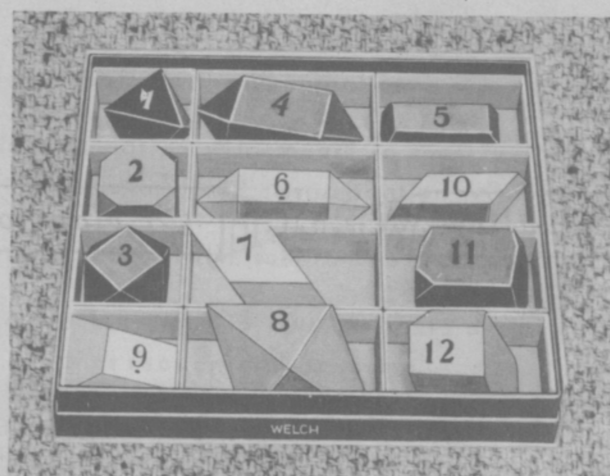
INSTRUCTIONS FOR No. 630
CRYSTAL MODELS

By Willis T. Maas



No. 630.

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AIMS OF THE TWELVE CRYSTAL MODELS

1. To represent the exact crystal shape of some common chemical substances with solids large enough that they may be easily viewed and enjoyed.

2. To present forms from which the kinds of symmetry may be visualized and mastered with less strain on the imagination.

3. To give specific information with regard to the crystal habit of some common substances as to their form and identification with the six crystal systems.

4. To show the natural color of the substances represented.

5. To be used as a teaching tool to give students definite information about the geometrical shapes that real crystals assume.

6. To stimulate interest in crystals.

7. To be studied and appreciated by students in high schools both junior and senior and also by college and university students.

TWELVE CRYSTAL MODELS

Part 1

GENERAL INSTRUCTIONS ABOUT CRYSTALS

1. A CRYSTAL DEFINED. A crystal is a regular polyhedral form, bounded by smooth surfaces, which is assumed by a chemical compound, under the action of its interatomic forces, when passing, under suitable conditions, from the state of liquid or gas to that of a solid. Thus, a crystal owes its form to the nature of the substance, and not to any shaping or cutting process.

A. THE SYMMETRY OF CRYSTALS

2. SYMMETRY DEFINED. The recurrence or repetition of the faces, interfacial angles, and vertices of crystals in accordance with some fixed law is called symmetry. Symmetry is perhaps the most important property of crystals, for among natural objects it is a property peculiar to crystals and besides furnishes the basis for the classification of crystals. At this time it may be mentioned that a few crystals lack symmetry of any kind (e.g., hydrous calcium thiosulfate, $CaS_2O_3 \cdot 6H_2O$).

The symmetry of crystals may be interpreted by the operations necessary to bring it into coincidence with its original position. The symmetry operations are ROTATION about an axis, REFLECTION in a plane, a COMBINATION OF ROTATION AND REFLECTION, AND INVERSION about a center.

3. AXIS OF SYMMETRY. If a solid can be revolved about some line through its center so that similar faces recur a certain number of times in a complete revolution, that line is called an axis of symmetry. In crystals the period of the axis or the number of times of recurrence is either two, three, four, or six. An axis about which similar faces recur every 180 degrees is said to be a two-fold axis; every 120 degrees, a three-fold axis; every 90 degrees, a four-fold axis; and every 60 degrees a six-fold axis. These axes of symmetry are denoted in TABLE 1 by A_2, A_3, A_4, and A_6, respectively.

4. PLANE OF SYMMETRY. A plane that divides a solid into two parts so that similar faces occur on opposite sides of the plane is called plane of symmetry. Unless the crystal is misshapen, one half is the mirror image of the other half. Plane of symmetry is denoted in TABLE 1 by P.

5. COMPOSITE SYMMETRY. The recurrence of similar faces by rotation about an axis, combined with reflection in a plane normal to the axis, is called composite symmetry. Denoted in TABLE 1 by AP_4 and AP_6.

6. CENTER OF SYMMETRY. A solid is said to have a center of symmetry if a line drawn from any point through the center encounters an exactly similar point on the opposite side. The operation is called inversion. Denoted in TABLE 1 by C.

7. ELEMENTS OF SYMMETRY. Axis, plane, composite axis with plane, and center are collectively known as elements of symmetry.

B. THE CLASSIFICATION OF CRYSTALS

8. THIRTY-TWO CRYSTAL CLASSES. The modern classification of crystals is based upon symmetry. Various methods of combining the elements of symmetry with each other lead to the result that only thirty-one combinations are possible among crystals. Also, it may be proved mathematically that only thirty-one combinations of symmetry are possible. These thirty-one divisions together with the one division devoid of symmetry constitute the thirty-two crystal classes.

Of these thirty-two natural classes among crystals based upon their symmetry, seven classes include by far the larger number of crystallized minerals. Besides these, some thirteen or fourteen others are distinctly represented, though several of these are of rare occurrence. The remaining classes, with possibly one or two exceptions, are known among the crystallized salts made in the laboratory.

It is interesting to note that just as MENDELEEF, the Russian chemist, predicted the existence and even the properties of several chemical elements by the discovery of the periodic law, so HESSEL, a German minerologist, in 1830 predicted the thirty-two possible crystal classes when representatives of only about half of them were known.

9. SIX CRYSTAL SYSTEMS. Although the thirty-two classes are fundamental in the classification of crystals, it is convenient to assemble them in larger groups called crystal systems. If directions fixed by symmetry are chosen for axes of reference it is found that all equivalent faces are represented by indices which differ from each other only in their order of succession and sign. Accordingly, the following six systems are recognized:

ISOMETRIC	TETRAGONAL	HEXAGONAL
ORTHORHOMBIC	MONOCLINIC	TRICLINIC

10. ISOMETRIC SYSTEM: three equal axes all at right angles to each other. See Fig. 1, and Model 1-2-3. There are three like or interchangeable directions of symmetry at right angles to each other. These three directions are either two-fold or four-fold axes of symmetry.

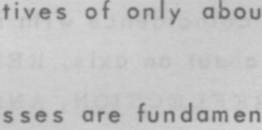

Fig. 1

11. TETRAGONAL SYSTEM: two equal axes and a third of different length, all at right angles. See Fig. 2, and Models 4-5. Crystals have a single four-fold symmetry, or a single composite four-fold axis, AP_4.

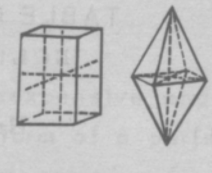

Fig. 2

12. HEXAGONAL SYSTEM: three equal axes in the same plane, intersecting at angles of 60 degrees, and a fourth axis at right angles to all of these. Crystals have single three-fold or six-fold symmetry (including AP_6). In addition to the two general forms shown by Fig. 3a, and Model No. 6, there are many rhombic forms belonging to this system, such as represented by Fig. 3b, and Model No. 7.

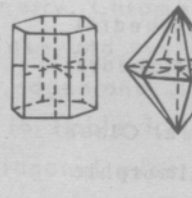

Fig. 3a

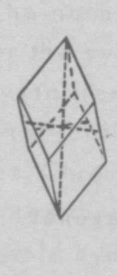

Fig. 3b

13. ORTHORHOMBIC SYSTEM; three unequal axes all at right angles. See Fig. 4, and Models 8-9. Crystals have three unlike or non-interchangeable directions of symmetry at right angles and no other directions of symmetry.

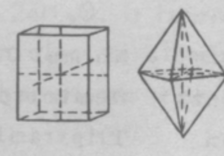

Fig. 4

14. MONOCLINIC SYSTEM: two axes at right angles and a third at right angles to one of these but inclined toward the other. See Fig. 5 and Models 10-11. The axes may be of any relative lengths, and the angle of inclination may vary from 0 degrees to 90 degrees. Crystals have one plane of symmetry, one axis of symmetry or both.

Fig. 5

15. TRICLINIC SYSTEM: three axes, all inclined toward each other. The axes may be of any relative length, and the angles of inclination may also vary. See Fig. 6, and Model 12. Crystals have no plane and no axis of symmetry, but symmetry solely with respect to the central point.

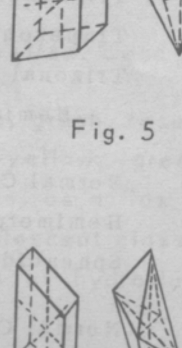

Fig. 6.

TABLE 1

TABLE OF THE THIRTY-TWO CRYSTAL CLASSES

INCLUDING THE TWELVE CRYSTAL MODELS

System	Name of Class	No	Symmetry	Example
Isometric	Normal Class	1	$(3A_4.4A_3.4AP_6.6A_2.9P.C)$	Models 1-2.
	Pyritohedral	2	$(3A_2.4A_3.3P.C.4AP_6)$	Model 3.
	Tetrahedral	3		
	Plagiohedral	4		
	Tetartohedral	5		
Tetragonal	Normal Class	6	$(A_4.4A_2.5P.C)$	Models 4-5.
	Hemimorphic	7		
	Tripyramidal	8		
	Pyramidal-Hemimorphic	9		
	Sphenoidal	10		
	Trapezohedral	11		
	Tetartohedral	12		
Hexagonal A. Hexagonal Division	Normal Class	13		
	Hemimorphic	14		
	Tripyramidal	15		
	Pyramidal-Hemimorphic	16		
	Trapezohedral	17		
	Trigonal Class	18		
	Trigonal Tetartohedral	19		
B. Trigonal or Rhombohedral Division	Rhombohedral Class	20	$(A_3.AP_6.3A_2.3P.C)$	Model 7.
	Rhombohedral Hemimorphic	21		
	Trirhombohedral	22		
	Trapezohedral Class	23	$(A_3.3A_2)$	Model 6.
	Trigonal Tetartohedral Hemimorphic Class	24		
Orthorhombic	Normal Class	25	$(3A_2.3P.C)$	Models 8-9.
	Hemimorphic Class	26		
	Sphenoidal Class	27		
Monoclinic	Normal Class	28	$(A_2.P.C)$	Models 10-11.
	Hemimorphic	29		
	Clinohedral	30		
Triclinic	Normal Class	31	(C)	Model 12.
	Asymmetric	32		

part 2

SPECIFIC INFORMATION ABOUT MODELS

16. A MODEL DEFINED. A model is a material that is inexpensive and easily shaped so as to exactly duplicate the regular polyhedral form of a perfect real crystal and painted to represent as nearly as possible the actual color of the crystal.

17. CHROME ALUM. MODEL NO. 1. Isometric System. Normal Class. The normal class of any system exhibits the highest degree of symmetry possible for the system while other classes are lower in grade of symmetry. Chrome alum crystallizes in perfect octahedrons a form belonging to this class and system. Geometrically, it is bounded by eight equilateral triangles, twelve edges and six vertices. Chrome alum is represented in Fig. 1, page 2. According to Table 1, it possesses three principal axes of four-fold symmetry ($3A_4$), four diagonal axes of three-fold symmetry ($4A_3$), and six diagonal axes of 2-fold symmetry ($6A_2$). There are three principal planes of symmetry which are at right angles to each other and six diagonal planes of symmetry (9P). There is also, obviously, a center of symmetry (C) and four axes of six-fold composite symmetry ($4AP_6$).

Chrome alum is chromium potassium sulfate, $Cr_2K_2(SO_4)_4.24H_2O$. It is violet in color. Aluminum alum, which crystallizes in the octahedron also, is aluminum potassium sulfate, $Al_2K_2(SO_4)_4.24H_2O$. It is colorless. Other alums with ions of similar valence crystallize in octahedra.

A number of substances crystallize as perfect octahedrons, a list follows:

(1)	Spinel.	Color, red of various shades, also blue, green, yellow, brown and black. Formula, $MgO.Al_2O_3$.
(2)	Gold.	Symbol, Au. Distinct crystals rare, but the octahedron more common than other shapes.
(3)	Magnetite.	$FeO.Fe_2O_3$. Color, iron black. Use. – An important ore of iron.
(4)	Galena.	PbS. Color, lead-gray. Octahedrons rare. Use. Lead ore.
(5)	Fluorite.	CaF_2. Color, white, yellow, violet-blue, green, rose and crimson-red, sky-blue, and brown; wine-yellow, greenish-blue, violet-blue, most common; red rare. Use, as a flux in the making of steel; in the manufacture of opalescent glass; in enaming cooking utensils; the preparation of hydrofluoric acid; sometimes as ornaments.
(6)	Pyrite.	FeS_2. Color, a pale brass yellow.
(7)	Diamond.	C. Crystals often distorted.
(8)	Chromite.	$FeO. Cr_2O_3$. Color, iron black.

18. GALENA. MODEL NO. 2. Isometric System. Normal Class. Galena is commonly found in cubes, less often octahedral. It is also found as the cubo-octahedron, represented by the model. In this form, a combination of the cube and octahedron, the cube predominates but is modified by the eight faces of the octahedron cutting off the eight vertices of the cube. The student should be interested in counting and naming the faces of this model, and counting its edges and vertices. It exhibits all of the kinds of symmetry of its class, being the same number as the octahedron.

Galena is lead sulfide, PbS. Color pure lead-gray. Luster metallic. Opaque. Use; The most important ore of lead. Extensive deposits of galena are to be found in Missouri, Iowa, Illinois and Wisconsin.

While distinct crystals are rare in gold, nevertheless the form of Model No. 2 has been recorded.

19. PYRITE. MODEL NO. 3. Isometric System. Pyritohedral Class. Pyrite is often well crystallized. The most common forms are the cube, pyritohedron, octahedron, diploid, and trapezhedron. Model No. 3, also, represents a combination of the cube and octahedron, similar to Model No. 2, but different by the fact that the cube and octahedron are here said to be "in equilibrium", since the faces of the octahedron meet the middle points of the edges of the cube. The length of the sides of the equilateral triangles equals the length of the sides of the Model's squares. The Model is bounded by eight triangles, six squares, twenty-four edges, and twelve vertices.

The symmetry of the pyritohedral class is as follows: Three axes of 2-fold symmetry ($3A_2$); four diagonal axes of 3-fold symmetry ($4A_3$); three planes of symmetry (3P); also a center of symmetry (C); and four axes of 6-fold composite symmetry ($4AP_6$).

Pyrite, or fool's gold, is iron disulfide, FeS_2. Color pale brass yellow. Opaque. Galena is commonly found having the shape of Model No. 3.

It may seem unusual to list Model No. 3 in the Pyritohedral Class when Model No. 2 of similar shape is in the Normal Class, but in a number of instances forms (geometric shapes) appear in more than one Class, as for example, the cube, octahedron, dodecahedron, and trapezohedron are in the two Classes named above. Thus combinations of two forms may also appear in two Classee of the same system.

20. ZIRCON. MODEL NO. 4. Tetragonal System. Normal Class. Model No. 4 has one principal axis of 4-fold symmetry, (A_4), whence name of the system. It contains four horizontal axes of 2-fold symmetry, ($4A_2$); one principal plane of symmetry, which is horizontal, four vertical planes of symmetry, (5P); and a center of symmetry. (c).

Geometrically, Model No. 4 is a square prism with a square pyramid on each end. Chemically, Zircon, is a double oxide of zirconium and silicon with formula, $ZrO_2.SiO_2$. A little iron oxide, Fe_2O_3, is usually present. Other impurities give rise to such colors as pale yellowish, grayish, yellowish green, brownish yellow, reddish brown. Some crystals are colorless. Distinct crystals are very common.

Zircon is a common accessory constituent of igneous rock. It is one of the earliest minerals to crystallize from a cooling magma. Zircon is infusible. Very large crystals have been found in Ontario, Canada.

Hyacinth is the orange, reddish and brownish transparent kind used for gems. Jargon is a name given to the colorless or smoky zircons of Ceylon, in allusion to the fact that while resembling the diamond in luster, they are comparatively worthless; thence came the name zircon. A blue color has been given artifically to zircon by a special heat treatment in which the zircon is exposed to fumes liberated from a solution of cobalt nitrate and potassium ferrocyanide. Gem stones from this material have been called starlite. Besides its use as a gem stone zircon is a source of zirconium oxide used in the manufacture of incondescent gas mantles.

21. VESUVIANITE. Model No. 5. Tetragonal System; Normal Class. Composition: A basic calcium aluminum silicate, but of indefinite formula; perhaps $Ca_6/ALOH, F/AL_2(SiO_4)_5$. Ferric iron replaces part of the aluminum and magnesium the calcium. Fluorine, titanium, and boron may be present.

Vesuvianite is easily fusible. It was first found among the ancient ejections of Vesuvius, whence its name. It occurs in crystalline impure limestones that have undergone alteration at the contacts with igneous rocks. It is never a constituent of eruptive rocks.

Californite, found in Fresno County, California, a massive jade variety is used as a semi-precious stone. In Quebec large brownish yellow crystals occur, brownish red crystals, brown to green, and bright yellow crystals have also been found.

22. QUARTZ. Model No. 6. Hexagonal System. Rhombohedral Division.

Trapezohedral Class. (Class No. 23. Table 1) $A_3 3A_2$. The form of Model No. 6 is geometrically like those of the Normal Rhombohedral Class, Class No. 20, Table 1. Thus another instance of a form belonging to two Classes.

Geometrically, Model No. 6, consists of a regular hexagonal prism terminated by two hexagonal pyramids. Such a form is called a regular hexagonal bipyramid with subordinate prism.

Chemically, quartz, is silicon dioxide, called silica, with formula, SiO_2. It is colorless when pure and often referred to as rock crystal. When cut and polished, rock crystal is used in inexpensive jewelry under the name of rhinestone or quartz diamond. Impurities give it various shades of yellow, red, brown, green, blue, and black. Rock crystal, colored violet by a trace of manganese, is the semi-precious amethyst. Almost every high school chemistry text will list these additional varieties of quartz: rose-quartz, yellow, smoky and milky-quartz.

Amorphous (non-crystalline) quartz include such substances as flint, jasper, chalcedony, sard, carnelian, onyx, and agate which are commonly used in jewelry.

23. CRYSTAL SIZE. Crystals occur of all sizes, from the merest microscopic point to a yard or more in diameter. It is important to understand, however, that in a minute crystal the development is as complete as with a large one, and in the crystals of a given species there is constancy of angle between like faces.

A single crystal of quartz, now at Milan, is 3¼ feet long and 5½ feet in circumference, and its weight is estimated at 870 pounds. A single cavity in a vein of quartz near the Tiefen Glacier, in Switzerland, discovered in 1867, afforded smoky quartz crystals, a considerable number of which had a weight of 200 to 250 pounds. A gigantic beryl from Acworth, New Hampshire, measured 4 feet in length and 2½ in circumference; another, from Grafton, was over 4 feet long, and 32 inches in one of its diameters, and weighed about 2½ tons; the largest beryls, however, have been found at Albany, Oxford Co., Maine, where one crystal was 18 feet in length, 4 feet in diameter, and weighed 18 tons.

24. CALCITE TYPE CRYSTAL. Model No. 7. Hexagonal System.

Rhombohedral Division. Rhombohedral Class. Class No. 20. Model No. 7 is a perfect rhombohedron. Geometrically, it is bounded by six like faces, each a rhombus. It has six like lateral edges forming a zigzag line about the crystal, and six like terminal edges, three above and three in alternate position below. See Fig. 3b, p.3.

The geometrical shape of the rhombohedron varies widely as the angles of the faces change. The acute angle of each face of the Model is 60 degrees. If this angle is made larger until it becomes 90 degrees the rhombohedron becomes the cube. If it is made smaller than 60 degrees the rhombohedron becomes elongated or more acute. The acute angle, or normal rhombohedral angle, of Calcite is 74 degrees 55 minutes; but the crystal habit of Calcite is very varied, the rhombohedral angle having at least five different values, ranging larger and smaller than the 60 degree angle of Model No. 7. Since Calcite crystals exhibit a greater variety of forms and habits than any other mineral, it accomplishes this variety as explained above and by forming positive and negative rhombohedron crystals; by forming crystals of the form known as scalenohedrons, both positive and negative; then by combination and truncation of these forms and by twinning. Model No. 7 is therefore representative of the variety of rhombohedrons formed by crystallized calcite as well as other minerals that crystallize as rhombohedrons.

Pure calcite is calcium carbonate, $CaCO_3$, and colorless. It is found white, various pale shades of gray, red, green, blue, violet, yellow; also brown and black when impure. Small quantities of magnesium, iron, manganese, zinc and lead may be present replacing calcium. The transparent variety from Iceland, used for polarizing prisms, etc., is called Iceland Spar, or Double-refracting Spar.

Other minerals that are carbonates and crystallize in rhombohedrons of the rhombohedral class, unless otherwise states, are as follows:

1. DOLOMITE. $CaCO_3.MgCO_3$. Tri-rhombohedral Class. (Class No. 22) Color white, reddish, or greenish white; also rose-red, green, brown, gray and black.

2. MAGNESITE. $MgCO_3$. Color white, yellowish, or grayish white, and brown.

3. SIDERITE. $FeCO_3$. Color ash-gray, yellowish gray, brown and sometimes white.

4. SMITHSONITE. $ZnCO_3$. Color white, often grayish, greenish, brownish white, sometimes green, blue and brown. Use. An ore of zinc. Minerals that are oxides and form rhombohedrons of the rhombohedral class are:

5. CORUNDUM. Aluminum Oxide. Al_2O_3. Hardness 9, almost as hard as diamond which is 10 in scale of hardness. Color blue, red, brown, yellow, gray, and nearly white. Rubies and blue sapphires are crystalline Corundum containing an impurity that is colloidally dispersed. The impurity produces the color.

6. HEMATITE. Ferric Oxide. Fe_2O_3. Color steel gray or iron black. Use. The most important iron ore.

25. SULFUR. MODEL NO. 8. Orthorhombic System. Normal Class. Geometrically, Model No. 8 is a rhombic bipyramid. It has eight like scalene triangles for faces and its cross-section between the two pyramids is a rhombus. Individual sulfur crystals may have this shape. The habit of sulfur is varied and other crystal forms are also common. Color sulfur-yellow, straw and honey-yellow. Sulfur is too common in reference books or already familiar to many students to merit more attention here.

26. BARITE. MODEL NO. 9. Orthorhombic System. Normal Class. Barite, $BaSO_4$, is the most common mineral containing barium. It is of frequent and wide occurrence. One large transparent crystal found in England weighed 100 pounds. Color white; also inclining to gray, yellow, blue (rather common), red, brown and dark brown. Barite, barium sulfate, is insoluble in acids. Use. Source of barium hydroxide used in the refining of sugar; ground and used as a pigment; to give weight to paper, cloth, etc.

Celestite, $SrSO_4$, and Angelsite, $PbSO_4$, occurs in crystals like barite in habit, forms, and angles. Or crystals may contain all three metals, barium, strontium, and lead which means they are closely isomorphous.

A large number of sulfate minerals are known. The three above are normal anhydrous sulfates. They are salts of sulfuric acid. No sulfites, pyrosulfates, thiosulfates, or persulfates are known among minerals.

27. GYPSUM. MODEL NO. 10. Monoclinic System. Normal Class. Gypsum is the most common sulfate. Chemically it is hydrous calcium sulfate, $CaSO_4.2H_2O$. It is common and widespread in its occurrence. Very large crystals have been found in Utah. Color usually white; sometimes gray, flesh-red, honey-yellow, ocher-yellow, blue; impure varieties often black, brown, red, or reddish brown. Use. In the manufacture of Plaster of Paris used for molds and casts and as "staff" in erection of temporary buildings; in making adamant plaster for interior use; as land plaster for fertilizer; as alabaster for ornamental purposes.

28. NICKEL AMMONIUM SULFATE. MODEL NO. 11. Monoclinic System. Normal Class. Model No. 11 possesses a plane of symmetry, an axis of two-fold symmetry and a center of symmetry. Formula, $NiSO_4(NH_4)_2SO_4.6H_2O$. Color: Green. The color of Model No. 11 was duplicated from a laboratory crystal. All other models except No. 1 as chrome alum and No. 12 represent minerals or natural substances.

29. HYDROUS COPPER SULFATE. MODEL NO. 12. Triclinic System. Normal Class. Blue Vitriol, $CuSO_4.5H_2O$, or chalcanthite occurs in nature. Copper with a valence of two is isomorphous with the following metals when they have a valence of two, manganese, iron, zinc, and cobalt. These metals may replace part of the copper in chalcanthite. Natural crystals vary in color from Berlin-blue to sky-blue, of different shades; sometimes a little greenish.

The Model was painted to duplicate the color of an artificial laboratory crystal grown from technical hydrous copper sulfate. Model No. 12 is also a very accurate duplication of an artificial crystal.

Hydrous copper sulfate furnishes us an excellent example of a triclinic crystal possessing a center of symmetry only. For each face on the model there is duplicated a similar face on the opposite side. Thus the triclinic model is made up of pairs of parallel and opposite faces, similar and similarly placed and is characterized by the absence of any kind of symmetry plane.

30. REFERENCE. For supplementary and additional study, Dana's Textbook of Mineralogy, Fourth Edition, by W. E. Ford is recommended. (John Wiley and Sons, New York). This text was instructive and helpful in the preparation of the models.

Table 2

BRIEF SUMMARY ABOUT THE TWELVE CRYSTAL MODELS

Model Number	Name	System	Color	Formula
1	Chrome Alum	Isometric	Violet	$Cr_2K_2(SO_4)_4.24H_2O$
2	Galena	Isometric	Lead-gray	PbS
3	Pyrite	Isometric	Pale Brass Yellow	FeS_2
4	Zircon	Tetragonal	Yellowish Green	$ZrSiO_4$
5	Vesuvianite	Tetragonal	Brown	$Ca_6Al_3OH,F(SiO_4)_5$
6	Quartz	Hexagonal	Rose	SiO_2
7	Calcite	Hexagonal	Pale Gray	$CaCO_3$
8	Sulfur	Orthorhombic	Yellow	S
9	Barite	Orthorhombic	White	$BaSO_4$
10	Gypsum	Monoclinic	Flesh-red	$CaSO_4.2H_2O$
11	Nickel Ammonium Sulfate	Monoclinic	Green	$Ni(NH_4)_2(SO_4)_2.6H_2O$
12	Copper Sulfate	Triclinic	Blue	$CuSO_4.5H_2O$