AN ELEMENTARY INTRODUCTION TO CRYSTALLOGRAPHY

J. P. WINTRINGHAM
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It is impossible to think of a person being interested in mineralogy without being interested also in crystallography. The beauty of color is at once acknowledged but the beauty of form is not much behind it, and is generally of much more importance in the determination of a mineral or a chemical compound. Yet a great many collectors of minerals will acknowledge that the subject is to them a sealed book. There seems to be a lion in the way,—one that scares a great many people in other matters as well: mathematics.

The way the subject has been presented may be to blame. In a series of articles of which this is the first I am going to try to make the matter plain to any one who will apply himself to the subject. I will confine myself mostly to four figures, 0, 1, 2 and 3, and avoid complicated mathematics entirely.

The student may want to go further than this series of essays will take him, which can be done all the more readily if he has taken pains to master these easy lessons. I have tried them with entirely satisfactory results on a number of people without the slightest previous knowledge of the subject. A young chemical student read 38 pages of my notes with evident satisfaction and was able to correct an involved clerical error in one of my symbols.[1]

The study of crystallography involves certain facts, certain conventions and certain symbols.

The facts cannot be easily described without the conventions and symbols. A little attention given to these will enable any one to get a clear idea of the matter. The symbols I am going to make use of differ somewhat from those adopted by the foremost English writers on mineralogy, the Danas and H. A. Miers. The first great fact is that crystals are bounded by flat surfaces or planes. Our endeavor is to describe these planes and the forms they build up so clearly that any one can easily imagine or realize the forms or faces referred to.

[1] If any further errors should be detected, or the meaning is not reasonably plain at any point, I would be very much obliged to receive information about it.

If we hold a map up in front of us there is a line running north and south—up and down thru the center—which we call a meridian. This direction in a crystal we call *c*, or the *c* axis. There is also in general a straight line running east and west, from right to left, that might be the equator. In a crystal this would be *b*, or the *b* axis. Since crystals are not planes like the map, but solids, we require a third direction in space, or axis, to fully describe them. This may be represented by a long needle put through the map where the north-south line or axis crosses the east-west line or axis. This is *a* or the *a* axis.

The authors named use *a*, *b* and *c* in this way, but they also use them to indicate faces, which is confusing. Faces or planes should always be indicated by three numbers, as for instance 110 (read one, one, naught); 1 and 0 being used more frequently than all the other numbers put together. The figure 1 in the first place refers to the *a* axis and means that the plane or face passes thru the end of it nearest to the observer. The 1 in the second place means that the plane passes thru the right or east end of the b axis. We will take up the third figure, 0, later.

(*To be continued*)

In a note in *Science* (**44,** 161, Feb. 16, 1917) Professor John E. Wolff of Harvard University has given a brief account of the Hancock collection, which was referred to in our January number (**2,** 4, Jan. 1917). The late Mr. Hancock was a landscape artist and wood carver, and with an artist's eye and skilled manipulation with fine tools, developed the hidden beauties of crystals by removing the matrix.

"The collection contains about 1,600 specimens of generally the first quality, usually matrix specimens showing good crystals. The standard European and other non-American localities are fairly represented with excellent and well-chosen material but the greater interest is in the superb crystals from American localities such as Franklin Furnace, Tilly Foster mine, Amelia Court House, Va., and others where Mr. Hancock collected on the spot and then worked out his material with incredible skill and patience."

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Let us take the symbol 100 and consider the position it indicates for a plane.

We know the 1 in the first place indicates that the plane passes through the near end of the axis *a*. The 0 in the second place indicates that it is parallel to *b*; to help the memory, we may say that it would not cut the *b* axis no matter how far they were both prolonged, associating 0 with *not*.

In the same way the 0 in the third place means that the plane is parallel to *c*, the *c* axis. Let us assume that the axes are 1 inch or unit long from the center to the front and to the back, to the right or E, the left or W., upward or N., and down or S. Now to go back to the map, we have placed or imagined a plane say 1 inch in front of the map hanging in front of us. The symbol $\bar{1}00$, with a dash over the 1, read minus 1, 0, 0, indicates another plane in exactly the same way 1 inch back of the map. These two faces, in a way, cut out a board, and the faces are accordingly called pinacoids from the Greek for board. In the same way 010 and $0\bar{1}0$ would give two faces, or make a board, with its edge towards us standing upright. Of each of these two pairs of faces, pair by pair, it is said "they are not closed forms" because there is no limit given to their extension. If we combine the symbols 100, $\bar{1}00$, 010, 010 we would have cut out a pillar, sometimes called a second order prism, altho I think it best not to use the word prism in this way. If a crystal was of some length in this direction it would best be said to be elongated parallel to *c*, the third axis. Now we have four faces or planes and between them four edges, the latter all parallel. Such a set of faces are said to be in a zone. 100 indicates that the front face is parallel to *c*, 010 indicates that the side face is parallel to *c* so the line where they meet is also parallel to *c* or is *c* except that by convention we put the c axis thru the middle of the crystal. 001 and $00\bar{1}$ would indicate two more planes, one on either end of our pillar; either of these is called the base or the basal pinacoid.

By the three pairs of faces or pinacoids, our figure would now be closed. If we take the three axes as 1 inch long each way from the center and each axis at right angles to the other two, we have a cube, which every one knows. It has 6 faces, 12 edges and 8 corners. It has 3 zones, of 4 faces each, parallel to *a*, *b* or *c*, the first, parallel to *a*, taking in the four faces 010, 001, $0\bar{1}0$, and $00\bar{1}$. This would be called the *a* zone or the zone of the face 100; *a* would be called the zone axis and the 100 the zone face. The zone axis is parallel to the zone edges and the zone face is across or at right angles to them all. If we can make out the pinacoids, we may be able to place a crystal in the conventional position by putting one of the first pair toward us, one of the second pair to the right and one of the third above.

If we take a corner where three edges meet, these three edges may be taken as the three axes. If extended beyond the corner and moved to the center without changing their direction they would be our typical axes.

The cube, with two other forms to be described and four more are classed as belonging to the Cubic or Isometric System of crystals. They are characterized by three axes at right angles and of equal length.

(*To be continued.*)

BOOK REVIEW

DIAMONDS; A STUDY OF THE FACTORS THAT GOVERN THEIR VALUE. Frank B. Wade, of Shortridge High School, Indianapolis, Ind. G. P. Putnam's Sons, *New York*, 1916.

This little book of 150 pages is intended to furnish information to both dealer and purchaser of diamonds, as to the features of diamonds which are of influence on their market value. Chapter I is on color (spelt thruout colour), II on flaws, III on cutting or "make," IV on repairing and recutting, V on mounting, and VI on "Buying the engagement ring." The advice it contains is in every way excellent, and the presentation of the subject is so clear and so enlivened by specific cases illustrating the several points made that the book will make interesting reading to anyone even tho they do not plan to take up diamond-collecting as a hobby.

E. T. W.

NOTES AND NEWS

The collection of minerals at the Boston Society of Natural History has recently been rearranged and is now exhibited under modern conditions. The collection has been divided into two parts, one of which is entirely made up of New England minerals, the other a general collection from all over the world.

Eventually it is planned to keep only New England material with a small general synoptic collection, thus conforming to the policy adopted in other departments of the Museum.

The specimens are all exhibited on plate glass shelves without individual mounts. This method has been found to give the maximum light, and to prevent shadows; it has the additional advantage of being colorless and hence does not detract in any way from the color of the specimens.

Although the collection is very strong in New England minerals, especially those from the older localities, its curator desires to obtain specimens which will improve the present ones, and any from new or recent localities that are not as yet in the collection. For this purpose the Society is willing to exchange some of the specimens from outside of New England for particularly fine New England minerals.

Edward Wigglesworth, *Curator*,
234 Berkeley St., Boston, Mass.

other it is minutely corrugated by scarcely emergent wrinkles in concretionary groups. In a third specimen the surface is smooth to the naked eye, but under a glass is minutely pustulate with flat disks.

The specific gravity was determined by the balance as 3.84. Mr. Fair submitted a sample to J. P. Maider, city chemist of Spokane, who reported as follows: $FeCO_3$, 93.16; $MnCO_3$, trace; $CaCO_3$, 5.13; $MgCO_3$, 1.83; sum 100.12,% Sp. gr. by picnometer 3.673(?).

The optical properties of this siderite have been studied by Mr. E. S. Larsen of the U. S. Geological Survey, and will be described in a forthcoming number of the Journal of the Washington Academy of Sciences.

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The symbol 111 calls for a plane that passes thru the ends of the *a* axis in front, the end of the *b* to the right or E and of *c* above or to the N. $1\bar{1}1$ gives a plane cutting *a* in front, *b* to the left or W, and *c* above or to the N.

$\bar{1}11$ is a plane cutting *a* to the back, *b* to the right, and *c* above, $\bar{1}\bar{1}1$ *a* to the back, *b* to the left and *c* as before, above. These four would cut out a four sided pyramid. Four more which might be written at once by *reversing* the signs on the above, $\bar{1}\bar{1}\bar{1}$, $\bar{1}1\bar{1}$, $1\bar{1}\bar{1}$ and $11\bar{1}$, would give an inverted pyramid with its base to the base of the first. The whole figure will make an octahedron.

If we take the four symbols 110, $\bar{1}\bar{1}0$, $1\bar{1}0$ and $\bar{1}10$ they would indicate a square pillar or prism as the four 100, 010, $\bar{1}00$ and $0\bar{1}0$ did, but that had a face toward us, and this has an edge towards us. The three edges of a cube which meet in a point give us the direction of our three axes; here these four faces indicate that the two axes *a* and *b* are the same length or our pillar (or prism) would be diamond shaped, not square. These four faces are also in a zone parallel to *c*. They are properly called prism faces. They may be thought of as cutting off the corners of the first square pillars, whose face 100 is toward us. If they only cut off say half of the corners and left half we would have eight faces all in the *c* zone, the faces and edges all parallel to *c*.

The first four faces are the faces of a cube or are pinacoids, the last four are prism faces. As the cube has four faces parallel to *b* as well as parallel to *c*, this crystal form has four faces parallel to *b*; they are 101, $\bar{1}01$, $10\bar{1}$ and $\bar{1}0\bar{1}$, and indicate, if taken alone, a horizontal prism.

If the prism is square and not diamond shaped that shows that the lengths of the *a* and *c* axes are equal. If the crystal was drawn out that way it would be said to be elongated parallel to *b*.

These two sets taken together would make a closed form but not a perfect crystal.

There is plainly another set where the 0 is in the first place, 011, $0\bar{1}1$, $0\bar{1}\bar{1}$, and $01\bar{1}$.

They would make a prism parallel to *a*. The three pillars which combine to make a cube have for each pair two faces in common so the cube has only three times two, or six faces. Our last three prisms or pillars made with only one 0 in each symbol if combined would cut out or make a crystal form of three times four, or twelve faces, and for that reason is called the dodecahedron.

The dodecahedron has four faces meeting in a pyramid at each of the six ends of the axes; each face must thus go to the ends of two axes. As I have indicated each of these faces shows that two of the axes in the isometric system of crystals are equal. The octahedron, typified by (111), gives the indication by one of its faces that the three axes are all equal (but not so simply). These, the cube, the octahedron and the dodecahedron are the fundamental forms of the isometric system. There are four more forms in this system; they and all the forms in the other systems are derived from these three fundamental forms. The symbol 100 can only be modified by putting the 1 in each of three places and the 1 with the minus sign in three, making six planes or faces of the cube, the number of the permutations of the symbols being the same as the number of faces for the form it indicates. The same is true for the other crystal forms. The word form is used to indicate such a set of faces or planes. We use the symbol with a bracket to indicate the full set; thus:

(100) stands for all the faces of a cube.
(111) stands for all the faces of an octahedron.
(110) stands for all the faces of a dodecahedron.

The bracket is frequently put in by writers where it should be left out as only one face is intended. These crystal forms are not capable of any variation in the direction of their planes.

PROCEEDINGS OF SOCIETIES

The Philadelphia Mineralogical Society

Wagner Free Institute of Science, April 12, 1917.

President Trudell in the chair. Fifteen members and two visitors were present. Mr. M. L. Jandorf and Dr. Herman Burgin were elected active members. Mr. William C. Knabe was appointed Treasurer to take the place of Mr. Oscar Streland who has resigned the office.

Mr. Oldach reported a trip to the Falls of French Creek Mines which are now in active operation. Fine specimens of pyrite, magnetite, calcite, and heulandite (new) were exhibited. Mr. Benge reported the results of the trip of the Society to Mullica Hill, attended by seven members. Vivianite, beraunite and aragonite (besides eight or nine species of fossils) were obtained, the vivwith quartz crystals, the crystals being perfect, but looking as tho they had been twisted and mashed.

The district is noted for having produced large and well developed crystals of quartz, both single and grouped. One large group, taken out by the writer was studded with small brilliant pyritohedral crystals of pyrite.

The eastern part of the district yields large numbers of loose crystals found on the surface, some almost as brilliant as the "Herkimers." On the north side of the mountain, in an outcrop of limestone near the diorite, garnet is very abundant. Dodecahedral crystals of brown and green garnet implanted on calcite, associated with specularite (micaceous hematite) occur, and fine showy specimens were obtained. Good specimens of chabazite, epidote, muscovite, and a yellow garnet were taken from the southern contact. Further north and west coarse porphyritic granite appears, and here fine crystals of orthoclase, some twinned (Carlsbad law) were taken out of the rock.

The following minerals were reported from the locality, but were not observed by the writer: diopside, monticellite, ludwigite, phlogopite, magnetite, chalcocite, tetrahedrite, fluorite and pyromorphite.

The district is very favorable for collecting, interesting specimens being obtainable at any time. The country is not only noted for its variety of minerals and rocks, but also for some of the finest scenery in the West. To the south of Clayton Peak Big Cottonwood Canyon forms a large amphitheatre which is covered with timber, and built up with summer homes. Silver Lake lies at its base, while on the opposite side of the peak, but higher up, the beautiful Lackawaxen Lake is situated, making it an ideal spot to spend a summer vacation.

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The face 110 is referred to as the unit prism and the face 111 as the unit pyramid. As already indicated they, with the pinacoids, are the most important faces, for they will give the constants of the crystal, the angles between the axes, (thus far all right angles) and the lengths of the axes, (thus far all equal).

We have now described the three most important fundamental crystal forms; four other primary forms are derived from them, and all other isometric crystals are combinations of these seven. Every plane or face of a crystal we have described has cut one or more of the axes, and in every case where a plane has cut an axis it has been only and entirely at its outer end.

The next four forms cut the axes at some other point than the ends (or the center, where the axes cross).

This is indicated by symbols larger than 1, such as 2. The figured 2 indicates that the axis is cut equally in two, and that the plane cuts the axis at the halfway point. 3 or a larger figure would indicate that the axis was cut into that many parts, and that the plane cuts the axis at the dividing point nearest the center.

Let us take the form indicated by the symbol (210); it is called the four-faced-cube. Each face of the cube has on it a pyramid made by four planes, each bounded by one edge of the square face and by two lines extending from two corners to the center.

210 and $2\bar{1}0$ would be the two such faces on the front face of the cube that would be parallel to *c*. These would cut the *a* axis half way from the center and *b* at its ends.

They would not be as flat as the faces of the cube nor as steep as the faces of the dodecahedron. The symbols of these last, 100 and 110, may be multiplied by 2 and written 200 and 220, when it is at once seen that 210, the symbol for a face of the four-faced-cube, has a slant midway between them.

This suggests the second great law of crystallography— that the planes which cut one axis divide it into parts, which, for the different planes, bear simple numerical relations, as twice, three times, a half, a third, two thirds, (2 to 3), three halves, (3 to 2), etc.

All the angles in a zone, if measured not in degrees but in "offsets," as elevations, or as tangents, bear simple ratios or relations to each other (in other words, they are commensurable). This is called the rationality of the indexes, and is the second fundamental law of crystallography.

Each of the four faces of the cube parallel to *c* has two pyramid faces also parallel to *c*, making eight faces in the *c* zone.

I think it is plain that there are also eight independent faces in each of the zones *a* and *b*; in all, twenty-four faces. It would be good practice for a student to write down the symbols of the eight faces in each of these zones, thinking them out. For the *c* zone

on 100	on 010	on $\bar{1}00$	on $0\bar{1}0$
$2\bar{1}0$, 210	120, $\bar{1}20$	$\bar{2}10$, $\bar{2}\bar{1}0$	$\bar{1}\bar{2}0$, $1\bar{2}0$

It is plain that this could be done with very little thinking, indeed, mechanically. On 100 and on $\bar{1}00$ the symbols are the same, except that for faces that are opposite one another the signs are all reversed. To reverse the signs always indicates a face directly opposite a given face.

The faces in the *c* zone, the symbols of which always have 0 in the third place, are called prism faces, except when they are the faces of a cube or pinacoid.

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There are two more forms with twenty-four faces. These are best called the trigonal (three-edged) tris-(three-faced) octahedron and the tetragonal (four-edged), tris- (three-faced) octahedron. They both have a three-faced pyramid on each face of the octahedron. To develop them draw a triangle with equal sides and one corner at the top. This will represent one face of the octahedron. The top corner will be the end of the *c* axis, that to the left *a*, and that to the right *b*.

It is only necessary to remember that the larger symbol means further away from the ends of the axes. Take 221; this indicates that the *a* and *b* axes are cut half way in, towards the center, where the axes cross each other, while the *c* axis is cut at its end. The lower edge of our triangle is a line between the ends of the *a* and *b* axes.

If the points indicated by 2, 2 on these axes should be joined by a line, such a line would be parallel to the edge of the triangle or of the octahedron. The face indicated by 221 would thus be tipped down equally on the *a* and *b* axes and up on the *c* axis. The other two faces, 212 and 122 would be similarly placed. The three faces would build a little pyramid on a face 222. This face 222 is exactly parallel to 111, and can in fact not be distinguished from 111.

If in the center of our triangle we put a dot and join it to the three angles or tips it represents one face of the octahedron with its three sided pyramid, each side having three edges. With the other faces of the octahedron treated in the same way we would have our trigonal trisoctahedron of twenty-four faces.

(111) in brackets means all the eight faces of an octahedron, while 111 means the upper, right hand, forward face. The portion of a crystal in this direction is often called a quadrant, or, more properly, an octant. Note that this octant has all three symbols without a dash. This is generally true of any face in this octant. To reverse the sign by putting in dashes where there are none, and leaving them out where there are, indicates a face directly opposite a given face.

(221) and (211) are the symbols of two crystal forms that have twenty-four faces each. As each of them can only be varied by changing the position of the odd number, 1 in 221 and 2 in 211, it is evident there can be only three of these faces in each octant. The idea we can get of them from the symbol is the direction and the amount of the slant.

The four-faced cube (210) has edges at the base of the pyramid identical with the edges of the cube. The three-faced octahedron (221) has edges at the base of the pyramid identical with the edges of the octahedron.

The planes that make these faces cut two axes equally near the center and the third axis further out, or at the end.

(*To be continued*)

PROCEEDINGS OF SOCIETIES

The Philadelphia Mineralogical Society

Wagner Free Institute of Science, June 14, 1917.

The President, Mr. Trudell, in the chair. Eleven members and four visitors present. Mr. Frederick Oldach, proposed by Mr. Gordon, was elected to active membership.

Mr. Samuel G. Gordon gave a brief talk, illustrated with lantern slides, on "Some Philadelphia Mineral Collections."

Mr. Oldach reported the results of the Society's trip to Mineral Hill on May 6th. Chromite and anthophyllite were found at Moro Phillips' chrome mine, on Battles' farm. At Mineral Hill a little sunstone, moonstone, amazonstone, and deweylite were obtained.

The Secretary reported the trip to the Frankford localities on May 19th. The stilbite locality, now being filled with rubbish, looked uninviting and was not entered. This quarry is situated at Church and Leiper Sts., opposite the site of the molybdenite locality, which has been built over. Clark's quarry has again been abandoned, and is filled with water. It is doubtful if it will ever be reopened. At O'Neill's quarry the following were noted: orthoclase, hornblende, epidote, wernerite (?), biotite, vermiculite, stilbite, titanite and apatite.

The trip to Unionville on Decoration Day was reported by Mr. Knabe. At the corundum mines the following are obtainable: corundum, albite, tourmaline, margarite, and green quartz; at Beryl Hill: indifferent pieces of beryl, muscovite and microcline; at the Poorhouse Quarry, not at present being worked: quartz, calcite, dolomite and chesterlite (microcline).

The secretary reported the trip to the West Philadelphia localities on June 9th. At 64th and Lansdowne Ave. a hill is being leveled and the gneiss contains large cleavages of orthoclase showing Carlsbad twinning. Poor specimens of hyalite were obtained. A small quartz crystal was found at the Overbrook locality, back of the Blind Asylum.

In view of the fact that collectors may be thinking of visiting Franklin during the summer, the secretary told of some of the conditions there. The mines are carefully guarded by a dozen detectives, and permission to visit the mines and even the dumps is very difficult, if not impossible to obtain. In fact all visitors are followed by these men, and if a collector does pick up a specimen from one of the dumps, he is forced to put it back.

An amendment to the constitution was made extending the limit of the president's term to three successive years.

Field Excursion

Saturday, Sunday and Monday (Labor Day) Sept. 1–3. Falls of French Creek. Meet at 69th St. Terminal at 1.15 P. M., Saturday.

Stated Meeting

Thursday, September 13, 1917 8 P. M.

Reports of trips to Frankford, Lafayette, Leiperville, Friedensville, Perkiomen and the Falls of French Creek, by Messrs. Oldach, Gordon, Warford and Trudell.

Illustrated with specimens and lantern slides.

Samuel G. Gordon, *Secretary*.

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There is another form that is more difficult to picture to one's self but is well worthy of study. It cuts one axis near the center and the other two further out, or at their ends, so its symbol would be 211. On the face of an octahedron (222 which is the same as 111) its plane rises from one corner towards the other corners equally far out or at the ends. A little thought will show that three such planes will cut each other in a point in the center of a triangle drawn to represent the face of an octahedron and in a line to the middle of each side. This pyramid 211, it might appear, could not cut the edges of the octahedron; but that is taken care of by the pyramid on the next octahedron face. If we represent one of these pyramids by a triangle, with a point in its center joined to the middle of each side we should break each side at those points and push them a little further out. The important relation is that each of our pyramid faces is bounded by four edges, two from the apex of the pyramid and two from the corners of the octahedron. So this form is called a tetragonal tris-octahedron.

There is only one more fundamental form, which need not be described so elaborately. It has forty-eight sides and may be called an eight-faced cube or a six-faced octahedron. The eight-faced pyramid on each face of the cube may be shown by drawing a square connecting the opposite corners and the centers of the opposite edges.

The six-faced pyramid on each face of an octahedron may be shown by drawing a triangle as previously and drawing a line from each corner to the center and continuing them to the middle of each edge. Accordingly this form is called the hexoctahedron; its symbol would be three different numbers, as (321). Our four last symbols (210), (221), (211) and (321) would represent the same kinds of forms if they had been respectively (310), (441), (522) and (732), etc. There would then be slightly different slants or angles or relative heights to the pyramids. There are three forms (100), the cube, (111), the octahedron, and (110), the dodecahedron, which are invariable; and the remaining four are subject to variation in the above described manner.

(*To be continued*)

NOTES AND NEWS

Dr. Edgar T. Wherry, one of the associate editors of this magazine, has been transferred from the position of Assistant Curator, Division of Mineralogy and Petrology, U. S. National Museum, which he has held for the last four years, to that of Crystallographer, Bureau of Chemistry, U. S. Department of Agriculture.

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Do not forget to note that the symbols of the three fundamental forms taken singly represent: 100, a pinacoid; 110, a prism face; and 111, a pyramid face.

A pinacoid with two 0's cuts one axis and is parallel to two axes; a prism face with one 0 is parallel to one axis and cuts two; and a pyramid without any 0's cuts all three axes. This rule enables one at once to recall how any face lies, and to give the proper name to the face; or, having a named face, to give it an approximate symbol.

Any face with a dash over its first symbol lies at the back of a crystal; all without are in front. All without a dash over the second symbol are to the right of the *a* axis; if without a dash on the third symbol, above the *b* axis.

The student should know what kind of faces the following are: 100, 410, 310, 210 and 110. They are all in one zone. Note that 410 is a face slanting only slightly from the front pinacoid 100. Write the series 120 to the side pinacoid 010, also $\bar{1}40$ to the back pinacoid $\bar{1}00$. Continue in the same way to the other side pinacoid $0\bar{1}0$, and to the front pinacoid 100 again.

Such a series as 010, 041, 031, etc., could be represented by drawing the *b* and *c* axes as two lines on paper at right angles to each other and 12 inches long from the center. At 6 inches out from the center mark them 2, at 4 inches out 3, and at 3 inches out 4; the outer ends mark 1. Join the 1, (or 010) to the 1 (or 001) and also the 1, (010) to each of the other points 2, 002 the 3, 003 and the 4, 004 that would give you the slant of the faces 011, 012, 013 and 014 tho not their position. To get a clear idea of the series of faces draw a line at the end of the *c* axis parallel to the *b* axis this would represent the face 001. At 2 inches from the *c* axis on this line draw a second line parallel to the 014. From 2 inches further along on this second line draw a third parallel to 013. In the same way draw 012 and 011. This can be easily done with a pair of parallel rulers. Complete this quadrant by starting at 010, drawing four lines to where the 021 line meets the 011 line. See diagram on the following page.

If desired, complete the other three quadrants. The point to observe here is that the first set of lines drawn as indicated by the symbols give the directions, tho not the positions of the faces. In the isometric or cubic system, perfect crystals tend to have equal faces and be about equally thick each way, but this is not at all essential.