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CENTENARY OF THE FARADAY EFFECT

EXACTLY a century ago, in November 1845, Faraday announced to the Royal Society the discovery of the phenomenon now known as the Faraday effect in his honour. The discovery was not made by accident but was the result of systematic experiments undertaken by Faraday in the hope of establishing a connexion between the phenomena of light and those of electromagnetism. His first attempts were to find whether an electrostatic field influenced the propagation of light through a material medium. As these experiments failed to yield an observable result, he was led to try the effect of a magnetic field. It was known at the time that a plate of glass under mechanical strain placed between crossed nicols gives a visible restoration of light. Hence, probably, Faraday was led to try a somewhat similar experimental arrangement in which an unstrained block of glass was placed between the poles of the electromagnet. A beam of light polarised by a nicol traverses the glass along the lines of magnetic force and then enters a second nicol which is set in the crossed position with respect to the first. In the absence of a magnetic field, the light transmitted in succession by the first nicol and by the block of glass is blocked by the second nicol. Faraday observed that when the electromagnet was excited, there was a visible restoration of light. That this was due to a rotation of the plane of polarisation of the light was shown by the fact that the light could again be quenched by a suitable rotation of the second nicol, the rotation necessary for this purpose increasing with the strength of the field and changing sign when the direction of the magnetic field was reversed. The magnitude of the effect depends greatly on the substance placed in the field. That Faraday succeeded in observing the phenomenon with the electromagnet of modest dimensions available to him was due to the fortunate circumstance that he used a block of special glass of high refractive index which he had himself manufactured in some earlier researches.

Faraday's discovery must have seemed strange and almost incomprehensible at the time to his contemporaries. In the fullness of time, however, it exercised a profound influence on the progress of physics. The phenomenon showed clearly enough that Faraday was right in thinking of electrical and magnetic actions as field phenomena and not as actions at a distance, as was then generally believed. Faraday's ideas, as is well-known, inspired Maxwell to develop his well-known theory of the electromagnetic field which indicated that light itself is an electro-magnetic wave-motion in space. Hertz's successful experiments of 1888 on the artificial production of electromagnetic waves were inspired in their turn by Maxwell's theory of which they were a confirmation. The identity of all forms of radiation in respect of their nature is now a commonplace of physics, but its recognition is nevertheless one of the greatest achievements of modern science, and it is well to emphasise that Faraday's discovery of his magneto-optic effect pointed the way to its establishment. Incidentally, it may be remarked that the Faraday effect has itself since been observed with electromagnetic radiations over a wide range of frequency. The rotation of the plane of polarisation of radio-waves in the upper layers of the earth's atmosphere by the action of the earth's magnetic field is now a well-established result. A similar phenomenon has also been demonstrated in the laboratory with short electric waves and a strong magnetic field, the necessary density of free electrons in the path of the waves being obtained by sending an electric discharge through a gas such as neon, argon or nitrogen at low pressure. The Faraday effect in the region of infra-red frequencies was observed very early in the history of the subject. Curiously enough, its observation with ultra-violet radiation had to wait nearly half a century. More recently also, reports have appeared which indicate that the plane of polarisation of Rontgen rays is rotated in their passage through a thin sheet of iron placed in a magnetic field.

It is obvious that the presence of a magnetic field would have no effect on the passage of light through a transparent substance, unless the latter is itself capable of being magnetised by the field. This train of thought naturally induced Faraday to examine the question whether the block of glass used in his magneto-optic experiment was capable of magnetisation. Accordingly, he suspended the rod freely by means of a thread between the poles of the electromagnet and found to his astonishment that it set itself at right angles to the lines of magnetic force and not parallel to them as in the familiar case of an iron rod. This discovery naturally interested Faraday immensely, and he was so fully engaged in following it up that, as the story goes, he could not attend the meeting of the Royal Society at which his paper on the discovery of the magneto-optic effect was taken up for reading.

Most ordinary substances, both solid and liquid, which transmit light are diamagnetic like Faraday's block of glass. It is not surprising, therefore, that in practically all cases, the sense of the rotation of the plane of polarisation is the same, though the magnitude may be different in different substances. Even the so-called paramagnetic substances, which are attracted and not repelled by a magnetic field, show in most cases, rotation in the same sense as diamagnetic bodies. This is not surprising when we recall that diamagnetism is a universal property which must be assumed to exist, though in a suppressed form, even in paramagnetic substances. That the Faraday effect arises from the magnetisation of the medium is strikingly shown by the phenomenon (discovered by Kundt in 1884) of the rotation of the plane of polarisation of light in its passage through thin films of iron when placed in a magnetic field. The rotation in this case depends directly on the magnetisation of the film, reaching a saturation value at high field strengths, and altering with temperature in the same way as the magnetisation itself.

The observation of a special form of the Faraday effect characteristic of paramagnetic bodies was first made by J. Becquerel in 1906 and has recently received a great deal of attention. The distinction between the diamagnetic and the paramagnetic rotations arises in respect of the dependence of their magnitude on the temperature of the substance, the strength of the magnetic field and also its variation with the wavelength of the light. The most obvious difference between the two types of rotation is that the dispersion curve of the rotation is symmetric about a characteristic absorption frequency in the diamagnetic case and unsymmetric in the paramagnetic one.

The further question arises why, even granting the magnetisability of the medium, the propagation of light through it should be influenced by such magnetisation. It is clear enough that the answer to this question must be in the identity of the structures in the medium which are responsible alike for its magnetisability and for its influence on the propagation of light. Further, since the refractivity of a substance is connected with the possession by the substance of characteristic absorption and emission frequencies, it follows that the same structures must also be responsible for these latter properties. Thus, the successful observation of the Faraday effect involves as a necessary consequence that the characteristic emissions and absorptions of light by a substance would be influenced when the latter is placed in a magnetic field. It is on record that Faraday looked for such an effect but failed to find it. We may take it that the discovery of this phenomenon made by Zeeman in 1896 was prompted by the same train of ideas as that indicated above. Indeed, the magnetic behaviour of substances, the Faraday effect and the Zeeman effect are all intimately related to each other.

H. Becquerel in 1897 derived, from very simple considerations, a formula connecting the magnitude of the Faraday rotation with the field strength and the refractive dispersion of the medium for light of the particular frequency under consideration. Even according to the most recent theories, the diamagnetic part of the Faraday rotation in a medium composed of atoms is given exactly by Becquerel's formula. This is understood easily enough if we recall that a rotation of the plane of polarisation may be regarded as the result of a difference in the refractive index for left- and right-handed circularly polarised beams of light. In the absence of a magnetic field, the two indices would be identical. In the presence of the field, they would be different and the difference would be the same as that produced by a change of frequency of the light equal to twice the precession frequency of the electrons in the magnetic field given by the famous theorem of Larmor.

It is an interesting fact that the magnitude of the Faraday rotation in many ordinary substances (gas, liquid or solid) is given fairly accurately over the whole range of frequency of the visible spectrum and of the ultra-violet by the Becquerel formula. The observed rotation is, however, smaller than the calculated one by a constant numerical factor (less than unity) which may be called the magneto-optic anomaly of the substance. When we consider the complexity of the molecular structure of most ordinary substances, as also the complexity of their state of molecular aggregation, the appearance of such a simple numerical connection between the refractive dispersion and the Faraday rotation over a wide range of the spectrum must be considered very remarkable. Darwin and Watson, who in 1927 drew attention to the general validity of the Becquerel formula subject to this correction, remarked that while no anomaly greater than unity has been found and that while it is usually between 40 and 60 per cent., there did not appear to be any general principle governing the magnitude of the anomaly.

It is obvious that for real progress in the study of the Faraday effect, a satisfactory explanation of the magneto-optic anomaly referred to above is essential. We may regard the anomaly as a characteristic constant for the molecule, analogous to its optical anisotropy determined from studies on light scattering. A careful study of the figures given by Darwin and Watson shows that there is no direct or simple relationship between the magneto-optic anomaly and the optical anisotropy of a molecule. It is true that there are indications of such a connection, as for instance, in the fact that the constant is somewhat smaller for aromatic compounds than for aliphatic ones and is particularly small for substances such as carbon disulphide, nitrous oxide and nitrobenzene which show large depolarisations in light scattering. On the other hand, we have to consider the fact that the factor for carbon tetrachloride which is optically isotropic is 0·51, whereas for benzene which is highly anisotropic, it is 0·56. While, therefore, there is obviously no direct connection between the optical anisotropy and the magneto-optic anomaly of molelcules, the facts do not rule out a deeper connection in which the specific properties of the individual chemical bonds are involved. Long ago, in a remarkable series of investigations, W. H. Perkin showed that the magnetic rotatory power of organic compounds can be used as a powerful instrument for the study of their constitution. On the other hand, we also know that the optical anisotropy of a molecule is related both to its chemical constitution, and to its geometric configuration. The fuller elucidation of the relationship between these properties would obviously be a matter of great interest.

It is also now fairly certain that the Faraday effect can also be used with great success in the elucidation of the states of molecular aggregation. Here again, the problem centres round the explanation of the magneto-optic anomaly. Some progress has been made towards the solution of this problem in investigations undertaken recently at Bangalore. A fuller report of these investigations will appear in due course.

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SCIENTISTS' STUDY OF LAST SOLAR ECLIPSE

"Mass Attack" on Secrets of Radio-Wave Propagation

ACCORDING to a plan made by the Committee under Sir Edward Appleton, the British physicists and radio engineers co-operated in a series of observations lasting for seven days and centred on the day of the eclipse to obtain the effects of the last solar eclipse upon the upper and lower ionospheres. This particular eclipse afforded an unique opportunity for examination of the solar effects upon the ionosphere, because it occurred near about noon in summer when the lower ionospheric layers were highly ionised and the upper ones were clearly defined and separated one from the other.

It is well known that the formation of the ionized layers, upon which all long distance radio transmission depends has to do with the energy radiated from the sun. It is however, not yet fully known whether the ultra-violet sunlight is solely responsible for this ionisation. It may be that swiftly moving particles of matter from the sun towards the earth also contribute to the effect in some degree. If the latter phenomenon also contributes to the ionisation, the effect of the particles being cut-off by the moon in their path should be observed at a different time from the eclipse itself. The effects of the "corpuscular eclipse" and "optical eclipse" were, therefore, observed.

The normal equipment for measurement of signal intensity, equivalent height of the ionised layer, critical frequency, and maximum equivalent ionic density was arranged to be operated as far north as possible so as to be near the track of totality. In ultra short-wave case, the "Radar" equipment of war-time was employed in the detection of the ionisation responsible for the "bursts" as well as other abnormal patches in the lower ionosphere. Observations on American radio stations operating on very long wave-lengths were carried out by several organisations so that variation in their signal strength could yield information about the lower ionosphere. Observations on long and medium-wave stations in Scandinavia were taken to obtain the variation of radio-wave absorption during the eclipse and give information about the 'E' and 'D' layers. The short-waves came in for two classes of observations as follows:—(1) Stations in U.S.A., Canada, U.S.S.R. and South Africa were closely observed as to the variation in their signal strength during the eclipse and further information about "F_2" layer could thereby be obtained. The transmission paths of American and Russian stations passed near the track of totality while those of African stations remote from this served as a check upon the eclipse variations. (2) Stations in Norway and Sweden which were at shorter distances from Britain were observed for the variation in their signal strength.

The ultra short-wave stations were also observed for the "bursts" (sudden returns of energy from the upper regions lasting for a few seconds) to find out whether these were subject to a certain degree of solar control. Some observations were also made by direction-finding apparatus on stations laying far to the West, the East and the South of Britain to find out whether the incoming radio signals were diverted from their true great circle course due to the effect of the eclipse.

It is expected that the obsrvations when analysed thoroughly will contribute greatly to the phenomenon of radio-wave propagation on all wave-lengths.

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