THE MAGNETIC PROPERTIES OF TOURMALINE AND EPIDOTE

BY A. SIGAMONY

(*From the Department of Physics, Indian Institute of Science, Bangalore*)

Received September 1, 1944

(Communicated by Sir C. V. Raman, KT., F.R.S., N.L.)

1. *Introduction*

As is well known, tourmaline is a complex silicate of aluminium and boron crystallising in the rhombohedral system. Its dichroism, and the piezo- and the pyro-electric properties exhibited by it make it a crystal of great interest to the physicist. A few observations of its magnetic behaviour are on record, the most recent being those by Wilson (1920) and by Grenet (1930). Numerous specimens of tourmaline of various shades of colour and transparency were available in the crystallographic collection of Sir C. V. Raman, and it appeared to be of interest to make a systematic investigation of their magnetic susceptibility and anisotropy. The specimens had their natural prismatic form, with a rounded triangular section, the sides being lustrous and marked with strong striations parallel to the axis, except No. 4 which was a plate cut perpendicular to the axis. The specimens were of different colours, black, brown, green, rose and white. Most of the specimens were transparent, No. 4 was transparent only at the edges which were thin, and No. 1 was completely opaque.

Epidote is an ortho-silicate of calcium, aluminium and iron, crystallising in the monoclinic system. The analysis of a number of specimens reported (Tempel, 1938) shows that iron is the chief paramagnetic element in it; the ferric oxide varies from 4% to 17%, and the ferrous oxide is usually much smaller, being less than 1% in the majority of the specimens. Two crystals of epidote were obtained from the crystallographic collection of Sir C. V. Raman, and their magnetic properties were studied. They were brownish-green in colour, and were bounded by well-developed crystallographic faces on all the sides, the crystals being in the form of short prisms, extending along the *b*-axis.

2. *Experimental Results*

For all the tourmalines, the susceptibility along the axis was less than that perpendicular to it, agreeing with Wilson's observation, and all the specimens were isotropic in the symmetry plane.

The magnetic susceptibility of the tourmalines perpendicular to the axis was measured by Rabi's null method. They were all paramagnetic, and a solution of manganous chloride was used for the bath. The displacement of the crystals in the bath was measured very sensitively by suspending it from the beam of a Curie-balance of low torsional constant, and observing the deflection of the beam with a lamp and scale, so that any field-dependence of the susceptibility of the specimens could be easily detected. For specimens Nos. 1 to 6, a small unbalanced deflection of the crystal in the bath was observed at low fields, showing that the susceptibility decreased very slightly with increase of field strength, presumably due to traces of ferromagnetic impurities. Since their deflection was negligibly small compared with the deflection produced in air, no correction was necessary for the effect of the ferromagnetic impurities. The fine rose-coloured specimens 6 to 11 were completely free from such impurities.

The anisotropy of the tourmalines was measured by Krishnan's torsional method. Since the crystals were appreciably asymmetric in shape, they were surrounded by the solutions of their own volume susceptibility while measuring the critical torsion. The difference between the susceptibilities perpendicular and parallel to the axis ($\chi_{\perp} - \chi_{\parallel}$) was measured.

The results for the susceptibility and anisotropy, together with a description of the colour and density of the tourmalines are given in Table I.

TABLE I. *Tourmaline*

No.	Mass gm.	Specific Gravity	Colour	Mass Susceptibility $\chi \times 10^6$	Specific Anisotropy $(\chi_{\perp} - \chi_{\parallel}) \times 10^6$
1	3·010	3·12	Black	13·4	2·01
2	0·554	3·15	Dark brown with a clear zone at one end	11·0	0·295
3	2·052	3·13	Uniform dark green	10·8	1·65
4	4·042	3·11	Black	10·1	0·577
5	3·514	3·10	Light green with a clear zone at one end	$9{\cdot}7_8$	0·226
6	1·402	3·08	Colourless with a small red spot	4·96	0·0584
7	3·102	3·03	Uniform rose	1·18	0·0379
8	3·305	3·04	Rose, one end denser in colour	$0{\cdot}96_9$	0·0121
9	5·787	3·05	Rose, half the length denser in colour	$0{\cdot}95_8$	0·0138
10	4·553	3·04	Uniform rose	$0{\cdot}73_9$	0·0168
11	1·953	3·03	Uniform light rose	0·583	0·0375

The two crystals of epidote were found to have $\chi_3 > \chi_2 > \chi_1$, where χ_3 is the susceptibility along the *b*-axis, and χ_1 and χ_2 are the susceptibilities along the maximum and minimum axes of magnetisation respectively in the *b*-plane. The magnetic anisotropies $\chi_1 - \chi_2$ and $\chi_3 - \chi_2$ were measured by finding the period of oscillation of the crystal in a uniform magnetic field when suspended with the χ_3 and χ_1 axes respectively vertical. The magnetic anisotropy was found to be small, being less than half a per cent. of the susceptibility.

The susceptibility of the epidotes along the χ_1 axis was measured by a Curie-balance, and was found to be practically independent of field-strength. The values $22 \cdot 7 \times 10^{-6}$ and $23 \cdot 6 \times 10^{-6}$ were obtained for the two specimens and the magnitude of the susceptibility indicates that the amount of ferric oxide required to give these values come within the range of values reported by Tempel. The results for epidote are given in Table II.

TABLE II. *Epidote*

No.	Mass gm.	Specific Gravity	Mass Susceptibility $\chi \times 10^6$	Specific Anisotropy $\Delta\chi \times 10^6$
1	2·617	3·46	22·7	$\chi_1 - \chi_2 = 0 \cdot 094$ $\chi_1 - \chi_3 = 0 \cdot 046$
2	0·855	3·45	23·6	$\chi_1 - \chi_2 = 0 \cdot 077$ $\chi_1 - \chi_3 = 0 \cdot 066$

It will be seen from Table I that the brown, green and black tourmalines have a higher susceptibility and higher anisotropy, and also exhibit a greater density, associated presumably with a greater content of paramagnetic iron or chromium ions. The rose-coloured tourmalines have a low magnetic susceptibility and anisotropy, and also a slightly lower density. It may be remarked also that the characteristic variation of the intensity of the light transmitted by the tourmaline with the direction of the electric vector was generally more conspicuous for the tourmalines of the former kind which exhibit a high magnetic anisotropy.

In conclusion, the author wishes to record his deep sense of gratitude to Professor Sir C. V. Raman for suggesting the problem, for the loan of the crystals, and for the keen interest he took in the progress of the work.

3. *Summary*

The magnetic susceptibility and anisotropy, and also the density, of 11 specimens of tourmalines of different shades of colour and of 2 specimens of

epidote have been measured and are reported. The susceptibility of the tourmalines varied from 13·4 to 0·58 × 10^{-6}, and the anisotropy from 2·1 to 0·01 × 10^{-6}. It was found that those specimens which had a higher susceptibility had, in general, a larger anisotropy and a higher density. Their colour was also dark brown or black. Their dichroism was also more pronounced than with the rose-coloured specimens possessing low susceptibility. The mass susceptibility of the two specimens of epidote were 22·7 and 23·6 × 10^{-6}. Their anisotropy was found to be extremely small, being less than 0·5% of the susceptibility.

REFERENCES

1. Wilson .. *Proc. Roy. Soc.*, 1920, **A 96**, 429.
2. Grenet .. *Ann. Physique*, 1930, **10**, (13), 299.
3. Tempel .. *Chemi der Erde*, 1938, **2**, 525.