Royal Institution of Great Britain.

WEEKLY EVENING MEETING,

Friday, January 29, 1897.

SIR JAMES CRICHTON-BROWNE, M.D. LL.D. F.R.S. Treasurer and Vice-President, in the Chair.

PROFESSOR JAGADIS CHUNDER BOSE, M.A. D.Sc.
Professor of Physics in the Presidency College, Calcutta.

Electro-Magnetic Radiation and the Polarisation of the Electric Ray.

THE great work of Hertz in verifying the anticipations of Maxwell has been followed in this country by many important investigations on Electric Waves. The Royal Institution witnessed the repetition of some of the brilliant experiments of Professors Fitzgerald and Lodge. My interest in the subject, and inspiration for work, are to a great extent derived from the memorable addresses delivered in this hall, and I am glad to have an opportunity to lay before you, at this very same place, an account of some work I have been able to carry out.

As the subject of ether waves produced by periodic electric disturbances is to be dealt with in this lecture, a few models exhibiting the production of material waves by periodic mechanical disturbances may be of interest. A pendulum swings backwards and forwards at regular intervals of time; so does an elastic spring when bent and suddenly released. These periodic strokes produce waves in the surrounding medium; the aerial waves striking the ear may, under certain conditions, produce the sensation of sound. The necessary condition for audibility is, that the frequency of vibration should lie within certain limits.

As the air is invisible, we cannot see the waves that are produced. Here is a model in which the medium is thrown into visible waves by the action of periodic disturbances. The beaded string representing the medium is connected at its lower end with a revolving electric motor. The rotation of the motor is periodic; observe how the periodic rotation throws the string into wave forms; how these waves carry energy from the source to a distant place; how a suitable receiver, a bell for example, is made to respond. I now produce quicker rotation by sending a stronger current through the motor; the frequency or pitch is raised, and the waves formed are seen to become shorter. By means of the attached counter, the different frequencies are determined.

Here is a second model, a spiral spring, attached to which is a thin string. As the string is pulled, the spring is strained more and more, till the thread suddenly breaks. The spring, suddenly released, is seen to oscillate up and down. Electric vibration is produced in

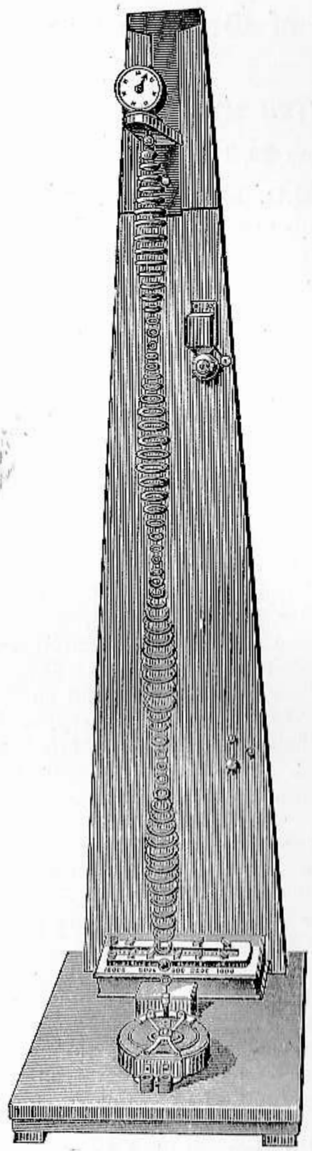

FIG. 1.—Mechanical Wave Apparatus.

(The current regulating the speed of rotation is varied by an interposed rheostat. The counter is at the top.)

a somewhat similar way. If two metallic spheres be strongly charged with opposite electrifications, the medium is electrically strained, and when this strain is suddenly removed by a discharge, waves are produced in the medium. The discharge is oscillatory, consisting of backward and forward rushes of electricity; positive electricity flowing now in one direction, and immediately afterwards in an opposite direction. These rapid alternate flows, giving rise to ether vibration, may be illustrated by a modification of the well-known Cartesian diver experiment. By means of a bulb and connecting tube, alternate compression and rarefaction may be produced in the cylinder, attended with alternate rushes of air-currents through the connecting tube. These give rise to oscillation of the immersed ball.

By oscillatory electric discharge, waves are produced in the ether. To produce oscillatory discharge, Hertz used plates or rods with sparking balls at the ends. He found that the sparks ceased to be oscillatory as soon as the surface of the sparking balls got roughened; there was then a leak of electricity, and no sudden discharge. The balls had to be taken out every now and then for repolishing, and the process was tedious in the extreme. Prof. Lodge made the important discovery that if two side balls were made to spark into an interposed third ball, the oscillatory nature of the discharge was not affected

to so great an extent by a change in the nature of the surface. But even here the disintegration of the sparking surface produced by a torrent of sparks soon puts an end to oscillation. I found this difficulty removed to a great extent by making the balls of platinum, which resists the disintegrating action. I also found that it was not at all necessary to have a series of useless sparks, which ultimately spoils the efficiency of the radiator and makes its action uncertain. A flash of radiation for an experiment is obtained from a single spark, and for a series of experiments one does not require more than fifty or a hundred sparks, which do not in any way affect the radiator. As an electric generator I use a small and modified form of Ruhmkorff's coil, actuated by a single storage cell. A spark is produced by a short contact and subsequent break of a tapping key. With these modifications one of the most troublesome sources of uncertainty is removed. The coil and the cell are inclosed in a small double-walled metallic box, with a tube for the passage of the electric beam. The magnetic variation due to the make and break of the primary of the Ruhmkorff's coil, disturbs the receiver. This difficulty is removed by making the inner box of soft iron, which acts as a magnetic screen.

A few words may here be said about the necessary conditions to be kept in view in making an electric wave apparatus an instrument of precision. If one merely wishes to produce response in a receiver at a distance, the more energetic the vibration is, the more likely it is to overcome obstacles. The waves may with advantage be of large size, as they possess very great penetrative power. The surface or the depth of the sensitive layer in the receiver may be extended, for if one part of it does not respond another part will. But for experimental investigations the conditions to be fulfilled are quite different. Too great an intensity of radiation makes it almost impossible to prevent the disturbance due to stray radiation. As the waves are invisible, it is difficult to know through what unguarded points they are escaping. They may be reflected from the walls of the room or the person of the experimenter, and falling on the receiver disturb it.

The radiation falling on any portion of the receiving circuit—the leading wires or the galvanometer—disturbs the delicate receiver. It is extremely difficult to shield the receiving circuit from the disturbing action of stray radiation. These difficulties were, however, successfully removed by the use of short electric waves. With these, it is not at all necessary to take special precautions to shield either the galvanometer or the leading wires, the sensitive layer in the receiver alone being affected by the radiation. The bare leading wires may be exposed in close proximity to the source of radiation, and yet no disturbance is produced.

For experimental investigations it is also necessary to have a narrow pencil of electric radiation, and this is very difficult to obtain, unless waves of very short length are used. With large waves diverging in all directions and curling round corners, all attempt at accurate work is futile. For angular measurements it is necessary to direct the electric beam in the given direction along narrow tubes, and receive it in another tube in which is placed the receiver. The waves experience great difficulty in passing through narrow apertures, and there are other troubles from the interference of direct and reflected waves. These difficulties were ultimately overcome by making suitable radiators emitting very short waves; the three radiators here exhibited, give rise to waves which are approximately $\frac{1}{4}$ inch, $\frac{1}{2}$ inch and 1 inch in length. The intensity of emitted radiation is moderately strong, and this is an advantage in many cases. It sometimes becomes necessary to have a greater intensity without the attendant trouble inseparable from too long waves. I have been able to secure this by making a new radiator, where the oscillatory discharge takes place between two circular plates and an interposed platinum ball. The sparking takes place at right angles to the circular plates. The intensity of radiation is by this expedient very greatly increased. The parallel pencil of electric radiation, used in many of the experiments to be described below, is only about half an inch in diameter. The production of such a narrow pencil became absolutely necessary for a certain class of investigations. Merely qualitative results for reflection or refraction may no doubt be obtained with gigantic mirrors or prisms, but when we come to study the phenomena of polarisation as exhibited by crystals, Nature imposes a limit, and this limitation of the size of the crystals has to be accepted in conducting any investigation on their polarising properties.

The greatest drawback, however, in conducting experimental investigations with electric radiation arises from the difficulty of constructing a satisfactory receiver for detecting these waves. For this purpose I at first used the original form of coherer made of metallic filings as devised by Professor Lodge. It is a very delicate detector for electric radiation, but unfortunately I found its indications often to be extremely capricious.

The conditions for a satisfactory receiver are the following:—

(1) Its indications should always be reliable.

(2) Its sensitiveness should remain fairly uniform during the experiment.

(3) The sensibility should be capable of variation, to suit different experiments.

(4) The receiver should be of small size, and preferably linear, to enable angular measurements to be taken with accuracy.

These conditions seemed at first almost impossible to be attained. The coherer sometimes would be so abnormally sensitive that it would react without any apparent cause. At other times, when acting in an admirable manner, the sensitiveness would suddenly disappear at the most tantalising moment. It was a most dreary experience when the radiator and the receiver failed by turns, and it was impossible to find out which was really at fault.

From a series of experiments carried out to find the causes which may affect prejudicially the action of the receiver, I was led to suppose that the uncertainty in the response of the receiver is probably due to the following:—

(1) Some of the particles of the coherer might be too loosely applied against each other, whereas others, on the contrary, might be jammed together, preventing proper response.

(2) The loss of sensibility might also be due to the fatigue produced on the contact surfaces by the prolonged action of radiation.

(3) As the radiation was almost entirely absorbed by the outermost layer, the inner mass, which acted as a short circuit, was not necessary.

For these reasons I modified the receiver into a spiral-spring form. Fine metallic wires (generally steel, occasionally others, or a combination of different metals) were wound in narrow spirals and laid in a single layer on a groove cut in ebonite, so that the spirals could roll on a smooth surface. The ridges of the contiguous spirals made numerous and well-defined contacts, about one thousand in number. The useless conducting mass was thus abolished, and the resistance of the receiving circuit almost entirely concentrated at the sensitive contact surface exposed to radiation. If any change of resistance, however slight, took place at the sensitive layers, the galvanometer in circuit would show strong indications. The pressure throughout the mass was made uniform as each spring transmitted the pressure to the next. When the contact surfaces had too long been acted on, fresh surfaces could easily be brought into contact by the simultaneous rolling of all the spirals.

The sensibility of the receiver to a given radiation, I found, depends (1) on the pressure to which the spirals are subjected, and (2) on the E.M.F. acting on the circuit. The pressure on the spirals may be adjusted, as will be described later on, by means of a fine screw. The E.M.F. is varied by a potentiometer-slide arrangement. This is a matter of great importance, as I often found a receiver, otherwise in good condition, failing to respond when the E.M.F. varied slightly from the proper value. The receiver, when subjected to radiation, undergoes exhaustion. The sensibility can, however, be maintained fairly uniform by slightly varying the E.M.F. to keep pace with the fatigue produced.

The receiving circuit thus consists of a spiral-spring coherer, in series with a voltaic cell and a dead-beat galvanometer. The receiver is made by cutting a narrow groove in a rectangular piece of ebonite, and filling the groove with bits of coiled spirals arranged side by side in a single layer. The spirals are prevented from falling by a glass slide in front. They are placed between two pieces of brass, of which the upper one is sliding and the lower one fixed. These two pieces are in connection with two projecting metallic rods, which serve as electrodes. An electric current enters along the breadth of the top spiral and leaves by the lowest spiral, having to traverse the intermediate spirals along the numerous points of contact. When electric radiation is absorbed by the sensitive surface, there is a sudden diminution of the resistance, and the galvanometer spot is violently deflected.

By means of a very fine screw the upper sliding piece can be gently pushed in or out. In this way the spirals may be very gradually compressed, and the resistance of the receiver diminished. The galvanometer spot can thus easily be brought to any convenient position on the scale. When electric radiation falls on the sensitive surface the spot is deflected. By a slight unscrewing the resistance is increased, and the spot made to return to its old position. The receiver is thus re-sensitised for the next experiment.

The receiver thus constructed is perfectly reliable; the sensibility can be widely varied to suit different experiments, and this sensibility maintained fairly uniform. When necessary, the sensitiveness can be exalted to almost any extent, and it is thus possible to carry out some of the most delicate experiments (specially on polarisation) with certainty.

The main difficulties being thus removed, I attempted to construct a complete electric wave apparatus, which would be portable, with which all the experiments on electric radiation could be carried out with almost as great an ease and certainty as corresponding experiments on light, and which would enable one to obtain even quantitative results with fair accuracy.

The complete apparatus is here exhibited; all its different parts, including the galvanometer, and all the accessories for reflection, refraction, polarisation, and other experiments, are contained in a small case only 2 feet in length, 1 foot in height and 1 foot in breadth. The apparatus can be set up in a few minutes, the various adjustments requiring only a short time.

The radiating apparatus is 6 by 5 by 3 inches, the size of a small lantern. It contains the coil and a small storage cell; the radiator tube is closed with a thin plate of ebonite to prevent deposit of dust on the radiator. One charge of the cell stores enough energy for experiments to be carried out for nearly a month. It is always ready for use and requires very little attention. A flash of radiation for an experiment is produced by a single tap and break of the interrupting key.

The radiating apparatus and the receiver are mounted on stands sliding in an optical bench. Experiments are carried out with divergent or parallel beams of electric radiation. To obtain a parallel beam, a lens of sulphur or glass is mounted in a tube. Suitable lenses can be constructed from the accurate determination, which I have been able to make, of the indices of refraction of various substances for the electric ray, by a method which will be described later on. This lens-tube fits on the radiator-tube, and is stopped by a guide when the oscillatory spark is at the principal focus of the lens. The radiator-tube is further provided with a series of diaphragms by which the amount of radiation may be varied.

For experiments requiring angular measurement, a spectrometer-circle is mounted on one of the sliding stands. The spectrometer carries a circular platform, on which the various reflectors, refractors, &c., are placed. The platform carries an index, and can rotate independently of the circle on which it is mounted. The receiver is carried on a radial arm (provided with an index), and points to the centre of the circle. An observing telescope may also be used with a glass objective, and a linear receiver at the focus.

I shall now exhibit some of the principal experiments on electric radiation.

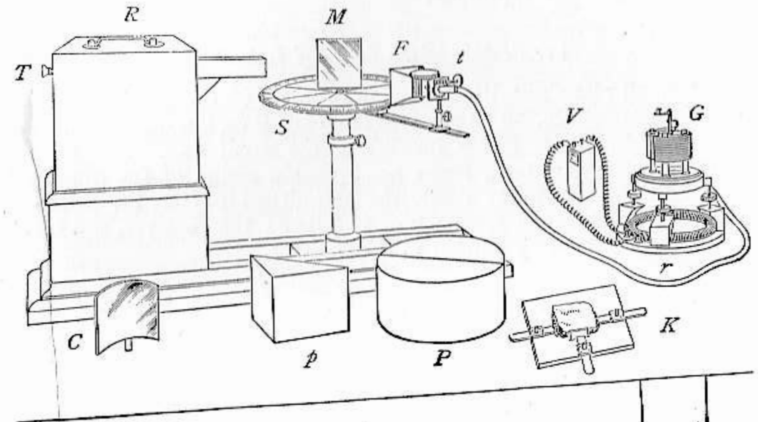

FIG. 2.—Arrangement of the Apparatus. One-sixth nat. size.

R, radiator; T, tapping key; S, spectrometer-circle; M, plane mirror; C, cylindrical mirror; *p*, totally reflecting prism; P, semi-cylinders; K, crystal-holder; F, collecting funnel attached to the spiral spring receiver; *t*, tangent screw, by which the receiver is rotated; V, voltaic cell; *r*, circular rheostat; G, galvanometer.

Selective Absorption.

I arrange the radiation apparatus so that a parallel beam of electric radiation proceeding from the lantern falls on the receiver placed opposite; the receiver responds energetically, the light-spot from the galvanometer being swept violently across the screen. I now interpose various substances to find out which of them allow the radiation to pass through and which do not. A piece of brick, or a block of pitch, is thus seen to be quite transparent, whereas a thick stratum of water is almost opaque. A substance is said to be coloured when it allows light of one kind to pass through, but absorbs light of a different kind. A block of pitch is opaque to visible light, but transparent to electric radiation; whereas water, which is transparent to light, is opaque to electric radiation. These substances exhibit selective absorption, and are therefore coloured.

There is an interesting speculation in reference to the possibility of the sun emitting electric radiation. No such radiation has yet been detected in sunlight. It may be that the electric rays are absorbed by the solar or the terrestrial atmosphere. As regards the latter supposition, the experiment which I am able to exhibit on the transparency of liquid air may be of interest. Professor Dewar has kindly lent me this large bulb full of liquid air, which is equivalent to a great thickness of ordinary air. This thick stratum allows the radiation to pass through with the greatest facility, proving the high transparency of the liquid air.

Verification of the Laws of Reflection.

A small plane metallic mirror is mounted on the platform of the spectrometer-circle. The receiver is mounted on a radial arm. The law of reflection is easily verified in the usual way. The second mirror, which is curved, forms an invisible image of the source of radiation. As I slowly rotate the cylindrical mirror, the invisible image moves through space; now it falls on the receiver, and there is a strong response produced in the receiver.

Refraction.

Deviation of the electric ray by a prism may be shown by a prism made of sulphur or ebonite. More interesting is the phenomenon of total reflection. A pair of totally-reflecting prisms may be obtained by cutting a cube of glass, which may be an ordinary paper-weight, across a diagonal. The critical angle of a specimen of glass I found to be 29°, and a right-angled isosceles prism of this material produces total reflection in a very efficient manner. When the receiver is placed opposite the radiator, and the prism interposed with one of its faces perpendicular to the electric beam, there is not the slightest action on the receiver. On turning the receiver through 90°, the receiver responds to the totally-reflected ray.

Opacity due to multiple refraction and reflection, analogous to the opacity of powdered glass to light, is shown by filling a long trough with irregularly-shaped pieces of pitch, and interposing it between the radiator and the receiver. The electric ray is unable to pass through the heterogeneous media, owing to the multiplicity of refractions and reflections, and the receiver remains unaffected. But on restoring partial homogeneity by pouring in kerosene, which has about the same refractive index as pitch, the radiation is easily transmitted.

Determination of the Index of Refraction.

Accurate determination of the indices of refraction becomes important when lenses have to be constructed for rendering the electric beam parallel. The index for electric radiation is often very different

from the optical index, and the focal distance of a glass lens for light gives no clue to its focal distance for electric radiation. I found, for example, the index of refraction of a specimen of glass to be 2·04, whereas the index of the same specimen for sodium light is only 1·53.

There are again many substances, like the various rocks, wood, coal-tar, and others, whose indices cannot be determined owing to their opacity to light. These substances are, however, transparent to electric radiation, and it is therefore possible to determine their electric indices. For the determination of the index, the prism-method is not very suitable. I found the following method, of which I shall exhibit the optical counterpart, to yield good results. When light passes from a dense to a light medium, then, at a certain critical angle, the light is totally reflected, and from the critical angle the index can be determined. I have here a cylindrical trough filled with water. Two glass plates enclosing a parallel air-film are suspended vertically across the diameter of the cylinder, dividing the cylinder into two halves. The cylinder, mounted on a graduated

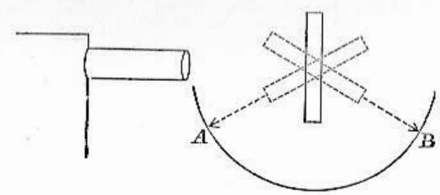

Fig. 3.

(The dotted lines show the two positions of the air-film for total reflection.)

circle, is adjusted in front of an illuminated slit, an image of the slit being cast by the water-cylinder on the screen. The divergent beam from the slit, rendered nearly parallel by the first half of the cylinder, is incident on the air-film, and is then focussed by the second half of the cylinder. As the cylinder is slowly rotated, the angle of incidence at the air-film is gradually increased, but the image on the screen remains fixed. On continuing the rotation you observe the almost sudden extinction of the image. I say almost, because the light is not monochromatic, and the different components of white light undergo total reflection in succession. Just before total extinction the image you observe is reddish in colour, the violet and the blue lights being already reflected. On continuing the rotation the image is completely extinguished. Rotation of the cylinder in an opposite direction gives another reading for total reflection, and the difference of the two readings is evidently equal to twice the critical angle.

In a similar way I have been able to determine the indices of refraction of various substances, both solid and liquid, for electric radiation. In the case of solids, two semi-cylinders, separated by a suitable parallel air-space, are placed on the spectrometer-circle, the receiver being placed opposite the radiator. The trouble of following the deviated ray is thus obviated. The index of refraction of glass I found to be $2 \cdot 04$; that of commercial sulphur is $1 \cdot 73$.

Double Refraction and Polarisation.

I now proceed to demonstrate some of the principal phenomena of polarisation, especially in reference to the polarisation produced by crystals and other substances, and by dielectrics when subjected to molecular stress due to pressure or unequal heating.

As the wave-length of electric radiation is many thousand times the wave-length of light, there is a misgiving as to whether it would

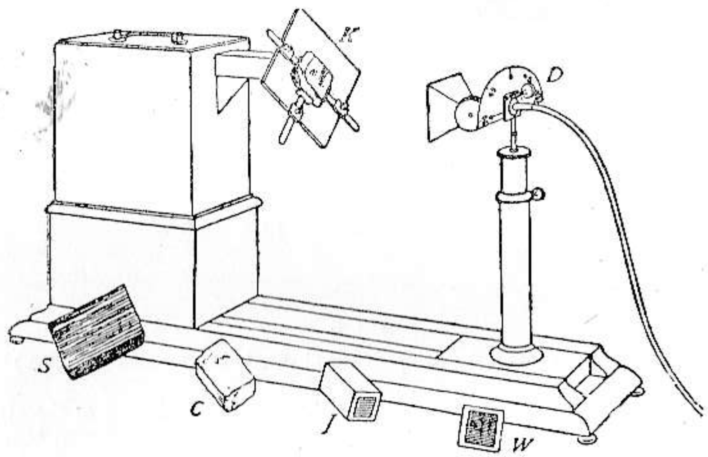

Fig. 4.—Polarisation Apparatus.

K, crystal-holder; S, a piece of stratified rock; C, a crystal; J, jute polariser; W, wire-grating polariser; D, vertical graduated disc, by which the rotation is measured.

be possible to exhibit polarisation effects with crystals of ordinary size. I hope to be able to demonstrate that such a misgiving is groundless.

A beam of ordinary light incident on a crystal of Iceland spar is generally bifurcated after transmission, and the two emergent beams are found polarised in planes at right angles to each other. The usual optical method of detecting the bi-refringent action of crystal, is to interpose it between the crossed polariser and analyser. The interposition of the crystal generally brightens the dark field. This is the so-called depolarisation effect, and is a delicate test for double-refracting substances. There is, however, no depolarisation when the

principal plane of the crystal coincides with the polarisation planes of either the polariser or the analyser. The field also remains dark when the optic axis of the crystal is parallel to the incident ray.

A similar method is adopted for experimenting with polarised electric radiation.

The spectrometer-circle is removed from the optical bench, and an ordinary stand for mounting the receiver substituted. By fitting the lens-tube, the electric beam is made parallel. At the end of the tube may be fixed either the grating polariser or the jute or serpentine polarisers, to be subsequently described.

The receiver fitted with the analyser is adjusted by a tangent screw, the rotation of the analyser being measured by means of an index and a graduated vertical disc.

The polarising gratings may be made, according to Hertz, by winding copper wires, parallel, round square frames. The polarisation apparatus is, however, so extremely delicate, that unless all the wires are strictly parallel, and the gratings *exactly* crossed, there is always a resolved component of radiation which acts on the sensitive receiver. It is a very difficult and tedious operation to cross the gratings. I have found it to be a better plan to take two thick square plates of copper of the same size, and, placing one over the other, cut a series of slits (which stop short of the edges) parallel to one of the edges. One of these square pieces serves as a polariser, and the other as an analyser. When the two square pieces are adjusted, face to face, with coincident edges, the gratings must either be parallel or exactly crossed. Such accurate adjustments make it possible to carry out some of the most delicate experiments.

The radiator-tube, with the lens and the attached polariser, is capable of rotation. The emergent beam may thus be polarised in a vertical or a horizontal plane. The analyser fitted on to the receiver may also be rotated. The gratings may thus be adjusted in two positions.

(1) Parallel position.
(2) Crossed position.

In the first position the radiation is transmitted through both the gratings, falls on the sensitive surface, and the galvanometer responds. The field is then said to be bright. In the second position the radiation is extinguished by the crossed gratings, the galvanometer remains unaffected, and the field is said to be dark. But in interposing a double-refracting substance in certain positions between the crossed gratings, the field is partially restored, and the galvanometer-spot sweeps across the scale.

I have now the analyser and the polariser exactly crossed, and there is not the slightest action on the receiver. Observe the great sensitiveness of the arrangement; I turn the polariser very slightly from the crossed position, and the galvanometer-spot is violently deflected.

I now readjust the gratings in a crossed position. I have in my hand a large block of the crystal beryl; it is perfectly opaque to light. I now hold the crystal with its principal plane inclined at 45° between the crossed gratings, and the galvanometer-spot, hitherto quiescent, sweeps across the scale. It is very curious to observe the restoration of the extinguished field of electric radiation, itself invisible, by the interposition of what appears to the eye to be a perfectly opaque block of crystal. If the crystal is slowly rotated, there is no action on the receiver when the principal plane of the crystal is parallel to either the polariser or the analyser. Thus, during one complete rotation there are four positions of the crystal when no depolarisation effect is produced.

Rotation of the crystal, when held with its optic axis parallel to the incident ray, produces no action. The field remains dark.

Here is another large crystal, idocrase, belonging to the orthorhombic system, which shows the same action. It is not at all necessary to have large crystals; a piece of calc-spar, taken out of an optical instrument, will polarise the electric ray. But the effect produced by the crystal epidote seems extraordinary. I have here a piece with a thickness of only ·7 cm.—a fraction of the wave-length of the electric radiation—and yet observe how strong is its depolarising effect.

I subjoin a representative list of crystals belonging to the different systems, which would be found to produce double refraction of the electric ray.

Tetragonal System.—Idocrase, scapolite.

Orthorhombic System.—Barytes, celestine, cryolite, andalusite, hypersthene.

Hexagonal System.—Calcite, apatite, quartz, beryl, tourmaline.

Monoclinic System.—Selenite, orthoclase, epidote.

Triclinic System.—Labradorite, microcline, amblygonite.

Double Refraction produced by a Strained Dielectric.

Effect due to Pressure.—A piece of glass, when strongly compressed, becomes double refracting for light. An analogous experiment may be shown with electric radiation. Instead of producing pressure artificially, it seemed to me that stratified rocks, which, from the nature of their formation, were subjected to great pressure, would serve well for my experiment. Here is a piece of slate about an inch in thickness. I interpose this piece with the plane of stratification inclined at 45°, and the spot of light flies off the scale. I now carefully rotate the piece of slate; there is no depolarisation effect when the plane of stratification is parallel to either the polariser or the analyser. Thus the existence of strain inside an opaque mass can easily be detected, and what is more, the directions of maximum and minimum pressures can be determined with great exactitude.

Effect due to Strains in Cooling.—An effect similar to that produced by unannealed glass may be shown by this piece of solid paraffin, which was cast in a mould, and chilled unequally by a freezing mixture. One of these blocks was cast two years ago, and it has still retained its unannealed property. This effect may even be shown without any special preparation. Pieces of glass or ebonite, too, are often found sufficiently strained to exhibit double refraction.

Phenomena of Double Absorption.

Being desirous of making a crystal polariser, I naturally turned to tourmaline, but was disappointed to find it utterly unsuitable as a polariser. There is a difference in transparency in directions parallel and perpendicular to the length, but even a considerable thickness of the crystal does not completely absorb one of the two rays. Because visible light is polarised by absorption by tourmaline, it does not follow that all kinds of radiation would be so polarised. The failure of tourmaline to polarise the Röntgen rays is therefore not unexpected, supposing such rays to be capable of polarisation.

It was a long time before I could discover crystals which acted as electric tourmalines. In the meanwhile I found many natural substances which produced polarisation by selective unilateral absorption. For example, I found locks of human hair to polarise the electric ray. I have here two bundles of hair; I interpose one at 45°, and you observe the depolarisation effect. The darker specimen seems to be the more efficient. Turning to other substances more easily accessible, I found vegetable fibres to be good polarisers. Among these may be mentioned the fibres of aloes (*Agave*), rhea (*Boehmeria nivea*), pine-apple (*Ananas sativus*), plantain (*Musa paradisiaca*). Common jute (*Corchorus capsularis*) exhibits the property of polarisation in a very marked degree. I cut fibres of this material about 3 cm. in length, and built with them a cell with all the fibres parallel. I subjected this cell to a strong pressure under a press. I thus obtained a compact cell 3 cm. by 3 cm. in area, and 5 cm. in thickness. This was mounted in a metallic case, with two openings 2 cm. by 2 cm. on opposite sides for the passage of radiation. This cell absorbs vibrations parallel to the length of the fibres, and transmits those perpendicular to the length. Two such cells could thus be used, one as a polariser and the other as an analyser.

Turning to crystals I found a large number of them exhibiting selective absorption in one direction. Of these nemalite and crysotile exhibit this property to a remarkable extent. Nemalite is a fibrous variety of brucite; crysotile being a variety of serpentine. The direction of absorption in these cases is parallel to the length, the direction of transmission being perpendicular to the length. I have here a piece of crysotile, only one inch in thickness. I adjust the polariser and the analyser parallel, and interpose the crysotile with its length parallel to the electric vibration. You observe that the radiation is completely absorbed, none being transmitted. I now hold the piece with its length perpendicular to the electric vibration; the radiation is now copiously transmitted. Crysotile is thus seen to act as a perfect electric tourmaline.

Anisotropic Conductivity exhibited by certain Polarising Substances.

In a polarising grating, the electric vibrations perpendicular to the bars of the grating are alone transmitted, the vibrations parallel to the grating being absorbed or reflected. In a grating we have a structure which is not isotropic, for the electric conductivity parallel to the bars is very great, whereas the conductivity across the bars (owing to the interruptions due to spaces) is almost nothing. We may, therefore, expect electric vibrations parallel to the bars to produce local induction currents, which would ultimately be dissipated as heat. There would thus be no transmission of vibrations parallel to the grating, all such vibrations being absorbed. But owing to the break of metallic continuity, no induction current can take place across the grating; the vibrations in this direction are, therefore, transmitted. From these considerations we see how non-polarised vibrations falling on a grating would have the vibration components parallel to the direction of maximum conductivity absorbed, and those in the direction of least conductivity transmitted in a polarised condition.

I have shown that nemalite and crysotile polarise by selective absorption, the vibration perpendicular to their length being transmitted, and those parallel to their length being absorbed. Bearing in mind the relation between the double conductivity and double absorption, as exhibited by gratings, I was led to investigate whether the directions of the greatest and least absorptions in nemalite and crysotile were also the directions of maximum and minimum conductivities respectively. I found the conductivity of a specimen of nemalite in the direction of absorption to be about fourteen times the conductivity in the direction of transmission. In crysotile, too, the directions of the greatest and least absorption were also the directions of maximum and minimum conductivities.

It must, however, be noted that the substances mentioned above are bad conductors, and the difference of conductivity in the two directions is not anything like what we get in polarising gratings. A thin layer of nemalite or crysotile will, therefore, be unable to produce complete polarisation. But by the cumulative effect of many such layers in a thick piece, the vibrations which are perpendicular to the direction of maximum conductivity are alone transmitted, the emergent beam being thus completely polarised.

A double-conducting structure will thus be seen to act as a polariser. I have here an artificial electric tourmaline, made of a bundle of parallel capillary glass fibres. The capillaries have been filled with dilute copper sulphate solution. A simple, and certainly the most handy,

polariser is one's outstretched fingers. I interpose my fingers at 45° between the crossed polariser and the analyser, and you observe the immediate restoration of the extinguished field of radiation. The double-conducting nature of the structure is here quite evident.

While repeating these experiments I happened to have by me this old copy of 'Bradshaw,' and it struck me that here was an excellent double-conducting structure which ought to polarise the electric ray. For looking at the edge of the book we see the paper continuous in one direction along the pages, whereas this continuity is broken across the pages by the interposed air-films. I shall now demonstrate the extraordinary efficiency of this book as an electric polariser. I hold it at 45° between the crossed gratings, and you observe the strong depolarisation effect produced. I now arrange the polariser and the analyser in a parallel position, and interpose the 'Bradshaw' with its edge parallel to the electric vibration; there is not the slightest action in the receiver, the book held in this particular direction being perfectly opaque to electric radiation. But on turning it round through 90°, the 'Bradshaw,' usually so opaque, becomes quite transparent, as is indicated by the violent deflection of the galvanometer-spot of light. An ordinary book is thus seen to act as a perfect polariser of the electric ray; the vibrations parallel to the pages are completely absorbed, and those at right angles transmitted in a perfectly polarised condition.

The electric radiation is thus seen to be reflected, refracted and polarised just in the same way as light is reflected, refracted and polarised. The two phenomena are identical. The anticipations of Maxwell have thus been verified by the great work of Hertz and his successors.

By pressing the key of this radiation apparatus I am able to produce ether vibrations, 30,000 millions in one second. A second stop in connection with another apparatus will give rise to a different vibration. Imagine a large electric organ provided with a very large number of stops, each key giving rise to a particular ether note. Imagine the lowest key producing one vibration in a second. We should then get a gigantic ether wave 186,000 miles long. Let the next key give rise to two vibrations in a second, and let each succeeding key produce higher and higher notes. Imagine an unseen hand pressing the different keys in rapid succession. The ether notes will thus rise in frequency from one vibration in a second, to tens, to hundreds, to thousands, to hundreds of thousands, to millions, to millions of millions. While the ethereal sea in which we are all immersed is being thus agitated by these multitudinous waves, we shall remain entirely unaffected, for we possess no organs of perception to respond to these waves. As the ether note rises still higher in pitch, we shall for a brief moment perceive a sensation of warmth. As the note still rises higher, our eye will begin to be affected, a red glimmer of light will be the first to make its appearance. From this point the few colours we see are comprised within a single octave of vibration—from about 400 to 800 billions in one second. As the frequency of vibration rises still higher, our organs of perception fail us completely; a great gap in our consciousness obliterates the rest. The brief flash of light is succeeded by unbroken darkness.

These great regions of invisible lights are now being slowly and patiently explored. In time the great gaps which now exist will be filled up, and light-gleams, visible and invisible, will be found merging one into the other in unbroken sequence.

Before I conclude I may be permitted to express my sincere thanks to the managers of the Royal Institution for according me the privilege of addressing you this evening. I cannot sufficiently express my gratefulness for all the kindness I have received in this country. When the managers of this Institution, which has done so much to advance the cause of Science and Arts, invited me here, I felt that the scope of this great Institution was not merely confined to these shores, but embraced other countries, even the most distant. The land from which I come did at one time strive to extend human knowledge, but that was many centuries ago; a dark age has since supervened. It is now the privilege of the West to lead in this work. I would fain hope, and I am sure I am echoing your sentiments, that a time may come when the East, too, will take her part in this glorious undertaking; and that at no distant time it shall neither be the West nor the East, but both the East and the West, that will work together, each taking her share in extending the boundaries of knowledge, and bringing out the manifold blessings that follow in its train.

[J. C. B.]

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, LIMITED, STAMFORD STREET AND CHARING CROSS.