Reprinted from "The Proceedings of the Indian Academy of Sciences,"
Vol. XXXIV, No. 2, Sec. A, 1951

FARADAY EFFECT AND BIREFRINGENCE—II

Corundum

BY S. RAMASESHAN
(*From the Department of Physics, Indian Institute of Science, Bangalore*)

Received June 7, 1951
(Communicated by Prof. R. S. Krishnan, F.A.SC.)

1. INTRODUCTION

IN most anisotropic crystals that have been studied so far [quartz; Disch (1903), Lowry (1912), cane sugar; Voigt (1908)] the Faraday rotation has been measured only along the optic axes. Chauvin (1890) has measured the rotation in a calcite crystal for directions of propagation two degrees away from the optic axis and he found practically no variation in the Faraday rotation. Becquerel and his collaborators (1928, 1929, 1930) have performed a series of elaborate experiments in some birefringent crystals which exhibit large paramagnetic rotations (tysonite, xenotime, etc.). They found the Faraday rotation to depend on the direction of propagation of light and were able to evaluate the Verdet constant parallel and perpendicular to the optic axis. A study of the literature revealed the absence of any magneto-optic data for corundum. This paper reports the values of the magneto-optic constants for this substance in the visible region when light travels along the optic axis. Measurements have also been made of the magnetic rotation for directions of propagation inclined to the optic axis with a view to find out whether the Verdet constant varies with direction. No such variation was found for inclinations upto 15° from the optic axis.

Corundum is pure Al_2O_3. It crystallises in the rhombohedral class of the hexagonal system with the fundamental rhombohedron differing very little in angle from a cube. The ratio of the length of the *c*-axis to that of *a* or *b* is 1·3630.

2. MAGNETIC ROTATION ALONG THE OPTIC AXIS

The specimens that were used for study were cut from synthetic boules of colourless corundum manufactured by the Verneuil process. This mode of production of single crystals involves the formation of irregular strains. A large number of thin plates were cut at various angles to the optic axis and were examined between crossed nicols with the light passing along the optic axis. While the crystals were generally found to contain irregular strains, one specimen of thickness 1·180 mm. which showed very little residual strain was chosen for study. The optic axis of the specimen was inclined at an angle of 13° to the normal of the plate.

The crystal was mounted on a flat brass plate consisting of two concentric rings which could rotate with respect to each other. There was a central hole of 6 mm. diameter in the inner ring. The brass plate was supported vertically by a rod which could be rotated about the vertical axis by a graduated head which could be turned by a worm wheel. By this arrangement the crystal could be rotated through known angles about vertical and horizontal axes. The crystal was placed between the pole pieces of a Faraday effect magnet fixed to this apparatus. Parallel plane polarised monochromatic light (λ 5,461) with its electric vector vertical was made to pass through the crystal *exactly* along the optic axis and the rotation due to the magnetic field was measured with the aid of a half shade at the analyser end. The final rotation recorded for any magnetic field was a mean of about 100 readings. The effective magnetic field was determined by noting the magnetic rotation produced in a crown glass plate of thickness 1·29 mm. placed exactly in the position of the crystal plate. The Verdet constant of the glass plate had been accurately determined previously to $\frac{1}{3}$%. The Verdet constant of the crystal was calculated using the Verdet Law.

$$\theta = \mathrm{VH}t \cos(i - r)/\cos r,$$

where θ is the rotation, H is the field, i and r are the angles of incidence and refraction and t is the thickness of the specimen. As was to be expected the Verdet constant was lower with other specimens that showed greater residual birefringence. Table I gives the measured data together with the

TABLE I

Magneto-optic constants in Alumina along the optic axis

Effective thickness = 1·190 mm.

Effective field = 15400 Oersteds.

λ in A.U.	Refractive Index n_ω	Refractive Index n_e	Rotation ρ in minutes	Verdet constant V per cm. per oersted	Magneto-optic anomaly γ (in per cent)
5893	1·7685	1·7605$_5$	38·5	0·0210	64·0
5461	1·7712	1·7630	44·0	0·0240′	65·6
4358	1·7823	1·7739	70·5	0·0386′	65·0

calculated values of the Verdet constant and magneto-optic anomaly, for the three wavelengths λ 5,893, λ 5,461 and λ 4,358.

3. Magnetic Rotation away from the Optic Axis

For measurements along directions inclined to the optic axis, the optic axis was first made to lie in the horizontal plane and the crystal was then rotated through known angles about the vertical axis by turning the worm wheel. It may be mentioned that the crystal could be accurately rotated through angles of the order of 20″ of arc. Since the incident light had its plane of vibration vertical, the emergent light which was also plane polarised could be extinguished by a perpendicular nicol. When the magnetic field is put on, the emergent light becomes elliptically polarised with its major axis rotated through an angle ψ with respect to the plane of vibration of the incident light. This angle ψ was measured with a half shade at the analyser end for different angles of incidence. In these measurements it is absolutely necessary to have the incident light accurately parallel, a divergence or convergence of a fifth of a degree being sufficient to vitiate the results.

If the plane of vibration of the incident light coincides with one of the principal planes of the solid, then ψ is given by the following two formulæ under appropriate conditions (Ramaseshan, 1951)

$$2\psi = 2\rho\,(1 - \delta^2/3!) \text{ when } \delta \text{ is small}$$

$$\text{and} \quad \tan 2\psi = \frac{2\rho}{\Delta} \sin \Delta \text{ when } 2\rho/\delta \text{ is small,}$$

where ρ is the total magnetic rotation in the hypothetical case when birefringence is absent and δ and Δ are respectively the total phase retardations when rotation is absent and present. In the case of alumina the approximations $\tan 2\psi = 2\psi$ and $\Delta = \delta$ can be made when the direction of propagation makes an angle greater than 7° with the optic axis. The value of δ when the direction of propagation makes an angle ϕ with the optic axis is given by

$$\delta = \frac{2\pi}{\lambda}\, t\,(n_{\epsilon\phi} - n_{\omega}) = -\frac{2\pi}{\lambda}\, t \left[1 + 3/2\, \frac{n_{\omega} - n_{\epsilon}}{n_{\epsilon}} \right] [n_{\omega} - n_{\epsilon}] \sin^2 \phi,$$

where t is the thickness. In the case of alumina for λ 5,461 $n_{\omega} - n_{\phi} = 0{\cdot}008257 \sin^2 \phi$. Using this and the two formulæ given above and assuming that the Verdet constant does not change with direction (*i.e.*, ρ in any direction has the same value as that along the optic axis) the values of ψ have been calculated.

The solid curve in Fig. 1 gives the theoretical variation of with ψ with ϕ. The crosses are the experimental points. These lie very nearly on the theoretical curve thus showing that the Verdet constant does not sensibly change for inclinations up to 15° away from the optic axis. This is not surprising as the optical properties of corundum do not vary appreciably with direction, the birefringence being of the order of 0·01.

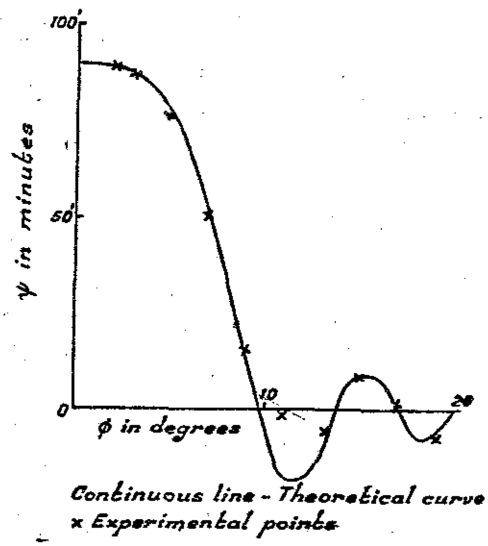

FIG. 1. Variation of ψ with ϕ in corundum

The author wishes to thank Professor R. S. Krishnan for the kind interest he took in this investigation and to Dr. G. N. Ramachandran for the helpful discussions he had with him.

SUMMARY

The Verdet constant and the magneto-optic anomaly for corundum for light travelling along the optic axis have been determined for the wavelengths λ 5,893, λ 5,461 and λ 4,358. The Verdet constant has the values $V_{5893} = 0 \cdot 0210'$, $V_{5461} = 0 \cdot 0240'$ and $V_{4358} = 0 \cdot 0381'$ minutes per cm. per Oersted and γ has a value of 0·64. Accurate measurements have also been made for directions of propagation inclined to the optic axis and it is found that the Verdet constant does not sensibly change for an inclination of about 15° away from the optic axis.

REFERENCES

Becquerel	.. *Leiden Communications*, 188, 191, 193, etc. (1928, 1929, 1930).
Chauvin	.. *Jour. de Physique*, 1890 (2), **9**, 5.
Disch	.. *Ann. der Phys.*, 1903, **12**, 1153.
Lowry	.. *Phil. Trans.*, 1912, **212 A**, 261.
Ramaseshan	.. *Proc. Ind. Acad. Sci.*, 1951, **34 A**, 32.
Voigt	.. *Phys. Z. S.*, 1908, **9**, 689.