

parative set of values from Kuno (1954) for orthopyroxene with composition Fe<sub>50</sub>.

Optic orientation:  $a=Y$ ,  $b=X$ ,  $c=Z$ .

Common orthopyroxene (Unoxidized rock)	Abnormal orthopyroxene (Oxidized rock)	Orthopyroxene, Fe <sub>50</sub> (Kuno, 1954)
$a=18.320 \text{ \AA}$	$a=18.340 \text{ \AA}$	$a=18.360 \text{ \AA}$
$b=8.850 \text{ \AA}$	$b=8.945 \text{ \AA}$	$b=8.925 \text{ \AA}$
$c=5.14 \text{ \AA}$	$c=5.16 \text{ \AA}$	$c=5.230 \text{ \AA}$
$N_X \div 1.685^{**}$	$N_X \div 1.720$	$N_X = 1.710$
$N_Y = 1.693$	$N_Y = 1.733$	$N_Y = \text{—}$
$N_Z = 1.697$	$N_Z = 1.734$	$N_Z = 1.728$
$2V_X = 71^\circ$	$2V_X = 36^\circ$	$2V_X = 52^\circ$

Pleochroism distinct:

X=pale reddish brown  
Y=pale straw yellow  
Z=pale green  
Absorption:  $X > Y = Z$

X=pale pinkish brown  
Y=pale pinkish yellow  
Z=smoky green  
Absorption:  $Z = X > Y$

The photographs obtained were identical except for the larger unit cell dimensions of the abnormal orthopyroxene. The unit cell dimensions given are not absolute, but the relative values between the two crystals are accurate. It is not assumed that the two crystals measured have the same Fe:Mg composition ratio.

Because of practical difficulties in obtaining a pure sample, the abnormal pyroxene has not been chemically analyzed, but it is probable that the unusual optical properties of the mineral are due to oxidation and heating rather than to extreme primary composition.

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THE AMERICAN MINERALOGIST, VOL. 45, SEPTEMBER-OCTOBER, 1960

#### BIREFRINGENCE OF SYNTHETIC GARNETS

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Single crystals of the synthetic garnets  $R_3Ga_5O_{12}$  and  $R_3Al_5O_{12}$  (where R is Y, Yb, or Tm) were grown from lead oxide-lead fluoride melts,

\*\* R.I. =  $\pm 0.003$ .

using compositions and procedures approximating those suggested by Nielsen for gallium garnets (1). The melts were heated to 1250° C. in covered 50-cc. platinum crucibles, soaked for 12 to 24 hours, and cooled at a uniform rate of 4.2° C./hr. to 1000° C. The majority of the  $R_3Ga_5O_{12}$  crystals were subhedral to euhedral and approximately 0.2–1 cm. in size, with faces parallel to dodecahedral {110} and trapezohedral {211} crystal planes. The trapezohedron was the dominant form, with dodecahedral modification occurring only in the very early and late growth stages. The crystals usually contained an array of inclusions and voids oriented parallel to the growth surfaces. The inclusions contained normal components of the melt and varied from sub-micron to about 1 mm. in size. The voids were approximately the same in size and all degrees of filling by the flux components were observed. The refractive index of the gallium garnets was approximately 1.95 (measured with white light and standard index oils.)

The  $R_3Al_5O_{12}$  crystals were euhedral to subhedral and approximately 1–3 mm. in size. The dominant form was dodecahedral, with trapezohedral modification occurring near the end of the crystal growth. Inclusions and voids similar to those encountered in the gallium garnets were also present in these crystals. The refractive index of the aluminum garnets was approximately 1.85.

Under the microscope, sections of the garnets exhibited marked birefringence. Two types of structures were observed under crossed nicols: a birefringent halo around large inclusions and a well defined banding or zoning resembling twinning in the plagioclase feldspars. The birefringence varied from near zero to approximately 0.002. All of the crystals examined exhibited banding birefringence but the birefringent halo associated with the larger inclusions was rarely encountered. The birefringence was best observed in polished sections of 1–2 mm. thickness.

The birefringent halos associated with large inclusions extended outward for a distance of about one tenth of the diameter of the inclusion. The extinction was undulatory and pivoted about any sharp angles formed by the surfaces bounding the inclusion. The birefringence had a maximum value of about one quarter of that associated with banding and decreased in the vicinity of voids. This birefringence decreased sharply on annealing the sections for 24 hours at 1200° C., suggesting that it was caused by strain developed in the crystal during cooling, probably as a result of differences in the coefficients of expansion of the garnet and the included materials (2).

The banding normally exhibited the greatest birefringence in the peripheral zones of the crystals. The bands were parallel to the crystal faces and not to a single set of equivalent crystallographic planes. The

bands varied in thickness from 0.01 to 1 mm. and did not possess observable boundaries. However, a becke line could be seen between bands in the regions of greatest difference in birefringence. The bands exhibited an undulatory extinction that varied plus or minus six degrees to the direction of the bands. The birefringence of individual bands decreased in the vicinity of voids. Sections prepared parallel to a growth face and at the periphery of the crystal appeared isotropic, except around inclusions. These sections showed off-centered biaxial optic axis figures with  $2V$  varying from 5 to 20 degrees. The banding birefringence also decreased on annealing the samples at 1200° C.

The sections were more strongly birefringent in areas where edges and corners were formed by crystal faces during growth than in regions along the faces. When this condition was well developed, the crystal appeared to have rays of birefringence extending from the center to the corners and edges. When both the general banding and the rays were well developed, changes in crystal morphology that occurred during growth could be observed.

X-ray back reflection photographs provided information concerning the source of the birefringence in the banded areas. Birefringence in natural garnets is generally attributed to twinning (3). However, no evidence of twinning was observed in the synthetic garnets. In all crystals examined, the Laue spots exhibited a weak asterism oriented perpendicular to the line formed by the intersection of the nearest crystal face with the surface of the section. The asterism was greatest when the crystal face nearest to the area examined was perpendicular to the surface of the section. The asterism is interpreted as resulting from strain. The fact that the birefringent banding is oriented with respect to the asterism indicates that the birefringence is also due to strain, rather than twinning. Preliminary work with natural garnets indicates that birefringence in these crystals may also be primarily the result of strain. The strain probably results from variations in such properties as composition, purity and perfection of the crystals which, in turn, reflect variations in growth conditions.

We wish to express our appreciation to Dr. John Reed for assistance with the x-ray work and Mrs. Juanita W. Torpy for assistance with the crystal growth and sample processing.

#### REFERENCES

1. NIELSEN, J. W., *J. Appl. Phys., Supplement*, **31**, 51S (1960).
2. A more detailed treatment of birefringence and strain associated with inclusions is contained in the paper, "Pressure and Temperature of Crystallization from Elastic Effects around Solid Inclusions in Minerals," by J. L. ROSENFELD AND A. B. CHASE, (to be published by *Am. Jour. Sci.*)

3. See for example, E. INGERSON AND J. D. BARKSDALE, *Am. Mineral.* **28**, 303 (1943); A. N. WINCHELL AND H. WINCHELL, "Elements of Optical Mineralogy. Part II." John Wiley and Sons, Inc., New York, 1956, 4th ed., p. 490.

## INTERNATIONAL MINERALOGICAL ASSOCIATION

The papers in the two symposia given at the Zürich meeting of the I.M.A. (*Am. Mineral.* **44**, 460, 1319) have now been published in magnificent quarto form of 106 pages with numerous illustrations by the Instituto Lucas Mallada (Paseo de la Castellana 84, Madrid) as Fasc. VII, May 1960. Copies are available for residents of North America by sending \$1.50. to D. J. Fisher, Rosenwald Hall, University of Chicago, Chicago 37, Illinois before January 1961. Others may order from Madrid, from where later orders will also be handled. The table of contents of this Fasciculo is as follows:

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## ERRATUM

In the May-June, 1960 issue of the AMERICAN MINERALOGIST, page 615, the equation  $2ZnO + 3S = 2ZnO + SO_2$  should read  $2ZnO + 3S = 2ZnS + SO$ .