THE EFFECTS OF A MAGNETIC FIELD ON RADIATION: MEMOIRS BY FARADAY, KERR AND ZEEMAN

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SCIENTIFIC MEMOIRS

EDITED BY

J. S. AMES, PH.D.

PROFESSOR OF PHYSICS IN JOHNS HOPKINS UNIVERSITY

VIII.

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EDITED BY

E. P. LEWIS, PH.D.

ASSISTANT PROFESSOR OF PHYSICS, UNIVERSITY OF CALIFORNIA

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W. P. I

PREFACE

Historical

In the early part of this century possible relationships between the various "forces of nature" began to attract the attention of physicists. In 1800 William Herschel discovered that a "heat spectrum" is superimposed on and extends beyond the visible solar spectrum, indicating some relationship between heat and light. This seems to have suggested to Domenico Morichini, of Rome, the search for a relationship between light and magnetism. In 1812 he claimed that he had been able to magnetize steel needles by exposing them to the violet radiation in the solar spectrum. Others, including Mrs. Somerville, in England, believed that they had verified his results, but many were unable to reproduce them, and it was finally demonstrated that all these effects had been due to other causes. The dispute over this question extended over many years, and is an instructive illustration of the difficulty which even skilled experimenters may have in solving a comparatively simple experimental problem.

About 1825 Sir John Herschel sent a polarized beam of light along the axis of a helix carrying an electric current. Examination with an analyzer showed no effect. He also intended to test the effect of a polarized beam passing tangentially by a conductor carrying a current, but never executed the experiment.

No other attempt to show a relationship between light and magnetism seems to have been made until Faraday undertook the investigation described in the following pages.

Theoretical

In the *Proceedings of the Royal Society* for June, 1856, Sir William Thomson wrote: "The magnetic influence on light discovered by Faraday depends on the direction of motion of moving particles. For instance, in a medium possessing it, particles in a straight line parallel to the lines of magnetic force, displaced to a helix round this line as axis, and then projected tangentially with such velocities as to describe circles, will have different velocities according as their motions are round in one direction (the same as the nominal direction of the galvanic current in the magnetizing coil) or in the contrary direction. But the elastic reaction of the medium must be the same for the same displacements, whatever be the velocities and directions of the particles; that is to say, the forces which are balanced by centrifugal force of the circular motions are equal, while the luminiferous motions are unequal. The absolute circular motions being, therefore, either equal, or such as to transmit equal centrifugal forces to the particles initially considered, it follows that the luminiferous motions are only components of the whole motion; and that a less luminiferous component in one direction, compounded with a motion existing in the medium when transmitting no light, gives an equal resultant to that of a greater luminiferous motion in the contrary direction, compounded with the same non-luminous motion."

Maxwell, in his *Electricity and Magnetism*, vol. ii., chap. xxi, offers the following partial physical explanation as an extension of the above remarks:* "It is a well-known theorem in kinematics that two uniform circular vibrations, of the same amplitude, having the same periodic time, and in the same plane, but revolving in opposite directions, are equivalent, when compounded together, to a rectilinear vibration. The periodic time of this vibration is equal to that of the circular vibrations, its amplitude is double, and its direction is in the line joining the points at which two particles, describing the circular vibrations in opposite directions around the same circle, would meet. . . . We may therefore express the phenomenon of the rotation of the plane of polarization in the following manner:—A plane-polarized ray falls on the medium. This is equivalent to two circularly polarized rays, one right-handed, the other left-handed (as regards the observer). After

* In 1855 Verdet suggested a similar explanation. (*Ann. Chim Phys.* 43, p. 37, 1856.)

passing through the medium the ray is still plane-polarized, but the plane of polarization is turned, say, to the right (as regards the observer). Hence, of the two circularly polarized rays, that which is right-handed must have had its phase accelerated with respect to the other during its passage through the medium.

"In other words, the right-handed ray has performed a greater number of vibrations, and therefore has a smaller wavelength, within the medium, than the left-handed ray which has the same periodic time. . . . From this we conclude, from the reasoning of art. 21, that in the medium, when under the action of magnetic force, some rotatory motion is going on, the axis of rotation being in the direction of the magnetic forces; and that the rate of propagation of circularly polarized light, when the direction of its vibratory rotation and the direction of the magnetic rotation of the medium are the same, is different from the rate of propagation when these directions are opposite.

"This angular velocity cannot be that of any portion of the medium of sensible dimensions rotating as a whole. We must, therefore, conceive the rotation to be that of very small portions of the medium, each rotating on its own axis. This is the hypothesis of molecular vortices.

"The motion of these vortices, though, as we have shown, it does not sensibly affect the vibratory motions of large bodies, may be such as to affect that vibratory motion on which the propagation of light, according to the undulatory theory, depends. The displacements of the medium during the propagation of light will produce a disturbance of the vortices, and the vortices, when so disturbed, may react on the medium so as to affect the mode of propagation of the ray.

"It is impossible, in our present state of ignorance as to the nature of the vortices, to assign the form of the law which connects the displacement of the medium with the variation of the vortices."

Righi proved experimentally that a right-handed circularly polarized beam travels more rapidly than a left-handed one in substances which cause a right-handed rotation in a magnetic field.

The physical explanation of the problem is complicated by the fact that the magnetic force does not affect the ethereal vibrations directly, but only through the intervention of matter.

Reference to some of the theories will be made in discussing the Kerr effect. Several of the theories lead to an expression for the rotation of the form

$$\theta = \mathrm{MH}l\frac{\mu^2}{\lambda^2}\left(\mu - \lambda\frac{d\mu}{d\lambda}\right),$$

where M is a constant depending on the medium, H the intensity of the field, l the thickness of the medium, μ its index of refraction, and λ the wave-length of the light. This expression is in fair accord with the results of experiments.

The decomposition of a linear vibration into two circular components travelling with different velocities in a magnetized medium will account for the Faraday effect, but the Kerr effect is much too complicated to be explained by such a simple lation.

E. H. Hall * in 1880 discovered that the stream lines of an electric current flowing through a thin conducting sheet transverse to a magnetic field are deflected, indicating the existence of a small "magnetic component" at right angles to the original current and the field. Rowland, assuming that a similar effect exists in a dielectric medium, showed that such an effect would account for rotation. Bassett, H. A. Lorentz, and others † have likewise explained the Kerr effect in an analogous manner, but in each case the explanation was incomplete in some point; moreover, the Hall effect itself was left unexplained.

Lorentz assumed that all electrical disturbances in dielectrics are due to the motions of charged "dielectric ions" (entirely different from electrolytic ions), which are subject to ponderomotive forces when moving in a magnetic field. If the anions and cations, the motion of which in opposite directions constitutes an electric current, move with equal velocities, they will be equally displaced by the field, and there can be no electrical separation.

Wind assumed that there are "conductive" as well as "dielectric" ions, and that the oppositely charged ions move

* [*Phil. Mag.* (5), 10. 136, 1880; *Am. Jl. Science* (3), 20, p. 52, 1880.]

† [*See Bibliography.*]