the ethnological specimens brought back from the Pacific islands by the Wilkes Exploring Expedition. Commissioner Bowers has notified the Smithsonian Institution that the naval and civil attachés of the vessel will be given special instructions to be on the look-out for desirable ethnological material.

There is every reason to believe that this expedition will yield valuable scientific results, and will be creditable to the United States. It is the most important marine expedition on which the Fish Commission has embarked, and one of the most promising scientific enterprises in which the U.S. Government has ever engaged. It is a matter for congratulation that, in the activity in exploration of the seas now being exhibited by various Governments, the United States will participate under such favourable auspices and be represented by a man of science of such wide experience in deep-sea investigation as Prof. Agassiz.

MAGNETO-OPTIC ROTATION AND ITS EXPLANATION BY A GYROSTATIC SYSTEM.[1]

THE action of magnetism on the propagation of light in a transparent medium has been rightly regarded as one of the most beautiful of Faraday's great scientific discoveries. Like most important discoveries it was no result of accidental observation, but was the outcome of long and patient inquiry. Guided by a conviction that (to quote his own words) "the various forms under which the forces of matter are made manifest have one common origin," he made many attempts to discover a relation between light and electricity, but for very long with negative results. Still, however, retaining a strong persuasion that his view was correct, and that some such relation must exist, he was undiscouraged, and only proceeded to search for it more strictly and carefully than ever. At last, as he himself says, he "succeeded in *magnetising and electrifying a ray of light, and in illuminating a magnetic line of force.*"

Faraday pictured the space round a magnet as permeated by what he called lines of force; these he regarded as no mere mathematical abstractions, but as having a real physical existence represented by a change of state of the medium brought about by the introduction of the magnet. That there is such a medium surrounding a magnet we take for granted. The lines of force are shown by the directions which the small elongated pieces of iron we have in iron filings take when sprinkled on a smooth horizontal surface surrounding a horizontal bar magnet, as in the experiment I here make. [*Experiment to show field of bar magnet by iron filings.*]

The arrangement of these lines of force depends upon the nature of the magnet producing them. If the magnet be of horse-shoe shape, the lines are crowded into the space between the poles; and if the pole faces be close together and have their opposed surfaces flat and parallel the lines of force pass straight across from one surface to the other in the manner shown in the diagram before you. [*Diagram of field between flat pole faces.*]

The physical existence of these lines of force was demonstrated for a number of different media by the discovery of Faraday to which I have already referred, and on which almost all the later work on the relation of magnetism to light has been founded. I am permitted by the kindness of the authorities of this Institution to exhibit here the very apparatus which Faraday himself employed, though for the various experiments I have to make it is necessary to actually use another set of instruments. [*Apparatus shown.*] Before repeating Faraday's experiment, let me describe shortly what I propose to do, and the effect to be observed.

A beam of plane polarised light is produced by passing white light from this electric lamp through a Nicol's prism. To understand the nature of plane polarised light, look for a moment at this other diagram (Fig. 1). It represents a series of particles displaced in a certain regular manner to different distances from the mean or equilibrium positions they originally had along a straight line. They are moving in the directions shown by the arrows and with velocities depending on their positions, as indicated by the lengths of the arrows. Suppose a certain interval of time to elapse. The particles will have moved in that time to the positions shown in this other diagram (Fig. 2) on the same sheet. It will be seen that the velocities as well as the positions of the particles have altered; but that the configuration is the same as would be given by the former diagram moved through a certain distance to the left.

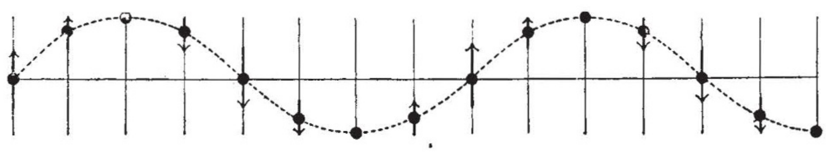

FIG. 1.

Thus an observer looking at the particles and regarding their configuration would see that configuration apparently move to the left; and this, it is very carefully to be noted, is a result of the transverse motions of the individual particles. In another interval of time equal to the former the arrangement of particles will appear to have moved a further distance of the same amount towards the left.

This transverse motion of the particles, thus shown displaced from their equilibrium positions, represents the vibration of the medium which is the vehicle of light, and the right to left motion of the configuration of particles is the wave motion resulting from that vibration. I do not say that the medium is thus made up of discrete particles, or that the different portions of it vibrate in this manner, but there is undoubtedly a directed quantity transverse to the direction in which the wave is travelling, the value of which at different points may be represented by the displacements of the particles, and which varies in the same manner, and results, as here shown, in the propagation of a wave of the quantity concerned.

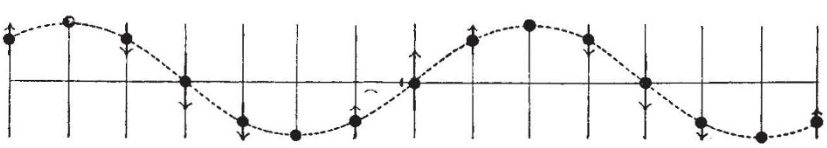

FIG. 2

In fact, we have here a representation of a wave of plane polarised light. The directions of vibration are right lines parallel at all points along the wave. Ordinary light consists of vibrations the directions of which are not parallel if rectilinear, and each vibration is therefore capable of being resolved into two in directions at right angles to one another. The Nicol's prism, in fact, splits a wave of ordinary unpolarised light into two waves, one in which the vibrations are in one plane containing the direction in which the light is travelling, the other in a plane containing the same direction, but at right angles to the former. One of these waves is stopped by the film of Canada balsam in the prism and thrown out of its course, while the other wave is allowed to pass on undisturbed.

If the wave thus allowed to pass by one Nicol's prism be received by another it is found that there are two positions of the latter in which the wave passes freely through the second

[1] A discourse delivered at the Royal Institution by Prof. Andrew Gray, F.R.S.

prism, and two others in which the wave is stopped. The prism can be turned from one position to another by properly placing it and then turning it round the direction of the ray. It is found that if the prism be thus turned from a position in which the light is freely transmitted we come after turning it through 90° to a position in which the light is stopped, and that if we go on turning through another angle of 90° a position is reached in which the light is again freely transmitted, and so on, the light being alternately stopped and transmitted by the second prisms in successive positions 90° apart.

The mode of passage of the wave by the Nicols when their planes are parallel, and its stoppage when the planes are crossed, are illustrated by this diagram (Fig. 3) of a vibrating cord and two slits. When the slits are parallel, the vibration

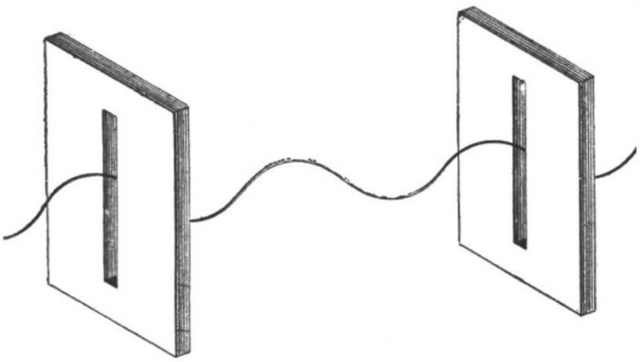

FIG. 3.

which is passed by one is passed by the other; when they are crossed, a vibration passed by one is stopped by the other.

Two planes of symmetry of the prisms parallel to the ray, and called their principal planes, are parallel to one another when the light passes through both, and are perpendicular to one another when the light passed by the first is stopped by the second. We shall call the first prism the polarising prism, or the *polariser*, from its effect in producing plane polarised light; the other, the *analyser*. The stoppage of the light in the two positions 180° apart of the second prism and its passage in the two intermediate positions show that the light passed by the first prism is plane polarised.

Now a beam of plane polarised light is passed through the perforated pole-pieces of this large electro-magnet (Fig. 4), so

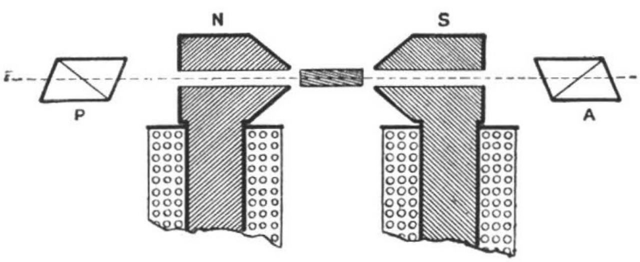

FIG. 4.

that the beam travels between the pole faces along the direction which the lines of force there would have if the magnet were excited by a current. The arrangement of the apparatus is as shown in the diagram. The light is polarised by the prism P, passes through the magnetic field, and then through the analysing prism A, to the screen. As you see, when the second prism is turned round the ray the light on the screen alternately shines out and is extinguished, and you can see also that the angle between the positions of free passage and extinction is 90°.

I now place in the path of the beam this bar of a very remarkable kind of glass, some of the properties of which were investigated by Faraday. It is a very dense kind of lead glass, which may be described as a silicated borate of lead; that is, it contains silica, boric acid and lead oxide. The beam is not disturbed although the light passes through the glass from end to end. I now adjust the analysing prism to very nearly complete extinction, and then excite the magnet. If the room is sufficiently darkened I think all will see that when the magnet is excited there is a very perceptible brightening of the dim patch of light on the screen, and that this brightening disappears when the current is removed from the magnet. This is Faraday's discovery.

How are we to describe this result? What effect has been produced by the magnetic field? It is clear that the direction of vibration of the light emerging from the specimen of heavy glass has been changed relatively to the prism so that the light now readily passes. It is found, moreover, that the amount of turning of the direction of vibration round the ray is proportional to the length of the specimen, so that the directions of vibration at different points along the wave within the specimen lie on a helically twisted surface, and may be regarded as represented by the straight rods in the model before you on the table (Fig. 5).

It is also found that the amount of the turning depends on the intensity of the magnetic field—is, in fact, simply proportional to that intensity. Hence the turning is proportional to the mean intensity of the field, and to the length of the path in the medium, that is, to the products of these two quantities. It also depends on the nature of the medium. The angle of turning produced by a field of known intensity when the ray passes through bisulphide of carbon has been very carefully measured by Lord Rayleigh, whose results are of great value for other magnetic work.

The law of proportionality of the amount of turning of the plane of polarisation to the intensity of the magnetic field in

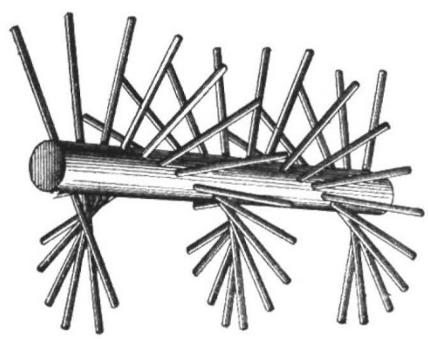

FIG. 5.

the space in which the substance is placed is not, however, to be regarded as established for strongly magnetic substances, such as iron, nickel or cobalt. The matter has not yet been completely worked out, but the turning in such cases seems to be more nearly proportional to the intensity of magnetisation, a different quantity from the intensity of the magnetic field producing the magnetisation. If this law be found correct the angle of turning will be proportional to the product of the intensity of magnetisation and to the length of the path; and the angle observed divided by this product will give another constant, which has been called Kundt's constant.

The rotation of the plane of polarisation in strongly magnetised substances was investigated by Kundt, the very eminent head of the Physical Laboratory of the University of Berlin, who died only a year or two ago. Kundt is remembered for many beautiful methods which he introduced into quantitative physical work; but no work he did was more remarkable than that which he performed in magneto-optic rotation when he succeeded in passing a beam of plane polarised light through plates of iron, nickel and cobalt. Such substances, though apparently opaque to light, are not really so when obtained in plates of sufficient thinness. In sufficiently thin films all metals, so far as I know, are transparent, not merely to Röntgen rays, but to ordinary light. Kundt conceived the idea of forming such films of the strongly magnetic metals, so as to investigate their properties as regards magneto-optic rotation. He succeeded in obtaining them by electroplating platinised glass with such thin stratums of these metals that light passed through them in sufficient quantity for observation. The rotation produced by the glass and the exceedingly thin film of platinum was determined once for all and allowed for. Kundt obtained the remarkable result that the magnetic rotatory power in iron is so great that light transmitted through a thickness of one centimetre of iron magnetised to saturation is turned through an angle of over 200,000°, that is, that light passing through a thickness of an inch of iron magnetised to saturation would have its plane of polarisation turned completely round more than a thousand times; in other words, one complete turn would be given by a film less than $\frac{1}{1000}$ of an inch in thickness. A scarcely smaller result has been found by Du Bois for cobalt, and a maximum rotation of rather less than half as much by the same experimenter for nickel.

The direction of turning in all the cases which have so far been specified—that is, Faraday's glass, bisulphide of carbon, iron, nickel and cobalt—is the same as that in which a current of electricity would have to flow round the spires of a coil of wire surrounding the specimen so as to produce the magnetic field. This we call the *positive* direction. There are, however, many substances in which the turning produced by the magnetic field is in the contrary or negative direction; for example, ferrous and ferric salts of iron, chromate and bichromate of potassium, and in fact most compound substances which are feebly magnetic.

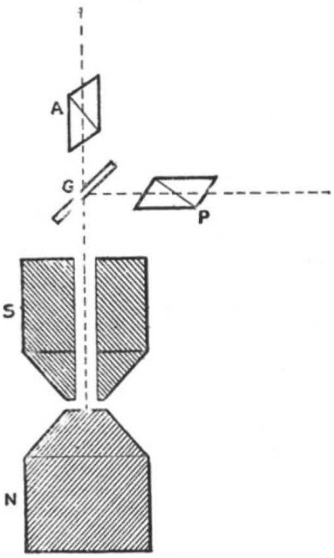

FIG. 6.

Faraday established by his experiments the fact that substances fall into two distinct classes as tested by their behaviour under the influence of magnetic force. For example, an elongated specimen of iron, nickel or cobalt, if freely suspended horizontally between the poles of our electro-magnet, would set itself with its length along the lines of force. On the other hand, a similar specimen of heavy glass, or a tube filled with bisulphide of carbon, would, if similarly suspended, set itself across the lines of force. The former substances were therefore called by Faraday paramagnetic, the latter diamagnetic.

It might be supposed that diamagnetics would show a turning effect opposed to that found in paramagnetics, but this is not the case. As we have seen, bisulphide of carbon and heavy glass, which are diamagnetics, show a turning in the same direction as that produced in iron—as indeed do most solid, fluid and gaseous diamagnetics. Feebly paramagnetic compound substances, on the other hand, produce negative rotation.

A theory of diamagnetism has been put forward in which the phenomena are explained by supposing that all substances are paramagnetic in reality, but that so-called diamagnetic bodies are less so than the air in which they are immersed when experimented on. Thus the diamagnetic quality is one of the substance relatively to air, in the same kind of way as the apparent levity of a balloon is due to the fact that its total weight has a positive value, but is less than that of the air displaced by the balloon and appendages. Lord Kelvin's dynamical explanation of magneto-optic rotation does not bear out this view of the matter.

Before passing to the dynamical explanation, however, I must very shortly call attention to some remarkable discoveries in this subject made by Dr. John Kerr, of Glasgow. I have here an electro-magnet arranged as in the diagram before you (Fig. 6). The light from the lamp is first plane polarised by the Nicol P, then it is thrown on the piece of silvered glass G, and part of it is thereby reflected through this perforated pole-piece so as to fall normally on the polished point of the other pole-piece. Reflection thus takes place at perpendicular incidence, and the reflected light is received by this second Nicol. When the magnet is unexcited the second Nicol is arranged so as to quench the reflected light. The magnet is then excited, and it is found that the light is faintly restored, showing that an effect on the polarisation of the light has been produced by the magnetisation. It is to be noticed here that the incident and reflected light is in the direction of magnetisation. We shall not pause to make this experiment. It was arranged this morning and successfully carried out; but the effect is slight, and might not be noticeable without precautions, which we have hardly time to make, to exclude all extraneous light from the screen.

It would perhaps be incorrect to say that the plane of polarisation has been rotated in this case, as it has been asserted by Righi that the light after reflection is no longer plane polarised, but that there are two components of vibration at right angles to one another, so related that the resultant vibration is not

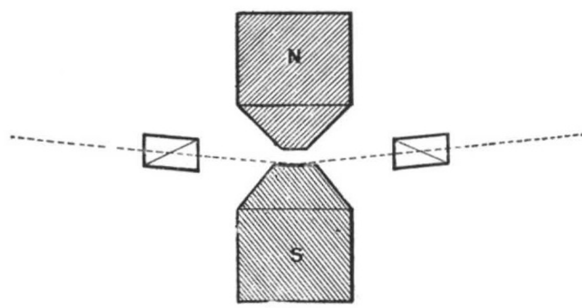

FIG. 7.

rectilinear but elliptical. There is therefore no position in which the analysing prism can be placed so as to extinguish the reflected light. The transverse component necessary to give the elliptic vibration is, however, in this case, if it exists, very small, and very nearly complete extinction of the beam can be obtained by turning the analysing prism round so as to stop the other component vibration. The angle through which the prism must be turned to effect this is the amount of the apparent rotation. The direction of rotation is reversed by reversing the magnetism of the reflecting pole. Dr. Kerr found that the direction is always that in which the current flows in the coils producing the magnetisation of the pole.

Dr. Kerr also made experiments with light obliquely incident on a pole-face, with the arrangement of apparatus shown in this other diagram (Fig. 7). He found that the previously plane polarised light was by the reflection rendered slightly elliptically polarised. A slight turning of the analysing Nicol was necessary to place it so as to stop the vibration corresponding to the long axis of the ellipse and so secure imperfect extinction.

These effects are, like those of normal incidence, very small, and they can hardly be shown to an audience.

(To be continued.)

SCIENCE SCHOOLS AND CLASSES.[1]

THE annual Report of the Department of Science and Art furnishes much information on the progress made in elementary scientific instruction year by year; and the following facts, derived from the Report just published, shows the vast extent of the Department's operations during 1898. The number of students under instruction in schools eligible for the

[1] Forty-sixth Report of the Department of Science and Art of the Committee of Council on Education, with appendices. Pp. 320. (H.M. Stationery Office, 1899.)