

India's debt to Faraday

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The idea of a life dedicated and consecrated to the service of humanity and involving the renunciation of personal advantages makes a powerful appeal to the mind of India. It is doubtful if, amongst men of science, a finer example of such a life could be discovered than that of Michael Faraday. His ideas and discoveries have benefited all mankind, and, in common with the rest of the world, India owes him a debt which can never be repaid. I consider it a great privilege to be allowed, on behalf of India, to offer my humble tribute of homage to the immortal soul of Faraday.

So long as seventy years ago the career and achievements of Faraday had made a profound impression in India. It is sufficient to mention the fact that, when the late Dr Mahendra Lal Sircar in the sixties of the last century laboured to promote science in India, he adopted the Royal Institution of Great Britain as the model to follow in establishing a centre for scientific research. The Association for the Cultivation of Science, which he founded at Calcutta in 1876, is thus itself an Indian memorial in honour of Faraday. It has been the great privilege of the present writer and of his numerous collaborators from all over India to have enjoyed the unique facilities for research provided by this institution during the last quarter of a century.

Amongst Faraday's discoveries, the most significant in its theoretical implications was the magneto-optic effect known by his name. It established an experimental connexion between light and electromagnetism, and thus paved the way for the demonstration by Maxwell and Hertz that light is itself an electromagnetic influence propagated through space. But a further implication of the discovery was that the particles of matter which are disturbed during the propagation of light are capable of being influenced by a magnetic field and are therefore themselves electromagnetic in their nature. It required the labours of Larmor, Lorentz, and many others to elucidate and develop this implication of the Faraday effect. But let it be emphasised that the discovery of magneto-optic rotation by Faraday was the seed from which grew the mighty tree of the electron theory of the dispersion and scattering of light.

It was the hope that fundamental advances in knowledge would result from a study of the relation between dispersion and scattering of light that induced me to make it the principal subject of my activities during the last ten years. The hopes

which inspired the work have not been unfulfilled. Incidentally, the researches it involved have had the result of taking the workers in Calcutta into other fields of work in which Faraday was also the pioneer. Amongst these may be mentioned diamagnetism, magne-crystallic action, and magneto-chemistry. The scattering of light by molecules stands in close relation not only with their optical dispersion but also with their magneto-optic behaviour, and especially the magnetic birefringence exhibited by fluids. The result of computations, based on the theory of magnetic birefringence, is to indicate that the molecule of benzene, the aromatic hydrocarbon discovered by Faraday, and even more so, the molecules of naphthalene, anthracene, and so on, possess an astonishing degree of magnetic anisotropy. Experiments undertaken at Calcutta led to the discovery that the aliphatic hydrocarbons also exhibit magnetic birefringence, but this is extraordinarily *feeble*, and *negative* in sign, while the magnetic birefringence of the aromatic hydrocarbons is known to be *strong* and *positive*. The significance of this discovery is, in the first place, that the magnetic anisotropy of the aliphatic molecules is very small. In other words, the chemical difference between the two classes of organic compounds corresponds to a striking magnetic difference. In the second place, the relations between the optic and magnetic axes of the two kinds of molecules are curiously different, and this gives rise to the difference in the sign of the magnetic birefringence. Experimental studies by Mr S Bhagavantam of the magne-crystallic behaviour of organic solids, especially of naphthalene, anthracene, and hexamethylbenzene, gave results in striking agreement with those inferred from magneto-optical experiments with solutions of these substances.

The importance of studying magne-crystallic behaviour, both of diamagnetic and of paramagnetic substances, cannot be over emphasised. Mr K S Krishnan has taken up this subject enthusiastically at the University of Dacca, and has developed very precise methods of measurement, and examined a large number of compounds both inorganic and organic. He has further attempted to correlate the magnetic results with the crystal structure of the substance wherever this is known from X-ray investigations. In the case of diamagnetic crystals, and especially of non-polar substances, we are probably justified in assuming the molecular susceptibility to be a constant characteristic of the substance. On the basis of this assumption, which admits of ready experimental test, it is possible to discuss the question whether the crystal structure assigned by X-ray workers is in accordance with the observed magnetic character of the crystal and the magnetic anisotropy of the molecule ascertained from magneto-optic experiments. It is possible, in fact, to determine what orientations of the molecules are possible within the crystal lattice which are consistent with its observed magnetic properties. This new method of crystal analysis developed by Krishnan appears to be full of promise.

The interpretation of the Faraday effect is itself at the present time not completely free from obscurity. Recent work by J Becquerel, Ladenburg, and

others indicates that we have to distinguish between two kinds of magneto-optic rotation, one associated with paramagnetic substances and the other with diamagnetic bodies. For the latter class, the theory originally suggested by Larmor indicates that the frequency of the 'Larmor precession' in the magnetic field, taken in conjunction with the known optical dispersion, determines the coefficient of magneto-optic rotation. Unfortunately for the theory, however, the observed rotation in many cases falls much short of the calculated value. It seems likely that this anomaly is connected with the known optical and magnetic anisotropy of the molecules, which is not taken into account in the Larmor theory of the Faraday effect. The consideration further suggests itself that, just as we have two kinds of Faraday effect, we should also have two kinds of magnetic birefringence in fluids. In addition to the diamagnetic type of birefringence which is already known, there should be a paramagnetic type of birefringence. Experiments made at my suggestion by Mr S W Chinchalkar indicate that solutions of salts of the rare earths, such as cerium chloride, actually exhibit such an effect. How this special type of birefringence actually arises is not clear. But it seems possible that the cerium ion is optically anisotropic, and that in consequence of the magnetic moment it possesses tends to orientate in the field.

The study of the magnetic behaviour of gases and vapours is a special field of great interest in which Faraday was a pioneer. The experimental technique is very difficult, especially in the case of diamagnetic bodies where slight traces of oxygen as impurity would wholly vitiate the result. Recently the subject has attracted much interest owing to the reported discovery by Dr Glaser of a curious anomaly at low pressures. The subject was taken up by Dr V I Vaidyanathan, who showed that in all probability the Glaser effect was spurious. Further, he found that ozone and ethylene are diamagnetic gases and not paramagnetic ones as had previously been reported by other workers. Measurements were also made and reported by him for a number of other gases and organic vapours.

The question arises whether diamagnetism is purely a molecular property or whether it is also influenced by the state of aggregation of the substance. The accuracy of measurement in the case of vapours is not sufficient to enable this question to be decided for the transition from the gaseous to the liquid condition. *Prima facie* we should not expect any appreciable changes in passing from the liquid to the solid state except in the case of metallic bodies and electrically polar substances where questions of molecular association enter into consideration. In certain well known cases, for example, those of metallic bismuth and graphite, large changes with temperature have been reported, and the susceptibility of bismuth is reduced to a very small fraction of itself on fusion. In such cases, the interesting question arises whether mechanical subdivision of the substance into a fine colloidal state would influence susceptibility. From experiments reported from Chidambaram, by Dr V I Vaidyanathan, and more recently by Dr S Ramachandra Rao, it would seem that this is actually the case.

Closely related to the general question of dependence of diamagnetism on the

state of aggregation is the problem whether the susceptibility of a liquid mixture strictly obeys the additive law in respect of the mass proportions of its constituents. In those cases where anomalies in density and other properties are known, we should expect small deviations from additivity of molecular susceptibilities. A high degree of precision in measurement is necessary to decide this question, and this has been attained by a special optical method developed at Calcutta by Mr S P Ranganadham. It would seem that in certain cases, for example, water and alcohol mixtures, distinct deviations from a straight-line graph are actually obtained.

Before leaving the subject of magneto-chemistry, reference should be made to the work of two notable Indian exponents of the subject, Prof D M Bose of Calcutta and Prof. S S Bhatnagar of Lahore respectively. The former has done extensive and valuable experimental work in tracing the relation between paramagnetic susceptibility and chemical constitution and correlating it with atomic and molecular structure. The theoretical considerations advanced by him in regard to the paramagnetism of the compounds of the transition group of elements lay emphasis on the magnetic moment derived from electron spin and yield results different from those indicated by the well known theory of Hund. They appear to agree better with the experimental facts than the results of Hund's theory. Prof. Bhatnagar is the author of a systematic treatise on magneto-chemistry. He has devised a sensitive interference apparatus for measuring the susceptibilities of small quantities of substances, and discussed very fully the relation between chemical constitution and diamagnetic susceptibility in organic compounds.

Limitations of space do not permit detailed mention of the work of Dr J C Ghosh and others in the field of electrochemistry, in which Faraday was a great pioneer. Reference may, however, be made to the subject of dielectric behaviour, which has received much attention from Indian workers. The study of light-scattering leads one very naturally to consider the question of dielectric behaviour. The birefringence shown by a gas or liquid in an electric field may be connected quantitatively with the electric polarity and anisotropy of its molecules. As was shown by the present writer with Mr Krishnan, it is actually possible to compute the electric moment of the molecule, and even to indicate its geometric position in the molecule from such considerations. Further, the connexion between dielectric behaviour and electric birefringence indicates that in the case of viscous liquids we should expect at low temperatures or in rapidly oscillating fields a disappearance, or even reversal, in the sign of their electric double refraction. Experiments by Mr S C Sircar and the present writer appear to indicate that the suggested phenomenon is actually observed. The interest of this observation lies in its furnishing a demonstration that the electric polarisation of a polar molecule is of two kinds, one arising from its deformation and the other from its orientation under the action of the field.