December 21, 1876.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read :—

I. "On the Rotation of the Plane of Polarization of Light by Reflection from the Pole of a Magnet." By GEORGE FRANCIS FITZGERALD, M.A. Communicated by G. JOHNSTONE STONEY, F.R.S. Received November 14, 1876.

At a meeting of the Dublin Scientific Club on Monday the 6th November, Professor Barrett gave the Club an account of Mr. Kerr's experiments on the rotation of the plane of polarization of a ray of light when reflected from the surface of the end of a magnet, to which additional interest was attached by the reading of a letter from Mr. Kerr to Professor Barrett giving an account of the mode of making and of the last results of his experiments. At the time I proposed trying whether any similar effects would be produced by reflection from the surface of a crystal of quartz cut perpendicularly to the axis, as I was led to think there might be, owing to the similarity of the rotatory polarization of quartz and of substances under magnetic action. Following out that clue, I obtained the following explanation of Mr. Kerr's experiment, and was enabled, through Professor Barrett's kindness in helping me to verify my recollections of Mr. Kerr's letter, to make sure that my theory explains the facts.

Faraday has shown, in the nineteenth series of his experimental researches, that a ray of plane-polarized light, when transmitted through any solid (diamagnetic ?) transparent medium under the action of a powerful magnet, has the plane of its polarization rotated in that direction in which a positive current must circulate round the ray in order to produce a magnetic force in the same direction as that which actually exists in the medium. Verdet, however, discovered that in certain *ferromagnetic* media (as, for instance, a strong solution of perchloride of iron in wood-spirit or ether) the rotation is in the opposite direction to the current which would produce the magnetic force.

Now Fresnel's explanation of the rotatory power of quartz has been applied by Professor Maxwell, in his 'Electricity and Magnetism,' vol. ii. p. 402, to explain the similar, though not identical, phenomenon of magnetic rotation of light. He there, in § 812, gives this explanation in the following words :—" A plane-polarized ray falls on the medium.

This is equivalent to two circularly polarized rays, one right- and the other left-handed (as regards the observer). After passing through the medium the ray is still plane-polarized, but the plane of its 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 wave-length within the medium than the left-handed ray which has the same periodic time." This is the same as saying that the velocity of the right-handed ray is less within the medium than the left-handed, or that the refractive index for right-handed rays is greater than for left-handed in a medium that rotates light to the right. Hence, from what Verdet has shown, it appears that, in a ferro-magnetic substance, *for a ray of light travelling from the south to the north pole, the magnetic action is such as to make the refractive index for right-handed circularly polarized rays less than for left-handed ones*; for in this case the plane of polarization is turned to the left, for it is a right-handed current that would produce the magnetic force.

By applying this to the case of light reflected from the south pole of a magnet, we get what I believe to be the true explanation of Mr. Kerr's interesting experiment. In like manner, as in the case of a transmitted ray, I consider the incident plane-polarized ray to be the resultant of two circularly polarized ones, one right- and the other left-handed. Now, for the right-handed one, the refractive index at the surface of the south pole of the magnet, being a ferro-magnetic substance, is less than for the left-handed ray. Hence if each of the two circularly polarized rays be supposed to be the resultant of two plane-polarized rays, one polarized in the plane of incidence and the other at right angles to it, the intensities of these four rays being equal, it is evident that the intensities of the pair of reflected rays corresponding to the left-handed ray will be greater than the corresponding intensities of those due to the right-handed ray. Hence the two rays which were polarized perpendicularly to the plane of incidence, and which originally destroyed one another, will, after reflection, have a component in the direction of the vibration of the left-handed ray after reflection. Now, on account of the change of direction of the ray on reflection, this latter is towards the right. This is completely explained in M. Jamin's 'Cours de Physique,' vol. iii. part 2, p. 674, where he shows that a ray the azimuth of whose plane of polarization was originally towards the right is by reflection turned towards the left. Hence the result of reflection is to furnish two rays, one polarized in the plane of incidence, and the other at right angles to it. The phases of these rays will, in general, be different; for they differed by 90° before reflection, and, except at the polarizing angle for iron, this difference of phase would not be completely destroyed, so that

the resultant would generally be an elliptically polarized ray the direction of whose major axis would make a small angle towards the right with the plane of incidence; and at the polarizing angle for iron this ellipse would become a plane-polarized ray whose plane of polarization was turned towards the right, which I understand to be the direction in which Mr. Kerr observed it to be turned—although from some ambiguity as to the meaning of right and left rotations in a ray, arising from not specifying whether it is relative to the direction in which the ray is going or in which it is observed, I am not quite sure whether I understand Mr. Kerr correctly. Also from the fact that there are exceptions* to the rule that rotations are positive for diamagnetic and negative for ferro-magnetic substances, neutral chromate of potash being diamagnetic, yet producing a negative rotation, I should be rather inclined to deduce the direction of the rotation that would be produced, if iron were transparent, from Mr. Kerr's experiment.

It would be quite easy to deduce the difference of the refractive indices of iron for the two circularly polarized rays if we knew the amount by which the plane of polarization is turned; but it would be necessary to employ MacCullagh's or Cauchy's formulæ for the intensities of the reflected rays; and these are so complicated that it is hardly worth while going through the calculations, as the effect Mr. Kerr has observed seems only barely observable.

Similar effects must, of course, occur in the cases of diamagnetic substances, organic solutions, and quartz; but the amounts in these cases would be entirely beyond the range of observation of our present instruments; for in quartz, for instance, the difference of the refractive indices of the two circularly polarized rays is only 0·00008.

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Observations confirmatory of the foregoing Explanation.

Since sending my explanation of Mr. Kerr's experiment I have made some experiments in confirmation of it. The instruments, with the exception of the electro-magnet, which was kindly lent to me by Mr. Yeates, are the property of Trinity College, Dublin, and were placed at my disposal by Professor Leslie.

The electro-magnet I used is of the horseshoe pattern, with movable soft iron armatures, a face of one of these being well polished. The magnet was placed vertically, and the armatures were arranged on the poles so that the polished face was vertical and a vertical edge of the other armature parallel and very close to this face. A folded piece of paper was inserted at the top between the edge and the face to prevent their being drawn together when the magnet was set in action. Two Nicol's prisms were so placed that a horizontal beam of light traversing

* Unless, indeed, these are due to the nature of the solvent.

one of them was reflected down the other by the polished face from that part of its surface which was opposite the edge.

A beam of sunlight was now transmitted through the apparatus and observed on emerging from the second Nicol. The following results were thus obtained:—When the light was polarized by the first Nicol, either in or perpendicularly to the plane of incidence, and when it had been extinguished by the analyzer, as soon as the electro-magnet was set in action the light immediately reappeared. On now slightly moving the analyzer the light could be partly extinguished; but no motion of the analyzer could make the field as black as it had been before the magnetism was excited, thus conclusively proving that what was produced was an elliptically polarized ray, as I had anticipated. When the light was reflected from a south pole the plane of polarization was rotated to the right of the observer, which is the direction of rotation assumed in my explanation.

I next covered a portion of the polished face with gold leaf, as Professor Barrett had suggested; and now the light reflected from this diamagnetic substance was unaffected by the magnetism, as I had also anticipated. I exhibited all these effects to Mr. Stoney, who entirely confirmed my observations.

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The angle of incidence in the experiments described above was about 60°. If the incidence were either perpendicular or grazing, the theory which I have proposed would lead to the conclusion that the angle between the major axis of elliptic polarization and the original plane of polarization would vanish. If, accordingly, the observation can be made at a perpendicular incidence, and if the Nicol's prisms be so placed as to extinguish the light before magnetizing the iron, then on exciting it light ought to reappear, as it does at oblique incidences; but the field should not become darker on moving the analyzer.

I attribute great weight to the verification of my theory arising from the fact that the polarization of the reflected ray is found by experiment to be in general elliptic, and also from the fact that there is no appreciable effect when gold, a diamagnetic substance and therefore feeble, is substituted for iron.

Since communicating my paper, I learn, through Professor Stokes, that when Mr. Kerr's paper was read before Section A of the British Association, both he and Sir W. Thomson spoke of the possibility of connecting Mr. Kerr's result with a powerful double refraction of the same kind as the feeble double refraction shown by transparent substances under the influence of magnetism. It is a connexion of this kind which I have endeavoured to demonstrate.