THE MAGNETIC SUSCEPTIBILITY AND ANISOTROPY OF CARBORUNDUM

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1. Introduction

THE study of the magne-crystallic behaviour of carborundum should be of considerable interest in view of the fact that the crystal is a valence structure in which the atoms of carbon are bound tetrahedrally to the atoms of silicon and *vice-versa*. Remarkably enough, five crystalline modifications of the substance have been reported, two of which are of the rhombohedral class, two hexagonal and one cubic. According to Moissan, carborundum may be transparent and colourless or vary in tint from emerald green to brown or black. It is not improbable that these variations of colour arise from the presence of impurities in the crystal. If this be the case, they might be expected to affect its magnetic behaviour.

Carborundum was available in Sir C. V. Raman's crystallographic collection in the form of an aggregate in which large crystalline plates had formed out of a matrix. It was possible to break off the crystals and each specimen thus obtained from the matrix was about 5 mm. square in area and a couple of millimeters thick. These crystals were perfectly black, but had smooth and lustrous surfaces. Another sample was also available in the form of a crystalline plate which was translucent and green in colour. This sample had been examined by Dr. C. S. Venkateswaran who found that the Laue pattern given by it with the X-ray beam normal to the plate had hexagonal symmetry. This sample as well as three samples detached from the aggregate were examined for their magnetic behaviour.

The magnetic susceptibility was measured in a Curie balance. A large electromagnet, the coils of which could be clamped at a suitable angle was employed for this purpose. The plates were suspended with the plane parallel to the magnetic field and the susceptibility perpendicular to the hexagonal axis ($\chi_\perp$) was measured by comparison with double distilled water.

The measurements of magnetic anisotropy were made by the torsional method of K. S. Krishnan (1933). A Cook electromagnet with large pole-pieces having an area of 8 cm. × 8 cm. was used and with a pole-gap of 1¼", field strengths of the order of 4000 to 6000 oersted were obtained for moderate currents. A quartz fibre was drawn out in the blast of an oxy-gas flame and used as the suspension. Its torsional constant was determined by the oscillation method with glass cylinders of known moments of inertia and then used for the measurement of the angle of critical torsion. The orientation of the crystal in the magnetic field was determined by the usual method with the help of a telemicroscope mounted on a circular scale and a plane mirror. The non-homogeneity of the field was tested and its effect was found to be negligible. The field was measured with a search-coil and a calibrated fluxmeter.

2. *Results*

The magnetic characteristics of the green plate conformed strictly to the known hexagonal symmetry of the crystal. There was no anisotropy in the plane perpendicular to the hexagonal axis and when suspended with the axis horizontal the orientation of the axis was parallel to the field, showing that $\chi_{\parallel}$ was greater than $\chi_{\perp}$ algebraically. Table I gives the experimental data.

TABLE I

Green Hexagonal Plate of Carborundum

Mass of the crystal = 35·0 mgm.

Torsional constant of the fibre = $1 \cdot 429 \times 10^{-3}$

Field strength	Critical angle of torsion a_c	$(\chi_{\parallel} - \chi_{\perp})$ per gm. mol.
oersted		
4640	357°	$0 \cdot 82_5 \times 10^{-6}$
5270	446°	$0 \cdot 82_1 \times 10^{-6}$
5760	526°	$0 \cdot 82_6 \times 10^{-6}$
6160	597°	$0 \cdot 83_0 \times 10^{-6}$

Mean = $0 \cdot 82 \times 10^{-6}$

Since the critical angle of torsion was small, the accurate formula

$$\chi_{\parallel} - \chi_{\perp} = \frac{2c}{m H^2}\left(\frac{a_c - \frac{\pi}{4} - \delta}{\cos 2\delta}\right).$$ M., was used where

$$\text{Tan } 2\delta = \frac{1}{2\left(a_c - \frac{\pi}{4} - \delta\right)}$$

The susceptibility was found to be independent of the field strength within the limits of experimental accuracy and a value $-13{\cdot}1 \times 10^{-6}$ per gm. mol. was obtained for $\chi_\perp$.

The deportment of the black crystals in the magnetic field was found to be irregular. All the specimens examined had appreciable anisotropy in the plane perpendicular to the axis. When suspended with the axis horizontal the plates set themselves with their axes at an angle to the field which was different for the different specimens and decreased slowly as the field strength increased. They were found to be diamagnetic but the numerical value of the susceptibility diminished at a rapid rate with the decrease of the magnetic field. Table II gives some experimental data.

TABLE II

Black Crystals of Carborundum

Field strength	$\chi_\perp$ per gm. mol.		
	Crystal I	Crystal II	Crystal III
oersted			
3560	$-5{\cdot}7\times10^{-6}$	$-7{\cdot}5\times10^{-6}$	$-5{\cdot}4\times10^{-6}$
3890	$-6{\cdot}8\times10^{-6}$	$-7{\cdot}9\times10^{-6}$	$-6{\cdot}0\times10^{-6}$
4250	$-7{\cdot}1\times10^{-6}$	$-8{\cdot}2\times10^{-6}$	$-6{\cdot}6\times10^{-6}$

3. *Discussion*

The gm. mol. anisotropy $(\chi_{\parallel} - \chi_\perp)$ obtained for the hexagonal green crystal of carborundum is $0{\cdot}82 \times 10^{-6}$ which is of the same order of magnitude as that for the sulphates and the selenates and much lower than that for the carbonates and the nitrates. In the latter crystals the complexes responsible for their anisotropy retain their characteristics practically unaltered in different compounds and hence the observed susceptibilities can be correlated with the magnetic constants of these complexes. The theory for the interpretation of the feeble diamagnetic anisotropy of crystals having isosthenic lattices is not developed. One example of this type of lattice is quartz which has a gm. mol. anisotropy $(\chi_\perp - \chi_{\parallel})$ of $0{\cdot}12 \times 10^{-6}$. The explanation for the anisotropy of such crystals has to be sought for in the deformation of the electron density distribution of the constituent atoms due to the interaction of their immediate neighbours. The anisotropy of carborundum is greater than that of quartz and this fact is intelligible in view of the fact that its bonds are much stronger and can produce a greater modification of the electron density distribution of the atoms.

The mean of the three principal susceptibilities of the green specimen is $-12{\cdot}8 \times 10^{-6}$ per gm. mol. Only a rough theoretical estimate of its susceptibility is possible. From Slater's expression for the mean square radius of the electron orbits, the susceptibilities of the free carbon and silicon atoms are calculated to be $-9{\cdot}1 \times 10^{-6}$ and $-25{\cdot}1 \times 10^{-6}$ respectively. The experimental value obtained by the author (1944, only the highest value obtained is used) for carbon in the form of diamond is $-0{\cdot}456 \times 10^{-6}$ per gm. which gives a gm. atomic susceptibility of $-5{\cdot}5 \times 10^{-6}$. The value obtained by Honda (1910) for silicon is $-3{\cdot}5 \times 10^{-6}$ and by Owen (1912) is $-3{\cdot}6 \times 10^{-6}$ and these values are much lower than the theoretical value. Assuming an additive law, from the experimental values given above for diamond and carborundum, the susceptibility of silicon is found to be $-7{\cdot}3 \times 10^{-6}$ which is also lower than the theoretical value. Pascal however gets the value -20×10^{-6} for the silicon atom in combination with organic compounds.

In conclusion the author wishes to express his gratitude to Professor Sir C. V. Raman for his keen interest and encouragement in this work.

4. *Summary*

The magnetic susceptibility and anisotropy of carborundum have been measured. The crystals of the black variety examined are found to be diamagnetic but irregular in their behaviour. A green hexagonal plate of carborundum was however found to behave in a regular way. It had a mean gm. mol. susceptibility of $-12{\cdot}8 \times 10^{-6}$ and anisotropy of $0{\cdot}82 \times 10^{-6}$, the susceptibility perpendicular to the hexagonal axis being numerically higher.

REFERENCES

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