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ASTERISM IN GARNET, SPINEL, QUARTZ, AND SAPPHIRE

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ASTERISM IN GARNET

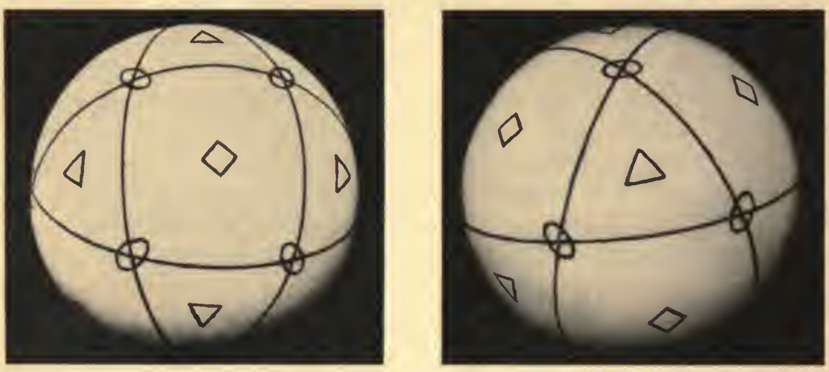
Two spheres of asteriated almandite garnet, respectively 1.86 inches and 1.47 inches in diameter, are on exhibition in H. N. Higinbotham Hall (Hall 31) of Field Museum of Natural History. The asterism of each sphere consists of four great circle, narrow, well defined chatoyant bands with definite angular relations to symmetry directions, and therefore with a definite angular relation to each other. The result is that at twelve identical crystallographic points on the sphere two bands intersect forming at each point a "four rayed star," thus forming twelve "four rayed stars" each with two angles of 70° 32′ and two angles of 109° 28′.

A microscopic examination of the spheres under strong illumination reveals an inclusion system of closely crowded, very fine, elongated crystals, much finer than the silk fibers of a cobweb. There are two sets of included crystals about each of the six axes at each of whose poles there is an intersection of two chatoyant bands. The elongated directions of the included crystals intersect to form two angles of 70° 32′ and two angles of 109°28′. These angles were determined by the usual method of measuring angles with a polarizing microscope.

The crystallographic relations of the included crystals and the chatoyant bands resulting from them may be visualized if the garnet sphere is considered as a projection of a rhombic dodecahedron.

Two sets of elongated crystals are parallel to each pair of parallel dodecahedron faces. These elongated crystals are also parallel respectively to two trigonal axes of symmetry which lie in a plane of symmetry designated by some authors as a diagonal plane of symmetry. The trigonal axes of symmetry intersect each other to form two angles of 70° 32′ and two angles of 109° 28′. Hence, the chatoyant bands which are produced by the included elongated crystals and whose planes are perpendicular to the elongated directions of the included crystals intersect at angles equal to the angles formed by the intersection of two trigonal axes of symmetry.

The plane of each great circle chatoyant band is perpendicular to a trigonal axis of symmetry. If such a band is traced on a crystal model of a rhombic dodecahedron, it will be drawn across six faces of the zone whose faces and edges are parallel to a trigonal axis of symmetry. If a similar band is traced for each trigonal axis of symmetry there will be four such bands, and two bands will be found to intersect on each rhombic dodecahedron face at the termination of a binary axis of symmetry. The two 70° 32′ angles formed by this intersection are opposite the two 109° 28′ angles of the crystal



a *b*

□ = tetragonal axis of symmetry. △ = trigonal axis of symmetry. ○ = binary axis of symmetry

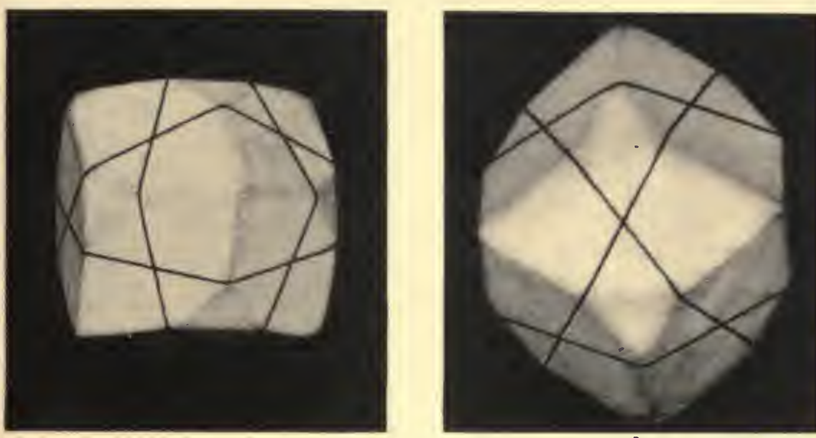
FIG. 19. Asterism of garnet sphere, Field Museum of Natural History. *a* shows four great circle chatoyant bands and four "four rayed stars." *b* three "four rayed stars."

face, and the two 109° 28′ angles formed by the intersection of two chatoyant bands are opposite the two 70° 32′ angles of the crystal face.

SUMMARY: The asterism on the sphere consists of four great circle chatoyant bands. The plane of each band is perpendicular to a trigonal axis of symmetry. Two bands intersect at angles equal to the angle of intersection of the two trigonal axes of symmetry, to which the planes of the bands are respectively perpendicular. These intersections occur at each pole of the six binary axes of symmetry, thus forming twelve "four rayed stars" on the entire sphere. Each "star" forms two angles of 70° 32′ and two angles of 109° 28′.

The asterism manifested by the garnet spheres may be explained as mainly a diffraction effect, produced by the system of regularly included elongated crystals, of the light reflected from the interior of the spheres. A similar effect may be seen by looking through a fine mesh at a light having a dark background, such as a distant street light at night-time or the headlights of an automobile at a distance of one hundred yards or more.

A single cabochon cut garnet showing asterism was loaned for study by Mr. Henry Franklin of Louis Franklin Company, New York City. The asterism of this stone is identical with the asterism of the garnet spheres of Field Museum. It shows five "four rayed stars" on the upper surface which are identical with the "stars" on Field Museum spheres.



a *b*

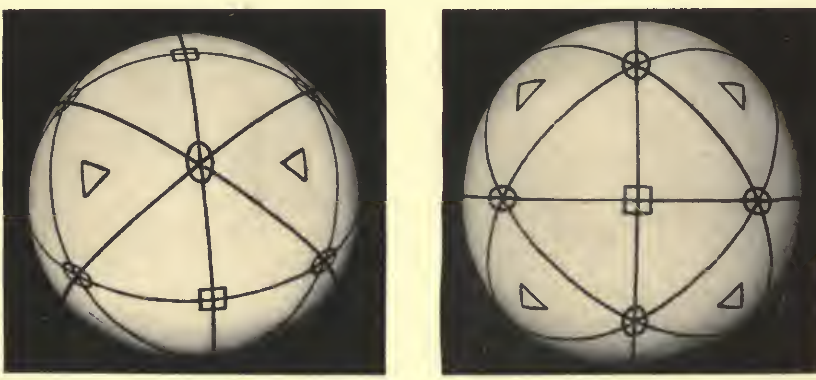
FIG. 20. Two views of model of a rhombic dodecahedron showing relations of chatoyant bands of *a* and *b* (Fig. 19) to crystal faces and to the trigonal and the binary axes of symmetry.

Another garnet, also cut single cabochon, was loaned by Mr. Theodore Pontius of the Chicago Lapidary. This stone is of particular interest because it shows on the upper surface seven chatoyant bands, seven "six rayed stars" and three "four rayed stars."

The asterism of this stone, like the asterism of the spheres, is caused by a system of included, very fine, elongated crystals. The relations of the included crystals and the chatoyant bands to the symmetry directions can be explained to advantage by considering how the phenomenon would appear on a sphere and how it would be related to a rhombic dodecahedron crystal of which the sphere may be considered a spherical projection.

In this stone there are three sets of included crystals about each of the six binary axes of symmetry. Each binary axis of symmetry is perpendicular to a diagonal plane of symmetry. In each of the six diagonal planes of symmetry there are two trigonal axes of symmetry, one tetragonal axis of symmetry, and one binary axis of symmetry. The elongations of the three sets of inclusions are respectively parallel to the two trigonal axes of symmetry and the tetragonal axis of symmetry which lie in the diagonal plane of symmetry.

In a rhombic dodecahedron two opposite dodecahedron faces are parallel to each diagonal plane of symmetry. In such a crystal, having the inclusion system referred to above, there are three sets of included crystals parallel to each opposite pair of dodecahedron faces. The symmetry relations of the great circle chatoyant bands



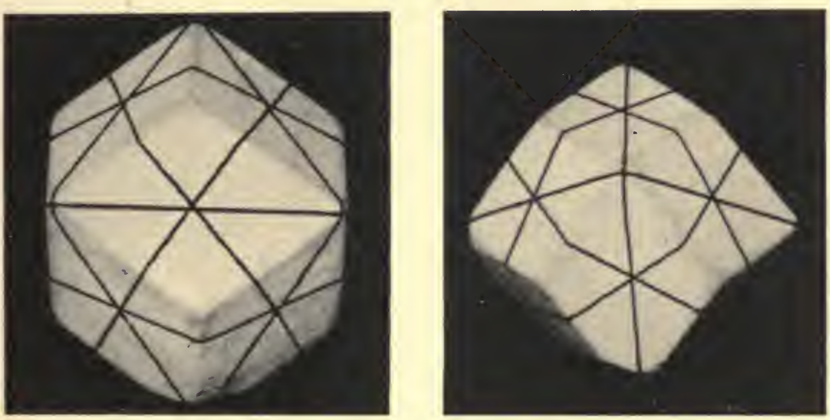
a *b*

□ = tetragonal axis of symmetry. △ = trigonal axis of symmetry. ○ = binary axis of symmetry.

FIG. 21. Asterism of a sphere of garnet having two sets of inclusions, one set parallel to the trigonal axes of symmetry and one set parallel to the tetragonal axes of symmetry. *a* shows seven great circle chatoyant bands, five "six rayed stars," two "four rayed stars." *b* shows one "four rayed star" and four "six rayed stars."

which would be produced on a sphere may be visualized if they are traced on a model of a dodecahedron. Four bands would have the same symmetry relations as the bands on the spheres of Field Museum. The plane of each band is perpendicular to a trigonal axis of symmetry, and two bands intersect at each pole of the six binary axes, forming two angles of 70° 32′ and two angles of 109° 28′.

The included crystals whose elongations are parallel to a tetragonal axis of symmetry would, on a sphere, produce a great circle chatoyant band whose plane is parallel to an axial plane of symmetry and perpendicular to a tetragonal axis of symmetry. The great circle chatoyant band passes through the poles of each of the two tetragonal axes of symmetry and the two binary axes of symmetry which lie in an axial plane of symmetry. Since there are three tetragonal axes of symmetry all at 90° to each other, it is self-evident that the sets of inclusions whose elongations are parallel to these axes produce three great circle chatoyant bands whose planes are at 90° to each other. Two bands intersect at 90° at the poles of each of the three tetragonal axes and therefore form on a sphere six "four rayed stars" with angles of 90°. Since each band passes through the poles of the two binary axes of symmetry which lie in an axial plane of symmetry, it forms with the two bands which intersect at these points four "six rayed stars." The axial plane of symmetry bisects the two opposite angles of 109° 28′ which are formed by the intersection of the two chatoyant bands. These bands are produced by the inclusions whose elongations are parallel to the trigonal axes of



a *b*

FIG. 22. Two views of model of a rhombic dodecahedron showing relation of chatoyant bands of *a* and *b* (Fig. 21) to crystal faces and to the axes of symmetry.

symmetry. The chatoyant band, therefore, whose plane is parallel to an axial plane of symmetry also bisects these angles, forming a "six rayed star" with four angles of 54° 44′ and two angles of 70° 32′.

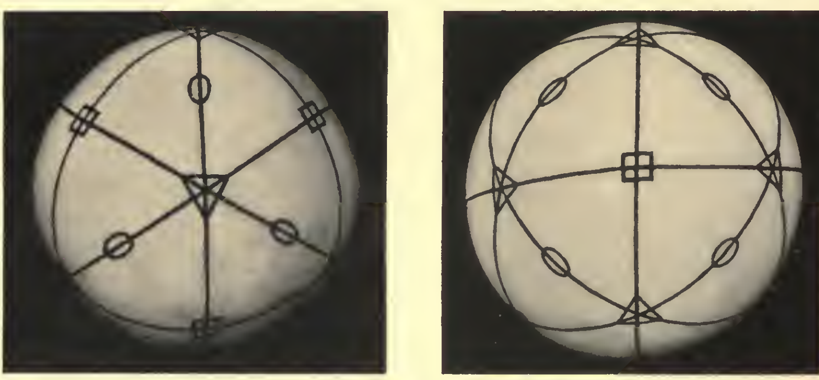
The asterism of a sphere of garnet with a system of inclusions like the single cabochon stone of the Chicago Lapidary would therefore consist of seven (4+3) great circle chatoyant bands, twelve "six rayed stars" each with four angles of 54° 44′ and two angles of 70° 32′, and six "four rayed stars" with angles of 90°. The planes of four of the great circle bands are each perpendicular to a trigonal axis of symmetry. The planes of three of the great circle chatoyant bands are each parallel to an axial plane of symmetry and perpendicular to a tetragonal axis of symmetry. The direction of a tetragonal axis of symmetry is also the direction of a crystallographic axis.

ASTERISM IN SPINEL

A gem stone, cabochon cut, showing well defined asterism was submitted for identification by B. J. Hersch of Frederick J. Essig & Company, Chicago.

From its optical and physical properties the stone was identified as a spinel. It is dark red in color and weighs a trifle over three carats. Near the center of the upper surface is a "six rayed star" with 60° angles, which may be clearly seen in a strong source of artifical light but shows up to the best advantage in direct sunlight.

The asterism of this stone is of special interest because there are three "six rayed stars" on the upper surface immediately above the girdle. Also, there are three "four rayed stars" a trifle higher



a *b*

□ = tetragonal axis of symmetry. △ = trigonal axis of symmetry. ○ = binary axis of symmetry.

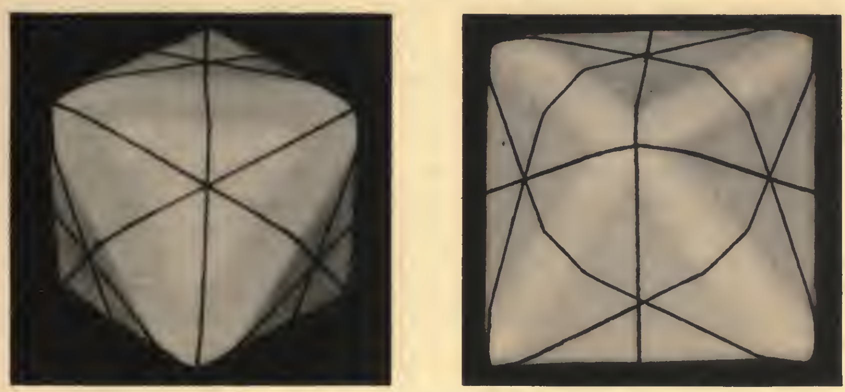
FIG. 23. Asterism of a spinel sphere. Inclusions are parallel to binary axes of symmetry. *a* shows six great circle chatoyant bands, four "six rayed stars," and three "four rayed stars." *b* shows one "four rayed star" and four "six rayed stars."

above the girdle than the "six rayed stars." This whole group of four "six rayed stars" and three "four rayed stars" is produced by the intersections of six narrow, sharply defined chatoyant bands.

An examination of the spinel stone with a microscope under strong illumination reveals an inclusion system of a large number of very fine elongated crystals. Around the center of each "six rayed star," over an appreciable area, there are three sets of included crystals whose elongations extend in three directions at angles of 60° to each other. The value of this angle was determined with a polarizing microscope, using the method for determining crystal angles or cleavage angles. It is quite evident that the system of included crystals produces the asterism in the spinel gem.

The relations of the chatoyant bands to symmetry directions may be visualized by assuming a spherical projection of an octahedron oriented so that a trigonal axis of symmetry is in a vertical position. Three binary axes of symmetry, intersecting at angles of 60°, lie in a plane perpendicular to the trigonal axis of symmetry. Three sets of included crystals are parallel to the pair of octahedron faces which intercept the vertical trigonal axis at 90°, and are respectively parallel to the three binary axes referred to above. This accounts for the 60° angles formed by the included crystals. Three chatoyant bands produced by the included crystals intersect at 60° on the octahedron faces at the terminations of the trigonal axis of symmetry.

The same condition with its resulting phenomenon prevails for



a *b*

FIG. 24. Two views of a crystal model showing relation of chatoyant bands of *a* and *b* (Fig. 23) to crystal faces and to the axes of symmetry.

each pair of parallel octahedron faces. If a chatoyant band is traced on an octahedron, it will be found that the plane of this band is perpendicular to a binary axis of symmetry and is parallel to a diagonal plane of symmetry. The plane of the band therefore, includes one tetragonal axis of symmetry, one binary axis of symmetry, and two trigonal axes of symmetry. It will readily be seen that for the whole crystal there are six chatoyant bands.

The interesting asterism phenomenon described above may be visualized more clearly if the octahedron is projected on a sphere. A sphere of spinel with inclusions like the stone here investigated will show six great circle chatoyant bands. Three bands will intersect, forming angles of 60°, at each of the poles of the four trigonal axes of symmetry thus producing eight "six rayed stars." Two bands will intersect at 90° at each of the poles of the three tetragonal axes of symmetry and therefore produce six "four rayed stars."

ASTERISM IN CUBIC MINERALS OF THE HEXOCTAHEDRAL CLASS

The asterism manifested by the two garnet spheres, the spinel cabochon, and the garnet cabochon stones is of special interest because it corrects the erroneous idea which prevails generally that the only asterism possible in minerals of the cubic system is a "four rayed star" with angles of 90°. They illustrate four well defined types of asterism each of which is the result of a system of very fine elongated crystals occurring as inclusions whose elongated directions are parallel to axes of symmetry. The examples described show two types of "four rayed stars," one type with two angles of 70° 32′ and two angles of 109° 28′ and one type with four angles of 90°. The examples also show two types of "six rayed stars," one type with four angles of 54° 44′ and two angles of 70° 32′ and one type with six angles of 60°. In the garnet spheres the elongated directions of the included crystals are parallel to the trigonal axes of symmetry. In the cabochon spinel the elongations are parallel to the binary axes of symmetry, and in the garnet cabochon stone the system of inclusions consists of elongations that are parallel to the tetragonal axes of symmetry and also elongations that are parallel to the binary axes of symmetry.

A further search for asterism in minerals of the cubic system may result in discovering other manifestations of the phenomenon. Many other types are possible in minerals of the hexoctahedral class of the cubic system in which asterism is produced by inclusions of fine elongated crystals, as is the case in the examples available for study.

The possible arrangements of elongated included crystals in cubic minerals of the hexoctahedral class may be considered under the following three groups:

Group I. Inclusions parallel to the trigonal axes of symmetry.
Group II. Inclusions parallel to the binary axes of symmetry.
Group III. Inclusions parallel to the tetragonal axes of symmetry.

The garnet spheres of Field Museum represent a possibility of group I consisting of the highest number of sets of inclusions possible in this group.

The spinel cabochon represents a possibility of group II consisting of the highest number of sets of inclusions possible in this group.

The cabochon garnet of the Chicago Lapidary represents a combination of the highest number of sets of inclusions possible in group I and group III.

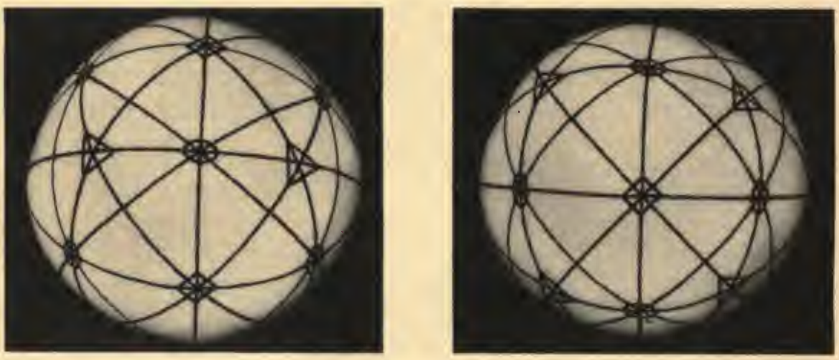
It is possible for a cubic mineral of the hexoctahedral class to contain a system of inclusions of group III, in which there would be three sets of inclusions each parallel to a tetragonal axis of symmetry. The asterism that would result from this system of inclusions has been described (p. 42) in connection with the cabochon garnet in which this system of inclusions occurs in combination with the system of inclusions of group I.

A cubic mineral with a system of inclusions consisting of a combination of the highest number of sets possible in group II and the highest number in group III would have nine (6+3) great circle chatoyant bands on a sphere. The bands would intersect to produce at the poles of the three tetragonal axes of symmetry six "eight rayed stars" with angles of 45°, twelve "four rayed stars" with angles of 90° at the poles of the six binary axes of symmetry, and eight "six rayed stars" with angles of 60° at the poles of the four trigonal axes of symmetry.

If a cubic mineral of the hexoctahedral class should contain a system of inclusions consisting of a combination of the highest number of sets possible in group I and the highest number of sets possible in group II, ten (6+4) great circle chatoyant bands would appear on a sphere. The bands would intersect to produce twelve "six rayed stars" at the poles of the six binary axes of symmetry. Each star would have four angles of 35° 16′ and two angles=109° 28′. Six "four rayed stars" with angles of 90° would be formed at the poles of the three tetragonal axes of symmetry.

Another system of inclusions is possible consisting of a combination of the highest number of sets of inclusions possible for each of the three groups. In a crystal consisting of such a system there would be a set of inclusions parallel to each of the four trigonal axes of symmetry, to each of the six binary axes of symmetry, and to each of the three tetragonal axes of symmetry. On a sphere consisting of this system of inclusions there would be four great circle chatoyant bands whose planes would be, respectively, perpendicular to the four trigonal axes of symmetry. There would be six great circle chatoyant bands whose planes would be, respectively, perpendicular to the six binary axes of symmetry and parallel to the six diagonal planes of symmetry. There would be three great circle chatoyant bands whose planes would be, respectively, perpendicular to the three tetragonal axes of symmetry and parallel to the three axial planes of symmetry. On such a sphere there would be thirteen (4+6+3) great circle chatoyant bands. These would intersect to form twelve "eight rayed stars" at the poles of the six binary axes of symmetry. Each "star" would consist of four angles of 35° 16′ and four angles of 54° 44′. At each of the six poles of the three tetragonal axes of symmetry there would be an "eight rayed star" with all angles of 45°. There would be eight "six rayed stars" formed at the eight poles of the four trigonal axes of symmetry, with all angles of 60°.

To summarize the above possibility: A sphere with the inclusions considered here would show thirteen (4+6+3) great circle chatoyant bands, twelve "eight rayed stars" each with four angles of 54° 44′



a *b*

□ = tetragonal axis of symmetry. △ = trigonal axis of symmetry. ○ = binary axis of symmetry.

FIG. 25. Asterism as it would appear on a sphere having three sets of inclusions. *a* shows seven "eight rayed stars" and two "six rayed stars." *b* shows five "eight rayed stars" and four "six rayed stars."

and four angles of 36° 16′, six "eight rayed stars" each with eight angles of 45°, and eight "six rayed stars" each with six angles of 60°.

This is the most complex manifestation of asterism that can result from a system of inclusions. The hexoctahedral class is the most complex class of symmetry of crystals, and all the axes of symmetry of this class have here been considered.

The examples and possibilities given here of asterism resulting from inclusions of very fine elongated crystals in cubic minerals of the hexoctahedral class are the result of a system consisting of the highest number of sets or a combination of the highest number of sets for the axes of symmetry to which the elongations of the included crystals are parallel. It seems reasonable to consider that asterism may occur in cubic minerals in which one or more of the sets possible may be lacking. For example, in group I there are four sets of inclusions if inclusions occur with elongations parallel to each of the four trigonal axes of symmetry. There are, however, three other possibilities in group I: (a) One set of inclusions with elongations parallel to one of the four trigonal axes of symmetry. (b) Two sets of inclusions with elongations parallel to each of two of the trigonal axes of symmetry. (c) Three sets of inclusions with elongations parallel to each of three of the trigonal axes of symmetry. The fourth possibility has been fully described. It consists of four sets of inclusions with elongations parallel to each of the four trigonal axes of symmetry.

The following is a list of the possibilities of asterism within each group, assuming that it is possible for included crystals to occur parallel to any number other than the complete set of the axes of symmetry of any one group. At the time of this writing, examples of such occurrences have not come to my attention.

GROUP I

(1) One set of inclusions parallel to a trigonal axis of symmetry.

Result: One great circle chatoyant band. The plane of this band is perpendicular to the trigonal axis of symmetry. On a rhombic dodecahedron the band may be traced on the six faces of the zone parallel to a trigonal axis of symmetry.

(2) Two sets of inclusions, each parallel to a trigonal axis of symmetry.

Result: Two great circle chatoyant bands and two "four rayed stars" formed by the intersection of these two bands on opposite poles of a binary axis of symmetry. Each "star" with two angles of 70° 32′ and two angles of 109° 28′.

(3) Three sets of inclusions, each parallel to a trigonal axis of symmetry.

Result: Three great circle chatoyant bands and six "four rayed stars." Each "star" with two angles of 70° 32′ and two angles of 109° 28′. The stars are at the poles of three binary axes of symmetry.

(4) Four sets of inclusions, each set parallel to a trigonal axis of symmetry.

Result: Four great circle chatoyant bands, twelve "four rayed stars" formed at the poles of the six binary axes of symmetry.

Example: Two garnet spheres of Field Museum.

In each of the four possibilities mentioned above, the plane of each great circle chatoyant band is perpendicular to a trigonal axis of symmetry.

GROUP II

(1) One set of inclusions parallel to a binary axis of symmetry.

Result: One great circle chatoyant band. The plane of this band is perpendicular to a binary axis of symmetry and is parallel to a diagonal plane of symmetry.

(2) Two sets of inclusions, each parallel to a binary axis of symmetry. The binary axes of symmetry lie in the same axial plane of symmetry and are at right angles to each other.

Result: Two great circle chatoyant bands, each plane perpendicular to a binary axis of symmetry and parallel to a diagonal plane of symmetry. The planes of the two bands are at right angles to each other. The bands intersect at the poles of the tetragonal axis which they have in common, to form two "four rayed stars" with angles of 90°.

(3) Three sets of inclusions, each parallel to a binary axis of symmetry.

Result: Three great circle chatoyant bands, each plane perpendicular to a binary axis of symmetry. The plane of each is parallel to a diagonal plane of symmetry. Two of the planes of the great circle chatoyant bands are at 90° to each other. Two "four rayed stars," angles of 90°, are found at the poles of a tetragonal axis of symmetry which two of the bands have in common as in (2). Four "four rayed stars" are formed at the poles of two trigonal axes of symmetry. Two angles of 60°, two angles of 120°.

(4) Four sets of inclusions, each parallel to a binary axis of symmetry.

Result: Four great circle chatoyant bands, each plane perpendicular to a binary axis of symmetry, and the plane of each band is parallel to a diagonal plane of symmetry. Two "four rayed stars" formed at the poles of a tetragonal axis of symmetry which the two planes of the chatoyant bands which are at right angles to each other have in common. The angles of these "stars" are 90°. Two "four rayed stars" formed at the poles of a trigonal axis of symmetry with two angles of 60° and two angles of 120°. Two "six rayed stars" formed at the poles of a trigonal axis of symmetry with angles of 60.

(5) Five sets of inclusions, each parallel to a binary axis of symmetry.

Result: Five great circle chatoyant bands, each plane perpendicular to a binary axis of symmetry. The plane of each is parallel to a diagonal plane of symmetry. Four "four rayed stars" formed at the poles of two tetragonal axes of symmetry with angles of 90°. Four "six rayed stars" with angles of 60° formed at the poles of two trigonal axes of symmetry. Two "four rayed stars" with two angles of 60° and two angles of 120°, formed at the poles of a trigonal axis of symmetry.

(6) Six sets of inclusions, each parallel to a binary axis of symmetry.

Result: Six great circle chatoyant bands, each perpendicular to a binary axis of symmetry. Eight "six rayed stars" with angles of 60° formed at the poles of the four trigonal axes of symmetry. Six "four rayed stars" with angles of 90°, formed at the poles of the three tetragonal axes of symmetry.

This type of asterism is represented by the cabochon spinel of Essig & Company.

There are two other possibilities with inclusions parallel to the binary axes of symmetry:

(7) Two sets of inclusions, each parallel to a binary axis of symmetry.

The two planes of the great circle chatoyant bands may be at angles of 60° instead of 90° as in (9). In this case there are two "four rayed stars" at the poles of a trigonal axis of symmetry, with two angles of 60° and two angles of 120°.

(8) Three sets of inclusions, each parallel to a binary axis of symmetry. The three binary axes lie in the same plane perpendicular to a trigonal axis of symmetry. The result is three great circle chatoyant bands at angles of 60°. One trigonal axis in common.

From such an arrangement of inclusions two "six rayed stars" are produced at the poles of the trigonal axis of symmetry which the three chatoyant bands have in common. The asterism thus produced is identical with that produced in minerals of the hexagonal system.

Asterism that is produced by parallel arrangement of inclusions to binary axes of symmetry offers eight possibilities: Inclusions parallel to from one to six axes. There are two possible arrangements of inclusions parallel to two binary axes and two possible arrangements of inclusions parallel to three binary axes of symmetry.

GROUP III

(1) One set of inclusions parallel to a tetragonal axis of symmetry.

Result: One great circle chatoyant band. The plane of this band is perpendicular to a tetragonal axis of symmetry and is parallel to an axial plane of symmetry.

(2) Two sets of inclusions, each set parallel to a tetragonal axis of symmetry.

Result: Two great circle chatoyant bands, each plane perpendicular to a tetragonal axis of symmetry and parallel to an axial plane of symmetry. The planes of the two bands are at right angles to each other, and the bands intersect at the poles of the tetragonal axis of symmetry which the two planes have in common, to form two "four rayed stars" with angles of 90°.

(3) Three sets of inclusions, each set parallel to a tetragonal axis of symmetry.

Result: Three great circle chatoyant bands, each plane perpendicular to a tetragonal axis of symmetry and parallel to an axial plane of symmetry. Their respective planes are perpendicular to each other. Two bands intersect at each pole of the three tetragonal axes of symmetry to form six "four rayed stars" with angles of 90°.

Possibilities resulting from combinations:

Each possibility that may occur with reference to any one of the axes of symmetry may occur in combination with any one of the possibilities for another class of axes of symmetry.

For example, the first and simplest possibility listed for group I may occur in combination with any one of the possibilities of group II. This is also true for any one of the other three possibilities of group I.

For group I and group II a minimum of 32 combinations are possible.

For group I and group III there are a minimum of 12 possibilities.

The four possibilities of group I may occur with each of the possibilities resulting from combinations of groups II and III. Since there are 24 possible combinations of groups II and III, the minimum number of combinations of the four possibilities of group I with the 24 possible combinations of groups II and III would be 96.

Total minimum number of possibilities, 179.

Summary of Asterism possibilities in the hexoctahedral class: Group I—Number of possibilities 4; group II—8; group III—3.

Possibilities from combinations: Groups I and II—Number of possibilities 12; groups I and III—32; groups II and III—24; groups I, II, and III—96. Total 179.

Examples are available for three of the above possibilities.

For completeness and continuity each example is here briefly reviewed.

(a) Garnet spheres of Field Museum represent possibility 4 of group I with four sets of inclusions each parallel to a trigonal axis of symmetry.

(b) Garnet cabochon of Chicago Lapidary represents a combination of two possibilities, 4 of group I and possibility 3 of group II.

(c) The cabochon spinel of Essig & Company represents possibility 6 of group III.

ASTERISM IN QUARTZ AND SAPPHIRE

A specimen of clear, colorless, transparent quartz showing well defined asterism is on exhibition in H. N. Higinbotham Hall of Field Museum of Natural History. The stone is cut double cabochon, the upper part somewhat higher than a hemisphere, girdle circular, and is 14 mm. in diameter through the girdle.

A sharply defined "six rayed star" appears at the upper part in direct sunlight. It is of interest to note that a star is also formed on the upper part of the stone by transmitted light, if the lower part is held toward the direct sunlight. The crystallographic **c** axis extends from approximately the center of the base to very nearly the center of the top.

At the time this was available for study an asteriated rose quartz, single cabochon cut, 18mm. x 13mm. was made available through the kindness of Mr. Theodore Pontius of the Chicago Lapidary.

The asterism of these stones like the asterism of star sapphires and star rubies is an intersection of three chatoyant bands forming angles of 60° at the pole of the crystallographic **c** axis. Each band extends over the entire upper surface. A sphere of asteriated quartz would show three meridional chatoyant bands and two "six rayed stars." Several spheres were made of asteriated sapphires to verify this in the case of the star sapphire.

The chief interest in the asterism of the quartz specimens is to determine the cause of the phenomenon. Nothing can be seen with a microscope under ordinary illumination that might be interpreted as causing asterism. However, if the substage diaphragm is adjusted to admit a very narrow beam of light using artificial light and working in a room free from reflections and direct light from windows, with a magnification of 100x, a network of very fine striae may be seen. When these striae are observed, looking in the direction parallel to the crystallographic **c** axis, it will be noted that they cross in three directions at angles of 60°.

The conclusion is that the system of striae is a system of included edges. These correspond to the horizontal striations on the prism faces formed there by an oscillatory development of the rhombohedron faces and the prism faces. When the habit of a crystal is a combination of a prism of the first order, a first order unit rhombohedron, and several modifications of the first order rhombohedron, a large number of very fine striations may be formed. Many of the striations are microscopic. When these striations become included in the crystal, they produce the phenomenon of asterism through a diffraction effect on light.

Many specimens of star sapphire have been examined to determine the cause of asterism in corundum. The entire collection of Field Museum was made available. In each of the sapphires examined there was found a system of a large number of very fine striae. If a polished convex surface is produced at one end of a crystal having well defined bipyramid faces, the chatoyant bands which intersect to form a "star" extend across the top in the planes of the crystallographic **a** axes. In other words they are perpendicular to the second order prism faces.

Asterism in sapphires as in quartz, spinel, and garnet is clearly a diffraction effect. In the specimen of clear quartz of Field Museum the star produced by transmitted light substantiates this. If anyone of the bands of a star sapphire is examined in direct sunlight with a binocular microscope, a repetition of the spectrum colors red, orange, yellow, green, blue may be distinctly seen. This is identical with the effect obtained when a strong light against a dark background is observed through a very fine mesh.

In connection with asteriated corundum it is well known that star sapphires occur in far greater abundance than star rubies. To this it should be added that in general the prevailing crystal habit of star sapphires is a combination of several modified hexagonal bipyramids of the second order and sometimes a second order prism and a basal pinacoid, while the prevailing habit of the ruby is a combination of a hexagonal prism of the second order, rhombohedron of the first order and basal pinacoid. The oscillatory growth of the bipyramids produces on many crystals an abundance of striations. Such striations occur sparingly on the prevailing habit of ruby crystals because rubies with the prevailing habit of sapphire are found sparingly. The chance for crystals with an abundance of included striations is therefore much more favorable for sapphire than for rubies.

A microscopic examination of the striae in the direct sunlight lying in the path of a chatoyant band reveals characteristics that are identical with the striations that occur on the crystal faces. The striations occurring on the crystals of quartz and sapphire are slightly wavy and jagged and in many instances interrupted, instead of continous clean straight lines like the elongated included crystals of garnet and spinel. These same characteristics may be observed on the striae in asteriated crystals of quartz and sapphire.

In many star sapphires striae extend across the entire diameter of the stone. When a large percentage of the striae for each of the three directions extend in this manner, a fine network is formed by their crossing. In some sapphires such a network of striae crossing in three directions exists over the entire diameter of the stones. In some stones the network occurs in patches. There is generally a set of fine striae at 90° to each of the crystallographic a axes. Many of these striae do not extend beyond the width of the crystal face on which they were originally formed. However, some extend in length and the result is that in a few small areas striae cross in two directions and in other places they cross in three directions. In some stones most of the striae extend only a few millimeters beyond their original length, and in such stones the striae form a hexagonal pattern.

Striae are flat and some appear slightly angular. Striae in the shape of rounded tubes have not been observed in this study. The width is a very small dimension, in many cases microscopic. The terminations of the striae which do not extend greatly beyond their original length commonly appear like short extensions of microscopically narrow cracks varying in length and generally show interference colors. These observations suggest that when the striae extend in length considerably beyond the striae originally formed on the surface of the sapphire crystal, the extensions are minute cracks. These extension cracks of the striae, which in many sapphires result in a network of crossing striae, crossing at angles of 60°, may have been produced under the severe metamorphic conditions to which these sapphires were subjected.

Striae vary considerably in size and number in different stones. Sharply defined narrow bands are produced by stones in which a hexagonal pattern is formed by fine striae and in which there is no appreciable amount of network. The chatoyant bands formed in a stone in which there is a network of striae are generally feathery and are not sharply defined. While each of the three chatoyant bands is a diffraction effect of the striae which it crosses at right angles, some influence is produced by the other two sets of striae extensions, resulting in a feathery band. Coarse striae produce wide, irregular bands which are pronouncedly feathery. There are other factors which influence the quality of the chatoyant bands. Pronounced zonal development, twinning striae, and various inclusions absorb and scatter the light that enters the stone, and the chatoyant bands produced in such stones appear faded and dull.

In some stones striae occur mainly along one of the crystallographic **a** axes; such a system of included striae produces a single chatoyant band, and if properly cut will yield a sapphire cat's eye.

SUMMARY

Asterism may be produced in garnet and in spinel by an inclusion system of very fine elongated crystals, the elongated directions being parallel to axes of symmetry.

There are two types of "four rayed stars" and two types of "six rayed stars" on the garnet and spinel stones available for study. "Four rayed stars" and "six rayed stars" occur on each of a cabochon garnet and a cabochon spinel.

A third type of "six rayed star" is possible on a stone whose system of inclusions consists of elongations parallel to each of the four trigonal axes of symmetry and to each of the six binary axes of symmetry.

Two types of "eight rayed stars" would result from a system of inclusions whose elongations are parallel to each of the thirteen axes of symmetry.

Asterism is produced in quartz and in corundum by a system of fine striae which appear to be included striations formed by an oscillatory growth of two or more crystal forms on one crystal. The striae are parallel to the prism of the first order in quartz and to the prism of the second order in corundum.

In many sapphires the striae extend in length beyond that of the striations originally formed on the crystal. These extensions appear to be minute cracks which may have been produced under the influence of metamorphism.

Asterism is a diffraction effect caused by a system of very fine included crystals in garnet and in spinel and by a system of fine striae in quartz and in corundum.

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