}_{5}\left(\mathrm{AsO}_{4}\right)_{3} \mathrm{Cl}$, Mimetite | 2.128 | 2.147 |  | 0.019 | - 00 | 204 |
| 3 | $\mathrm{Pb}_{2} \mathrm{Cl}_{2} \mathrm{CO}_{3}$, Phosgenite |  | 2.1181 | 2.1446 | 0.0265 | +00 | 97 |
| 4 | $\mathrm{PbWO}_{4}$, Raspite | 2.27 | 2.27 | 2.30 | 0.03 | $+10$ | 182 |
| 5 | $\mathrm{BiOCl}, \mathrm{Bismoclite}$ |  | 2.15 |  | 0.03 | - 00 | 52 |
| 6 | $\mathrm{PbZrO}_{3}$ | 2.16 | 2.18 | 2.2 | 0.039 | - 85 | 81 |
| 7 | $\mathrm{BiAsO}_{4}$; Rooseveltite | 2. 14 | 2.15 | 2.18 | 0.04 | + 50 | 191 |
| 8 | $\mathrm{Pb}_{2} \mathrm{SiO}_{4}$ | 2.13 | 2.15 | 2.18 | 0.05 | - 80 | 304 |
| 9 | $\mathrm{Ca}_{3} \mathrm{Ti}_{2} \mathrm{O}_{7}$ | 2.16 | 2.22 |  | 0.06 | - 00 | 81 |
| 10 | $\mathrm{PbCl}_{2}$, Cotunnite | 2.199 | 2.217 | 2. 260 | 0.061 | +66 | 26 |
| 11 | Aln |  | 2.13 | 2.20 | 0.07 | +00 | 8 |
| 12 | $\mathrm{ZrO}_{2}$, Baddeleyite | 2.13 | 2.19 | 2.20 | 0.07 | - 30 | 66 |
| 13 | $\mathrm{Pb}_{3} \mathrm{O}_{2} \mathrm{Cl}_{2}$, Mendipite | 2.24 | 2.27 | 2.31 | 0.07 | $+85$ | 52 |
| 14 | $\mathrm{PbWO}_{4}$, Stolzite | 2.19 | 2.27 |  | 0.08 | - 00 | 181 |
| 15 | $\mathrm{Pb}(\mathrm{OH}) \mathrm{Cl}$, Laurionite | 2.077 | 2.116 | 2.158 | 0.081 | - 70 | 31 |
| 15 | $\mathrm{PbO} \cdot 3 \mathrm{UO}_{3} \cdot 2 \mathrm{H}_{2} \mathrm{O}$, Curite | 2.06 | 2.11 | 2.15 | 0.09 | - 70 | 84 |
| 16 | $\mathrm{Ca}_{2} \mathrm{Fe}_{2} \mathrm{O}_{5}$ | 2.20 | 2.22 | 2.29 | 0.09 | +50 | 78 |
| 17 | $\mathrm{H}_{2} \mathrm{~K}_{2} \mathrm{TeI}_{2} \mathrm{O}_{10} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 2.030 | 2.142 |  | 0.112 | - 00 | 113 |
| 18 | $\mathrm{MgTi}_{2} \mathrm{O}_{5}$ | 2.11 | 2.19 | 2.23 | 0.12 | -70 | 81 |
| 19 | $\mathrm{MnWO}_{4}$, Huebnerite | 2.150 | 2.195 | 2.283 | 0.133 | +75 | 181 |
| 17 | PbClF , Matlockite | 2.006 | 2.145 |  | 0.139 | - 00 | 26 |
| 17 | $\mathrm{CaBi}_{2} \mathrm{O}_{2}\left(\mathrm{CO}_{3}\right)_{2}$, Beyerite | 1.99 | 2.13 |  | 0.14 | -00 | 99 |
| 20 | $\mathrm{Zn}_{2} \mathrm{Mn}_{4} \mathrm{O}_{8} \cdot \mathrm{H}_{2} \mathrm{O}$, Hydrohetaerolite | 2.10 | 2.26 |  | 0.16 | - 00 | 83 |
| 21 | $\mathrm{H}_{2} \mathrm{WO}_{4}$, Tungstite | 2.09 | 2.24 | 2.26 | 0.17 | - 14 | 67 |
| 21 | $\mathrm{WO}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | 2.09 | 2.24 | 2. 26 | 0.17 | -14 | 67 |
| 22 | $\mathrm{MnO}(\mathrm{OH})$, Manganite | 2.25 | 2.25 | 2.53 | 0.28 | +25 | 70 |
| 23 | $\mathrm{MgTiO}_{3}$ | 1.95 | 2.28 |  | 0.33 | - 00 | 80 |
| 24 | $\mathrm{TeO}_{2}$, Tellurite | 2.00 | 2.18 | 2.35 | 0.35 | - 70 | 65 |
| 25 | $\mathrm{FeO}(\mathrm{OH})$, Lepidocrocite | 1.94 | 2.20 | 2.51 | 0.57 | - 83 | 70 |

$2.10<n_{y}<2.30$

${ }^{n} y=2.300$ to 2.499

| $\begin{aligned} & \text { No. } \\ & \text { on } \\ & \text { Chart } \end{aligned}$ | Substance | $n^{\prime}$ | $n y$ | $n_{z}$ | $n_{z}-n_{x}$ | 2V | Page |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\mathrm{BI}_{2} \mathrm{O}_{3}$, Bismite |  | 2.43 |  |  |  | 61 |
| 1 | $\mathrm{PbO}_{2}$, Plattnerite |  | 2.30 |  | 0.005 | - 00 | 63 |
| 1 | $\mathrm{Pb}_{3} \mathrm{O}_{4}$, Minium | 2.41 | 2.42 |  | 0.006 | - 00 | 77 |
| 2 | $\mathrm{BaTiO}_{3}$ | 2.395 | 2.401 | 2.406 | 0.011 | - 75 | 81 |
| 3 | ZnS |  | 2.46 | 2.48 | 0.02 | +00 | 9 |
| 4 | ZnS , Wurtzite |  | 2.365 | 2.378 | 0.022 | +00 | 9 |
| 5 | $\mathrm{Fe}_{2} \mathrm{TiO}_{5}$, Pseudobrookite | 2.38 | 2.39 | 2.42 | 0.04 | +50 | 81 |
| 6 | $\mathrm{Pb}_{5}\left(\mathrm{VO}_{4}\right)_{3} \mathrm{Cl}$, Vanadinite | 2.350 | 2.416 |  | 0.066 | - 00 | 205 |
| 7 | $\mathrm{Pb}_{4} \mathrm{O}_{2} \mathrm{SiO}_{4}$ | 2.31 | 2.34 | 2.38 | 0.07 | +40 | 308 |
| 8 | $\mathrm{PbSbO}_{2} \mathrm{Cl}$, Nadorite | 2.30 | 2.35 | 2.40 | 0.10 | +85 | 53 |
| 9 | $\mathrm{PbBr}_{2}$ | 2.434 | 2.476 | 2.553 | 0.119 | +70 | 27 |
| 10 | $\mathrm{PbMoO}_{4}$, Wulfenite | 2.2826 | 2.4053 |  | 0.1227 | - 00 | 181 |
| 11 | $\mathrm{HFeO}_{2}$, Goethite | 2.260 | 2.393 | 2.398 | 0.138 | - 10 | 73 |
| 12 | $\mathrm{FeWO}_{4}$, Ferberite | 2.255 | 2.305 | 2.414 | 0.159 | +68 | 181 |
| 13 | $\mathrm{Sb}_{2} \mathrm{O}_{3}$, Valentinite | 2.18 | 2.35 | 2.35 | 0.17 | - 10 | 61 |
| 14 | $\mathrm{ZnMn}_{2} \mathrm{O}_{4}$, Hetaerolite | 2.10 | 2.35 |  | 0.25 | - 00 | 77 |
| 14 | $\mathrm{MnTiO}_{3}$, Pyrophanite | 2.210 | 2.481 |  | 0.271 | - 00 | 80 |
| 15 | $\mathrm{MnMn}_{2} \mathrm{O}_{4}$, Hausmannite | 2.15 | 2.45 |  | 0.30 | - 00 | 77 |
| 16 | $\mathrm{MgTiO}_{3}$, Geikielite | 1.95 | 2.31 |  | 0.36 | - 00 | 80 |
| 17 | $\mathrm{PbCrO}_{4}$, Crocoite | 2.29 | 2.36 | 2.66 | 0.37 | +57 | 131 |
| 18 | Asİ3 ${ }^{\text {S }}$ S | 1.8636 | 2.3036 |  | 0.440 | - 00 | 54 |



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| $\mathrm{CaHAsO} 4_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 194 | $\mathrm{Ca}_{2} \mathrm{OCl}_{2} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 51 |
| $\mathrm{CaHAsO} 4_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 194 | $\mathrm{Ca}_{4} \mathrm{O}_{3} \mathrm{Cl}_{2} \cdot 15 \mathrm{H}_{2} \mathrm{O}$ | 51 |
| $\mathrm{Ca}_{5} \mathrm{H}_{2}\left(\mathrm{AsO}_{4}\right)_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 195 | $\mathrm{Ca}_{5} \mathrm{O}_{4} \mathrm{Cl}_{2} \cdot 14 \mathrm{H}_{2} \mathrm{O}$ | 51 |
| $\mathrm{CaHPO}_{4}$ | 188 | $\mathrm{Ca}_{4} \mathrm{O}_{3} \mathrm{I}_{2} \cdot 15 \mathrm{H}_{2} \mathrm{O}$ | 51 |
| $\mathrm{CaH}_{4}\left(\mathrm{PO}_{4}\right)_{2}$ | 188 | $\mathrm{Ca}(\mathrm{OH})_{2}$ | 69 |
| $\mathrm{CaH}_{2} \mathrm{P}_{2} \mathrm{O}_{7}$ | 214 | $\mathrm{Ca}_{4}(\mathrm{OH})_{2} \mathrm{Si}_{6} \mathrm{O}_{15} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 265 |
| $\mathrm{CaHPO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 194 | $\mathrm{Ca}_{3}(\mathrm{OH})_{2} \mathrm{SiO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 306 |
| $\mathrm{CaH}_{4}\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 196 | $\mathrm{Ca}(\mathrm{OH}) \mathrm{VO}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | 104 |
| $\mathrm{CaI}_{2}$ | 27 | $\mathrm{Ca}_{3} \mathrm{OSiO}_{4}$ | 308 |
| $\mathrm{Ca}\left(\mathrm{IO}_{3}\right)_{2}$ | 109 | $5 \mathrm{CaO} \cdot \mathrm{SiO}_{2} \cdot \mathrm{~B}_{2} \mathrm{O}_{3}$ | 119 |
| $\mathrm{Ca}\left(\mathrm{IO}_{3}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 109 | $\mathrm{CaP}_{2} \mathrm{O}_{6}$ | 211 |
| $\mathrm{Ca}\left(\mathrm{IO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 112 | $\mathrm{Ca}_{2} \mathrm{P}_{2} \mathrm{O}_{7}$ | 213 |
| $\mathrm{CaMg}_{4} \mathrm{Al}_{5}(\mathrm{OH})_{4}\left(\mathrm{BO}_{3}\right)_{3} \mathrm{Si}_{6} \mathrm{O}_{18}$ | 289 | $\mathrm{CaP}_{4} \mathrm{O}_{11}$ | 215 |
| $\mathrm{Ca}_{2} \mathrm{Mg}_{3} \mathrm{Al}_{2} \mathrm{Si}_{6} \mathrm{Al}_{2} \mathrm{O}_{22}(\mathrm{OH})_{2}$ | 286 | $\mathrm{Ca}_{2} \mathrm{P}_{6} \mathrm{O}_{17}$ | 215 |
| $\mathrm{CaMgB}_{6} \mathrm{O}_{8}(\mathrm{OH})_{6} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 118 | $\mathrm{Ca}_{2} \mathrm{PbSi}_{3} \mathrm{O}_{9}$ | 293 |
| $\mathrm{CaMg}\left(\mathrm{CO}_{3}\right)_{2}$ | 95 | $\mathrm{CaPd}(\mathrm{CN})_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 32 |
| $\mathrm{CaMg}_{2} \mathrm{Cl}_{6} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 28 | $\mathrm{Ca}_{3}\left(\mathrm{PO}_{4}\right)_{2}$ | 189 |


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| $\mathrm{Ca}{ }_{10}\left(\mathrm{PO}_{4}\right)_{6} \mathrm{CO}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | 204 | $\mathrm{Ca}_{10} \mathrm{Si}_{5} \mathrm{O}_{20} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 306 |
| $\mathrm{Ca}_{2} \mathrm{PO}_{4} \mathrm{Cl}$ | 201 | $\mathrm{Ca}_{5} \mathrm{SiO}_{4}\left(\mathrm{BO}_{3}\right)_{2}$ | 119 |
| $\mathrm{Ca}_{5}\left(\mathrm{PO}_{4}\right)_{3} \mathrm{Cl}$ | 203 | $\left(\mathrm{Ca}, \mathrm{Sr}\left(\mathrm{SiO}_{3}\right.\right.$ | 280 |
| $\mathrm{Ca}_{5}\left(\mathrm{PO}_{4}\right)_{3} \mathrm{~F}$ | 203 | CaTe | 12 |
| $\mathrm{Ca}_{4}\left(\mathrm{PO}_{4}\right)_{2} \mathrm{O}$ | 202 | $\mathrm{CaTiO}_{3}$ | 81 |
| $\mathrm{Ca}_{5}\left(\mathrm{PO}_{4}\right)_{3} \mathrm{OH}$ | 203 | $\mathrm{Ca}_{3} \mathrm{TiO}_{7}$ | 81 |
| $\mathrm{Ca}_{5}\left(\mathrm{PO}_{4}\right)_{2} \mathrm{SiO}_{4}$ | 215 | $\mathrm{CaTiOSiO}_{4}$ | 310 |
| $\mathrm{Ca}_{3}\left(\mathrm{PO}_{4}\right)_{2} \cdot 2 \mathrm{Ca}_{2} \mathrm{SiO}_{4}$ | 215 | $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2}$ | 207 |
| $\mathrm{Ca}_{12}\left(\mathrm{PO}_{4}\right)_{6} \mathrm{SiO}_{5}$ | 215 | $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2}+\mathrm{nH}_{2} \mathrm{O}$ | 207 |
| $\mathrm{CaPt}(\mathrm{CN})_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 32 | $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right) \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 207 |
| CaS | 9 | $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right) \cdot 3-8 \mathrm{H}_{2} \mathrm{O}$ | 208 |
| $\mathrm{CaSO}_{4}$ | 129 | $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right) \cdot 10-12 \mathrm{H}_{2} \mathrm{O}$ | 207 |
| $2 \mathrm{CaSO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 161 | $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{4}\left(\mathrm{PO}_{4}\right)_{2}(\mathrm{OH})_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 210 |
| $\mathrm{CaSO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 164 | $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{4}\left(\mathrm{PO}_{4}\right)_{2}(\mathrm{OH})_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 210 |
| $\mathrm{CaS}_{4} \mathrm{O}_{6}$ | 123 | $\mathrm{Ca}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{VO}_{4}\right)_{2} \cdot \mathrm{nH}_{2} \mathrm{O}$ | 209 |
| $\mathrm{CaS}_{2} \mathrm{O}_{6} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 133 | $\mathrm{CaV}_{2} \mathrm{O}_{6} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 212 |
| $\mathrm{CaS}_{2} \mathrm{O}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 135 | $\mathrm{CaV}_{2} \mathrm{O}_{4} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 212 |
| CaSe | 11 | $\mathrm{CaWO}_{4}$ | 180 |
| $\mathrm{CaSi}_{2} \mathrm{AlGaO}_{8}$ | 232 | $\mathrm{CaZnF}_{4}$ | 25 |
| $\mathrm{Ca}_{2} \mathrm{Si}_{4} \mathrm{Al}_{3} \mathrm{GaO}_{16}$ | 232 | $\mathrm{Ca}_{2} \mathrm{ZnSi}_{2} \mathrm{O}_{7}$ | 295 |
| $\mathrm{CaSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8}$ | 236 | $2 \mathrm{CdCl}_{2} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 29 |
| $\mathrm{CaSi} 2 \mathrm{Al}_{2} \mathrm{O}_{8} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 242 | $\mathrm{Cd}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 112 |
| $\mathrm{CaSi}_{3} \mathrm{Al}_{2} \mathrm{O}_{10} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 246 | $\mathrm{CdF}_{2}$ | 24 |
| $\mathrm{CaSi}_{3} \mathrm{Al}_{2} \mathrm{O}_{10} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 241 | $\mathrm{CdFe}_{2} \mathrm{O}_{4}$ | 76 |
| $\mathrm{CaSi}_{4} \mathrm{Al}_{2} \mathrm{O}_{12} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 247 | $\mathrm{Cd}_{2} \mathrm{MgCl}_{6} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 30 |
| $\mathrm{CaSi}_{4} \mathrm{Al}_{2} \mathrm{O}_{12} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 240 | CdO | 58 |
| $\mathrm{CaSi}_{5} \mathrm{Al}_{2} \mathrm{O}_{14} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 251 | CdS | 10 |
| $\mathrm{CaSi}_{6} \mathrm{Al}_{2} \mathrm{O}_{16} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 249 | $3 \mathrm{CdSO}_{4} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 165 |
| $\mathrm{CaSi}_{6} \mathrm{AlO}_{16} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 248 | $\mathrm{Cd}_{2} \mathrm{SiO}_{4}$ | 304 |
| $\mathrm{Ca}_{4} \mathrm{Si}_{8} \mathrm{Al}_{8} \mathrm{O}_{32} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 247 | $(\mathrm{Ce}, \mathrm{La}) \mathrm{PO}_{4}$ | 191 |
| $\mathrm{CaSi}_{2} \mathrm{Ga}_{2} \mathrm{O}_{8}$ | 232 | $\mathrm{Ce}_{2}\left(\mathrm{MoO}_{4}\right)_{3}$ | 182 |
| $\mathrm{CaSiGeAl} \mathrm{O}_{8}$ | 232 | $\mathrm{CePO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 201 |
| $\mathrm{CaSi}_{2} \mathrm{La}_{2} \mathrm{O}_{8}$ | 228 | $\mathrm{Ce}_{2} \mathrm{Pt}_{3}(\mathrm{CN})_{12} \cdot 18 \mathrm{H}_{2} \mathrm{O}$ | 49 |
| $\mathrm{CaSi}_{2} \mathrm{Nd}_{2} \mathrm{O}_{8}$ | 228 | $\mathrm{Ce}_{2}\left(\mathrm{~S}_{2} \mathrm{O}_{6}\right)_{3} \cdot 15 \mathrm{H}_{2} \mathrm{O}$ | 135 |
| $\mathrm{Ca}_{2} \mathrm{SiO}_{4}$ | 301 | $\mathrm{Co}_{3}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 198 |
| $\mathrm{Ca}_{3} \mathrm{Si}_{2} \mathrm{O}_{7}$ | 296 | $\mathrm{CoAl}_{2} \mathrm{O}_{4}$ | 76 |
| $\mathrm{Ca}_{3} \mathrm{Si}_{3} \mathrm{O}_{9}$ | 291 | $\mathrm{CoB}_{2} \mathrm{~F}_{8}$ | 49 |
| $\mathrm{CaSiO}_{3} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 281 | $\mathrm{CoCO}_{3}$ | 93 |
| $\mathrm{CaSi}_{2} \mathrm{O}_{5} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 259 | $\mathrm{CoCO}_{3} \mathrm{SO}_{4} \cdot 4 \mathrm{NH}_{3} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 179 |
| $\mathrm{Ca}_{2} \mathrm{SiO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 305 | $\mathrm{CoCl}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{NH}_{3}$ | 112 |
| $\mathrm{Ca}_{2} \mathrm{Si}_{2} \mathrm{O}_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ | 281 | $\mathrm{CoCl}_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 28 |
| $\mathrm{Ca}_{2} \mathrm{Si}_{2} \mathrm{O}_{6} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 282 | $\mathrm{Co}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 111 |
| $\mathrm{Ca}_{3} \mathrm{Si}_{3} \mathrm{O}_{9} \cdot \mathrm{H}_{2} \mathrm{O}$ | 291 | $\mathrm{Co}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{NH}_{3}$ | 112 |
| $\mathrm{Ca}_{3} \mathrm{Si}_{2} \mathrm{O}_{7} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 297 | $\mathrm{CoF}_{2} \cdot 5 \mathrm{HF} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 54 |
| $\mathrm{Ca}_{6} \mathrm{Si}_{3} \mathrm{O}_{12} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 281 | $4 \mathrm{Co}\left(\mathrm{NH}_{2}\right)_{2} \cdot \mathrm{CaSO}_{4}$ | 179 |
| $\mathrm{Ca}_{6} \mathrm{Si}_{3} \mathrm{O}_{12} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 306 | $\mathrm{Co}\left(\mathrm{NH}_{3}\right)_{6} \mathrm{Cl}_{3}$ | 54 |
| $\mathrm{Ca}_{8} \mathrm{Si}_{3} \mathrm{O}_{14} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 281 | $\mathrm{Co}\left(\mathrm{NH}_{3}\right)_{6} \cdot \mathrm{Fe}(\mathrm{CN})_{6}$ | 53 |
| $\mathrm{Ca}_{9} \mathrm{Si}_{6} \mathrm{O}_{21} \cdot \mathrm{H}_{2} \mathrm{O}$ | 281 | $\mathrm{Co}\left(\mathrm{NO}_{3}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 103 |


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| $\mathrm{CoSO}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 133 | $\mathrm{Cs}\left(\mathrm{NO}_{3}\right)$ | 101 |
| $\mathrm{CoSO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 164 | $\mathrm{Cs}_{2} \mathrm{PdCl}_{4}$ | 37 |
| $\mathrm{CoSO}_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 170 | $\mathrm{CsRh}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 |
| $\mathrm{CoSO}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 161 | $\mathrm{Cs}_{2} \mathrm{SO}_{4}$ | 127 |
| $\mathrm{CoSO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 168 | $\mathrm{Cs}_{2} \mathrm{~S}_{2} \mathrm{O}_{6}$ | 121 |
| $\mathrm{CoSeO}_{4}$ | 167 | $\mathrm{CsSO}_{3} \mathrm{~F}$ | 173 |
| $\mathrm{CoSiF}_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 50 | $\mathrm{Cs}_{2} \mathrm{SeO}_{4}$ | 128 |
| $\mathrm{Cr}_{2} \mathrm{O}_{3}$ | 60 | $\mathrm{CsSiAlO}_{4}$ | 228 |
| $\mathrm{CrPO}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 201 | $\mathrm{CsSi}_{2} \mathrm{AlO}_{6}$ | 226 |
| $\mathrm{Cr}_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 199 | $\mathrm{Cs}_{6} \mathrm{Te}\left(\mathrm{MoO}_{4}\right)_{6} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 184 |
| $\mathrm{Cr}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 18 \mathrm{H}_{2} \mathrm{O}$ | 171 | $\mathrm{CsTi}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 |
| $\mathrm{Cs}_{3} \mathrm{Ag}_{2} \mathrm{Ba}(\mathrm{CNS})_{7}$ | 38 | $\mathrm{Cs}_{3} \mathrm{Tl}_{2} \mathrm{Cl}_{9}$ | 44 |
| $\mathrm{CsAl}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 160 | $\mathrm{Cs}_{2}\left(\mathrm{UO}_{2}\right) \mathrm{Cl}_{4}$ | 37 |
| $\mathrm{CsAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\mathrm{CsV}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 |
| $\mathrm{CsBF}_{4}$ | 43 | $\mathrm{Cs}_{2} \mathrm{Zn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 144 |
| CsBr | 18 | $\mathrm{Cs}_{2} \mathrm{Zn}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 150 |
| $\mathrm{Cs}_{2} \mathrm{Cd}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 145 | Cu | 3 |
| CsCl | 17 | $\mathrm{CuAl} \mathrm{C}_{6}\left(\mathrm{PO}_{4}\right)_{4}(\mathrm{OH})_{8} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 207 |
| $\mathrm{CsClO}_{4}$ | 111 | $\mathrm{CuB}_{2} \mathrm{~F}_{8} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 49 |
| $\mathrm{Cs}_{2} \mathrm{Co}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 147 | CuBr CuCl | 19 |
| $\mathrm{CsCr}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\mathrm{CuCl}_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 29 |
| $\mathrm{Cs}_{2} \mathrm{CoSe}_{2} \mathrm{O}_{8} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 153 | $\mathrm{Cu}\left(\mathrm{ClO}_{4}\right)_{2} \div 6 \mathrm{H}_{2} \mathrm{O}$ | 112 |
| $\mathrm{Cs}_{3} \mathrm{Cu}_{2} \mathrm{Ba}(\mathrm{CNS})_{7}$ | 38 | $\mathrm{CuF} \mathrm{F}_{2} \cdot 5 \mathrm{HF} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 55 |
| $\mathrm{Cs}_{2} \mathrm{CuCl}_{4}$ | 37 | $(\mathrm{Cu}, \mathrm{Fe})_{12} \mathrm{As}_{4} \mathrm{~S}_{13}$ | 13 |
| $\mathrm{Cs}_{2} \mathrm{Cu}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 149 | $\mathrm{CuFe}_{4}\left(\mathrm{SO}_{4}\right)_{6}(\mathrm{OH})_{2} \cdot 20 \mathrm{H}_{2} \mathrm{O}$ | 178 |
| $\mathrm{Cs}_{2} \mathrm{CuSe}_{2} \mathrm{O}_{8} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 154 | $(\mathrm{Cu}, \mathrm{Fe})_{12} \mathrm{Sb}_{4} \mathrm{~S}_{13}$ | 13 |
| $\mathrm{Cs}_{3} \mathrm{Cu}_{2} \mathrm{Sr}(\mathrm{CNS})_{7}$ | 38 | CuI | 19 |
| CsF | 18 | $3 \mathrm{Cu}\left(\mathrm{IO}_{3}\right)_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 109 |
| $\mathrm{Cs}_{2} \mathrm{Fe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 146 | $\mathrm{Cu}_{2} \mathrm{O}$ | 57 |
| $\mathrm{CsFe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | CuO | 59 |
| $\mathrm{CsGa}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\mathrm{CuO} \cdot \mathrm{UO}_{3} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 84 |
| $\mathrm{CsFe}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 160 | $\mathrm{Cu}_{3}(\mathrm{OH})_{2}\left(\mathrm{CO}_{3}\right)_{2}$ | 97 |
| $\mathrm{Cs}_{2} \mathrm{Fe}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 152 | $\mathrm{Cu}_{2}(\mathrm{OH})_{2} \mathrm{CO}_{3}$ | 98 |
| $\mathrm{Cs}_{2} \mathrm{GeCl}_{6}$ | 47 | $\mathrm{Cu}_{2}(\mathrm{OH})_{3} \mathrm{Cl}$ | 30 |
| $\mathrm{CsHgCl}_{3}$ | 37 | $\mathrm{Cu}(\mathrm{OH}) \mathrm{IO}_{3}$ | 109 |
| CsI | 18 | $\mathrm{Cu}_{2}(\mathrm{OH})_{3} \mathrm{NO}_{3}$ | 104 |
| $\mathrm{CsICl}_{2}$ | 21 | $\mathrm{Cu}_{4}(\mathrm{OH})_{2} \mathrm{Si}_{2} \mathrm{O}_{7}$ | 297 |
| $\mathrm{CsIn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\mathrm{Cu}_{2} \mathrm{PO}_{4}(\mathrm{OH})$ | 201 |
| $\mathrm{Cs}_{2} \mathrm{Mg}\left(\mathrm{CrO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 156 | $\mathrm{CuPbSO}_{4}(\mathrm{OH})_{2}$ | 175 |
| $\mathrm{Cs}_{2} \mathrm{Mg}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ $\mathrm{Cs} \mathrm{S}_{2} \mathrm{Mg}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 143 | $\mathrm{CuS}_{\mathrm{CuSeO}}^{3} \cdot 2 \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 11 134 |
| $\mathrm{Cs}_{2} \mathrm{Mg}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ $\mathrm{Cs}_{2} \mathrm{MnCl}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 150 39 | $\mathrm{CuSeO}_{3} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ CuSeO 4 $\mathrm{H}_{2} \mathrm{O}$ | 134 170 |
| $\mathrm{Cs}_{2} \mathrm{Mn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 145 | $\mathrm{CuSiF}_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 50 |
| $\mathrm{CsMn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\mathrm{Cu}_{4} \mathrm{Si}_{2} \mathrm{O}_{7} \mathrm{~F}_{2}$ | 296 |
| $\mathrm{Cs}_{2} \mathrm{Mn}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 151 | $\mathrm{CuSO}_{4}$ | 130 |
| $\mathrm{Cs}_{2} \mathrm{Ni}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 148 | $\mathrm{CuSO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 164 |
| $\mathrm{Cs}_{2} \mathrm{Ni}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 154 | $\mathrm{CuSO}_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 166 |


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| $\mathrm{CuSO}_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 169 | $\mathrm{Fe}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 171 |
| $\mathrm{CuSO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 167 | $\mathrm{Fe}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 9 \mathrm{H}_{2} \mathrm{O}$ | 171 |
| $\mathrm{Cu}_{2}\left(\mathrm{SO}_{4}\right)_{4} \mathrm{O}$ | 175 | $\mathrm{FeSO}_{4}(\mathrm{OH}) \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 177 |
| $\mathrm{Cu}_{3} \mathrm{SO}_{4}(\mathrm{OH})_{4}$ | 173 | $\mathrm{FeSO}_{4}(\mathrm{OH}) \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 177 |
| $\mathrm{Cu}_{4} \mathrm{SO}_{4}(\mathrm{OH})_{6}$ | 173 | $\mathrm{FeSiF}_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 50 |
| $\mathrm{Cu}_{4} \mathrm{SO}_{4}(\mathrm{OH})_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ | 175 | $\mathrm{Fe}_{2} \mathrm{SiO}_{4}$ | 303 |
| $\mathrm{Cu}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 209 | $\mathrm{Fe}_{7} \mathrm{Si}_{8} \mathrm{O}_{22} \mathrm{~F}_{2}$ | 284 |
| $\mathrm{Cu}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 209 | $\mathrm{FeTiO}_{3}$ | 80 |
| $\mathrm{Cu}_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 10 \mathrm{H}_{2} \mathrm{O}$ | 209 | $\mathrm{Fe}_{2} \mathrm{TiO}_{5}$ | 81 |
| $\mathrm{Cu}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 16 \mathrm{H}_{2} \mathrm{O}$ | 209 | $\mathrm{FeWO}_{4}$ | 181 |
| $\mathrm{Cu}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 208 | $\mathrm{Gd}\left(\mathrm{BrO}_{3}\right)_{3} \cdot 9 \mathrm{H}_{2} \mathrm{O}$ | 110 |
| $\mathrm{Cu}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 208 | $\mathrm{GdCl}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 34 |
| Fe | 3 | $\mathrm{GeBr}_{4}$ | 35 |
| $\mathrm{FeAsO}_{4}$ | 190 | $\mathrm{GeO}_{2}$ | 63 |
| $\mathrm{FeAsO} 4 \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 200 | $\mathrm{HAlO}_{2}$ | 73 |
| $\mathrm{Fe}_{3}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 199 | $\mathrm{HCa}_{2} \mathrm{Fe}^{\prime \prime} \mathrm{Fe}^{\text {"' }} \mathrm{Si}_{5} \mathrm{O}_{15}$ | 294 |
| $\mathrm{FeAl}_{2} \mathrm{O}_{4}$ | 75 | $\mathrm{HFeO}_{2}$ | 73 |
| $\mathrm{Fe}_{2} \mathrm{Al}_{3} \mathrm{Si}_{5} \mathrm{AlO}_{18}$ | 290 | $\mathrm{H}_{2} \mathrm{~K}_{2} \mathrm{TeI}_{2} \mathrm{O}_{10} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 113 |
| $\mathrm{Fe}_{3} \mathrm{Al}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$ | 298 | $\mathrm{H}_{6} \mathrm{Mg}\left(\mathrm{WO}_{4}\right)_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 183 |
| $\mathrm{FeAl}_{2}\left(\mathrm{SO}_{4}\right)_{4} \cdot 22 \mathrm{H}_{2} \mathrm{O}$ | 170 | $\mathrm{HNH}_{2} \mathrm{SO}_{3}$ | 121 |
| $\mathrm{FeBaSi}_{4} \mathrm{O}_{10}$ | 254 | $\mathrm{HNa}(\mathrm{Ca}, \mathrm{Mn})_{2} \mathrm{Si}_{3} \mathrm{O}_{9}$ | 293 |
| $\mathrm{FeCO}_{3}$ | 93 | $\mathrm{HNaCa}_{2} \mathrm{Si}_{3} \mathrm{O}_{9}$ | 293 |
| $\mathrm{FeCl}_{2}$ | 26 | $\mathrm{H}_{8} \mathrm{Na}_{6}\left(\mathrm{MoO}_{4}\right)_{7} \cdot 18 \mathrm{H}_{2} \mathrm{O}$ | 183 |
| $\mathrm{FeCl}_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 28 | $\mathrm{H}_{2} \mathrm{O}$ | 57 |
| $\mathrm{Fe}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 111 | $\left(\mathrm{H}_{2} \mathrm{O}\right) \mathrm{Fe}_{3}\left(\mathrm{SO}_{4}\right)_{4}\left[(\mathrm{OH})_{5} \mathrm{H}_{2} \mathrm{O}\right]$ | 174 |
| $\mathrm{FeCr}_{2} \mathrm{O}_{4}$ | 76 | $\mathrm{H}_{3} \mathrm{PO}_{4}$ | 189 |
| $\mathrm{Fe}_{9}^{\prime \prime} \mathrm{Fe}_{2}^{\prime \prime \prime}(\mathrm{OH})_{16} \mathrm{Si}_{8} \mathrm{O}_{20}$ | 260 | $\mathrm{H}_{6}\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 197 |
| $\mathrm{Fe}^{\prime \prime} \mathrm{Fe}_{2}^{\text {"' }}\left(\mathrm{PO}_{4}\right)_{2}(\mathrm{OH})_{2}$ | 203 | $\mathrm{H}_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 205 |
| $\mathrm{Fe}^{\prime \prime} \mathrm{Fe}^{\text {"' }} \mathrm{Si}_{2} \mathrm{O}_{6}$ | 273 | $\mathrm{H}_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 205 |
| $\mathrm{Fe}^{\prime \prime} \mathrm{Fe}_{4}^{\prime \prime \prime}\left(\mathrm{SO}_{4}\right)_{6}(\mathrm{OH})_{2} \cdot 20 \mathrm{H}_{2} \mathrm{O}$ | 178 | $\mathrm{H}_{2}\left(\mathrm{UO}_{2}\right)\left(\mathrm{SO}_{4}\right)_{2} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 177 |
| $\mathrm{FeH}\left(\mathrm{SO}_{4}\right)_{2} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 136 | $\mathrm{H}_{2} \mathrm{WO}_{4}$ | 67 |
| $\mathrm{FeMgSi}_{2} \mathrm{O}_{6}$ | 273 | $\mathrm{H}_{2} \mathrm{WO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 67 |
| $\mathrm{Fe}_{3} \mathrm{Mg}_{4} \mathrm{Si}_{8} \mathrm{O}_{22}(\mathrm{OH})_{2}$ | 283 | $\mathrm{HfF}_{4}$ | 35 |
| $\mathrm{Fe}_{2}\left(\mathrm{MoO}_{4}\right)_{3} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 183 | $\mathrm{HfOCl}_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 52 |
| FeO | 57 | $\mathrm{Hg}(\mathrm{CN})_{2}$ | 27 |
| $\mathrm{Fe}_{2} \mathrm{O}_{3}$ | 60, 76 | HgCl | 20 |
| $\mathrm{Fe}_{3}(\mathrm{OH})_{2} \mathrm{Si}_{4} \mathrm{O}_{10}$ | 259 | $\mathrm{HgCl}_{2}$ | 26 |
| $\mathrm{FeOHSi}_{2} \mathrm{O}_{5} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 266 | $\mathrm{Hg}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 112 |
| $\mathrm{FeO}(\mathrm{OH})$ | 70 | $\mathrm{HgI}_{2}$ | 27 |
| $\mathrm{FePO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 200 | HgO | 58 |
| $\mathrm{Fe}_{3}\left(\mathrm{PO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 198 | $\mathrm{Hg}_{2} \mathrm{OCl}$ | 52 |
| $\mathrm{FeS}_{2}$ | 12 | $\mathrm{Hg}_{3} \mathrm{OCl}_{4}$ | 51 |
| $\mathrm{Fe}_{2}\left(\mathrm{SO}_{4}\right)_{3}$ | 131 | $2 \mathrm{Hg}(\mathrm{OH})\left(\mathrm{NO}_{3}\right) \cdot \mathrm{H}_{2} \mathrm{O}$ | 104 |
| $\mathrm{FeSO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 163 | HgS | 10 |
| $\mathrm{FeSO}_{4} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 166 | $\mathrm{HgSb}_{4} \mathrm{~S}_{7}$ | 14 |
| $\mathrm{FeSO}_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 167 | I | 4 |
| $\mathrm{Fe}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 171 | $\mathrm{IrCl}_{3}\left(\mathrm{NH}_{3}\right)_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 53 |
| FeSO ${ }_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 167 | $\mathrm{KAg}(\mathrm{CN})_{2}$ | 22 |


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| $\mathrm{KAlH}_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 195 | $\mathrm{K}_{2} \mathrm{Cd}\left(\mathrm{NO}_{2}\right)_{4}$ | 106 |
| $\mathrm{K}_{2} \mathrm{Al}_{3} \mathrm{H}_{4}\left(\mathrm{PO}_{4}\right)_{5} \cdot 11 \mathrm{H}_{2} \mathrm{O}$ | 195 | $2 \mathrm{~K}_{2} \mathrm{Cd}\left(\mathrm{SO}_{4}\right)_{2} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 138 |
| $\mathrm{K}_{2} \mathrm{Al}_{6} \mathrm{H}_{10}\left(\mathrm{PO}_{4}\right)_{10} \cdot 15 \mathrm{H}_{2} \mathrm{O}$ | 196 | $\mathrm{KCl}{ }^{\text {K }}$ | 15 |
| $\mathrm{KAlO}_{2}$ | 72 | $\mathrm{KClO}_{3}$ | 108 |
| $\mathrm{K}_{2} \mathrm{Al}_{12} \mathrm{O}_{19}$ | 80 | $\mathrm{KClO}_{4}$ | 110 |
| $\mathrm{KAl}_{2}(\mathrm{OH})_{2} \mathrm{Si}_{3} \mathrm{AlO}_{10}$ | 263 | $\mathrm{KCo}\left(\mathrm{NH}_{3}\right)_{2}\left(\mathrm{NO}_{2}\right)_{4}$ | 107 |
| $\mathrm{KAl}_{2}\left(\mathrm{PO}_{4}\right)_{2} \mathrm{~F} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 210 | $\mathrm{K}_{2} \mathrm{Co}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 146 |
| $\mathrm{KAl}_{2}\left(\mathrm{PO}_{4}\right)_{2} \mathrm{OH} \cdot 0.5 \mathrm{H}_{2} \mathrm{O}$ | 210 | $\mathrm{K}_{2} \mathrm{Co}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 152 |
| $\mathrm{KAl}_{2}\left(\mathrm{PO}_{4}\right)_{2} \mathrm{OH} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 209 | $\mathrm{K}_{3} \mathrm{Cr}(\mathrm{CN})_{6}$ | 44 |
| $\mathrm{KAl}_{2}\left(\mathrm{PO}_{4}\right)_{2} \mathrm{OH} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 210 | $\mathrm{K}_{2} \mathrm{CrO}_{4}$ | 127 |
| $\mathrm{K}_{2} \mathrm{Al}_{2}\left(\mathrm{SO}_{4}\right)_{4}$ | 132 | $\mathrm{K}_{2} \mathrm{Cr}_{2} \mathrm{O}_{7}$ | 122 |
| $\mathrm{KAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 158 | $\mathrm{K}_{2} \mathrm{Cr}_{2} \mathrm{O}_{7} \cdot \mathrm{Hg}(\mathrm{CN})_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 134 |
| $\mathrm{KAl}_{3}\left(\mathrm{SO}_{4}\right)_{2}(\mathrm{OH})_{6}$ | 173 | $\mathrm{KCr}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 |
| $\mathrm{KAl}(\mathrm{SeO})_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 160 | $\mathrm{K}_{3} \mathrm{Cu}(\mathrm{CN})_{4}$ | 22 |
| $\mathrm{KAuBr}_{4}$ | 43 | $\mathrm{K}_{2} \mathrm{CuCl}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 39 |
| KAuBr ${ }_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 45 | $\mathrm{K}_{2} \mathrm{Cu}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 148 |
| $\mathrm{KAuCl}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 45 | $\mathrm{K}_{2} \mathrm{Cu}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 154 |
| $\mathrm{KBF}_{4}$ | 43 | KF | 17 |
| $\mathrm{KB}_{5} \mathrm{O}_{8} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 116 | $\mathrm{KF} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 23 |
| $\mathrm{K}_{4} \mathrm{Be}_{3} \mathrm{Si}_{4} \mathrm{O}_{12}$ | 267 | $\mathrm{K}_{3} \mathrm{Fe}(\mathrm{CN})_{6}$ | 44 |
| KBr | 17 | $\mathrm{K}_{4} \mathrm{Fe}(\mathrm{CN})_{6} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 41 |
| $\mathrm{KBrO}_{3}$ | 108 | $\mathrm{K}_{2} \mathrm{FeCl}_{5} \cdot \mathrm{H}_{2} \mathrm{O}$ | 45 |
| KCNO | 22 | $\mathrm{KFe}_{2}(\mathrm{Fe}, \mathrm{Mg}, \mathrm{Al})_{5} \mathrm{Si}_{8} \mathrm{O}_{20} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 265 |
| KCNS | 22 | $\mathrm{KFe}{ }^{2} \mathrm{Fe}$ " $\left(\mathrm{SO}_{4}\right)_{3} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 157 |
| $\mathrm{K}_{2} \mathrm{CaB}_{8} \mathrm{O}_{14} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 116 | $\mathrm{KFeH}_{2}\left(\mathrm{PO}_{4}\right)_{4}{ }^{\text {a }}$ | 188 |
| $\mathrm{K}_{2} \mathrm{Ca}\left(\mathrm{CO}_{3}\right)_{2}$ | 96 | $\mathrm{KFeH} 2\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 195 |
| $\mathrm{K}_{6} \mathrm{Ca}_{2}\left(\mathrm{CO}_{3}\right)_{5} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 96 | $\mathrm{KFe}_{3} \mathrm{H}_{8}\left(\mathrm{PO}_{4}\right)_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 196 |
| $\mathrm{KCaCl}_{3} \mathrm{KCa}_{3}{ }^{\text {a }}$ | 36 | $\mathrm{K}(\mathrm{Fe}, \mathrm{Mg})_{3} \mathrm{~F}_{2} \mathrm{Si}_{3} \mathrm{AlO}_{10}$ | 262 |
| $\mathrm{KCa}_{4} \mathrm{FSi}_{8} \mathrm{O}_{20} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 264 | $\mathrm{KFe}\left(\mathrm{PO}_{4}\right)_{2} \mathrm{OH} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 210 |
| $\mathrm{KCa}_{4} \mathrm{FSi}_{8} \mathrm{O}_{20} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 264 | $\mathrm{KFe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 |
| $\begin{aligned} & \mathrm{K}_{2} \mathrm{Ca}_{2} \mathrm{Mg}_{2}\left(\mathrm{SO}_{4}\right)_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O} \\ & \mathrm{~K}_{2} \mathrm{Ca}\left(\mathrm{SO}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O} \end{aligned}$ | 157 138 | $\mathrm{K}_{2} \mathrm{Fe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 146 |
| $\mathrm{K}_{2} \mathrm{Ca}\left(\mathrm{SO}_{4}\right)_{2} \cdot{ }_{2} \mathrm{H}_{2} \mathrm{O}$ $\mathrm{K}_{2} \mathrm{Ca}_{5}\left(\mathrm{SO}_{4}\right)_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ | 138 | $\mathrm{KFe}_{3}\left(\mathrm{SO}_{4}\right)_{2}(\mathrm{OH})_{6}$ $\mathrm{~K}_{2} \mathrm{Fe}\left(\mathrm{SeO}_{4} \cdot 6 \cdot 6 \mathrm{H}_{2} \mathrm{O}\right.$ | 174 152 |
| $\mathrm{K}_{2} \mathrm{CaSiO}_{4}$ | 300 | ${ }_{\text {K }} \mathrm{K}_{2} \mathrm{Fe}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 152 |
| $\mathrm{K}_{8} \mathrm{CaSi}_{10} \mathrm{O}_{25}$ | 255 | ${ }^{\mathrm{KFESH}\left(\mathrm{SO}_{4}\right)_{2}} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 279 159 |
| $\mathrm{K}_{2} \mathrm{Ca}_{2} \mathrm{Si}_{6} \mathrm{O}_{15}$ $\mathrm{~K}_{2} \mathrm{Ca}_{2}\left(\mathrm{Si}_{3} \mathrm{O}_{7}\right)_{3}$ | 257 267 | $\mathrm{KGa}_{3} \mathrm{AlO}_{8}{ }^{\text {a }}$ | 152 |
| $\mathrm{K}_{2} \mathrm{Ca}_{2} \mathrm{Si}_{9} \mathrm{O}_{21}$ | 258 | $\mathrm{K}_{2} \mathrm{GeF}_{6}$ | $\begin{array}{r}47 \\ \hline\end{array}$ |
| $\mathrm{K}_{2} \mathrm{Ca}_{3} \mathrm{Si}_{6} \mathrm{O}_{16}$ | 257 | $\mathrm{KGH}_{3} \mathrm{KGO}_{8}$ | 232 22 |
| $\mathrm{K}_{2} \mathrm{Ca}_{3} \mathrm{Si}_{6} \mathrm{O}_{16}$ | 266 | $\mathrm{KH}_{2} \mathrm{AsO}_{4}$ | 22 187 |
| $\begin{aligned} & \mathrm{K}_{2} \mathrm{Ca}_{23} \mathrm{Si}_{12} \mathrm{O}_{48} \\ & \mathrm{~K}_{4} \mathrm{CaSi}_{3} \mathrm{Ca}_{9} \end{aligned}$ | 300 267 | $\mathrm{KHCO}_{3}$ | 187 89 |
| $\mathrm{K}_{4} \mathrm{CaSi}_{3} \mathrm{O}_{9}$ $\mathrm{~K}_{4} \mathrm{CaSi}_{6} \mathrm{O}_{15}$ | 267 258 | $\mathrm{KHF}_{2}$ | 21 |
| $\mathrm{KCN}{ }^{\text {a }}$ | 22 | $\mathrm{K}_{2} \mathrm{H}_{2} \mathrm{O}_{6} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 212 |
| $\mathrm{K}_{2} \mathrm{CO}_{3}$ | 90 | $\mathrm{KH}_{2} \mathrm{PO}_{4}$ | 187 |
| $2 \mathrm{~K}_{2} \mathrm{CO}_{3} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 91 | $\mathrm{K}_{2} \mathrm{H}_{2} \mathrm{P}_{2} \mathrm{O}_{6} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 213 |
| $\mathrm{K}_{2} \mathrm{Cd}(\mathrm{CN})_{4}$ | 38 | $\begin{aligned} & \mathrm{KHSO}_{4} \\ & \mathrm{~K}_{3} \mathrm{H}\left(\mathrm{SO}_{4}\right) \end{aligned}$ | 123 |
| $\mathrm{K}_{4} \mathrm{CdCl}_{6}$ | 36 | $\begin{aligned} & \mathrm{K}_{3} \mathrm{H}\left(\mathrm{SO}_{4}\right)_{2} \\ & \mathrm{~K}_{8} \mathrm{H}_{6}\left(\mathrm{SO}_{4}\right)_{7} \end{aligned}$ | 123 |


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| $\mathrm{KHSi}_{2} \mathrm{O}_{5}$ | 258 | $\mathrm{K}_{2} \mathrm{PbCu}\left(\mathrm{NO}_{2}\right)_{6}$ | 105 |
| $\mathrm{K}_{2} \mathrm{HfF}_{6}$ | 47 | $\mathrm{K}_{2} \mathrm{~Pb}\left(\mathrm{SO}_{4}\right)_{2}$ | 132 |
| $\mathrm{K}_{3} \mathrm{HfF}_{7}$ | 47 | $\mathrm{K}_{2} \mathrm{PbSi}_{4} \mathrm{O}_{10}$ | 257 |
| $\mathrm{K}_{2} \mathrm{Hg}(\mathrm{CN})_{4}$ | 38 | $\mathrm{K}_{2} \mathrm{~Pb}_{2} \mathrm{Si}_{2} \mathrm{O}_{7}$ | 295 |
| $\mathrm{KHg}(\mathrm{CNS})_{3}$ | 38 | $\mathrm{K}_{2} \mathrm{~Pb}_{4} \mathrm{Si}_{8} \mathrm{O}_{21}$ | 255 |
| $\mathrm{K}_{2} \mathrm{Hg}(\mathrm{CNS})_{4}$ | 38 | $\mathrm{K}_{2} \mathrm{PdCl}_{4}$ | 36 |
| $\mathrm{K}_{2} \mathrm{HgCl}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 39 | $\mathrm{K}_{2} \mathrm{PtBr}_{2}\left(\mathrm{NO}_{2}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 106 |
| KI | 17 | $\mathrm{K}_{2} \mathrm{Pt}(\mathrm{CN})_{6}$ | 48 |
| $\mathrm{KIO}_{3}$ | 108 | $\mathrm{K}_{2} \mathrm{Pt}(\mathrm{CN})_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 42 |
| $\mathrm{KIO}_{4}$ | 110 | $\mathrm{K}_{2} \mathrm{Pt}(\mathrm{CNS})_{6}$ | 48 |
| $\mathrm{K}_{2} \mathrm{LiAlF}_{6}$ | 43 | $\mathrm{K}_{2} \mathrm{PtCl}_{4}$ | 36 |
| $\mathrm{KLiFeAl}(\mathrm{OH})_{2} \mathrm{Si}_{3} \mathrm{AlO}_{10}$ | 263 | $\mathrm{K}_{2} \mathrm{PtCl}_{6}$ | 47 |
| $\mathrm{K}_{2} \mathrm{Mg}_{5} \mathrm{Al}(\mathrm{OH})_{4} \mathrm{Si}_{5} \mathrm{Al}_{3} \mathrm{O}_{20}$ | 262 | $\mathrm{KPtCl} 3 \cdot \mathrm{NH}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | 53 |
| $\mathrm{KMgBr}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 39 | $\mathrm{K}_{2} \mathrm{PtI}_{2}\left(\mathrm{NO}_{2}\right)_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 106 |
| $\mathrm{K}_{2} \mathrm{Mg}\left(\mathrm{CO}_{3}\right)_{2}$ | 96 | $\mathrm{K}_{2} \mathrm{Pt}\left(\mathrm{NO}_{2}\right)_{4}$ | 106 |
| $\mathrm{K}_{2} \mathrm{Mg}\left(\mathrm{CO}_{3}\right)_{2} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 96 | $\mathrm{KReO}_{4}$ | 82 |
| $\mathrm{KMgCl}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 39 | $\mathrm{K}_{3} \mathrm{Rh}(\mathrm{CN})_{6}$ | 44 |
| $\mathrm{K}_{2} \mathrm{MgF}_{4}$ | 36 | $2 \mathrm{KRh}\left(\mathrm{NH}_{3}\right)_{2}\left(\mathrm{NO}_{2}\right)_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 107 |
| $\mathrm{KMg}_{3} \mathrm{~F}_{2} \mathrm{Si}_{3} \mathrm{AlO}_{10}$ | 262 | $\mathrm{K}_{3} \mathrm{Rh}\left(\mathrm{SO}_{3}\right)_{3}\left(\mathrm{NH}_{3}\right)_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 133 |
| $\mathrm{KMg}_{3}(\mathrm{OH})_{2} \mathrm{Si}_{3} \mathrm{AlO}_{10}$ | 261 | $\mathrm{K}_{4} \mathrm{Ru}(\mathrm{CN})_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 42 |
| $\mathrm{K}_{2} \mathrm{Mg}_{2}\left(\mathrm{SO}_{4}\right)_{3}$ | 132 | $\mathrm{K}_{2} \mathrm{SO}_{4}$ | 125 |
| $\mathrm{KMgSO} 4 \mathrm{Cl} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 176 | $\mathrm{K}_{2} \mathrm{~S}_{2} \mathrm{O}_{6}$ | 121 |
| $\mathrm{K}_{2} \mathrm{Mg}\left(\mathrm{SO}_{4}\right)_{2} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 139 | $\mathrm{K}_{2} \mathrm{~S}_{2} \mathrm{O}_{8}$ | 122 |
| $\mathrm{K}_{2} \mathrm{Mg}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 142 | $\mathrm{K}_{2} \mathrm{~S}_{3} \mathrm{O}_{6}$ | 121 |
| $\mathrm{K}_{2} \mathrm{Mg}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 149 | $\mathrm{K}_{2} \mathrm{~S}_{4} \mathrm{O}_{6}$ | 122 |
| $\mathrm{K}_{2} \mathrm{MgSi}_{3} \mathrm{O}_{8}$ | 255 | $3 \mathrm{~K}_{2} \mathrm{~S}_{5} \mathrm{O}_{6} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 134 |
| $\mathrm{K}_{2} \mathrm{MgSi}_{5} \mathrm{O}_{12}$ | 254 | $\mathrm{K}_{2} \mathrm{SeO}_{4}$ | 128 |
| $\mathrm{K}_{2} \mathrm{Mg}_{5} \mathrm{Si}_{120} \mathrm{O}_{30}$ | 255 | $\mathrm{KSiAlO}_{4}$ | 226 |
| $\mathrm{K}_{3} \mathrm{Mn}(\mathrm{CN})_{6}$ | 44 | $\mathrm{KSi}_{2} \mathrm{AlO}_{6}$ | 227 |
| $\mathrm{K}_{4} \mathrm{MnCl}_{6}$ | 36 | $\mathrm{KSi}_{3} \mathrm{AlO}_{8}$ | 229 |
| $\mathrm{KMnO}_{4}$ | 82 | $\mathrm{KSi}_{2} \mathrm{AlO}_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ | 239 |
| $\mathrm{K}_{2} \mathrm{Mn}_{2}\left(\mathrm{SO}_{4}\right)_{3}$ | 132 | $\mathrm{KSiAlO}_{4} \cdot \mathrm{nH}_{2} \mathrm{O}$ | 239 |
| $\mathrm{K}_{4} \mathrm{Mn}_{2}\left(\mathrm{SO}_{4}\right)_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 138 | $\mathrm{K}_{2} \mathrm{SiF}_{6}$ | 46 |
| $\mathrm{KNH}_{2} \mathrm{SO}_{3}$ | 121 | $\mathrm{KSi}_{3} \mathrm{FeO}_{8}$ | 232 |
| $\mathrm{K}_{2} \mathrm{NaAlF}_{6}$ | 43 | $\mathrm{KSi}_{3} \mathrm{GaO}_{8}$ | 232 |
| $\mathrm{K}_{2} \mathrm{NaFe}(\mathrm{CN})_{6}$ | 45 | $\mathrm{KSiLaO}_{4}$ | 228 |
| $\mathrm{K}_{2} \mathrm{NbF}_{7}$ | 48 | $\mathrm{K}_{2} \mathrm{Si}_{2} \mathrm{O}_{5}$ | 256 |
| $\mathrm{K}_{2} \mathrm{Ni}(\mathrm{CN})_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 41 | $\mathrm{K}_{2} \mathrm{SiO}_{3}$ | 268 |
| $\mathrm{K}_{2} \mathrm{Ni}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 147 | $\mathrm{K}_{2} \mathrm{Si}_{4} \mathrm{O}_{9}$ | 286 |
| $\mathrm{K}_{2} \mathrm{Ni}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 153 | $\mathrm{K}_{2} \mathrm{Si}_{2} \mathrm{O}_{5} \cdot \mathrm{H}_{2} \mathrm{O}$ | 259 |
| $\mathrm{K}\left(\mathrm{NO}_{3}\right)$ | 101 | $\mathrm{K}_{2} \mathrm{SiO}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | 282 |
| $(\mathrm{K}, \mathrm{Na})_{5} \mathrm{Fe}_{3}\left(\mathrm{SO}_{4}\right)_{6} \mathrm{OH} \cdot 9 \mathrm{H}_{2} \mathrm{O}$ | 177 | $\mathrm{K}_{4} \mathrm{SiO}_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ | 281 |
| $(\mathrm{K}, \mathrm{Na})_{3} \mathrm{Na}\left(\mathrm{SO}_{4}\right)_{2}$ | 124 | $\mathrm{K}_{2} \mathrm{SnCl}_{6}$ | 47 |
| KOH | 68 | $\mathrm{K}_{2} \mathrm{TaF}_{7}$ | 48 |
| $\mathrm{K}_{4} \mathrm{O}(\mathrm{CN})_{6} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 42 | $\mathrm{K}_{6} \mathrm{Te}\left(\mathrm{MoO}_{4}\right)_{6} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 183 |
| $\mathrm{KPO}_{3}$ | 211 | $\mathrm{K}_{2} \mathrm{UO}_{2}\left(\mathrm{NO}_{3}\right)_{4}$ | 105 |
| $\mathrm{K}_{4} \mathrm{P}_{2} \mathrm{O}_{7}$ | 213 | $\mathrm{K}_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathrm{nH}_{2} \mathrm{O}$ | 206 |
| $\mathrm{K}_{5} \mathrm{P}_{3} \mathrm{O}_{10}$ | 213 | $\mathrm{K}_{2} \mathrm{UO}_{2}\left(\mathrm{SO}_{4}\right)_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 176 |


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| $\mathrm{K}_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{VO}_{4}\right)_{2} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 206 | $\mathrm{LiRbPt}(\mathrm{CN})_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 40 |
| $\mathrm{K}_{2} \mathrm{Zn}(\mathrm{CN})_{4}$ | 38 | $\mathrm{Li}_{2} \mathrm{SO}_{4}$ | 129 |
| $\mathrm{K}_{2} \mathrm{Zn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 143 | $\mathrm{Li}_{2} \mathrm{SO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 136 |
| $\mathrm{K}_{2} \mathrm{Zn}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 150 | $\mathrm{Li}_{2} \mathrm{~S}_{2} \mathrm{O}_{6} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 134 |
| $\mathrm{K}_{2} \mathrm{ZnSiO}_{4}$ | 299 | $\mathrm{LiSiAlO}_{4}$ | 227 |
| $\mathrm{K}_{2} \mathrm{ZrF}_{6}$ | 47 | $\mathrm{LiSi}_{4} \mathrm{AlO}_{10}$ | 228 |
| $\mathrm{K}_{3} \mathrm{ZrF}_{7}$ | 47 | $\mathrm{LiSiAlO} \mathbf{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 242 |
| $(\mathrm{La}, \mathrm{Ce})_{2}\left(\mathrm{CO}_{3}\right)_{3} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 95 | $\mathrm{Li}_{2} \mathrm{Si}_{8} \mathrm{Al}_{2} \mathrm{O}_{20} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 240 |
| $\mathrm{La}(\mathrm{OH})_{3}$ | 71 | $\mathrm{Li}_{2} \mathrm{SiF}_{6} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 46 |
| $\mathrm{LaO}(\mathrm{OH})$ | 70 | $\mathrm{LiSiLaO}_{4}$ | 228 |
| $\mathrm{La}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 9 \mathrm{H}_{2} \mathrm{O}$ | 171 | $\mathrm{Li}_{2} \mathrm{SiO}_{3}$ | 267 |
| $\mathrm{LiAlO}_{2}$ | 73 | $\mathrm{Li}_{2} \mathrm{Si}_{2} \mathrm{O}_{5}$ | 256 |
| $\mathrm{LiAl}_{5} \mathrm{O}_{8}$ | 74 | $\mathrm{Li}_{4} \mathrm{SiO}_{4}$ | 304 |
| $\mathrm{LiAlSi}_{2} \mathrm{O}_{6}$ | 280 | $\mathrm{Li}_{6} \mathrm{Te}\left(\mathrm{MoO}_{4}\right)_{6} \cdot 13 \mathrm{H}_{2} \mathrm{O}$ | 183 |
| $\mathrm{LiBeF}_{3}$ | 35 | $\mathrm{Li}_{2} \mathrm{TiO}_{3}$ | 72 |
| $\mathrm{Li}_{2} \mathrm{BeF}_{4}$ | 35 | $\mathrm{MgAl}_{2} \mathrm{O}_{4}$ | 74 |
| LiBr | 17 | $\mathrm{Mg}_{6} \mathrm{Al}_{2}(\mathrm{OH})_{16} \mathrm{CO}_{3} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 85 |
| $\mathrm{Li}_{2} \mathrm{CO}_{3}$ | 90 | $\mathrm{Mg}_{5} \mathrm{Al}(\mathrm{OH})_{8} \mathrm{Si}_{3} \mathrm{AlO}_{10}$ | 260 |
| LiCl | 17 | $\mathrm{MgAl}_{2}\left(\mathrm{SO}_{4}\right)_{4} \cdot 22 \mathrm{H}_{2} \mathrm{O}$ | 170 |
| $\mathrm{LiClO}_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 110 | $\mathrm{Mg}_{2} \mathrm{Al}_{3} \mathrm{Si}_{5} \mathrm{AlO}_{18}$ | 290 |
| LiF | 17 | $\mathrm{Mg}_{3} \mathrm{Al}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$ | 297 |
| $\mathrm{Li}_{3} \mathrm{FeF}_{6}$ | 42 | $\mathrm{Mg}_{4} \mathrm{Al}_{10} \mathrm{Si}_{2} \mathrm{O}_{23}$ | 86 |
| LiFeO | 72 | $\mathrm{Mg}_{3}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 198 |
| $\mathrm{LiFePO}_{4}$ | 191 | $\mathrm{MgB}_{2} \mathrm{~F}_{8}$ | 49 |
| LiI | 17 | $\mathrm{Mg}_{3} \mathrm{~B}_{2} \mathrm{O}_{6}$ | 114 |
| $\mathrm{LiI} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 23 | $\mathrm{MgB}_{2} \mathrm{O}_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 115 |
| $\mathrm{Li}_{2} \mathrm{~K}_{2} \mathrm{Fe}(\mathrm{CN})_{6} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 40 | $\mathrm{MgB}_{4} \mathrm{O}_{7} \cdot 9 \mathrm{H}_{2} \mathrm{O}$ | 116 |
| $\mathrm{LiKPt}(\mathrm{CN})_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 40 | $2 \mathrm{MgB}_{6} \mathrm{O}_{10} \cdot 15 \mathrm{H}_{2} \mathrm{O}$ | 117 |
| $\mathrm{LiKSO}_{4}$ | 124 | $\mathrm{Mg}_{3} \mathrm{~B}_{7} \mathrm{O}_{13} \mathrm{Cl}$ | 117 |
| $\mathrm{LiKSi}_{2} \mathrm{O}_{5}$ | 256 | $\mathrm{MgB}_{3} \mathrm{O}_{4}(\mathrm{OH})_{3} \cdot 15 \mathrm{H}_{2} \mathrm{O}$ | 118 |
| $\mathrm{LiK}_{5} \mathrm{Si}_{2} \mathrm{O}_{7}$ | 296 | $\mathrm{Mg}_{3} \mathrm{~B}_{2}(\mathrm{OH})_{6}\left(\mathrm{PO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 215 |
| $\mathrm{Li}_{2} \mathrm{~K}_{4} \mathrm{Si}_{6} \mathrm{O}_{15}$ | 256 | $\mathrm{MgBeAl}_{4} \mathrm{O}_{8}$ | 78 |
| $\mathrm{Li}_{2} \mathrm{~K}_{10} \mathrm{Si}_{7} \mathrm{O}_{20}$ | 270 | $\mathrm{Mg}\left(\mathrm{BrO}_{3}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 109 |
| $\mathrm{Li}_{4} \mathrm{~K}_{10} \mathrm{Si}_{7} \mathrm{O}_{21}$ | 267 | $\mathrm{MgCO}_{3}$ | 91 |
| LiMnPO 4 | 191 | $\mathrm{MgCO}_{3} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 94 |
| $\mathrm{LiNH}_{2}$ | 22 | $\mathrm{MgCO}_{3} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 94 |
| $\mathrm{LiNH}_{2} \mathrm{SO}_{3}$ | 121 | $\mathrm{Mg}_{3} \mathrm{Ce}_{2}\left(\mathrm{NO}_{3}\right)_{12} \cdot 24 \mathrm{H}_{2} \mathrm{O}$ | 104 |
| $\mathrm{Li}_{3} \mathrm{Na}_{3} \mathrm{Al}_{2} \mathrm{~F}_{12}$ | 42 | $\mathrm{MgCl}_{2}$ | 26 |
| $\mathrm{LiNaB}_{2} \mathrm{~F}_{6}$ | 35 | $\mathrm{MgCl}_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 27 |
| $\mathrm{LiNaCO}_{3}$ | 90 | $\mathrm{Mg}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 111 |
| $\mathrm{LiNO}_{3}$ | 100 | $\mathrm{MgCr}_{2} \mathrm{O}_{4}$ | 75 |
| $\mathrm{LiNO}_{3} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 102 | $\mathrm{MgCrO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 163 |
| $\mathrm{LiNaSO}_{4}$ | 124 | $\mathrm{MgF}_{2}$ | 23 |
| $\mathrm{LiNaSiO}_{3}$ | 268 | $\mathrm{Mg}(\mathrm{F}, \mathrm{OH})_{2} \cdot \mathrm{Mg}_{2} \mathrm{SiO}_{4}$ | 307 |
| $\mathrm{Li}_{2} \mathrm{O}$ | 56 | $\mathrm{Mg}(\mathrm{F}, \mathrm{OH})_{2} \cdot 2 \mathrm{Mg}_{2} \mathrm{SiO}_{4}$ | 307 |
| LiOH | 68 | $\mathrm{Mg}(\mathrm{F}, \mathrm{OH})_{2} \cdot 3 \mathrm{MgSiO}_{4}$ | 307 |
| $\mathrm{Li}_{2} \mathrm{Pt}(\mathrm{CN})_{6}$ | 48 | $\mathrm{Mg}(\mathrm{F}, \mathrm{OH})_{2} \cdot 4 \mathrm{MgSiO}_{4}$ | 308 |


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| $(\mathrm{Mg}, \mathrm{Fe})_{2} \mathrm{FeBO}_{5}$ | 114 | $\mathrm{MgSiO}_{3}$ | 271 |
| $\mathrm{MgFe}_{2} \mathrm{O}_{4}$ | 76 | $\mathrm{Mg}_{2} \mathrm{SiO}_{4}$ | 302 |
| $(\mathrm{Mg}, \mathrm{Fe})_{3}(\mathrm{OH})_{2} \mathrm{Si}_{3} \mathrm{AlO}_{10} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 265 | $\mathrm{Mg}_{7} \mathrm{Si}_{8} \mathrm{O}_{22} \mathrm{~F}_{2}$ | 284 |
| $\mathrm{Mg}_{5} \mathrm{Fe}\left(\mathrm{PO}_{4}\right)_{4} \cdot 16 \mathrm{H}_{2} \mathrm{O}$ | 198 | $\mathrm{Mg}_{7} \mathrm{Si}_{8} \mathrm{O}_{22}(\mathrm{OH})_{2}$ | 283 |
| $\mathrm{MgFe}_{4}\left(\mathrm{SO}_{4}\right)_{6}(\mathrm{OH})_{2} \cdot 20 \mathrm{H}_{2} \mathrm{O}$ | 178 | $\mathrm{Mg}_{3} \mathrm{Si}_{4} \mathrm{O}_{11} \cdot \mathrm{nH}_{2} \mathrm{O}$ | 260 |
| $\mathrm{MgFeSi} \mathrm{O}_{6}$ | 272 | $\mathrm{MgSnCl}_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 50 |
| $\mathrm{Mg}_{2} \mathrm{Fe}_{5} \mathrm{Si}_{8} \mathrm{O}_{22} \mathrm{~F}_{2}$ | 284 | $\mathrm{MgTiO}_{3}$ | 80 |
| $\mathrm{Mg}_{3} \mathrm{Fe}_{4} \mathrm{Si}_{8} \mathrm{O}_{22} \mathrm{~F}_{2}$ | 284 | $\mathrm{MgTi}_{2} \mathrm{O}_{5}$ | 81 |
| $\mathrm{Mg}_{5} \mathrm{Fe}_{2} \mathrm{Si}_{8} \mathrm{O}_{22} \mathrm{~F}_{2}$ | 282 | $\mathrm{Mg}_{2} \mathrm{TiO}_{4}$ | 77 |
| $\mathrm{MgFe} \mathrm{SiO}_{8} \mathrm{O}_{22}(\mathrm{OH})_{2}$ | 284 | $\mathrm{Mg}_{2} \mathrm{UO}_{2}\left(\mathrm{CO}_{3}\right)_{3} \cdot 18 \mathrm{H}_{2} \mathrm{O}$ | 99 |
| $\mathrm{Mg}_{4} \mathrm{Fe}_{3} \mathrm{Si}_{8} \mathrm{O}_{22}(\mathrm{OH})_{2}$ | 283 | $\mathrm{Mg}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2}: 8 \mathrm{H}_{2} \mathrm{O}$ | 208 |
| $\mathrm{MgHAsO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 194 | $\mathrm{MgWO}_{4}$ | 182 |
| $\mathrm{MgHPO}_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 193 | $\mathrm{MgZnF}_{4}$ | 25 |
| $\mathrm{MgHPO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 194 | $\mathrm{MnAl}_{2} \mathrm{O}_{4}$ | 76 |
| $\mathrm{MgKH}\left(\mathrm{CO}_{3}\right)_{2} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 90 | $\mathrm{Mn}_{2} \mathrm{Al}_{3} \mathrm{Si}_{5} \mathrm{AlO}_{18}$ | 291 |
| $\mathrm{Mg}_{3} \mathrm{La}_{2}\left(\mathrm{NO}_{3}\right)_{12} \cdot 24 \mathrm{H}_{2} \mathrm{O}$ | 104 | $\mathrm{Mn}_{3} \mathrm{Al}_{2} \mathrm{Si}_{3} \mathrm{O}_{12}$ | 298 |
| $\mathrm{MgMgSi} \mathrm{O}_{6}$ | 273 | $\mathrm{MnB}_{2} \mathrm{~F}_{8}$ | 49 |
| $\mathrm{Mg}\left(\mathrm{NH}_{2} \mathrm{SO}_{3}\right)_{2}$ | 122 | $\mathrm{Mn}_{3} \mathrm{~B}_{4} \mathrm{O}_{9}$ | 115 |
| $\mathrm{Mg}\left(\mathrm{NO}_{3}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 103 | $\mathrm{MnCO}_{3}$ | 92 |
| $\mathrm{Mg}_{3} \mathrm{Nd}_{2}\left(\mathrm{NO}_{3}\right)_{12} \cdot 24 \mathrm{H}_{2} \mathrm{O}$ | 104 | $\mathrm{MnCl}_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 28 |
| MgO | 57,68 | $\mathrm{MnCl}_{2} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 29 |
| $\mathrm{Mg}(\mathrm{OH})_{2}$ | 68 | $\mathrm{Mn}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 111 |
| $\mathrm{Mg}_{4}(\mathrm{OH})_{2}\left(\mathrm{CO}_{3}\right)_{3} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 98 | $\mathrm{Mn}_{5} \mathrm{H}_{2}\left(\mathrm{PO}_{4}\right)_{4} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 195 |
| $\mathrm{Mg}_{3}(\mathrm{OH})_{2} \mathrm{Si}_{4} \mathrm{O}_{10}$ | 259 | $\mathrm{MnMn}_{2} \mathrm{O}_{4}$ | 77 |
| $\mathrm{Mg}_{3}(\mathrm{OH})_{4} \mathrm{Si}_{2} \mathrm{O}_{5}$ | 261 | MnO | 57 |
| $\mathrm{Mg}_{6}(\mathrm{OH})_{8} \mathrm{Si}_{4} \mathrm{O}_{10}$ | 260 | $\mathrm{MnO}(\mathrm{OH})$ | 70 |
| $\mathrm{Mg}_{2} \mathrm{P}_{2} \mathrm{O}_{7}$ | 214 | $\mathrm{Mn}(\mathrm{OH})_{2}$ | 69 |
| $\mathrm{Mg}_{3}\left(\mathrm{PO}_{4}\right)_{2} \cdot 3-5 \mathrm{H}_{2} \mathrm{O}$ | 198 | $\mathrm{Mn}_{2} \mathrm{P}_{2} \mathrm{O}_{7}$ | 214 |
| $\mathrm{Mg}_{3}\left(\mathrm{PO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 197 | MnS | 11 |
| $\mathrm{Mg}_{3}\left(\mathrm{PO}_{4}\right)_{2} \cdot 22 \mathrm{H}_{2} \mathrm{O}$ | 198 | $\mathrm{MnS}_{2}$ | 12 |
| $\mathrm{Mg}_{2} \mathrm{PO}_{4} \mathrm{~F}$ | 202 | $\mathrm{MnSO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 163 |
| $\mathrm{Mg}_{2} \mathrm{PO}_{4} \mathrm{OH}$ | 201 | $\mathrm{MnSO}_{4} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 166 |
| $\mathrm{Mg}_{3} \mathrm{Pr}_{2}\left(\mathrm{NO}_{3}\right)_{12} \cdot 24 \mathrm{H}_{2} \mathrm{O}$ | 104 | $\mathrm{MnSO}_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 170 |
| $\mathrm{MgPt}(\mathrm{CN})_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 31 | $\mathrm{MnSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8}$ | 238 |
| $\mathrm{MgPt}(\mathrm{CN})_{4} \cdot \mathrm{C}_{3} \mathrm{H}_{8} \mathrm{O}_{3} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 31 | $\mathrm{MnSiF} \mathrm{F}_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 50 |
| MgS | 9 | $\mathrm{Mn}_{2} \mathrm{SiO}_{4}$ | 303 |
| $\mathrm{MgSO}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 133 | $\mathrm{MnTiO}_{3}$ | 80 |
| $\mathrm{MgSO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 163 | $\mathrm{Mn}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 3-8 \mathrm{H}_{2} \mathrm{O}$ | 208 |
| $\mathrm{MgSO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 164 | $\mathrm{MnWO}_{4}$ | 181 |
| $\mathrm{MgSO}_{4} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 166 | $\mathrm{MnZnF}_{4}$ | 25 |
| $\mathrm{MgSO}_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 168 | $\mathrm{N}\left(\mathrm{C}_{2} \mathrm{H}_{5}\right)_{4} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 |
| $\mathrm{MgSO}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 166 | $\mathrm{NH}_{4} \mathrm{AlSe}_{2} \mathrm{O}_{8} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 160 |
| $\mathrm{MgSO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 162 | $\mathrm{NH}_{3} \mathrm{BF}_{3}$ | 54 |
| $4 \mathrm{MgSO}_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 164 | $\mathrm{NH}_{3} \mathrm{CH}_{3} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 |
| MgSe | 11 | $\mathrm{NH}_{3} \mathrm{C}_{2} \mathrm{H}_{5} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 |
| $\mathrm{MgSeO}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 166 | $\mathrm{NH}_{3} \mathrm{C}_{3} \mathrm{H}_{7} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 |
| $\mathrm{MgSiF}_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 50 | $\mathrm{NH}_{3} \mathrm{C}_{4} \mathrm{H}_{9} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 |


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| $\mathrm{NH}_{3} \mathrm{C}_{5} \mathrm{H}_{11} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Fe}_{2} \mathrm{H}_{4}\left(\mathrm{PO}_{4}\right)_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 195 |
| $\mathrm{NH}_{3} \mathrm{CH}_{3} \mathrm{AlSe}_{2} \mathrm{O}_{8} \cdot \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 160 | $\left(\mathrm{NH}_{4}\right) \mathrm{Fe}_{3} \mathrm{H}_{8}\left(\mathrm{PO}_{4}\right)_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 195 |
| $\mathrm{NH}_{3} \mathrm{CH}_{3} \mathrm{Cr}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 160 | $\left(\mathrm{NH}_{4}\right) \mathrm{Fe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 |
| $\left(\mathrm{N}_{2} \mathrm{H}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{GeF}_{6}$ | 54 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Fe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 146 |
| $\left(\mathrm{NH}_{2} \mathrm{OH}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{GeF}_{6} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 54 | $\left(\mathrm{NH}_{4}\right) \mathrm{Fe}_{3}\left(\mathrm{SO}_{4}\right)_{2}(\mathrm{OH})_{6}$ | 174 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Al}_{2} \mathrm{H}_{4}\left(\mathrm{PO}_{4}\right)_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 195 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Fe}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 152 |
| $\left(\mathrm{NH}_{4}\right) \mathrm{Al}_{2}\left(\mathrm{PO}_{4}\right)_{2}(\mathrm{OH}) \cdot 2.5 \mathrm{H}_{2} \mathrm{O}$ | 210 | $\left(\mathrm{NH}_{4}\right) \mathrm{Ga}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 |
| $\left(\mathrm{NH}_{4}\right) \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 158 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{GeF}_{6}$ | 47 |
| $\left(\mathrm{NH}_{4}\right) \mathrm{Al}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 160 | $\left(\mathrm{NH}_{4}\right) \mathrm{H}_{2} \mathrm{AsO}_{4}$ | 187 |
| $\left(\mathrm{NH}_{4}\right) \mathrm{B}_{5} \mathrm{O}_{8} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 117 | $\left(\mathrm{NH}_{4}\right)_{3} \mathrm{H}_{6} \mathrm{Al}\left(\mathrm{MoO}_{4}\right)_{6} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 183 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{~B}_{10} \mathrm{O}_{16} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 117 | $\left(\mathrm{NH}_{4}\right)_{3} \mathrm{H}_{6} \mathrm{Al}\left(\mathrm{MoO}_{4}\right)_{6} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 183 |
| $\left(\mathrm{NH}_{4}\right) \mathrm{Br}$ | 21 | $\left(\mathrm{NH}_{4}\right) \mathrm{HCO}_{3}$ | 89 |
| $\mathrm{N}\left(\mathrm{CH}_{3}\right)_{4} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\left(\mathrm{NH}_{4}\right) \mathrm{HF}_{2}$ | 21 |
| $\mathrm{N}\left(\mathrm{C}_{2} \mathrm{H}_{5}\right)_{4} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\left(\mathrm{NH}_{4}\right) \mathrm{H}_{2} \mathrm{PO}_{4}$ | 187 |
| $\mathrm{NH}\left(\mathrm{C}_{2} \mathrm{H}_{5}\right)_{3} \mathrm{Al}\left(\mathrm{SO}_{4}\right) \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{HPO}_{4}$ | 187 |
| $\mathrm{NH}_{2}\left(\mathrm{CH}_{3}\right)_{2} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\left(\mathrm{NH}_{4}\right) \mathrm{HSO}_{4}$ | 123 |
| $\mathrm{NH}_{2}\left(\mathrm{C}_{2} \mathrm{H}_{5}\right)_{2} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\left(\mathrm{NH}_{4}\right)_{3} \mathrm{H}\left(\mathrm{SO}_{4}\right)_{2}$ | 123 |
| $\mathrm{NH}_{3} \mathrm{CH}_{3} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\left(\mathrm{NH}_{4}\right)_{3} \mathrm{HfF}_{7}$ | 47 |
| $\mathrm{NH}_{3} \mathrm{C}_{2} \mathrm{H}_{5} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\left(\mathrm{NH}_{4}\right) \mathrm{I}$ | 17 |
| $\mathrm{NH}_{3} \mathrm{C}_{3} \mathrm{H}_{7} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\left(\mathrm{NH}_{4}\right) \mathrm{In}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 |
| $\mathrm{NH}_{3} \mathrm{C}_{4} \mathrm{H}_{9} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\left(\mathrm{NH}_{4}\right)_{3} \mathrm{IrCl}_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ | 46 |
| $\mathrm{NH}_{3} \mathrm{C}_{5} \mathrm{H}_{22} \mathrm{Al}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\left(\mathrm{NH}_{4}\right) \mathrm{LiSO}_{4}$ | 126 |
| $\mathrm{NH}_{3} \mathrm{CH}_{3} \mathrm{AlSe}_{2} \mathrm{O}_{8} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 160 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{MgCr}_{2} \mathrm{O}_{8} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 155 |
| $\mathrm{NH}_{3} \mathrm{CH}_{3} \mathrm{Cr}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 160 | $\left(\mathrm{NH}_{4}\right) \mathrm{Mg}_{3} \mathrm{~F}_{2} \mathrm{Si}_{3} \mathrm{AlO}_{4}$ | 262 |
| $\left(\mathrm{NH}_{4}\right)_{4} \mathrm{CH}_{3} \mathrm{PtCl}_{6}$ | 47 | $\left(\mathrm{NH}_{4}\right) \mathrm{MgPO}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 197 |
| $\left(\mathrm{NH}_{4}\right) \mathrm{CNS}$ | 22 | $\left(\mathrm{NH}_{4}\right) \mathrm{Mg}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 142 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Ca}_{2}\left(\mathrm{SO}_{4}\right)_{3}$ | 132 | $\left(\mathrm{NH}_{4}\right)_{2}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 149 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Ca}\left(\mathrm{SO}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 138 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{MnCl}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 39 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Ca}_{5}\left(\mathrm{SO}_{4}\right)_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ | 157 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{MnFF}_{5}$ | 44 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Cd}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 144 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Mn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 145 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Cd}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 151 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Mn}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 151 |
| $\mathrm{NH}_{4} \mathrm{Cl}$ | 21 | $\left(\mathrm{NH}_{4}\right) \mathrm{NH}_{2} \mathrm{SO}_{3}$ | 121 |
| $\mathrm{NH}_{4} \mathrm{ClO}_{4}$ | 110 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{NaFe}(\mathrm{CN})_{6}$ | 45 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{CoCl}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 39 | $\left(\mathrm{NH}_{4}\right) \mathrm{NaHAsO} \mathrm{S}_{4} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 192 |
| $\mathrm{NH}_{4} \mathrm{Co}\left(\mathrm{NH}_{3}\right)_{2}\left(\mathrm{NO}_{2}\right)_{4}$ | 107 | $\left(\mathrm{NH}_{4}\right) \mathrm{NaHPO}_{4} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 193 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Co}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 146 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Ni}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 148 |
| $\left(\mathrm{NH}_{4}\right) \mathrm{Co}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 153 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Ni}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 153 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Cr}_{2} \mathrm{O}_{7}$ | 122 | $\left(\mathrm{NH}_{4}\right)\left(\mathrm{NO}_{3}\right)$ | 101 |
| $\left(\mathrm{NH}_{4}\right) \mathrm{Cr}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\left(\mathrm{NH}_{4}\right)_{4}\left(\mathrm{NO}_{3}\right)_{2} \mathrm{SO}_{4}$ | 179 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{CuCl}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 40 | $\left(\mathrm{NH}_{4}\right)_{5}\left(\mathrm{NO}_{3}\right)_{3} \mathrm{SO}_{4}$ | 179 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Cu}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 148 | $\mathrm{NH}_{2}(\mathrm{OH}) \mathrm{HAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Cu}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 154 | $\left(\mathrm{NH}_{4}\right)_{3}(\mathrm{OH}) \mathrm{Cr}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 160 |
| $\left(\mathrm{NH}_{4}\right) \mathrm{F}$ | 21 | $\left(\mathrm{NH}_{4}\right) \mathrm{PO}_{3}$ | 211 |
| $\left(\mathrm{NH}_{4}\right) \mathrm{Fe}(\mathrm{CN})_{6} \cdot 2\left(\mathrm{NH}_{4}\right) \mathrm{Cl} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 42 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{PdCl}_{4}$ | 37 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{FeCl}_{4}$ | 36 | $\left(\mathrm{NH}_{4}\right)_{3} \mathrm{PdSO}_{3} \mathrm{Cl}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | 173 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{FeCl}_{5} \cdot \mathrm{H}_{2} \mathrm{O}$ | 45 189 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{PtCl}_{4}$ | 37 |
| $\left(\mathrm{NH}_{4}\right) \mathrm{FeH} \mathrm{F}_{2}\left(\mathrm{PO}_{4}\right)_{2}$ | 189 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{PtCl}_{6}$ | 47 |


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| $\left(\mathrm{NH}_{4}\right)_{3} \mathrm{RhCl}_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ | 45 | $\mathrm{Na}_{2} \mathrm{BeF}_{4}$ | 35 |
| $\left(\mathrm{NH}_{4}\right) \mathrm{Rh}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\mathrm{NaBeOHSi} 3_{3}$ | 266, 267 |
| $\left(\mathrm{NH}_{4}\right) \mathrm{SH}$ | 9 | $\mathrm{NaBe}\left(\mathrm{PO}_{4}\right)$ | 191 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SO}_{4}$ | 126 | $\mathrm{Na}_{6} \mathrm{Be}_{6} \mathrm{Si}_{14} \mathrm{O}_{37}$ | 258 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{~S}_{2} \mathrm{O}_{8}$ | 122 | NaBr | 17 |
| $4\left(\mathrm{NH}_{4}\right)_{2} \mathrm{~S}_{2} \mathrm{O}_{3} \cdot \mathrm{AgBr} \cdot\left(\mathrm{NH}_{4}\right) \mathrm{Br}$ | 121 | $\mathrm{NaBr} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 23 |
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| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SeO}_{4}$ | 128 | NaCN | 22 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SiF}_{6}$ | 46 | NaCNS | 22 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SnCl}_{6}$ | 47 | $\mathrm{Na}_{2} \mathrm{CO}_{3}$ | 90 |
| $\left(\mathrm{NH}_{4}\right)_{6} \mathrm{Te}_{2}(\mathrm{OH})_{6}\left(\mathrm{MoO}_{4}\right)_{6} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 184 | $\mathrm{Na}_{2} \mathrm{CO}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | 90 |
| $\left(\mathrm{NH}_{4}\right)_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 206 | $\mathrm{Na}_{2} \mathrm{CO}_{3} \cdot 10 \mathrm{H}_{2} \mathrm{O}$ | 91 |
| $\left(\mathrm{NH}_{4}\right)_{4} \mathrm{UO}_{2} \mathrm{CO}_{3}$ | 99 | $\mathrm{Na}_{4}\left(\mathrm{CO}_{3}\right)_{2} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 91 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{UO}_{2} \mathrm{Cl}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 40 | $\mathrm{Na}_{6}\left(\mathrm{CO}_{3}\left(\mathrm{SO}_{4}\right)_{2}\right.$ | 178 |
| $\left(\mathrm{NH}_{4}\right)_{3} \mathrm{UO}_{2} \mathrm{~F}_{5}$ | 37 | $\mathrm{NaCaAlF}{ }_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ | 48 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{UO}_{2}\left(\mathrm{NO}_{3}\right)_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 105 | $\mathrm{NaCa}_{4} \mathrm{Al}_{3} \mathrm{O}_{9}$ | 73 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{UO}_{2}\left(\mathrm{SO}_{4}\right)_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 177 | $\mathrm{Na}_{4} \mathrm{Ca}_{3} \mathrm{Al}_{10} \mathrm{O}_{20}$ | 73 |
| $\left(\mathrm{NH}_{4}\right) \mathrm{V}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\mathrm{NaCaAlSi} 2 \mathrm{O}_{7}$ | 295 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{ZnCl}_{4}$ | 37 | $\mathrm{NaCaB} \mathrm{S}_{9} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 116 |
| $\left(\mathrm{NH}_{4}\right)_{9} \mathrm{ZnCl}_{5}$ | 37 | $\mathrm{NaCaB} 5 \mathrm{O}_{9} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 116 |
| $\left(\mathrm{NH}_{4}\right) \mathrm{ZnF}_{3}$ | 37 | $\mathrm{NaCaBeSi} 2_{2} \mathrm{O}_{6}$ | 295 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Zn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 143 | $\mathrm{Na}_{2} \mathrm{Ca}\left(\mathrm{CO}_{3}\right)_{2}$ | 96 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Zn}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 150 | $\mathrm{Na}_{2} \mathrm{Ca}\left(\mathrm{CO}_{3}\right)_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 96 |
| $\left(\mathrm{NH}_{4}\right)_{3} \mathrm{ZrF}_{7}$ | 47 | $\mathrm{Na}_{2} \mathrm{Ca}\left(\mathrm{CO}_{3}\right)_{2} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 96 |
| $\mathrm{NaAgS} \mathrm{O}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | 134 | $\mathrm{Na}_{3} \mathrm{CaCO}_{3}(\mathrm{OH})_{2} \mathrm{Si}_{3} \mathrm{Al}_{3} \mathrm{O}_{12}$ | 254 |
| $\mathrm{Na}_{7}\left(\mathrm{AsO}_{4}\right)_{2} \mathrm{~F} \cdot 19 \mathrm{H}_{2} \mathrm{O}$ | 205 | $\mathrm{NaCaCb} 2 \mathrm{O}_{6} \mathrm{~F}$ | 85 |
| $\mathrm{Na}_{3} \mathrm{AsO}_{4} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 196 | $\mathrm{Na}_{4} \mathrm{Ca}_{4} \mathrm{ClCO}_{3} \mathrm{Si}_{25} \mathrm{Al}_{9} \mathrm{O}_{48}$ | 253 |
| $\mathrm{NaAlAsO} \mathrm{S}_{4} \mathrm{~F}$ | 202 | $\mathrm{NaCa}_{2} \mathrm{Fe}_{4}^{\text {I' }} \mathrm{Fe}^{\text {"'' }} \mathrm{Si}_{6} \mathrm{Al}_{,} \mathrm{O}_{22}(\mathrm{OH})_{2}$ | $)_{2} \quad 286$ |
| $\mathrm{NaAlCO}_{3}(\mathrm{OH})_{2}$ | 99 | $\mathrm{NaCa}_{2} \mathrm{Fe}_{5} \mathrm{Si}_{7} \mathrm{AlO}_{22}(\mathrm{OH})_{2}$ | 286 |
| $\mathrm{Na}_{3} \mathrm{AlF}_{6}$ | 42 | $\mathrm{NaCa}_{2} \mathrm{Mg}_{4} \mathrm{AlSi}_{6} \mathrm{Al}_{2} \mathrm{O}_{22}(\mathrm{OH})_{2}$ | 286 |
| $\mathrm{Na}_{5} \mathrm{Al}_{3} \mathrm{~F}_{14}$ | 43 | $\mathrm{NaCa} 2 \mathrm{Mg}_{5} \mathrm{Si}_{7} \mathrm{AlO}_{22}(\mathrm{OH})_{2}$ | 286 |
| $\mathrm{NaAlO}_{2}$ | 73 | $\mathrm{NaCa} 2 \mathrm{Mg}_{5} \mathrm{Si}_{7} \mathrm{AlO}_{22} \mathrm{~F}_{2}$ | 286 |
| $\mathrm{Na}_{2} \mathrm{Al}_{12} \mathrm{O}_{19}$ | 80 | $\mathrm{NaCa}_{2} \mathrm{Mg}_{5} \mathrm{Si}_{7} \mathrm{BO}_{22} \mathrm{~F}_{2}$ | 286 |
| $\mathrm{NaAl}_{2}(\mathrm{OH})_{2} \mathrm{Si}_{3} \mathrm{AlO}_{10}$ | 263 | $\mathrm{Na}_{2} \mathrm{CaMg}_{5} \mathrm{Si}_{8} \mathrm{O}_{22}(\mathrm{OH})_{2}$ | 285 |
| $\mathrm{NaAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 160 | $\mathrm{Na}_{2} \mathrm{CaMg}_{5} \mathrm{Si}_{8} \mathrm{O}_{22} \mathrm{~F}_{2}$ | 285 |
| $\mathrm{NaAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 158 | $\mathrm{Na}_{4} \mathrm{Ca}\left(\mathrm{PO}_{4}\right)_{6}$ | 212 |
| $\mathrm{NaAlSi} \mathrm{O}_{6}$ | 279 | $\mathrm{Na}_{2} \mathrm{Ca}\left(\mathrm{SO}_{4}\right)_{2}$ | 132 |
| $\mathrm{Na}_{2} \mathrm{Al}_{2} \mathrm{Si}_{2} \mathrm{O}_{8} \cdot \mathrm{H}_{2} \mathrm{O}$ | 259 | $\mathrm{Na}_{2} \mathrm{Ca}_{5}\left(\mathrm{SO}_{4}\right)_{6} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 157 |
| $\mathrm{NaAl}\left(\mathrm{WO}_{4}\right)_{2}$ | 182 | $\mathrm{Na}_{4} \mathrm{Ca}\left(\mathrm{SO}_{4}\right)_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 157 |
| $\mathrm{NaAsO}_{3}$ | 211 | $\mathrm{Na}_{3} \mathrm{Ca}\left(\mathrm{SO}_{4}\right) \mathrm{Si}_{3} \mathrm{Al}_{3} \mathrm{O}_{12}$ | 252 |
| $\mathrm{Na}_{3} \mathrm{AsS}_{4} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 14 | $\mathrm{NaCa} 2 \mathrm{Si}_{5} \mathrm{Al}_{5} \mathrm{O}_{20} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 243 |
| $\mathrm{NaAuCl} 4 \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 45 | $\mathrm{Na}_{2} \mathrm{CaSi}_{10} \mathrm{Al}_{4} \mathrm{O}_{28} \cdot 20 \mathrm{H}_{2} \mathrm{O}$ | 239 |
| $\mathrm{NaBF}_{4}$ | 43 | $\mathrm{Na}_{2} \mathrm{Ca}_{2} \mathrm{Si}_{9} \mathrm{Al}_{6} \mathrm{O}_{30} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 246 |
| $\mathrm{Na}_{2} \mathrm{BO}_{2} \mathrm{Cl} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 117 | $\mathrm{Na}_{2} \mathrm{CaSi}_{20} \mathrm{Al}_{4} \mathrm{O}_{48} \cdot 14 \mathrm{H}_{2} \mathrm{O}$ | 245 |
| $\mathrm{NaBO}_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 115 | $\mathrm{Na}_{2} \mathrm{CaSiO}_{4}$ | 299 |
| $\mathrm{Na}_{2} \mathrm{~B}_{4} \mathrm{O}_{7} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 115 | $\mathrm{Na}_{2} \mathrm{Ca}_{2} \mathrm{Si}_{3} \mathrm{O}_{9}$ | 288 |
| $\mathrm{Na}_{2} \mathrm{~B}_{4} \mathrm{O}_{7} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 115 | $\mathrm{Na}_{2} \mathrm{Ca}_{2} \mathrm{Si}_{2} \mathrm{O}_{7}$ | 296 |
| $\mathrm{Na}_{2} \mathrm{~B}_{4} \mathrm{O}_{7} \cdot 10 \mathrm{H}_{2} \mathrm{O}$ | 116 | $\mathrm{Na}_{2} \mathrm{Ca}_{3} \mathrm{Si}_{6} \mathrm{O}_{16}$ | 256 |


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| $\mathrm{Na}_{4} \mathrm{CaSi}_{3} \mathrm{O}_{9}$ | 267 | $\mathrm{Na}_{2} \mathrm{H}_{2} \mathrm{P}_{2} \mathrm{O}_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 213 |
| $\mathrm{Na}_{8} \mathrm{Ca}_{3} \mathrm{Si}_{5} \mathrm{O}_{17}$ | 270 | $2 \mathrm{NaH}_{2} \mathrm{PO}_{3} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 211 |
| $(\mathrm{Na}, \mathrm{Ca})_{2} \mathrm{Ta}_{2} \mathrm{O}_{6}(\mathrm{O}, \mathrm{OH}, \mathrm{F})$ | 85 | $\mathrm{Na}_{3} \mathrm{HP}_{2} \mathrm{O}_{6} \cdot 9 \mathrm{H}_{2} \mathrm{O}$ | 213 |
| $\mathrm{Na}_{2} \mathrm{CaUO}_{2}\left(\mathrm{CO}_{3}\right)_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 99 | $\mathrm{NaHSO}_{3}$ | 120 |
| $\mathrm{NaCa} \mathrm{UO}_{2}\left(\mathrm{CO}_{3}\right)_{3} \mathrm{SO}_{4} \mathrm{~F} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 179 | $\mathrm{NaHSO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 136 |
| $\mathrm{NaCa}_{3} \mathrm{UO}_{2}\left(\mathrm{CO}_{3}\right)_{3} \mathrm{SO}_{4} \mathrm{~F} \cdot 10 \mathrm{H}_{2} \mathrm{O}$ | 179 | $\mathrm{NaH}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 206 |
| NaCl | 15 | NaI | 17 |
| $\mathrm{NaCl}-\mathrm{KCl}$ series | 16 | $\mathrm{Na}_{3} \mathrm{Ir}\left(\mathrm{SO}_{3}\right)_{3}\left(\mathrm{NH}_{3}\right)_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 133 |
| $\mathrm{NaClO}_{3}$ | 108 | $\mathrm{Na}_{22} \mathrm{~K}\left(\mathrm{CO}_{3}\right)_{2}\left(\mathrm{SO}_{4}\right)_{9} \mathrm{Cl}$ | 178 |
| $\mathrm{NaClO}_{4}$ | 110 | $\mathrm{NaK}(\mathrm{CN})_{2}$ | 22 |
| $\mathrm{Na}_{4} \mathrm{ClSi}_{3} \mathrm{Al}_{3} \mathrm{O}_{12}$ | 251 | $\mathrm{NaK}_{3}\left(\mathrm{CrO}_{4}\right)_{2}$ | 125 |
| $\mathrm{Na}_{4} \mathrm{ClSi}_{9} \mathrm{Al}_{3} \mathrm{O}_{24}$ | 253 | $\mathrm{NaK}_{3} \mathrm{FeCl}_{6}$ | 35 |
| $\mathrm{Na}_{2} \mathrm{Co}(\mathrm{CNS})_{4} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 42 | $\mathrm{Na}_{3} \mathrm{~K}\left(\mathrm{PO}_{3}\right)_{4}$ | 211 |
| $\mathrm{Na}_{2} \mathrm{CrO}_{4} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 137 | $\mathrm{NaKPt}(\mathrm{CN})_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 40 |
| $\mathrm{Na}_{2} \mathrm{Cr}_{2} \mathrm{O}_{7} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 135 | $\mathrm{NaK}_{3}\left(\mathrm{SO}_{4}\right)_{2}$ | 124 |
| $\mathrm{Na}_{10} \mathrm{Cu}_{2} \mathrm{Ag}_{4}\left(\mathrm{~S}_{2} \mathrm{O}_{3}\right)_{8} \cdot 6 \mathrm{NH}_{3}$ | 121 | $\mathrm{Na}_{8} \mathrm{~K}_{2}\left(\mathrm{SO}_{4}\right)_{5}$ | 124 |
| $\mathrm{Na}_{2} \mathrm{Cu}\left(\mathrm{CO}_{3}\right)_{2} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 97 | $\mathrm{Na}_{2} \mathrm{~K}_{8}\left(\mathrm{SO}_{4}\right)_{5}$ | 124 |
| $\mathrm{Na}_{2} \mathrm{Cu}\left(\mathrm{SO}_{4}\right)_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 138 | $\mathrm{Na}_{2} \mathrm{~K}_{4}\left(\mathrm{SO}_{4}\right)_{3}$ | 124 |
| NaF | 16 | $\mathrm{Na}_{3} \mathrm{~K}_{3}\left(\mathrm{SO}_{4}\right)_{3}$ | 124 |
| $\mathrm{NaFe} \mathrm{Al}_{6}(\mathrm{OH})_{4}\left(\mathrm{BO}_{3}\right)_{3} \mathrm{Si}_{6} \mathrm{O}_{18}$ | 289 | $\mathrm{Na}_{2} \mathrm{Li}_{3} \mathrm{Al}_{5}(\mathrm{OH})_{4}\left(\mathrm{BO}_{3}\right)_{3} \mathrm{Si}_{6} \mathrm{O}_{18}$ | 289 |
| $\mathrm{Na}_{3} \mathrm{Fe}(\mathrm{CN})_{6} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 46 | $\mathrm{NaMg}_{3} \mathrm{Al}_{6}(\mathrm{OH})_{4}\left(\mathrm{BO}_{3}\right)_{3} \mathrm{Si}_{6} \mathrm{O}_{18}$ | 289 |
| $\mathrm{Na}_{4} \mathrm{Fe}(\mathrm{CN})_{6} \cdot 10 \mathrm{H}_{2} \mathrm{O}$ | 40 | $\mathrm{Na}_{3} \mathrm{MgBr}\left(\mathrm{CO}_{3}\right)_{2}$ | 99 |
| $\mathrm{Na}_{12} \mathrm{Fe}_{8} \mathrm{O}_{8} \mathrm{Si}_{5} \mathrm{O}_{20}$ | 308 | $\mathrm{Na}_{2} \mathrm{Mg}\left(\mathrm{CO}_{3}\right)_{2}$ | 96 |
| $\mathrm{Na}_{2} \mathrm{Fe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 138 | $\mathrm{Na}_{3} \mathrm{MgCl}\left(\mathrm{CO}_{3}\right)_{2}$ | 98 |
| $\mathrm{Na}_{3} \mathrm{Fe}\left(\mathrm{SO}_{4}\right)_{3} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 157 | $\mathrm{Na}_{6} \mathrm{Mg}_{2} \mathrm{CrO}_{4}\left(\mathrm{CO}_{3}\right)_{4}$ | 100 |
| $\mathrm{Na}_{2} \mathrm{Fe}\left(\mathrm{SO}_{4}\right)_{2}(\mathrm{OH}) \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 176 | $\mathrm{Na}_{6} \mathrm{Mg}\left(\mathrm{SO}_{4}\right)_{4}$ | 132 |
| $\mathrm{Na}_{4} \mathrm{Fe}_{2}\left(\mathrm{SO}_{4}\right)_{4}(\mathrm{OH})_{2} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 176 | $\mathrm{Na}_{2} \mathrm{Mg}\left(\mathrm{SO}_{4}\right)_{2} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 138 |
| $\mathrm{NaFeSi} \mathrm{O}_{6}$ | 279 | $\mathrm{Na}_{4} \mathrm{Mg}_{2}\left(\mathrm{SO}_{4}\right)_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 137 |
| $\mathrm{Na}_{10} \mathrm{Fe}_{2} \mathrm{Si}_{8} \mathrm{O}_{24}$ | 267 | $\mathrm{Na}_{6} \mathrm{Mg}_{2} \mathrm{SO}_{4}\left(\mathrm{CO}_{3}\right)_{4}$ | 100 |
| $\mathrm{NaGe}_{3} \mathrm{AlO}_{8}$ | 232 | $\mathrm{Na}_{2} \mathrm{MgSiO}_{4}$ | 299 |
| $\mathrm{Na}_{2} \mathrm{GeF}_{6}$ | 46 | $\mathrm{Na}_{2} \mathrm{Mg}_{2} \mathrm{Si}_{6} \mathrm{O}_{15}$ | 258 |
| $\mathrm{NaGe}_{3} \mathrm{GaO}_{8}$ | 232 | $\mathrm{Na}_{2} \mathrm{Mg}_{2} \mathrm{Si}_{2} \mathrm{O}_{7}$ | 296 |
| NaH | 21 | $\mathrm{NaMn}_{3} \mathrm{Al}_{6}(\mathrm{OH})_{4}\left(\mathrm{BO}_{3}\right)_{3} \mathrm{Si}_{6} \mathrm{O}_{18}$ | 289 |
| $\mathrm{NaH}_{2} \mathrm{AsO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 193 | $\mathrm{NaNH}_{2}$ | 22 |
| $\mathrm{NaH}_{2} \mathrm{AsO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 193 | $\mathrm{Na}\left(\mathrm{NH}_{4}, \mathrm{~K}\right) \mathrm{SO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 136 |
| $\mathrm{Na}_{2} \mathrm{HAsO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 192 | $\mathrm{NaNH}_{2} \mathrm{SO}_{3}$ | 121 |
| $\mathrm{Na}_{2} \mathrm{HAsO}_{4} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 192 | $\mathrm{NaNO}_{2}$ | 106 |
| $\mathrm{NaHCO}_{3}$ | 89 | $\mathrm{NaNO}_{3}$ | 101 |
| $\mathrm{Na}_{3} \mathrm{H}\left(\mathrm{CO}_{3}\right)_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 89 | NaOH | 68 |
| $\mathrm{NaHF}_{2}$ | 21 | $\mathrm{NaOH} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 68 |
| $\mathrm{Na}_{2} \mathrm{H}_{2} \mathrm{P}_{2} \mathrm{O}_{7}$ | 214 | $\mathrm{Na}_{4} \mathrm{OHSi}_{3} \mathrm{Al}_{3} \mathrm{O}_{12}$ | 252 |
| $\mathrm{Na}_{2} \mathrm{H}\left(\mathrm{PO}_{4}\right)$ | 187 | $\mathrm{Na}_{4}(\mathrm{OH})_{3} \mathrm{Si}_{3} \mathrm{Al}_{3} \mathrm{O}_{12}$ | 254 |
| $\mathrm{NaH}\left(\mathrm{PO}_{4}\right) \cdot \mathrm{H}_{2} \mathrm{O}$ | 193 | $4 \mathrm{Na}_{2} \mathrm{O} \cdot \mathrm{P}_{2} \mathrm{O}_{5} \cdot 24 \mathrm{WO}_{3} \cdot \mathrm{nH}_{2} \mathrm{O}$ | 185 |
| $\mathrm{NaH}_{2}\left(\mathrm{PO}_{4}\right) \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 193 | $\mathrm{Na}_{6} \mathrm{OSiO}_{4}$ | 308 |
| $\mathrm{Na}_{2} \mathrm{H}\left(\mathrm{PO}_{4}\right) \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 192 | $\mathrm{Na}_{6} \mathrm{P}_{2} \mathrm{Mo}_{5} \mathrm{O}_{23} \cdot 14 \mathrm{H}_{2} \mathrm{O}$ | 184 |
| $\mathrm{Na}_{2} \mathrm{H}\left(\mathrm{PO}_{4}\right) \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 192 | $\mathrm{NaPO}_{3}$ | 212 |
| $\mathrm{Na}_{2} \mathrm{H}\left(\mathrm{PO}_{4}^{\prime}\right) \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 192 | $\mathrm{Na}_{3} \mathrm{PO}_{4}$ | 189 |
| $\mathrm{Na}_{2} \mathrm{HPO}_{3} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 211 | $\mathrm{Na}_{4} \mathrm{P}_{2} \mathrm{O}_{7}$ | 214 |


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| $\mathrm{Na}_{5} \mathrm{P}_{3} \mathrm{O}_{10}$ | 214 | $\mathrm{Na}_{6} \mathrm{Si}_{2} \mathrm{O}_{7}$ | 296 |
| $\mathrm{Na}_{4} \mathrm{PO}_{4} \mathrm{BO}_{2} \cdot 18 \mathrm{H}_{2} \mathrm{O}$ | 215 | $\mathrm{Na}_{2} \mathrm{SiO}_{3} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 282 |
| $\mathrm{Na}_{7}\left(\mathrm{PO}_{4}\right)_{2} \mathrm{~F} \cdot 19 \mathrm{H}_{2} \mathrm{O}$ | 205 | $\mathrm{Na}_{2} \mathrm{SiO}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 282 |
| $\mathrm{NaPO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 212 | $\mathrm{Na}_{2} \mathrm{SiO}_{3} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 282 |
| $\mathrm{Na}_{3} \mathrm{PO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 197 | $\mathrm{Na}_{2} \mathrm{SiO}_{3} \cdot 9 \mathrm{H}_{2} \mathrm{O}$ | 282 |
| $\mathrm{Na}_{3} \mathrm{PO}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 197 | $\mathrm{Na}_{6} \mathrm{Si}_{2} \mathrm{O}_{7} \cdot 11 \mathrm{H}_{2} \mathrm{O}$ | 296 |
| $\mathrm{Na}_{3} \mathrm{PO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 197 | $\mathrm{NaSiPrO}_{4}$ | 228 |
| $\mathrm{Na}_{3} \mathrm{PO}_{4} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 197 | $\mathrm{NaSiSmO}_{4}$ | 228 |
| $\mathrm{Na}_{3} \mathrm{PO}_{4} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 196 | $\mathrm{NaSiYO}_{4}$ | 228 |
| $\mathrm{Na}_{4} \mathrm{P}_{2} \mathrm{O}_{7} \cdot 10 \mathrm{H}_{2} \mathrm{O}$ | 21.3 | $\mathrm{Na}_{2} \mathrm{Sn}(\mathrm{OH})_{6}$ | 72 |
| $\mathrm{Na}_{5} \mathrm{P}_{3} \mathrm{O}_{10} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 214 | $\mathrm{Na}_{4} \mathrm{Sn}_{5} \mathrm{O}_{2} \mathrm{~S}_{10} \cdot 18 \mathrm{H}_{2} \mathrm{O}$ | 14 |
| $\mathrm{Na}_{6}\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 197 | $\mathrm{Na}_{4} \mathrm{Sn}_{5} \mathrm{O}_{2} \mathrm{~S}_{10} \cdot 20 \mathrm{H}_{2} \mathrm{O}$ | 14 |
| $5\left(\mathrm{Na}_{3} \mathrm{PO}_{4} \cdot 11 \mathrm{H}_{2} \mathrm{O}\right) \cdot \mathrm{NaCl}$ | 205 | $\mathrm{Na}_{8} \mathrm{Sn}_{5} \mathrm{O}_{2} \mathrm{~S}_{12} \cdot 32 \mathrm{H}_{2} \mathrm{O}$ | 14 |
| $4\left(\mathrm{Na}_{3} \mathrm{PO}_{4} \cdot 11 \mathrm{H}_{2} \mathrm{O}\right) \cdot \mathrm{NaNO}_{3}$ | 215 | $\mathrm{Na}_{2} \mathrm{SnS}_{3} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 14 |
| $4\left(\mathrm{Na}_{3} \mathrm{PO}_{4} \cdot 11 \mathrm{H}_{2} \mathrm{O}\right) \cdot \mathrm{NaOCl}$ | 205 | $\mathrm{Na}_{2} \mathrm{SnS}_{3} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 14 |
| $5\left(\mathrm{Na}_{3} \mathrm{PO}_{4} \cdot 12 \mathrm{H}_{2} \mathrm{O}\right) \cdot \mathrm{NaOH}$ | 205 | $\mathrm{Na}_{4} \mathrm{SnS}_{4} \cdot 18 \mathrm{H}_{2} \mathrm{O}$ | 14 |
| $\mathrm{Na}_{2} \mathrm{Pt}(\mathrm{CN})_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 41 | $\mathrm{Na}_{6} \mathrm{Te}\left(\mathrm{MoO}_{4}\right)_{6} \cdot 22 \mathrm{H}_{2} \mathrm{O}$ | 184 |
| $\mathrm{Na}_{2} \mathrm{Ru}\left(\mathrm{NO}_{2}\right)_{5} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 106 | $\mathrm{Na}_{2} \mathrm{TiF}_{6}$ | 47 |
| $\mathrm{Na}_{2} \mathrm{~S} \cdot 9 \mathrm{H}_{2} \mathrm{O}$ | 9 | $\mathrm{Na}_{2} \mathrm{Ti}_{2} \mathrm{Si}_{2} \mathrm{O}_{9}$ | 268 |
| $\mathrm{Na}_{2} \mathrm{SO}_{3}$ | 120 | $\mathrm{Na}_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 206 |
| $\mathrm{Na}_{2} \mathrm{SO}_{4}$ | 125 | $\left(\mathrm{Na}_{2}\right) \mathrm{U}_{2} \mathrm{O}_{7} \cdot \mathrm{nH}_{2} \mathrm{O}$ | 84 |
| $\mathrm{Na}_{3} \mathrm{SO}_{4} \mathrm{~F}$ | 173 | $\mathrm{Na}_{2}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 206 |
| $\mathrm{Na}_{2} \mathrm{~S}_{2} \mathrm{O}_{6} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 134 | $\mathrm{Na}_{7}\left(\mathrm{VO}_{4}\right)_{2} \mathrm{~F} \cdot 19 \mathrm{H}_{2} \mathrm{O}$ | 205 |
| $\mathrm{Na}_{2} \mathrm{~S}_{2} \mathrm{O}_{3} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 135 | $\mathrm{Na}_{3}\left(\mathrm{VO}_{4}\right) \cdot 10 \mathrm{H}_{2} \mathrm{O}$ | 196 |
| $\mathrm{Na}_{2} \mathrm{SO}_{4} \cdot 10 \mathrm{H}_{2} \mathrm{O}$ | 136 | $\mathrm{Na}_{3}\left(\mathrm{VO}_{4}\right) \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 196 |
| $\mathrm{Na}_{3} \mathrm{SO}_{4}\left(\mathrm{NO}_{3}\right) \cdot \mathrm{H}_{2} \mathrm{O}$ | 105 | $\mathrm{Na}_{2} \mathrm{WO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 183 |
| $\mathrm{Na}_{8} \mathrm{SO}_{4} \mathrm{Si}_{6} \mathrm{Al}_{6} \mathrm{O}_{24}$ | 252 | $\mathrm{Na}_{8}(\mathrm{WO})_{4} \mathrm{Si}_{6} \mathrm{Al}_{6} \mathrm{O}_{24}$ | 252 |
| $\mathrm{Na}_{4} \mathrm{SSi}_{3} \mathrm{Al}_{3} \mathrm{O}_{12}$ | 252 | $\mathrm{Na}_{6} \mathrm{Zn}_{8}\left(\mathrm{CO}_{3}\right)_{11} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 96 |
| $\mathrm{NaSiAlO}_{4}$ | 224 | $\mathrm{Na}_{2} \mathrm{ZrO}_{3}$ | 73 |
| $\mathrm{NaSi}_{3} \mathrm{AlO}_{8}$ | 233 | $\mathrm{Na}_{2} \mathrm{ZrOSiO}_{4}$ | 308 |
| $\mathrm{NaSi}_{3} \mathrm{AlO}_{8}$ | 235 | $\mathrm{Na}_{2} \mathrm{ZrSi}_{2} \mathrm{O}_{7}$ | 296 |
| $\mathrm{NaSiAlO}{ }_{4} \cdot \mathrm{CaAl}_{2} \mathrm{O}_{4}$ | 225 | $\mathrm{Na}_{4} \mathrm{Zr}\left(\mathrm{SiO}_{4}\right)_{3}$ | 300 |
| $\mathrm{NaSi}_{2} \mathrm{AlO}_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ | 239 | $\mathrm{Nd}(\mathrm{OH})_{3}$ | 71 |
| $\mathrm{NaSi}_{2} \mathrm{AlO}_{6} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 240 | NdOOH | 70 |
| $\mathrm{NaSi} \mathrm{AlO}_{8} \cdot \mathrm{H}_{2} \mathrm{O}$ | 245 | $\mathrm{Nd}_{2}\left(\mathrm{MoO}_{4}\right)_{3}$ | 182 |
| $\mathrm{Na}_{2} \mathrm{Si}_{3} \mathrm{Al}_{2} \mathrm{O}_{10} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 245 | $(\mathrm{Nd}, \mathrm{Pr})_{2}\left(\mathrm{MoO}_{4}\right)_{3}$ | 182 |
| $2 \mathrm{NaSiAlO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 242 | $\mathrm{Nd}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 172 |
| $\mathrm{Na}_{4} \mathrm{Si}_{4} \mathrm{Al}_{4} \mathrm{O}_{8} \cdot \mathrm{H}_{2} \mathrm{O}$ | 242 | $\mathrm{Ni}_{3}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 199 |
| $\mathrm{Na}_{26} \mathrm{Si}_{22} \mathrm{Al}_{18} \mathrm{O}_{84} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 240 | $\mathrm{NiB}_{2} \mathrm{~F}_{8}$ | 49 |
| $\mathrm{Na}_{56} \mathrm{Si}_{42} \mathrm{Al}_{38} \mathrm{O}_{169} \cdot 24 \mathrm{H}_{2} \mathrm{O}$ | 240 | $\mathrm{NiCl}_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 28 |
| NaSiBO 4 | 226 | $\mathrm{NiCl}_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 29 |
| $\mathrm{Na}_{2} \mathrm{SiF}_{6}$ | 46 | $\mathrm{Ni}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 111 |
| $\mathrm{NaSi}_{3} \mathrm{GaO}_{8}$ | 232 | $\mathrm{Ni}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{NH}_{3}$ | 112 |
| $\mathrm{NaSiLaO}_{4}$ | 228 | $\mathrm{NiF}_{2} \cdot 5 \mathrm{HF} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 54 |
| $\mathrm{NaSiNdO}_{4}$ | 228 | $(\mathrm{Ni}, \mathrm{Mg})_{6}(\mathrm{OH})_{6} \mathrm{Si}_{4} \mathrm{O}_{11} \cdot \mathrm{H}_{2} \mathrm{O}$ | 260 |
| $\mathrm{Na}_{2} \mathrm{SiO}_{3}$ | 268 | NiO | 58 |
| $\mathrm{Na}_{2} \mathrm{Si}_{2} \mathrm{O}_{5}$ | 255 | $\mathrm{Ni}_{3}(\mathrm{OH})_{4} \mathrm{CO}_{3} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 98 |
| $\mathrm{Na}_{4} \mathrm{SiO}_{4}$ | 304 | NiS | 11 |


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| $\mathrm{NiSO}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 133 | $\mathrm{Pb}_{3} \mathrm{Si}_{3} \mathrm{O}_{9}$ | 291 |
| $\mathrm{NiSO}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 160 | $(\mathrm{Pb}, \mathrm{Tl})_{2}(\mathrm{Cu}, \mathrm{Ag}) \mathrm{As}_{5} \mathrm{~S}_{10}$ | 14 |
| $\mathrm{NiSO}_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 163 | $\mathrm{Pb}\left(\mathrm{UO}_{2}\right)_{2}\left(\mathrm{PO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 209 |
| $\mathrm{NiSeO}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 161 | $\mathrm{Pb}_{2}\left(\mathrm{UO}_{2}\right)\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 210 |
| $\mathrm{NiSiF} \mathrm{F}_{6} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 50 | $\mathrm{Pb}\left(\mathrm{UO}_{2}\right)_{4}\left(\mathrm{PO}_{4}\right)_{2}(\mathrm{OH})_{4} \cdot 7 \mathrm{H}_{2} \mathrm{O}$ | 210 |
| $\mathrm{Ni}_{2} \mathrm{SiO}_{4}$ | 304 | $\mathrm{Pb}_{2}\left(\mathrm{UO}_{2}\right) \mathrm{SiO}_{4} \cdot \mathrm{H}_{2} \mathrm{O}$ | 311 |
| P | 5 | $\mathrm{Pb}_{5}\left(\mathrm{VO}_{4}\right)_{3} \mathrm{Cl}$ | 205 |
| $\mathrm{PNO}_{2} \mathrm{H}_{2}$ | 8 | $\mathrm{PbWO}_{4}$ | 181 |
| $\mathrm{PNO}_{4} \mathrm{H}_{6}$ | 8 | $\mathrm{PbZrO}_{3}$ | 81 |
| $\mathrm{P}_{2} \mathrm{O}_{5}$ | 66 | $\mathrm{Pr}_{2}\left(\mathrm{MoO}_{4}\right)_{3}$ | 182 |
| $\mathrm{PbAl}_{2} \mathrm{O}_{4}$ | 78 | $\mathrm{Pr}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 171 |
| $\mathrm{PbAs}_{2} \mathrm{O}_{7}$ | 214 | $\mathrm{PtCONH}_{3} \mathrm{Cl}_{2}$ | 54 |
| $\mathrm{Pb}\left(\mathrm{AsO}_{4}\right)_{3} \mathrm{Cl}$ | 204 | $\mathrm{Pt}^{\left(\mathrm{NH}_{3}\right)_{2} \mathrm{BrNO}_{2}}$ | 107 |
| $\mathrm{Pb}_{2} \mathrm{As}_{2} \mathrm{~S}_{5}$ | 14 | $\mathrm{Pt}\left(\mathrm{NH}_{3}\right)_{2} \mathrm{Cl}_{2}$ | 54 |
| $\mathrm{PbBr}_{2}$ | 27 | $\mathrm{Pt}\left(\mathrm{NH}_{3}\right)_{5} \mathrm{ClCl}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | 53 |
| $\mathrm{PbCO}_{3}$ | 94 | $\mathrm{Pt}\left(\mathrm{NH}_{3}\right)_{2} \mathrm{ClNO}_{2}$ | 107 |
| $\mathrm{PbCl}_{2}$ | 26 | $\mathrm{Pt}\left(\mathrm{NH}_{3}\right)_{2} \mathrm{Cl}\left(\mathrm{NO}_{2}\right)_{3}$ | 107 |
| $\mathrm{Pb}_{2} \mathrm{Cl}_{2} \mathrm{CO}_{3}$ | 97 | $\mathrm{Pt}\left(\mathrm{NH}_{3}\right)_{2}\left(\mathrm{NO}_{2}\right)_{2}$ | 107 |
| PbClF | 26 | $\mathrm{Pt}\left(\mathrm{NH}_{3}\right)_{2} \mathrm{O}_{2}(\mathrm{OH})_{2} \mathrm{Cl}_{2}$ | 53 |
| $\mathrm{PbCrO}_{4}$ | 131 | $\mathrm{Pt}\left(\mathrm{NH}_{3}\right)_{5}\left(\mathrm{SO}_{4}\right) \mathrm{Cl}_{2}$ | 54 |
| $\mathrm{Pb}(\mathrm{Cu}, \mathrm{Ag}) \mathrm{Cl}_{2}(\mathrm{OH})_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 31 | $\mathrm{RbAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 |
| $\mathrm{PbCu}(\mathrm{OH})_{2} \mathrm{Cl}_{2}$ | 31 | $\mathrm{RbAlSe}_{2} \mathrm{O}_{8} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 160 |
| $\mathrm{PbFe}_{6}\left(\mathrm{SO}_{4}\right)_{4}(\mathrm{OH})_{12}$ | 174 | RbBr | 17 |
| $\mathrm{PbHAsO}_{4}$ | 187 | $\mathrm{Rb}_{2} \mathrm{Cd}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 145 |
| $\mathrm{PbH}_{4}\left(\mathrm{AsO}_{4}\right)_{2}$ | 188 | RbCl | 17 |
| $\mathrm{PbMoO}_{4}$ | 181 | $\mathrm{RbClO}_{4}$ | 111 |
| $\mathrm{Pb}\left(\mathrm{NH}_{3}\right)_{4} \mathrm{Cl}_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 53 | $\mathrm{Rb}_{2} \mathrm{Co}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 147 |
| $\mathrm{Pb}\left(\mathrm{NO}_{3}\right)_{2}$ | 103 | $\mathrm{Rb}_{2} \mathrm{CoSe}_{2} \mathrm{O}_{8} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 153 |
| PbO | 59 | $\mathrm{Rb}_{2} \mathrm{CrO}_{4}$ | 128 |
| $\mathrm{Pb}_{3} \mathrm{O}_{4}$ | 77 | $\mathrm{RbCr}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 |
| $\mathrm{PbO}_{2}$ | 63 | $\mathrm{Rb}_{2} \mathrm{Cu}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 149 |
| $\mathrm{Pb}_{3} \mathrm{O}_{2} \mathrm{Cl}_{2}$ | 52 | $\mathrm{Rb}_{2} \mathrm{CuSe}_{2} \mathrm{O}_{8} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 154 |
| $\mathrm{Pb}_{3}(\mathrm{OH})_{2}\left(\mathrm{CO}_{3}\right)_{2}$ | 97 | RbF | 17 |
| $\mathrm{Pb}(\mathrm{OH}) \mathrm{Cl}$ | 31 | $\mathrm{RbFe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 |
| $\mathrm{Pb}_{4} \mathrm{O}_{2} \mathrm{SiO}_{4}$ | 308 | $\mathrm{Rb}_{2} \mathrm{Fe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 146 |
| $\mathrm{PbO} \cdot \mathrm{UO}_{3} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 84 | $\mathrm{RbFe}_{3}\left(\mathrm{SO}_{4}\right)_{2}(\mathrm{OH})_{6}$ | 174 |
| $\mathrm{PbO} \cdot 3 \mathrm{UO}_{3} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 84 | $\mathrm{Rb}_{2} \mathrm{Fe}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 152 |
| $\mathrm{Pb}_{3}\left(\mathrm{PO}_{4}\right)_{2}$ | 189 | $\mathrm{RbFe}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 160 |
| $\mathrm{Pb}_{3}\left(\mathrm{PO}_{4}\right)_{2} \cdot \mathrm{CePO}_{4}$ | 189 | $\mathrm{RbGa}(\mathrm{SC} .)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 |
| $\mathrm{Pb}_{5}\left(\mathrm{PO}_{4}\right)_{3} \mathrm{Cl}$ | 204 | $\mathrm{RbHSO}_{4}$ | 123 |
| PbS | 11 | RbI | 17 |
| $\mathrm{PbS}_{2} \mathrm{O}_{6} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 133 | $\mathrm{RbIn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 |
| $\mathrm{PbSbO}_{2} \mathrm{Cl}$ | 53 | $\mathrm{Rb}_{2} \mathrm{MgCr}_{2} \mathrm{O}_{8} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 156 |
| $\mathrm{PbSO}_{4}$ | 131 | $\mathrm{Rb}_{2} \mathrm{Mg}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 142 |
| $\mathrm{Pb}_{4} \mathrm{SO}_{4}\left(\mathrm{CO}_{3}\right)_{2}(\mathrm{OH})_{2}$ | 100 | $\mathrm{Rb}_{2} \mathrm{Mg}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 149 |
| $\mathrm{Pb}_{2} \mathrm{SO}_{4} \mathrm{O}$ | 174 | $\mathrm{Rb}_{2} \mathrm{Mn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 145 |
| $\mathrm{Pb}_{2} \mathrm{SO}_{4}(\mathrm{OH})_{2}$ | 173 | $\mathrm{Rb}_{2} \mathrm{Mn}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 151 |
| $\mathrm{Pb}_{2} \mathrm{SiO}_{4}$ | 304 | $\mathrm{RbNH}_{2} \mathrm{SO}_{3}$ | 122 |


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| $\mathrm{Rb}_{2} \mathrm{Ni}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 148 | $\mathrm{SrCO}_{3}$ | 93 |
| $\mathrm{Rb}_{2} \mathrm{Ni}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 153 | $\mathrm{SrCl}_{2}$ | 26 |
| $\mathrm{Rb}_{2} \mathrm{PdCl}_{4}$ | 37 | $\mathrm{SrCl}_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 28 |
| $\mathrm{Rb}_{2} \mathrm{Pt}(\mathrm{CN})_{4} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 42 | $\mathrm{SrCl}_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 29 |
| $\mathrm{RbRh}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | SrClF | 25 |
| $\mathrm{Rb}_{2} \mathrm{SO}_{4}$ | 127 | $\mathrm{Sr}\left(\mathrm{ClO}_{3}\right)_{2}$ | 109 |
| $\mathrm{Rb}_{2} \mathrm{~S}_{2} \mathrm{O}_{3}$ | 120 | $\mathrm{SrCr}_{2} \mathrm{O}_{7} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | 135 |
| $\mathrm{Rb}_{2} \mathrm{~S}_{2} \mathrm{O}_{6}$ | 121 | $\mathrm{SrF}_{2}$ | 23 |
| $\mathrm{Rb}_{2} \mathrm{~S}_{3} \mathrm{O}_{6}$ | 121 | $\mathrm{Sr}_{3} \mathrm{Fe}_{2} \mathrm{~F}_{12} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 49 |
| $\mathrm{Rb}_{2} \mathrm{~S}_{2} \mathrm{O}_{8}$ | 122 | $\mathrm{SrHAsO}_{4}$ | 188 |
| $\mathrm{Rb}_{2} \mathrm{SeO}_{4}$ | 128 | $\mathrm{SrHPO}_{4}$ | 187 |
| $\mathrm{RbSiAlO}_{4}$ | 227 | $\mathrm{SrMoO}_{4}$ | 181 |
| $\mathrm{RbSi}_{3} \mathrm{AlO}_{8}$ | 232 | $\mathrm{SrMoO}_{4} \cdot 39.7 \% \mathrm{Ce}_{2}\left(\mathrm{MoO}_{4}\right)_{3}$ | 181 |
| $\mathrm{RbSi}_{2} \mathrm{AlO}_{6} \cdot \mathrm{H}_{2} \mathrm{O}$ | 227 | $\mathrm{Sr}\left(\mathrm{NO}_{3}\right)_{2}$ | 103 |
| $\mathrm{RbTi}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\mathrm{Sr}\left(\mathrm{NO}_{2}\right)_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 106 |
| $\mathrm{RbV}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\mathrm{SrNi}(\mathrm{CN})_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 32 |
| $\mathrm{Rb}_{2} \mathrm{Zn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 144 | SrO | 58 |
| $\mathrm{Rb}_{2} \mathrm{Zn}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 150 | $\mathrm{Sr}(\mathrm{OH})_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 68 |
| $\mathrm{Rh}\left[\left(\mathrm{NH}_{3}\right)_{5} \mathrm{Cl}\right] \mathrm{Cl}_{2}$ | 53 | $\mathrm{Sr}_{10}\left(\mathrm{PO}_{4}\right)_{6} \mathrm{CO}_{3}$ | 204 |
| $\mathrm{Rh}\left(\mathrm{NH}_{3}\right)_{3}\left(\mathrm{NO}_{2}\right)_{3}$ | 107 | $\mathrm{Sr}_{5}\left(\mathrm{PO}_{4}\right)_{3} \mathrm{Cl}$ | 204 |
| S | 4 | $\mathrm{Sr}_{5}\left(\mathrm{PO}_{4}\right)_{3} \mathrm{~F}$ | 204 |
| ( $\mathrm{S}, \mathrm{Se}$ ) (liquid) | 4 | $\mathrm{SrPd}(\mathrm{CN})_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 32 |
| $\mathrm{SbBr}_{3}$ | 34 | $\mathrm{SrPt}(\mathrm{CN})_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 33 |
| $\mathrm{SbI}_{3}$ | 34 | SrS | 9 |
| $\mathrm{Sb}_{2} \mathrm{O}_{3}$ | 61 | $\mathrm{SrS}_{2} \mathrm{O}_{6} \cdot 4 \mathrm{H}_{2} \mathrm{O}$ | 133 |
| $\mathrm{Sb}_{2} \mathrm{O}_{4} \cdot \mathrm{nH}_{2} \mathrm{O}$ | 66 | SrSe | 11 |
| $\mathrm{Sb}_{3} \mathrm{O}_{6} \mathrm{OH}$ | 66 | $\mathrm{SrSi}_{2} \mathrm{Al}_{2} \mathrm{O}_{8}$ | 237 |
| $\mathrm{Sb}_{2} \mathrm{~S}_{3}$ | 12 | $\mathrm{Sr}_{3} \mathrm{~S}_{13} \mathrm{O}_{9}$ | 288 |
| $\mathrm{Sb}_{2} \mathrm{~S}_{2} \mathrm{O}$ | 12 | $\mathrm{Sr}_{2} \mathrm{SiO}_{4}$ | 302, 305 |
| Se | 3 | $\mathrm{SrSO}_{4}$ | 131 |
| Se (liquid) | 4 | $\mathrm{Sr}_{2} \mathrm{SiW}_{12} \mathrm{O}_{40} \cdot 16 \mathrm{H}_{2} \mathrm{O}$ | 184 |
| $\mathrm{SeCl}_{4}$ | 35 | SrTe | 12 |
| $\mathrm{SeO}_{2}$ | 63 | $\mathrm{SrTiO}_{3}$ | 79 |
| SiC | 6 | $\mathrm{SrZnF}_{4}$ | 25 |
| $\mathrm{SiO}_{2}$ | 63, 65 | $\mathrm{TeO}_{2}$ | 65 |
| $\mathrm{Sm}\left(\mathrm{BrO}_{3}\right)_{3} \cdot 9 \mathrm{H}_{2} \mathrm{O}$ | 110 | $\mathrm{ThO}_{2}$ | 62 |
| $\mathrm{SmCl}_{3} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 34 | $\mathrm{Th}\left(\mathrm{SO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 172 |
| $\mathrm{Sm}(\mathrm{OH})_{3}$ | 72 | $\mathrm{TiO}_{2}$ | 62, 65 |
| SmOOH | 71 | $\mathrm{TiTi}_{2} \mathrm{O}_{5}$ | 81 |
| $\mathrm{Sm}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 172 | $\mathrm{TlAl}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 |
| $\mathrm{SnI}_{4}$ | 35 | $\mathrm{Tlal}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 160 |
| $\mathrm{SnO}_{2}$ | 62 | TlAsS 2 | 14 |
| $\mathrm{SrAl}_{2} \mathrm{O}_{4}$ | 78 | $\mathrm{TlBr}_{\text {TlCl }}$ | 19 |
| $\mathrm{SrAl}_{4} \mathrm{O}_{7}$ | 79 | $\mathrm{TlCl}^{\mathrm{TlClO}}$ | 18 |
| $\mathrm{SrAl}_{12} \mathrm{O}_{19}$ $\mathrm{Sr}_{3} \mathrm{Al}_{2} \mathrm{O}_{6}$ | 80 77 | $\mathrm{TlClO}_{4}$ $\mathrm{Tl}_{2} \mathrm{Co}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 111 |
| ${ }^{\mathrm{Sr}_{3} \mathrm{Al}_{2} \mathrm{O}_{6}} \mathrm{SrB}_{2} \mathrm{~F}_{8}$ | 47 | $\mathrm{Tl}_{2} \mathrm{Co}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 153 |
| $\mathrm{SrBr}_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 29 | $\mathrm{TlCr}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 |


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| $\mathrm{Tl}_{2} \mathrm{Cu}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 149 | $\mathrm{Y}_{2} \mathrm{Pt}_{3}(\mathrm{CN})_{12} \cdot 21 \mathrm{H}_{2} \mathrm{O}$ | 49 |
| $\mathrm{Tl}_{2} \mathrm{Cu}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 155 | $\mathrm{Y}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 171 |
| $\mathrm{Tl}_{2} \mathrm{Fe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 146 | $\mathrm{Zn}_{3}\left(\mathrm{AsO}_{4}\right)_{2} \cdot 8 \mathrm{H}_{2} \mathrm{O}$ | 199 |
| $\mathrm{TlFe}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\mathrm{Zn}_{2} \mathrm{AsO}_{4}(\mathrm{OH})$ | 202 |
| $\mathrm{TlFeSe} \mathrm{O}_{8} \mathrm{O}^{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 152 | $\mathrm{ZnAl}_{2} \mathrm{O}_{4}$ | 76 |
| $\mathrm{TlGa}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $\mathrm{Zn}\left(\mathrm{BF}_{4}\right)_{2}$ | 48 |
| TII | 19 | $\mathrm{Zn}\left(\mathrm{BrO}_{3}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 109 |
| $\mathrm{Tl}_{2} \mathrm{Mg}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 143 | $\mathrm{ZnCO}_{3}$ | 93 |
| $\mathrm{Tl}_{2} \mathrm{Mg}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 150 | $\mathrm{ZnCl}_{2}$ | 26 |
| $\mathrm{Tl}_{2} \mathrm{Mn}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 145 | ZnClF | 25 |
| $\left.\mathrm{Tl}_{2} \mathrm{MN}_{4} \mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 151 | $\mathrm{Zn}\left(\mathrm{ClO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 112 |
| $\mathrm{Tl}_{2} \mathrm{Ni}\left(\mathrm{SO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 148 | $(\mathrm{Zn}, \mathrm{Cu}) \mathrm{SO}_{4} \cdot 5 \mathrm{H}_{2} \mathrm{O}$ | 170 |
| $\mathrm{Tl}_{2} \mathrm{Ni}\left(\mathrm{SeO}_{4}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 154 | $\mathrm{ZnF}_{2}$ | 23 |
| $\mathrm{Tl}\left(\mathrm{NO}_{3}\right)$ | 102 | $\mathrm{ZnF}_{2} \cdot \mathbf{4} \mathrm{H}_{2} \mathrm{O}$ | 30 |
| $\mathrm{TlRh}\left(\mathrm{SO}_{4}\right)_{2} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 159 | $(\mathrm{Zn}, \mathrm{Fe}, \mathrm{Mn}) \mathrm{Al}_{2}\left(\mathrm{SO}_{4}\right)_{2} \cdot 22 \mathrm{H}_{2} \mathrm{O}$ | 171 |
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| $\mathrm{Tl}_{2} \mathrm{SeO}_{4}$ | 128 | $\mathrm{ZnGa} \mathrm{O}_{4}$ | 76 |
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| $\left(\mathrm{UO}_{2}\right)\left(\mathrm{NO}_{3}\right)_{2} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 105 | $\mathrm{ZnS}_{2} \mathrm{ZnO}_{4}(\mathrm{OH})$ | 201 9 |
| $\left(\mathrm{UO}_{2}\right)_{6}(\mathrm{OH})_{10} \mathrm{SO}_{4} \cdot 12 \mathrm{H}_{2} \mathrm{O}$ | 177 | $\begin{aligned} & \mathrm{ZnS}_{2 n S O}^{4} \\ & \mathrm{ZnSO}_{4} \end{aligned}$ | 9 130 |
| $\begin{aligned} & \left(\mathrm{UO}_{2}\right)\left(\mathrm{SO}_{4}\right) \cdot 3 \mathrm{H}_{2} \mathrm{O} \\ & \left(\mathrm{UO}_{2}\right)_{3}\left(\mathrm{SO}_{4}\right)_{2}\left(\mathrm{OH}_{2}\right) \cdot 8 \mathrm{H}_{2} \mathrm{O} \end{aligned}$ | 177 | $\mathrm{ZnSO}_{4} \cdot 6 \mathrm{H}_{2} \mathrm{O}$ | 166 |
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    Yale University, New Haven, Connecticut
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[^139]:    ${ }^{1}$ A few silicates (called "subsilicates") contain one or more oxygen atoms not directly connected with a silicon atom, as in sillimanite, $\mathrm{AlOAlSiO}_{4}$, and kornerupine, $\mathrm{Mg}(\mathrm{AlO})_{2} \mathrm{AlSiO}_{4}$.

[^140]:    ${ }^{3}$ The names of the classes were given by Strunz (Mineral. Tabellen, 1941) and Fleischer (1947 Reprint 117, A.S.T.M.). The prefixes mean: neso, island; soro, group; cyclo, ring; ino, thread (or chain); phyllo, sheet; tecto, framework.

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[^143]:    ${ }^{3}$ Winkler: Am. Min. XXXII, p. 131 (1947).
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