IRIDESCENT GARNET FROM THE ADELAIDE MINING DISTRICT, NEVADA

EARL INGERSON, *Geophysical Laboratory, Carnegie Institution of Washington,*

AND

JULIAN D. BARKSDALE, *Department of Geology, University of Washington, Seattle.*

ABSTRACT

Garnets from a lime-rich layer in the contact zone of a granodiorite stock near Golconda, Nevada, show brilliant iridescence both on striated crystal faces and in thin section. They have a birefringence a little more than a third of that shown by orthoclase (0.0025±) and show, superposed on the triangular segments that are common in lime contact garnets, lamellae that look like polysynthetic twinning. Universal stage measurements show that the lamellae are parallel to (110) and (111). It appears that the iridescence is due to the very fine (111) lamellae and that it is more intense where the individual lamellae are finer. Sections of the garnets heated in a furnace show a decrease in birefringence beginning at about 1060° C. and continuing practically to the melting point just below 1250° C. In thin sections that have been heated almost to the melting point (1225° C.) the birefringence is very low, but the twinning lamellae and iridescence are still visible.

INTRODUCTION

Approximately one mile east of the abandoned Adelaide mining district, ten miles south of Golconda, Nevada, a granodiorite stock intruded shales, sandstones, and carbonate rocks of Permo-Triassic (?) age to form a varied series of hornfels and calc-silicate rocks (Fig. 1). At the south margin of the intrusion a carbonate bed was changed into a mass of dark honey colored to dark brown garnet.

DESCRIPTION OF THE GARNET

Much of the garnet is in massive form, but many crystals are found at the surface outcrop and in an abandoned prospect pit. Crystals are rarely over two centimeters in diameter, more often under half a centimeter. Some are dodecahedrons; some are dodecahedrons modified by the trapezohedron; but most of the garnet occurs in crystals with irregularly shaped, mutually interfering faces which are striated in a manner similar to that seen on some pyrite crystals (Fig. 2). The garnet ranges in specific gravity from 3.50 for the light honey colored variety to 3.64 for the dark brown material. No complete quantitative analysis was made, but CaO and Fe_2O_3 were determined in several specimens. The former runs as high as 23 per cent and the latter up to 28.5 per cent. Some

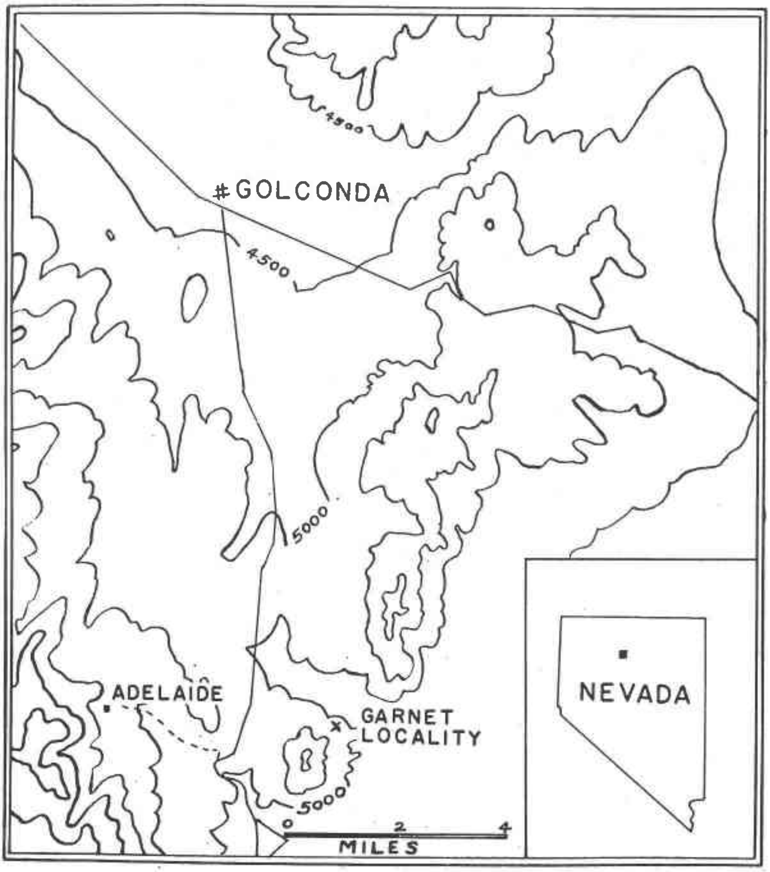


FIG. 1. Index map showing location of garnet locality.

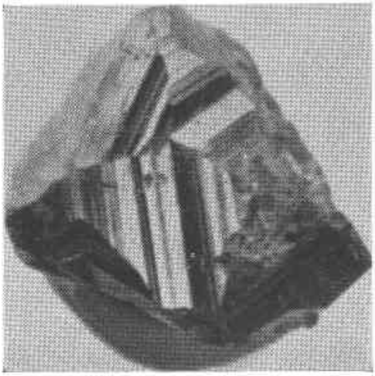
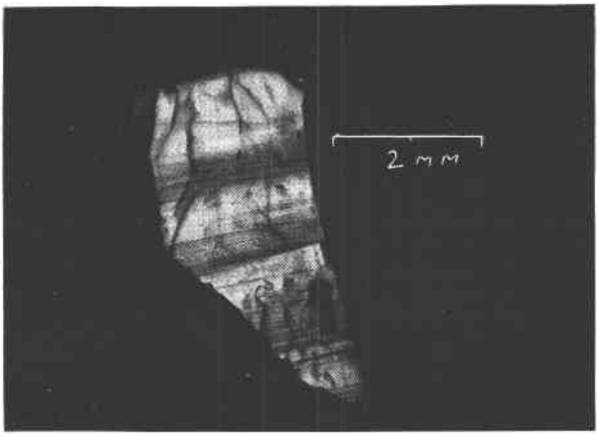
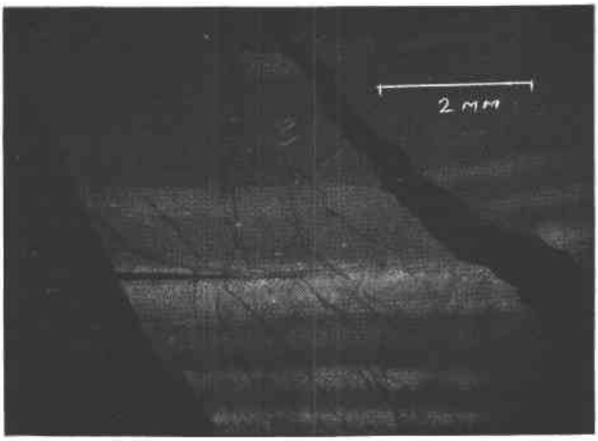


FIG. 2. Garnet crystal with striations. ×3.



A Crystal face showing color banding parallel to striations. ×10



B. Thin section by reflected light. ×10.

Plate I. Iridescence in garnets from Nevada.

ferrous iron is present. The tests for magnesium were negative These data, together with a rough index determination of 1.81, indicate that the garnet has more of the grossularite than the andradite molecule, and a little almandite.

The most striking feature about the garnet is the brilliant play of colors brought out by reflected light on the striated compound faces of most of the lighter colored crystals. The colors red, blue, green, orange, and yellow occur in bands parallel to the surface striations and are in places interrupted by interference colors due to thin air films in random cracks. The angle of incidence of the reflected light giving the most brilliant colors varies with each compound face. The color phenomenon is not due to a surface film; thin sections cut approximately parallel to the faces sharpen the color bands and eliminate the effects of random cracks. Plate 1 shows this iridescence; A, on a crystal face and B, in thin section.

Under the microscope the garnet is birefringent. Three types of structure are seen in thin section under crossed nicols: (1) A well defined banding which resembles twinning in plagioclase feldspars occurs parallel to the external striations (Fig. 3). This well defined banding is commonly confined to the peripheral zone of the crystals. The bands are dark when parallel to the vibration planes of the nicols. The peripheral zone is missing entirely in one of the thin sections; if it was present on the original crystal it was lost during grinding. One section, on the other hand, shows hardly any core (Fig. 3). Figure 4 shows this same crystal in parallel light.

Universal stage measurements indicate that the outer banding is parallel to the dodecahedron (110). The banding is relatively coarse, individuals ranging from 0.02 mm. to 1.7 mm. in thickness in the sections studied. Only rarely do these outer zones show any play of colors. When they do show it the color bands are always parallel to the outer banding, and upon closer study the latter are seen to have superposed upon them another much finer structure, (2), "herringbone" lamellae that universal stage measurements show to be parallel to the octahedral planes (111). This structure is shown in Fig. 5, which was taken at a higher magnification from the upper right hand corner of the crystal shown in Fig. 3. This appears to be true polysynthetic twinning; adjacent lamellae extinguish differently and alternate lamellae together. These lamellae do not have a uniform orientation throughout an entire crystal, or even in a given block of a segmented crystal, since they are developed parallel to more than one set of octahedral planes.

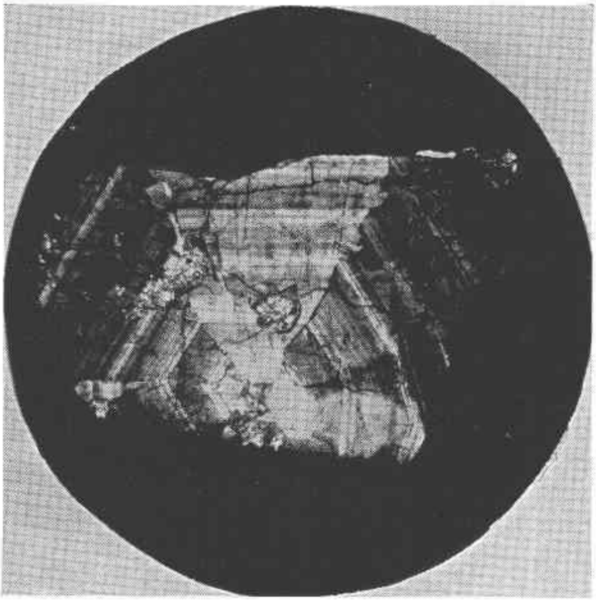


FIG. 3. Crystal in which the peripheral banding parallel to (110) is dominant. Crossed nicols. ×10.

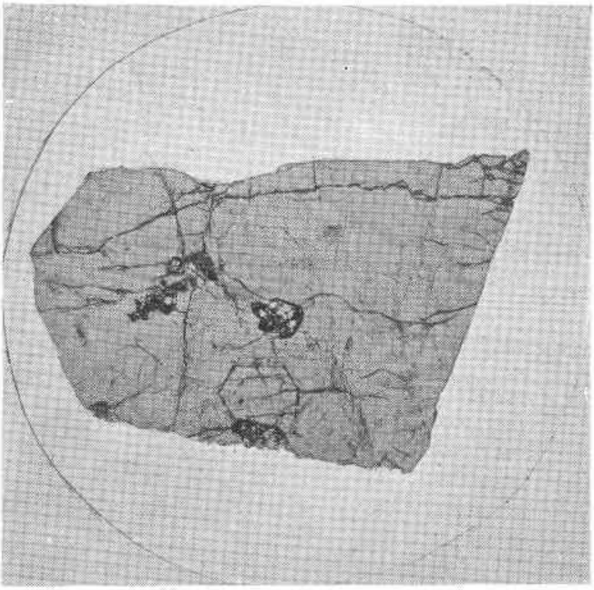


FIG. 4. Crystal of Fig. 3 in plane light.

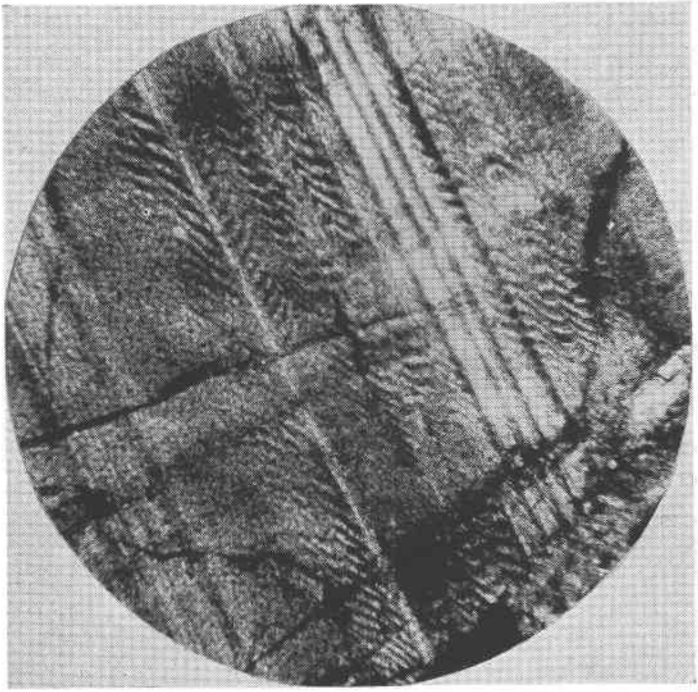


FIG. 5. Fine octahedral lamellae superposed on the dodecahedral lamellae. Crossed nicols. ×100. From the upper right hand segment of the crystal shown in Fig. 3.

The highly iridescent cores of the garnet crystals show this fine twinning well developed and there appears to be a general correlation between twinning and iridescence. The cores show another structure; (3) a complex mottling not unlike the twinning in some varieties of microcline (Fig. 8). It is most pronounced in the 45° position, while in the parallel position a faint banding in the core parallel to the peripheral banding is seen. The color bands are parallel to this direction. There is no complete extinction of the mottled areas. That the mottling may be another aspect of the octahedral lamellae is indicated by an intimate association of the mottled and herringbone patterns. The mottling is too vague and the lamellae so broad that they cannot, in general, be sharpened up and measured accurately on the universal stage. This is probably due to the angle at which they are cut by the thin section, since some of them can be measured accurately and prove to be parallel to octahedral planes.

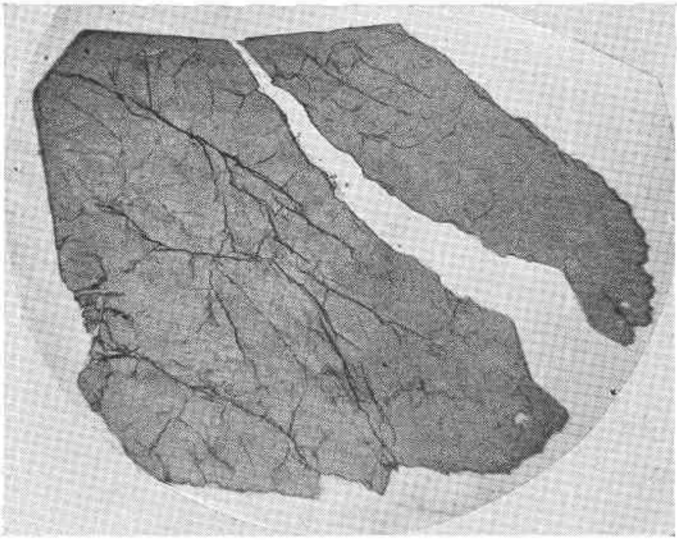


FIG. 6. Crystal of Plate I, B, as seen in plane transmitted light. ×8.

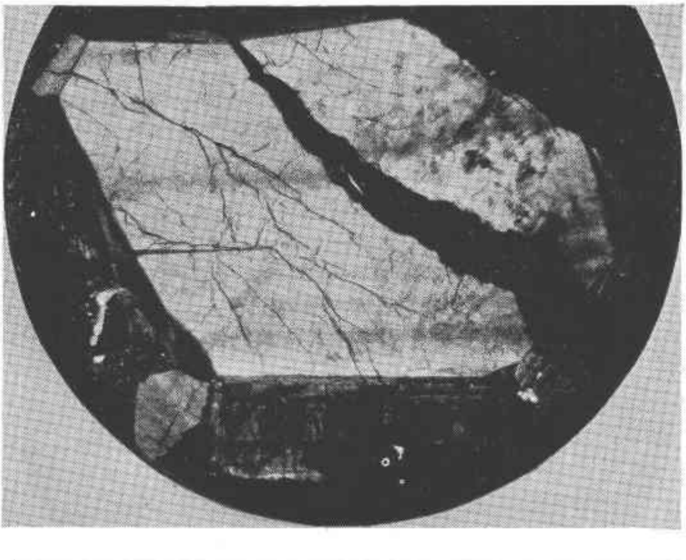


FIG. 7. Crystal of Fig. 6 between crossed nicols, showing strong peripheral (110) banding and faint banding in the core. ×8.

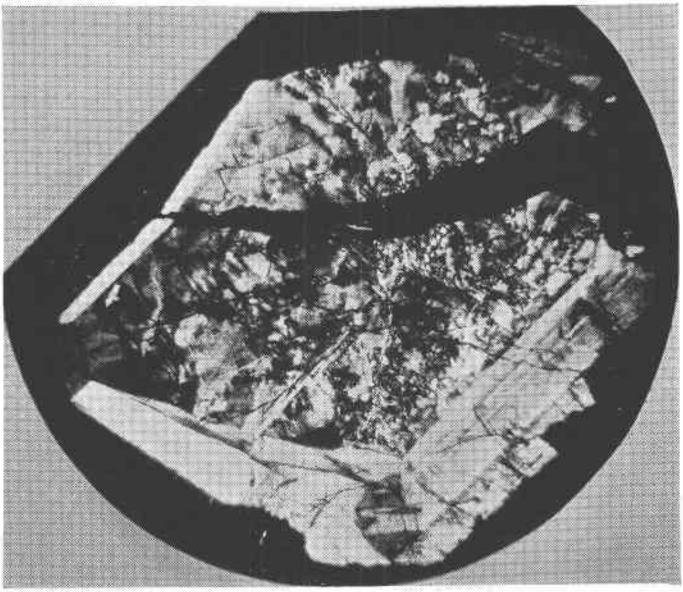


Fig. 8. Crystal of Fig. 6 in the 45° position between crossed nicols, showing the mottling of the core. ×8.

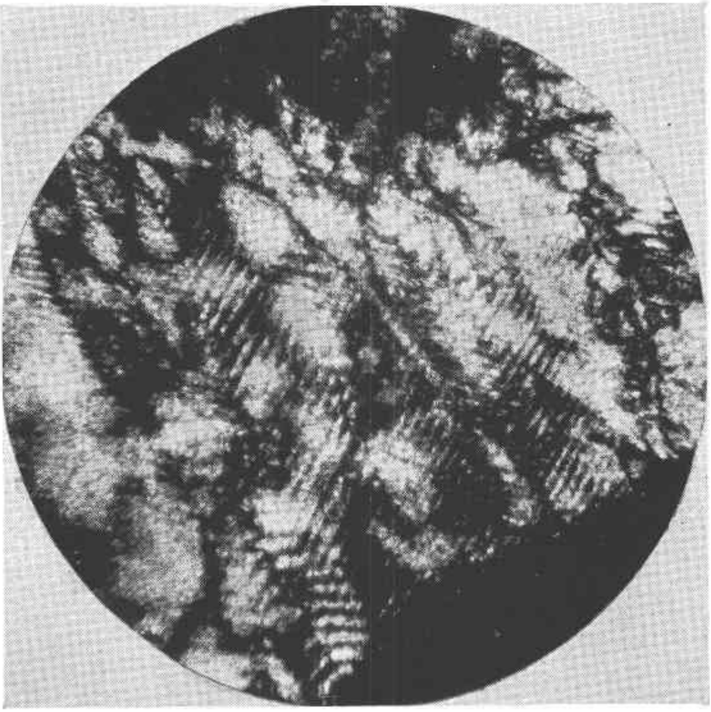


Fig. 9. Relation of mottling and octahedral lamellae. From lower edge of the smaller fragment of the crystal shown in Figs. 6–8. Crossed nicols. ×100.

The relations of these various structures are shown in the photomicrographs. Figure 6 shows the crystal of Plate 1, B, as seen by plane transmitted light, the angle of incidence being such that the iridescence does not show. Figure 7 is the same crystal between crossed nicols and shows the sharp peripheral banding and the faint bands in the core parallel to the outer banding. Figure 8 is the same crystal in the 45° position, where the complex mottling obscures the banding in the core. Figure 9 is taken at a much higher magnification from the lower part of the smaller fragment of the same crystal and shows the relation of the fine octahedral lamellae to the mottling, as seen in one plane. Figure 5 shows the relation of dodecahedral and octahedral lamellae in the crystal shown in Figs. 3 and 4.

The universal stage measurements were made on sections normal to a dodecahedral crystal face, on sections approximately parallel to such faces, and on sections of unknown orientation. From each section several sets of lamellae were measured and the poles to the planes plotted on a stereographic projection and the angles between the various poles measured. The only advantage of oriented sections is that the orientation of one crystallographic plane is known and can be used for reference, whereas with the unoriented sections the identity of all lamellae has to be inferred from the angles measured. The answer was the same, of course, and probably was as trustworthy with the unoriented as with the oriented sections.

Twinning and birefringence are characteristic of contact garnets of grossularitic composition.[1,2,3,4]

The temperature at which such garnets become isotropic has been taken as an indication of the temperature below which they must have formed. Merwin[5] found, for example, that some contact garnets from Alaska lost their birefringence when they were heated to about 800° C. for a few hours, and did not regain it after several hours heating at 600°.

Similar experiments were performed with iridescent fragments and thin sections of the Nevada garnets. The thin sections were removed from the glass slides by heating and the balsam was removed by careful washing with xylol. They were heated on a piece of platinum foil and then transferred to a clean slide for examination. Each heating was continued for at least twelve hours. When any change was observed it took place in considerably less time than this.

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[1] Schaller, W. T., Personal communication.

[2] Rogers and Kerr, Optical Mineralogy, 2nd ed., Fig. 284, p. 302.

[3] Wright, C. W., *U.S.G.S. Prof. Paper* **87**, p. 50.

[4] Brauns, R., Die optischen Anomalien der Kristalle, Leipzig (**1891**) pp. 243–252.

[5] *U.S.G.S. Prof. Paper* **87**, p. 108.

No change in the garnet was observed below 1060° C. At that temperature the birefringence weakened somewhat, but maintained the same pattern. Iridescence was as strong as ever. Reddish tinges began to appear, as if some Fe_2O_3 was separating. At 1100° no further change occurred, but at 1185° the birefringence was still weaker. The octahedral lamellae were still visible in the center and the dodecahedral lamellae in the outer zones. Iridescence was still strong. At 1225° much of the garnet had broken up into spinel and pseudo-wollastonite, especially around the little stringers of calcite, but the general pattern and iridescence were unchanged. In the part that remained clear the octahedral and dodecahedral lamellae were clearly visible, but the birefringence was very weak. At 1250° the sections melted to a dark brown glass.

Cause of the Play of Colors

The play of colors in labradorite has been ascribed by Dana[6] (after Vogelsang) to a combination of lamellar structure and fine inclusions. The common peacock blue color is regarded as due to lamellar structure; the golden or reddish schiller as due to minute inclusions, or "to the combined effect of these with the blue reflections."

Kraus and Slawson[7] believe that the colors in labradorite may be due to reflections from fine inclusions or to fine twinning. This is essentially the same explanation given above from Dana.

Brögger[8] ascribed the play of colors in soda orthoclase to a cryptoperthitic development of the feldspar. Later work with x-rays[9] has borne out Brögger's deduction.

The play of colors in opal has been investigated by Baier[10] who concludes that the phenomena are due to interference of a series of reflections from internal faces arranged in hexagonal symmetry, inherited from a calcite residue in the primordial silica gel. He mentions also the development of ultra-microscopic twin lamellar structure.

Lord Rayleigh[11] has shown that the iridescence of many crystals of

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[6] Dana, J. D., System of Mineralogy, 6th edition, John Wiley & Sons, Inc., New York (**1892**), p. 334.

[7] Kraus, E. H., and Slawson, C. B., Gems and Gem Materials, Third edition, McGraw-Hill Book Company, New York (**1939**), p. 216.

[8] Brögger, W. C., Die Mineralien der Syenitpegmatitgänge der südnorwegischen Augit und Nephelinsyenit: *Zeits. Kryst.*, **16**, 540–551 (1890).

[9] Kozu, Sh., and Endo, Y., *X*-ray analysis of adularia and moonstone, and the influence of temperature on the atomic arrangement of these minerals: *Sc. Rep. Tôhoku Imp. Univ.*, Series 3, **1**, No. 1, 1–17 (1921). This paper is abstracted in *Zeits. Krist.*, **57**, 116 (1922).

[10] Baier, E., Optik der Edelopale: *Zeits. Krist.*, **81**, 183–218 (1932).

[11] Lord Rayleigh, *Phil. Mag.* (5) **26**, 256 (1888); also, Iridescent crystals, Royal Institute Lecture, April 12, 1889. This theory is outlined in F. Pockels, Lehrbuch der Kristalloptik, Leipzig (**1906**), pp. 207–208.

potassium chlorate can be explained as due to reflections from a system of many very fine twinning lamellae of approximately equal thickness.

In the garnets described above there are no inclusions in the composition plane of the twinning that show up even under the highest power available (about 1350×). There are no visible cleavage planes parallel to the fine octahedral lamellae, and the fractures are too coarse and too irregular to explain the colors.

It appears, therefore, that the play of colors is due to reflection and interference phenomena related to the fine twin lamellae. This is indicated by the association of color bands and octahedral lamellae. The relation between iridescence and size of lamellae tends to confirm this opinion. The finer the lamellae the more intense the play of colors. In the brightest band seen in any section, the "herringbones" average 0.004 mm. in thickness. Where they are 0.006 mm. the colors are well developed, weaker at 0.0075, little or no color at 0.012, and colors were not found when the thickness of lamellae as seen in thin section exceeded 0.015 mm.

In one section each end shows color bands, but the central band shows no color. Under the microscope the central band shows mottling that is about twice as coarse as that of the two ends. The ends show the typical herringbone structure, which was not observed in the central band. In some cases this apparent difference in thickness of the lamellae, and the difference in iridescence, are due to different orientations of different parts of the crystal. This is true of Section W (Fig. 3), which is composed of six segments. However, the banded section referred to above is in uniform orientation, and the differences in lamellae thickness and iridescence are real.

It is concluded, therefore, that the play of colors in these garnets is due to very fine polysynthetic twinning, and that the intensity of the iridescence is dependent upon the thickness of the individual lamellae.