The indices of each face are obtained directly by taking these intercepts upon the three horizontal axes in their proper order and by adding a 1 as the fourth figure. If necessary clear of fractions, as in the case of the second order pyramid, $11\bar{2}2$.

173. To determine the axial ratio of a hexagonal mineral from the gnomonic projection of its forms. The gnomonic projection of the beryl forms, Fig. 295, may be used as an illustrative example. The radius of the fundamental circle, *a*, is taken as equal to the length of the horizontal axes and is given a value of 1. Then the length of the fundamental intercept of the lines dropped perpendicularly from the poles, *i.e.* the distance *c*, will equal the length of the *c* axis when expressed in terms of the length of *a*. In the case of beryl this ratio is $a : c = 1{\cdot}00 : 0{\cdot}499$. That this relationship is true can be proved in the same manner as in the case of the tetragonal system, see Art. **117**, p. 93.

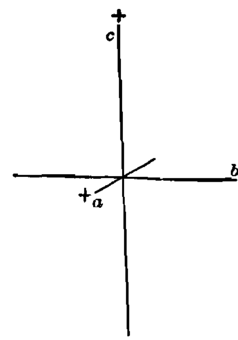
IV. ORTHORHOMBIC SYSTEM

(Rhombic or Prismatic System)

174. Crystallographic Axes. — The *orthorhombic system* includes all the forms which are referred to three axes at right angles to each other, all of different lengths.

Any one of the three axes may be taken as the vertical axis, *c*. Of the two horizontal axes the longer is always taken as the *b* or macro-axis * and when orientated is parallel to the observer. The *a* or brachy-axis is the shorter of the two horizontal axes and is perpendicular to the observer. The length of the *b* axis is taken as unity and the lengths of the other axes are expressed in terms of it. The axial ratio for barite, for instance, is $a : b : c = 0{\cdot}815 : 1{\cdot}00 : 1{\cdot}31$. Fig. 296 shows the crystallographic axes for barite.

296



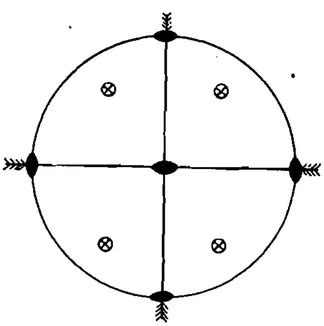
Orthorhombic Axes
(Barite)

1. NORMAL CLASS (25). BARITE TYPE

(Orthorhombic Bipyramidal or Holohedral Class)

175. Symmetry. — The forms of the *normal class* of the orthorhombic system are characterized by three axes of binary symmetry, which directions are coincident with the crystallographic axes. There are also three unlike planes of symmetry at right angles to each other in which lie the crystallographic axes.

297



Symmetry of Normal Class
Orthorhombic System

The symmetry of the class is exhibited in the accompanying stereographic projection, Fig. 297. This should be compared with Fig. 91 (p. 53) and Fig. 167 (p. 77), representing the symmetry of the normal classes of the isometric and tetragonal systems respectively. It will be seen that while normal isometric crystals are developed alike in the three axial directions, those of the tetragonal type have a like development only in the direction of the two horizontal axes, and

* The prefixes *brachy-* and *macro-* used in this system (and also in the triclinic system) are from the Greek words, *βραχύς, short,* and *μακρός, long.*

those of the orthorhombic type are unlike in the three even axial directions. Compare also Figs. 92 (p. 54), 171 (p. 78) and 298 (p. 122).

176. Forms. — The various forms possible in this class are as follows:

		Indices
1.	Macropinacoid or *a*-pinacoid	(100)
2.	Brachypinacoid or *b*-pinacoid	(010)
3.	Base or *c*-pinacoid	(001)
4.	Prisms	(*hk*0)
5.	Macrodomes	(*h*0*l*)
6.	Brachydomes	(0*kl*)
7.	Pyramids	(*hkl*)

In general, as defined on p. 31, a *pinacoid* is a form whose faces are parallel to two of the axes, that is, to an axial plane; a *prism* is one whose faces are parallel to the vertical axis, but intersect the two horizontal axes; a *dome* * (or *horizontal prism*) is one whose faces are parallel to one of the horizontal axes, but intersect the vertical axis. A pyramid is a form whose faces meet all the three axes.

These terms are used in the above sense not only in the orthorhombic system, but also in the monoclinic and triclinic systems; in the last each form consists of two planes only.

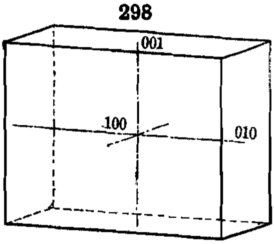
177. Pinacoids. — The *macropinacoid* includes two faces, each of which is parallel both to the macro-axis *b* and to the vertical axis *c*; their indices are respectively 100 and $\bar{1}00$. This form is uniformly designated by the letter *a*, and is conveniently and briefly called the *a-face* or the *a-pinacoid.*

The *brachypinacoid* includes two faces, each of which is parallel both to the brachy-axis *a* and to the vertical axis *c*; they have the indices 010 and $0\bar{1}0$. This form is designated by the letter *b*; it is called the *b-face* or the *b-pinacoid.*

The *base* or *basal pinacoid* includes the two faces parallel to the plane of the horizontal axes, and having the indices 001 and $00\bar{1}$. This form is designated by the letter *c*; it is called the *c-face* or the *c-pinacoid.*

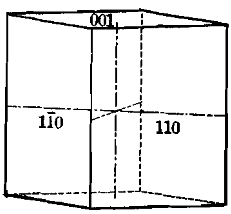
Each one of these three pinacoids is an open-form,† but together they make the so-called *diametral prism*, shown in Fig. 298, a solid which is the analogue of the cube of the isometric system. Geometrically it cannot be distinguished from the cube, but it differs in having the symmetry unlike in

298



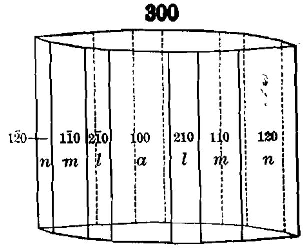
Macro-, Brachy- and Basal Pinacoids

299



Prism and Basal Pinacoid

300



the three axial directions; this may be shown by the unlike physical character of the faces, *a*, *b*, *c*, for example as to luster, striations, etc.; or, again, by the cleavage. Further, it is proved at once by optical properties. This

* From the Latin *domus*, because resembling the roof of a house; cf. Figs. 301, 302.

† See p. 30.

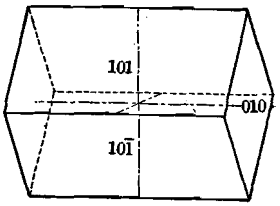
diametral prism, as just stated, has three pairs of unlike faces. It has three kinds of edges, four in each set, parallel respectively to the axes a, b, and c; it has, further, eight similar solid angles. In Fig. 298 the dimensions are arbitrarily made to correspond to the relative lengths of the chosen axes, but the student will understand that a crystal of this shape gives no information as to these values.

178. Prisms. — The prisms proper include those forms whose faces are parallel to the vertical axis, while they intersect both the horizontal axes; their general symbol is, therefore, $(hk0)$. These all belong to one type of *rhombic prism*, in which the interfacial angles corresponding to the two unlike vertical edges have different values.

The *unit prism*, (110), is that form whose faces intersect the horizontal axes in lengths having a ratio corresponding to the accepted axial ratio of $a : b$ for the given species; in other words, the angle of this unit prism fixes the unit lengths of the horizontal axes. This form is shown in combination with the basal pinacoid in Fig. 299; it is uniformly designated by the letter m. The four faces of the unit prism have the indices 110, $\bar{1}10$, $\bar{1}\bar{1}0$, $1\bar{1}0$.

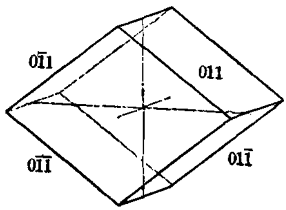
There is, of course, a large number of other possible prisms whose intercepts upon the horizontal axes are not proportionate to their unit lengths. These may be divided into two classes as follows: *macroprisms*, whose faces lie between those of the macropinacoid and the unit prism, *brachyprisms* with faces between those of the brachypinacoid and the unit prism. A macroprism has the general symbol $(hk0)$ in which $h > k$ and is represented by the form $l(210)$, Fig. 300. A brachyprism has the general symbol $(hk0)$ with $h < k$ and is represented by $n(120)$, Fig. 300.

301



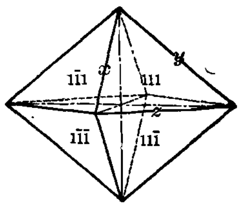
Macrodome and Brachypinacoid

302



Brachydome and Macropinacoid

303



Pyramid

179. Macrodomes, Brachydomes. — The *macrodomes* are forms whose faces are parallel to the macro-axis b, while they intersect the vertical axis c and the horizontal axis a; hence the general symbol is $(h0l)$. The angle of the unit macrodome, (101), fixes the ratio of the axes $a : c$. This form is shown in Fig. 301 combined (since it is an open form) with the brachypinacoid.

In the macrodome zone between the base $c(001)$ and the macropinacoid $a(100)$ there may be a large number of macrodomes having the symbols, taken in the order named, (103), (102), (203), (101), (302), (201), (301), etc. Cf. Figs. 318 and 319 described later.

The *brachydomes* are forms whose faces are parallel to the brachy-axis, a, while they intersect the other axes c and b; their general symbol is $(0kl)$. The angle of the unit brachydome, (011), which is shown with $a(100)$ in Fig. 302, determines the ratio of the axes $b : c$.

The brachydome zone between $c(001)$ and $b(010)$ includes the forms (013), (012), (023), (011), (032), (021), (031), etc. Cf. Figs. 318 and 319.

Both sets of domes are often spoken of as *horizontal prisms*. The propriety of this expression is obvious, since they are in fact prisms in geometrical form; further, the choice of position for the axes which makes them domes, instead of prisms in the narrower sense, is more or less arbitrary, as already explained elsewhere.

180. Pyramids. — The pyramids in this system all belong to one type, the double *rhombic pyramid*, bounded by eight faces, each a scalene triangle. This form has three kinds of edges, x, y, z (Fig. 303), each set with a different interfacial angle; two of these angles suffice to determine the axial ratio. The symbol for this, the general form for the system, is (hkl).

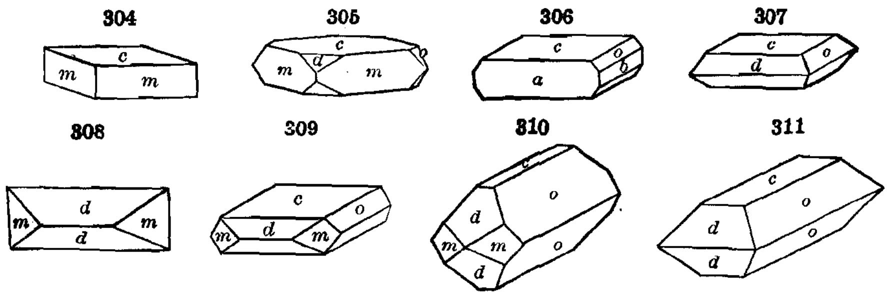
The pyramids may be divided into three groups corresponding respectively to the three prisms just described, namely, unit pyramids, macropyramids, and brachypyramids.

The *unit pyramids* are characterized by the fact that their intercepts on the horizontal axes have the same ratio as those of the unit prism; that is, the assumed axial ratio $(a : b)$ for the given species. For them, therefore, the general symbol becomes (hhl).

There may be different unit pyramids on crystals of the same species with different intercepts upon the vertical axis, and these form a *zone* of faces lying between the base $c(001)$ and the unit prism $m(110)$. This zone would include the forms, (119), (117), (115), (114), (113), (112), (111). In the symbol of all of the forms of this zone $h = k$, and the lengths of the vertical axes are hence, in the example given, $\frac{1}{9}$, $\frac{1}{7}$, $\frac{1}{5}$, $\frac{1}{4}$, $\frac{1}{3}$, $\frac{1}{2}$ of the vertical axis c of the unit pyramid.

The *macropyramids* and *brachypyramids* are related to each other and to the unit pyramids, as were the macroprisms and brachyprisms to themselves and to the unit prism. Further, each vertical zone of macropyramids (or brachypyramids), having a common ratio for the horizontal axes (or of $h : k$ in the symbol), belongs to a particular macroprism (or brachyprism) characterized by the same ratio. Thus the macropyramids (214), (213), (212), (421), etc., all belong in a common vertical zone between the base (001) and the prism (210). Similarly the brachypyramids (123), (122), (121), (241), etc., fall in a common vertical zone between (001) and (120).

181. Illustrations. — The following figures of barite (304–311) give



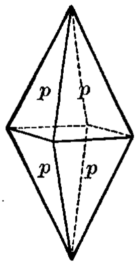
Barite Crystals

excellent illustrations of crystals of a typical orthorhombic species, and show also how the habit of one and the same species may vary. The axial ratio for this species is $a : b : c = 0{\cdot}815 : 1 : 1{\cdot}314$. Here d is the macrodome

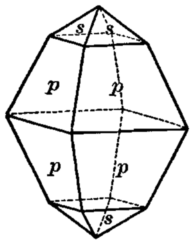
(102) and *o* the brachydome (011); *m* is, as always, the prism (110). Figs. 304–307 and 309 are described as tabular || *c*; Fig. 308 is prismatic in habit in the direction of the macro-axis (*b*), and 310, 311 prismatic in that of the brachy-axis (*a*).

Figs. 312–314 of native sulphur show a series of crystals of pyramidal habit with the dome *n*(011), and the pyramids *p*(111), *s*(113). Note *n* truncates the terminal edges of the fundamental pyramid *p*. In general it should

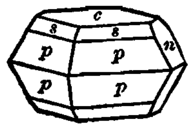
312



313

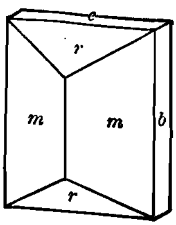


314

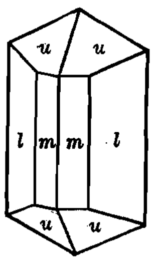


Sulphur Crystals

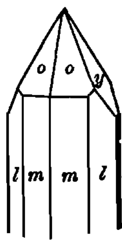
315



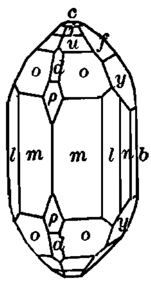
316



317



318



Staurolite

Figs. 316-318, Topaz

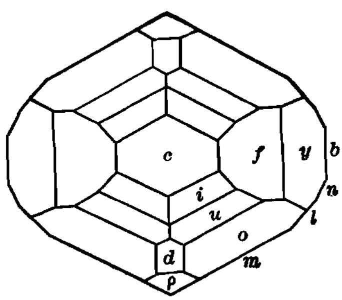
be remembered that a macrodome truncating the edge of a pyramid must have the same ratio of $h : l$; thus, (201) truncates the edge of (221), etc. Similarly of the brachydomes: (021) truncates the edge of (221), etc. Cf. Figs. 319–321.

Again, Fig. 315, of staurolite, shows the pinacoids *b*(010), *c*(001), the prism *m*(110), and the macrodome *r*(101).

Figs. 316–318 are prismatic crystals of topaz. Here *m* is the prism (110); *l* and *n* are the prisms (120), (140); *d* and *ρ* are the macrodomes (201) and (401); *f* and *y* are the brachydomes (021) and (041); *i*, *u*, and *o* are the pyramids (223), (111), (221).

182. Projections. — Basal, stereographic, and gnomonic projections are given in Figs. 319–320*a*, on pp. 125, 126, 127 for a crystal of the species topaz. Fig. 319 is the basal projection

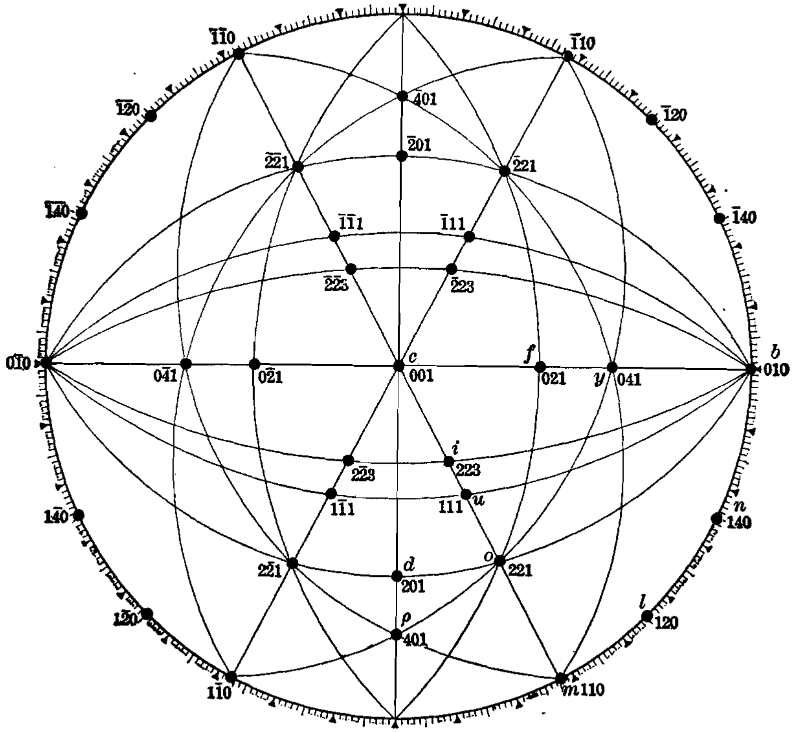
319



Topaz

of the crystal shown in Fig. 318. Figs. 320 and 320*a* give the stereographic and gnomonic projections of these forms present upon it.

320



Stereographic Projection Topaz Crystal

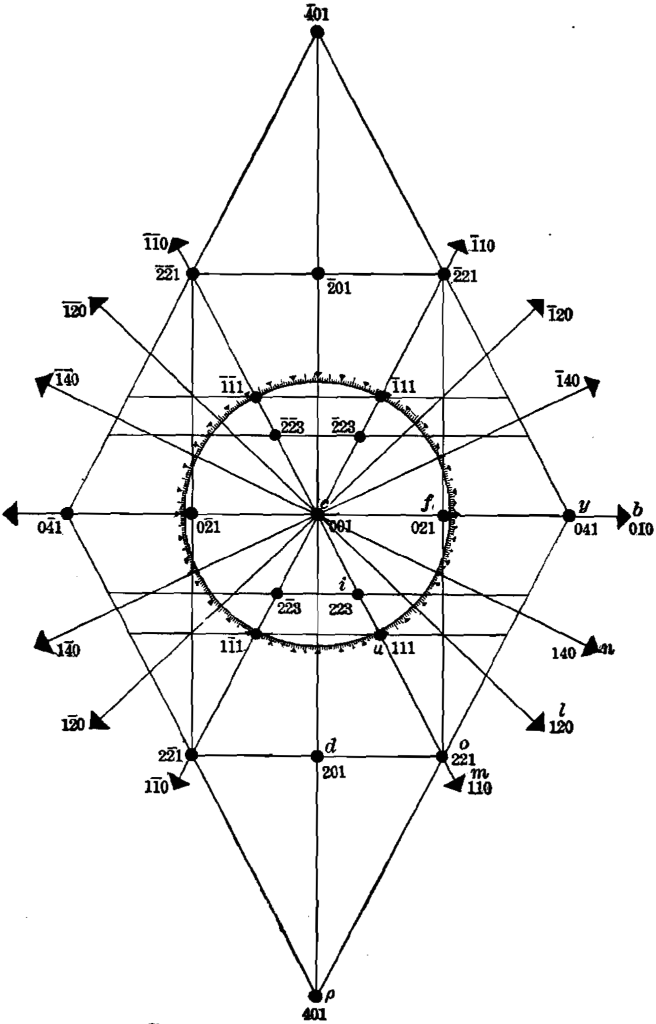
2. HEMIMORPHIC CLASS (26). CALAMINE TYPE

(*Orthorhombic Pyramidal Class*)

183. Class Symmetry and Typical Forms. — The forms of the *orthorhombic-hemimorphic* class are characterized by two unlike planes of symmetry and one axis of binary symmetry, the line in which they intersect; there is no center of symmetry. The forms are therefore hemimorphic, as defined in Art. **29.** For example, if, as is usually the case, the vertical axis is made the axis of symmetry, the two planes of symmetry are parallel to the pinacoids *a*(100) and *b*(010). The prisms are then geometrically like those of the normal class, as are also the macropinacoid and brachypinacoid; but the two basal planes become independent forms, (001) and (00$\bar{1}$). There are also two macrodomes, (101) and (10$\bar{1}$), or in general (*h*0*l*) and (*h*0$\bar{l}$); and similarly two sets, for a given symbol, of brachydomes and pyramids.

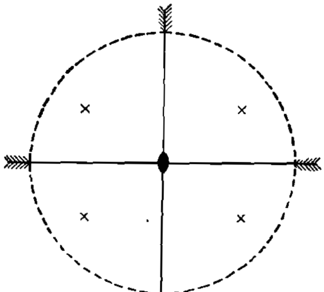
The general symmetry of the class is shown in the stereographic projec-

320a



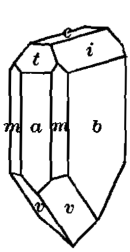
Gnomonic Projection Topaz Crystal

321



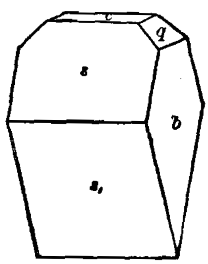
Symmetry of Hemimorphic Class

322



Calamine

323



Struvite

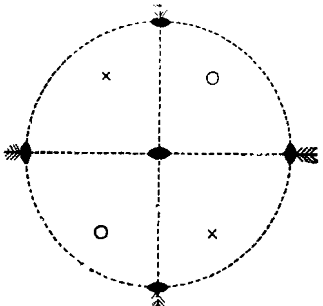
tion, Fig. 321. Further, Figs. 322, of calamine, and 323, of struvite, represent typical crystals of this class. In Fig. 322 the forms present are $t(301)$, $i(031)$, $v(12\bar{1})$; in Fig. 323 they are $s(101)$, $s_1(10\bar{1})$, $q(011)$.

3. SPHENOIDAL CLASS (27). EPSOMITE TYPE.

(Orthorhombic Bisphenoidal Class)

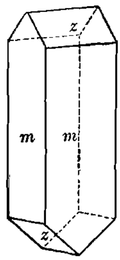
184. Symmetry and Typical Forms. — The forms of the remaining class of the system, the *ortho-rhombic-sphenoidal* class, are characterized by three unlike rectangular axes of binary symmetry which coincide with the crystallographic axes, but they have no plane and no center of symmetry (Fig. 324). The general form *hkl* here has four faces only, and the corresponding solid is a rhombic sphenoid, analogous to the sphenoid of the tetragonal system. The complementary positive and negative sphenoids are enantiomorphous. Fig. 325 represents a typical crystal, of epsomite, with the positive sphenoid, $z(111)$. Other crystals of this species often show both positive and negative complementary forms, but usually unequally developed.

324



Symmetry of Sphenoidal Class

325



Epsomite

Mathematical Relations of the Orthorhombic System

185. Choice of Axes. — As explained in Art. **175**, the three crystallographic axes are fixed as regards direction in all orthorhombic crystals, but any one of them may be made the vertical axis, c; and of the two horizontal axes, which is the longer (b) and which the shorter (a) cannot be determined until it is decided which faces to assume as the fundamental, or unit, pyramid, prism, or domes.

The choice is generally so made, in a given case, as to best bring out the relation of the crystals of the species in hand to others allied to them in form or in chemical composition, or in both respects; or, so as to make the cleavage parallel to the fundamental form; or, as suggested by the common habit of the crystals, or other considerations.

186. Axial and Angular Elements. — The *axial elements* are given by the ratio of the lengths of the three axes in terms of the macro-axis, b, as unity. For example, with barite the axial ratio is

$$a : b : c = 0{\cdot}81520 : 1 : 1{\cdot}31359.$$

The *angular elements* are usually taken as the angles between the three pinacoids and the unit faces in the three zones between them. Thus, again for barite, these elements are

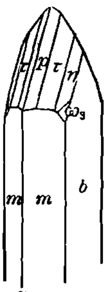
$$100 \wedge 110 = 39^\circ\ 11'\ 13'',\quad 001 \wedge 101 = 58^\circ\ 10'\ 36'',\quad 001 \wedge 011 = 52^\circ\ 43'\ 8''.$$

Two of these angles obviously determine the third angle as well as the axial ratio. The degree of accuracy to be attempted in the statement of the axial ratio depends upon the character of the fundamental measurements from which this ratio has been deduced. There is no good reason for giving the values of a and c to many decimal places if the probable error of the measurements amounts to many minutes. In the above case the measurements (by Helmhacker) are supposed to be accurate within a few seconds. It is convenient, however, to have the angular elements correct, say, within 10″, so that the calculated angles obtained from them will not vary from those derived direct from the measured angles by more than 30″ to 1′.

187. Calculation of the Axes. — The following simple relations (cf. Art. **48**) connect the axes with the angular elements:

$$\tan(100 \wedge 110) = a, \quad \tan(001 \wedge 011) = c, \quad \tan(001 \wedge 101) = \frac{c}{a}$$

326



Stibnite

These equations serve to give either the axes from the angular elements, or the angular elements from the axes. It will be noted that the axes are not needed for simple purposes of calculation, but it is still important to have them, for example to use in comparing the morphological relations of allied species.

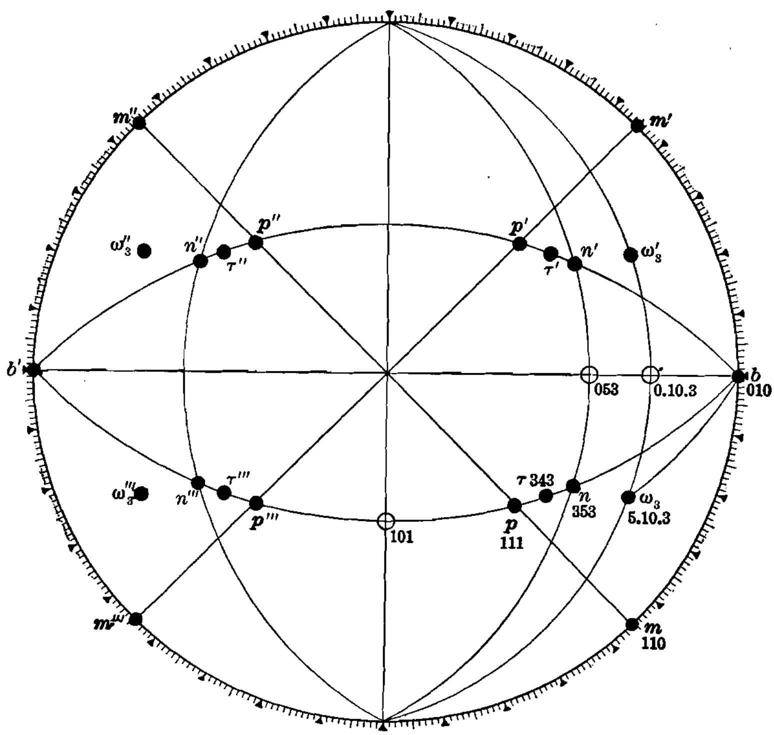
In practice it is easy to pass from the measured angles, assumed as the basis of calculation (or deduced from the observations by the method of least squares), to the angular elements, or from either to any other angles by the application of the tangent principle (Art. **49**) to the pinacoidal zones, and by the solution of the right-angled spherical triangles given on the sphere of projection.

Thus any face *hkl* lies in the three zones, 100 and 0*kl*, 010 and *h*0*l*, 001 and *hk*0. For example, the position of the face 312 is fixed if the positions of two of the poles, 302, 012, 310, are known. These last are given, respectively, by the equations

$$\tan(001 \wedge 302) = \tfrac{3}{2} \times \tan(001 \wedge 101),$$

$$\tan(001 \wedge 012) = \tfrac{1}{2} \times \tan(001 \wedge 011) \quad \tan(100 \wedge 310) = \tfrac{1}{3} \times \tan(100 \wedge 110).$$

327



Stereographic Projection Stibnite Crystal

188. Example. — Fig. 326 represents a crystal of stibnite from Japan and Fig. 327 the stereographic projection of its forms, $p(111)$, $\tau(343)$, $\eta(353)$, $\omega_3(5{\cdot}10{\cdot}3)$, $m(110)$ and $b(010)$. On this the following measured angles were taken as fundamental:

$$\eta\eta' \ (353 \wedge \bar{3}53) = 55° \ 1' \ 0'',$$
$$\eta\eta''' \ (353 \wedge 3\bar{5}3) = 99° \ 39' \ 0''.$$

Hence, the angles $353 \wedge 010 = 40° \ 10\frac{1}{2}'$ and $353 \wedge 053 = 27° \ 30\frac{1}{2}'$ are known without calculation. The right-angled spherical triangle * 010·053·353 yields the angle $(010 \wedge 053)$ and hence $(001 \wedge 053)$; also the angle at 010, which is equal to $(001 \wedge 101)$. But $\tan\,(001 \wedge 011) = \frac{3}{5} \times \tan\,(001 \wedge 053)$, and $\tan\,(001 \wedge 011) = c$. Also, since $\tan\,(001 \wedge 101) = \frac{c}{a}$, the axial ratio is thus known, and two of the angular elements.

The third angular element $(001 \wedge 110)$ can be calculated independently, for the angle at 001 in the triangle 001·053·353 is equal to $(010 \wedge 350)$ and $\tan\,(010 \wedge 350) \times \frac{5}{3} = (010 \wedge 110)$, the complement of $(100 \wedge 110)$.

Then since $\tan\,(100 \wedge 110) = a$, this can be used to check the value of a already obtained. The further use of the tangent principle with the occasional solution of a right-angled triangle will serve to give any desired angle from either the fundamental angles direct, or from the angular elements.

Again, the symbol of any unknown face can be readily calculated if two measured angles of tolerable accuracy are at hand. For example, for the face ω, suppose the measured angles to be

$$b\omega \ (010 \wedge hkl) = 30° \ 15', \quad \omega\omega' \ (hkl \wedge \bar{h}kl) = 51° \ 32'.$$

The solution of the triangle $b{\cdot}\omega{\cdot}0kl$ gives the angle $(010 \wedge 0kl) = 16° \ 25' \ 20''$, and

$$\frac{\tan\,(001 \wedge 0kl)}{\tan\,(001 \wedge 011)} = \frac{\tan 73° \ 34\frac{5}{8}'}{\tan 45° \ 30\frac{1}{2}'} = 3{\cdot}333+, = \frac{k}{l}.$$

But the ratio of $k : l$ must be rational and the number derived agrees most closely with $10 : 3$.

Again, the angle $(001 \wedge h0l)$ may now be calculated from the same triangle and the value $59° \ 38\frac{2}{3}'$ obtained. From this the ratio of h to l is derived since

$$\frac{\tan\,(001 \wedge h0l)}{\tan\,(001 \wedge 101)} = \frac{\tan 59° \ 38\frac{2}{3}'}{\tan 45° \ 43\frac{1}{4}'} = 1{\cdot}665 = \frac{h}{l}.$$

This ratio is nearly equal to $5 : 3$, and the two values thus obtained give the symbol 5·10·3. If, however, from the triangle $001{\cdot}\ 0kl{\cdot}\omega$, the angle at 001 is calculated, the value $26° \ 42\frac{3}{4}'$ is obtained, which is also the angle $(010 \wedge hk0)$. From this the ratio $h : k$ is deduced, since

$$\frac{\tan\,(010 \wedge 110)}{\tan\,(010 \wedge hk0)} = \frac{\tan 45° \ 12\frac{5}{8}'}{\tan 26° \ 42\frac{3}{4}'} = 2{\cdot}002 = \frac{k}{h}.$$

The value of $\frac{k}{h}$ is hence closely equal to 2; this combined with that first obtained $\left(\frac{k}{l} = \frac{10}{3}\right)$ gives the same symbol 5·10·3.

This symbol being more than usually complex calls for fairly accurate measurements. How accurate the symbol obtained is can best be judged by comparing the measured angles with those calculated from the symbol. For example, in the given case the calculated angles for $\omega(5{\cdot}10{\cdot}3)$ are $b\omega(010 \wedge 5{\cdot}10{\cdot}3) = 30° \ 16'$, $\omega\omega'(\bar{5}{\cdot}10{\cdot}3) = 51° \ 35'$. The correctness of the value deduced is further established if it is found that the given face falls into prominent zones.

It will be understood further that the zonal relations, explained on pp. 45-47, play an important part in all calculations. For example, in Fig. 326, if the symbol of τ were unknown, it could be obtained from a single angle (as $b\tau$), since for this zone $h = l$.

189. Formulas. — Although it is not often necessary to employ formulas in calculations, a few are added here for sake of completeness. Here a and c in the formulas are the lengths of the two axes a and c.

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* The student in this as in every similar case should draw a projection, cf. Fig. 327 (not necessarily accurately constructed), to show, if only approximately, the relative position of the faces present.

(1) For the distance between the pole of any face P(*hkl*) and the pinacoids *a*, *b*, *c*, we have in general:

$$\cos^2 Pa = \cos^2 (hkl \wedge 100) = \frac{h^2c^2}{hc^2 + k^2a^2c^2 + l^2a^2};$$

$$\cos^2 Pb = \cos^2 (hkl \wedge 010) = \frac{k^2a^2c^2}{h^2c^2 + k^2a^2c^2 + l^2a^2};$$

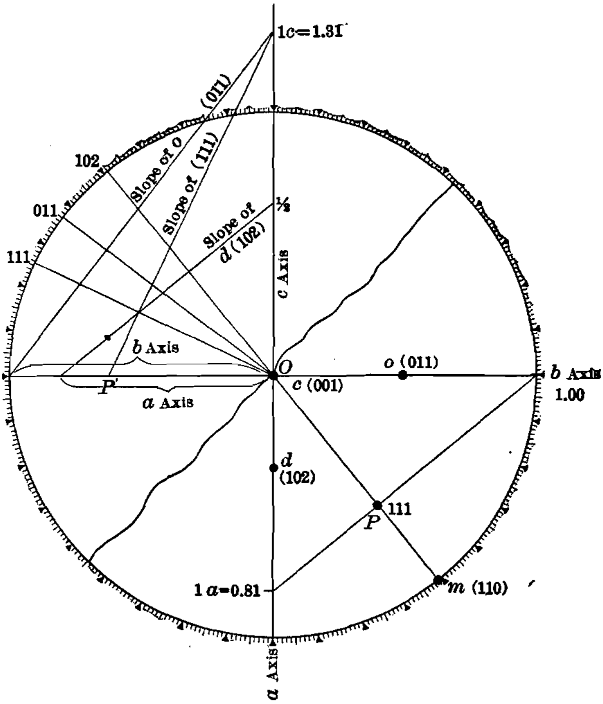
$$\cos^2 Pc = \cos^2 (hkl \wedge 001) = \frac{l^2a^2}{h^2c^2 + k^2a^2c^2 + l^2a^2}.$$

(2) For the distance (PQ) between the poles of any two faces (*hkl*) and (*pqr*)

$$\cos PQ = \frac{hpc^2 + kqa^2c^2 + lra^2}{\sqrt{[h^2c^2 + k^2a^2c^2 + l^2a^2]\ [p^2c^2 + q^2a^2c^2 + r^2a^2]}}.$$

190. To determine, by plotting, the axial ratio of an orthorhombic crystal, having given the stereographic projection of its forms. In order to solve this problem it is necessary that the position of the pole of a pyramid face of known indices be given or the position of the faces of a prism and one dome or of both a macro- and a brachydome. For illustration it is assumed that a crystal of barite, such as represented in Fig. 305, has been measured on the goniometer and the poles of its faces plotted in the stereographic projection. The lower right-hand quadrant of this projection is shown in Fig. 328. The forms present are common ones on barite crystals and have been given the symbols, *m*(110), *d*(102), *o*(011), *c*(001). The ratio of *a* : *b* can be determined readily from the position of the pole *m*(110). A radial line is drawn to the pole of the face and then a perpendicular erected to it from the end of the line representing the *b* crystallographic axis. The intercept of this perpendicular on the line representing the *a* axis, when expressed in terms of the assumed unit length of the *b* axis, gives the length of *a*. It is to be noted that the fact that this line in the present case passes very nearly through the pole 111 is wholly accidental. The length of the vertical axis can be determined from the position of the pole of either *d*(102) or *o*(011). The construction used is given in the upper left-hand quadrant of the figure. If the brachydome, *o*(011), is used the sloping line that gives the inclination of the face is started from a distance on the horizontal line equivalent to the length of the *b* axis, or 1, and its intercept on the *c* axis will equal the unit length of that axis. If, however, the position of *d*(102) is used the base line of the triangle must be made equal to the unit length of the *a* axis as already established and the intercept on the *c* axis will equal ½ of the latter's unit length.

328

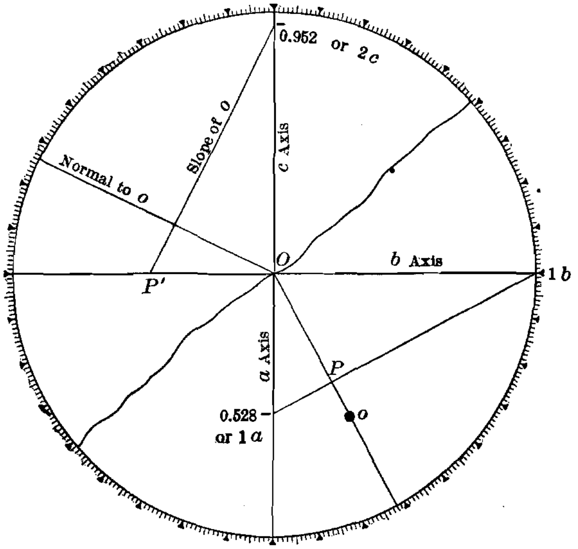


Determination of the Axial Ratio for Barite

The problem could have been wholly solved from the position of the pyramid face, 111, if that form had been present on the crystal. The construction in this case is also illustrated.

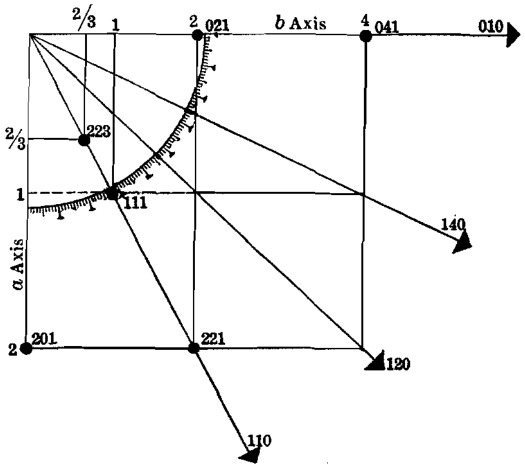
191. To determine, by plotting, the indices of a face upon an orthorhombic crystal, given the position of its pole upon the stereographic projection and the axial ratio of the mineral. To illustrate this problem it is assumed that the position of the pole in the stereographic projection of the face *o*, Fig. 329, upon a topaz crystal is known. First draw a radial line through the pole *o*. Next erect a perpendicular to this line, starting it from the distance selected as representing 1 on the *b* crystallographic axis. The intercept of this line upon the line representing the *a* axis when expressed in terms of the unit length of the *b* axis is 0·53. This is equivalent to the established unit length of the *a* axis and therefore the parameters of the face *o* on the horizontal crystallographic axes are 1*a*, 1*b*. Next the distance O–P is transferred into the upper left-hand quadrant of the figure. The position of the normal to the face is determined by measuring with a protractor the angular distance between O and *o*. The line giving the slope of the face is next drawn perpendicular to this normal and its intercept upon the line representing the vertical axis determined. This distance when expressed in terms of the length of the *b* axis is 0·95. This is twice the established length of the *c* axis (0·476) and consequently the third parameter of the face *o* is 2*c*. This gives the indices 221 for the face.

329



192. To determine, by plotting, the axial ratio of an orthorhombic crystal having given the gnomonic projection of its forms. To illustrate this problem the gnomonic projection of the crystal of topaz already given in Fig. 320a will be used. In Fig. 330 one quadrant of this projection is reproduced. From each pole lines are drawn perpendicular to the two lines representing the *a* and *b* crystallographic axes. It will be found that the intercepts made in this way upon the *a* axis have rational relations to each other. The same is true of the intercepts upon the *b* axis. The intercepts upon the two axes, however, are irrational in respect to each other. A convenient intercept upon each axis is chosen as 1 and the other intercepts upon that axis are then expressed in terms of this length. Of

330



course with a known mineral, whose forms have already had indices assigned to them, the intercept that shall be considered as 1 is fixed.

If we take r as equivalent to the radius of the fundamental circle of the projection, q as equal to the chosen intercept upon the b crystallographic axis and p that upon the a axis, then the axial ratio can be derived from the following expressions:

$$\frac{b}{c} = \frac{r}{q}; \quad \frac{a}{c} = \frac{r}{p}.$$

The proof of these relationships is similar to that already given under the Tetragonal System, Art. **117**, p. 93.

193. To determine, by plotting, the indices of a face upon an orthorhombic crystal, given the position of its pole upon the gnomonic projection and the axial ratio of the mineral. The method of construction in this case is the reverse of that given in the problem above and is essentially the same as given under the Isometric and Tetragonal Systems, Arts. **84** and **118.** In the case of an orthorhombic mineral the intercepts of the perpendiculars drawn from the pole of the face to the a and b axes must be expressed in each case in terms of the unit intercept on that axis. These values, p and q, can be determined from the equations given in the preceding problem.

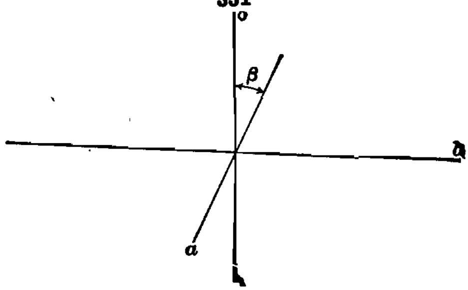
V. MONOCLINIC SYSTEM

(Oblique System)

194. Crystallographic Axes. — The *monoclinic system* includes all the forms which are referred to three unequal axes, having one of their axial inclinations oblique.

The axes are designated as follows: the inclined or clino-axis is a; the ortho-axis is b, the vertical axis is c. The acute angle between the axes a and c is represented by the letter β; the angles between a and b and b and c are right angles. See Fig. 331. When properly orientated the inclined axis, a, slopes down toward the observer, the b axis is horizontal and parallel to the observer and the c axis vertical.

331

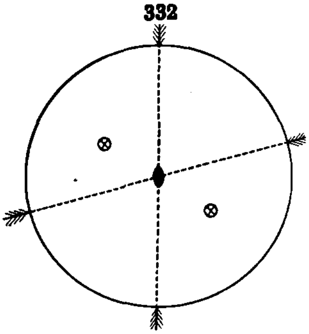


Crystal Axes of Orthoclase
$a:b:c = 0{\cdot}66:1:0{\cdot}55.\ \beta = 64°$

1. NORMAL CLASS (28). GYPSUM TYPE

(Prismatic or Holohedral Class)

332



Symmetry of Normal Class

195. Symmetry. — In the normal class of the monoclinic system there is one plane of symmetry and one axis of binary symmetry normal to it. The plane of symmetry is always the plane of the axes a and c, and the axis of symmetry coincides with the axis b, normal to this plane. The position of one axis (b) and that of the plane of the other two axes (a and c) is thus fixed by the symmetry; but the latter axes may occupy different positions in this plane. Fig. 332 shows the typical stereographic projection, projected on the plane of symmetry. Figs. 347, 348 are the projections of an actual