On polarisation of electric rays by double-refracting crystals

J. C. Bose

A beam of ordinary light incident on a crystal of Icelandspar is generally bifurcated after transmission, and the two emergent rays are found polarised in planes at right angles to each other. The object of the present enquiry is to find natural substances which polarise the transmitted electrical ray. It was thought that the analogy between electric radiation and light would be rendered more complete if the classes of substance which polarise light were also found to polarise the electric ray. The two phenomena may be regarded identical if the same specimen is found to polarise both the luminous and the electric rays.

As the wavelength of electrical radiation is very large compared with that of visible light, it may be thought that very large crystals, much larger than what occur in nature, would be required to produce polarisation of the electric ray. I have, however, succeeded in obtaining polarisation effects with crystals of moderate size. This I was able to do by reducing the length of electric waves to about 5 mm. or so.

These experiments show that certain crystals produce double refraction, and that the transmitted beams are polarised. With the help of a rudely constructed apparatus, I was able, last year, to detect traces of these effects, The apparatus has since been improved in detail; it is now possible to detect the polarisation effect with certainty.

The usual optical method of detecting the bi-refringent action of crystals, is to interpose the double refracting structure between two crossed Nicols. The interposition of the crystal generally brightens the dark field. This is known as the depolarising effect, and is regarded as a delicate test for double refracting substances. There is, however, no depolarising action when the principal plane of the crystal coincides with the polarisation planes of either the Polariser or Analyser. The field also remains dark when the optical axis of the crystal is parallel to the incident ray.

A similar method was adopted for experimenting with polarised electric radiation. A parallel electric beam is first polarised by a wire grating. A similar grating acts as an Analyser. The two gratings are crossed, and the crystal to be examined is interposed. The Receiver is a modified form of "Coherer" with its associated voltaic cell and Galvanometer. Brightening of the field is indicated by a throw of the Galvanometer needle.

Apparatus used

The following are the different parts of a complete apparatus:

Radiator

Electric oscillation is produced by sparking between hollow hemispheres, and a small interposed sphere. The two beads attached to the hemispheres and the interposed sphere were at first thickly coated with gold, and the surface highly polished. This worked satisfactorily for a time, but after long-continued action, the surface of the ball became roughened, and the discharge ceased to be oscillatory. After some difficulty in obtaining the requisite high temperature, I succeeded in casting a solid ball and two beads of platinum. There is now no difficulty in obtaining an oscillatory discharge; the sparks are made very small, as these are more effective with the receiver used. After a little experience, it is possible to tell whether the discharge is oscillatory or not. The effective sparks have a peculiar smooth sound, whereas non-oscillatory discharges give rise to peculiar cracked sound.

As an electric generator, I at first used a small Ruhm-korff coil actuated by a battery. I, however, soon found that the usual vibrating arrangement is a source of trouble; the contact points soon get worn out, and the break becomes irregular. The oscillation produced by a single break is quite sufficient for a single experiment, and it is mere waste to have a series of useless oscillations. But the most serious objection to the production of secondary sparks, unless absolutely wanted, is their deteriorating action on the spark balls. Anyone who has tried to obtain an oscillatory discharge knows how easily the discharge becomes irregular, and the most fruitful source of trouble is often traced to the disintegration of the sparking surface. In my later apparatus, I have discarded the use of the vibrating interrupter. The coil has also been somewhat modified. A long strip of paraffined paper is taken, and tin-foil pasted on opposite sides; this long roll is wound round the secondary to act as a condenser. In this way there is a great saving of space. The two ends of the primary are in connection with a small storage cell through a tapping key. The coil, a small storage cell, and the key are enclosed in a tin-box; a small opening behind allows the stud of the press-key to pass through. In front of the box there is an opening, through which the radiating tube projects. The radiating box, thus constructed, is very portable. The one I have been using for some time

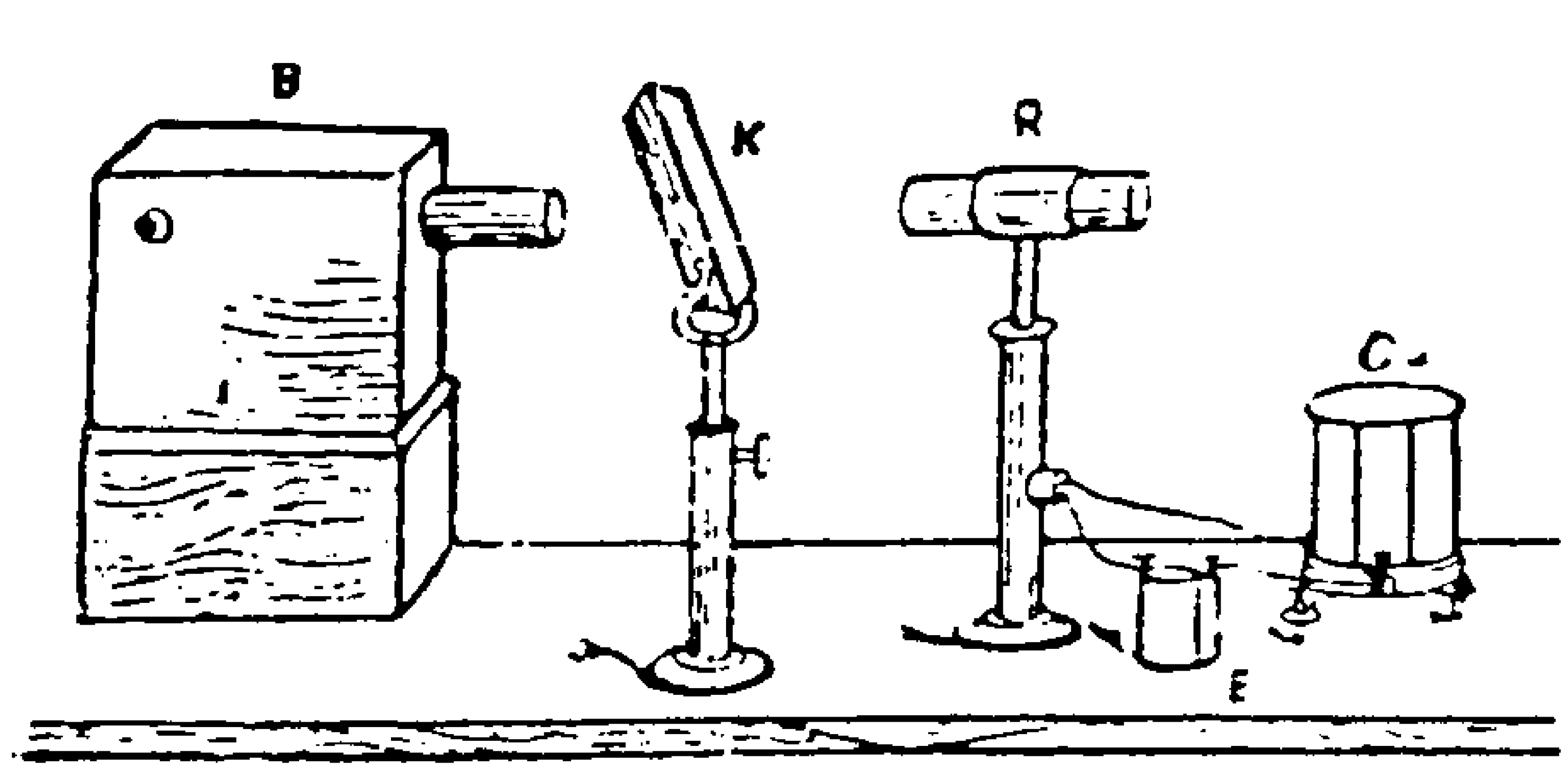

Figure 1. Polarisation Apparatus. B, Metallic box enclosing the Ruhmkorff coil and Radiator. K, The crystal to be examined. E, Voltaic Cell. G, The Galvanometer. R, tube enclosing sensitive radiator.

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s 7 inches in height, 6 inches in , and 4 inches in breadth. There is r one which is still smaller.

radiator tube is 2.5 cm. in diameter. instance of the efficiency of the ng apparatus, I may here mention :t that the storage cell was charged a month ago; I have since been the apparatus for electro-magnetic ɔn almost every day. All the while ıired no attention, and there was her necessity of polishing the spark-faces. To obtain a flash of radiation only to press the stud and release l on an average, I require about ashes for a day's work. For working re month it is therefore only neces-ɔ have a little over a thousand of the primary current. With the ·ibrating interrupter a larger number aks would have been necessary or one hour's work.

for rendering the beam paral- ı my first apparatus, with the help ordinary glass lens and suitable ıgms, the beam was made ap-ately parallel. This was more or guess-work, as the index of glass ː electric ray has not yet been ined. I have, however, succeeded

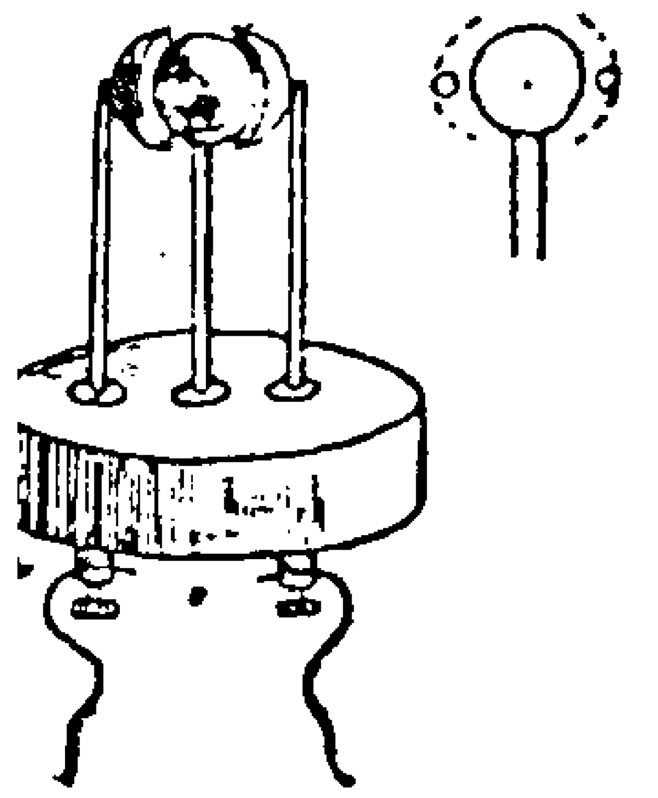
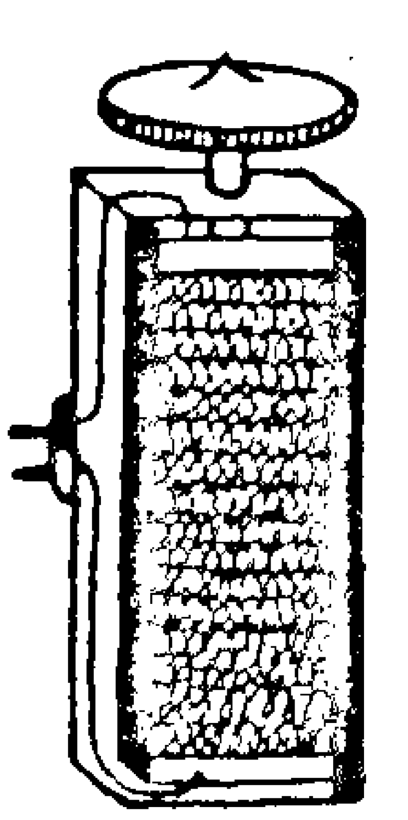


Figure 2. The Radiator.



ɜ **3.** The Spiral-spring Receiver.

in determining the electric index for Sulphur, which is very near 1.734. With the knowledge of this index, a cylindrical lens of Sulphur has been constructed, whose focal distance is known with accuracy. The source of radiation, the spark gap, is a line, and the lens is adjusted till its focal line and the spark gap coincide. In this way, a parallel beam of electric radiation is obtained.

Polariser and Analyser.—The success of the experiment depends greatly on the care with which the Polariser and the Analyser are constructed. Fine copper wire, 0.2 mm. in diameter, was carefully wound in parallel lines round two thin sheets of mica; there were about 25 lines in one centimeter. The mica pieces were then immersed in melted paraffin, and the wires thus fixed *in situ*. By cutting round, two circular pieces containing the gratings were obtained. One of these acted as a Polariser and the other as an Analyser.

Receiver.—The receiving circuit consists of a spiral-spring coherer in series with a modified Daniell cell and an aperiodic galvanometer of D'Arsonval type.

In a square piece of ebonite a shallow rectangular depression is cut out, and a single layer of steel spiral springs 2 mm. in diameter and 1 cm. in length is laid side by side, the sensitive surface being 1×2 cm. The springs are prevented from falling by a glass slide in front. The spirals may be compressed by means of a brass piece which slides in and out by the action of a screw. The resistance offered by this portion of the circuit can, therefore, be gradually varied. An electrical 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. The resistance of the receiving circuit is thus almost entirely concentrated at the sensitive contact-surface, there being little useless short-circuiting by the mass of the conducting layer. When electric radiation is absorbed by the sensitive contacts, there is a sudden diminution of resistance, and the galvanometer is violently deflected.

A pair of insulated wires from the ends of the receiver are led out to a galvanometer placed at a distance. The leading wires are shielded from radiation by enclosing them inside two coatings of tin-foil. As an additional precaution, the galvanometer and the voltaic cell are also enclosed in a metallic case with a slit in front of the galvanometer mirror. A spot of light reflected from the mirror is received on a scale. By adjusting the electromotive force of the circuit, the sensitiveness of the receiver may be increased to any extent desirable.

This is most simply effected by the following arrangement of a modified Daniell cell and a shunt. A small U tube is taken and the two limbs filled with copper sulphate and sulphuric acid, respectively; the bent portion of the tube is plugged with asbestos to prevent rapid mixing of the two liquids. A sliding ebonite piece carries a rod of zinc and a rod of copper, which are plunged in the two electrolytes. The cell is shunted with a resistance of about 10 ohms and the current flowing through the shunt, and therefore the derived E. M. F. is varied by varying the resistance of the cell by raising or lowering the electrodes. When no current is required, the rods are raised out of the liquids. A cell thus constructed is ready for use at a moment's notice, and will work for several days. The receiving circuit does not respond to the incident radiation unless a suitable E. M. F. acts on the circuit. The above simple method of adjusting the proper E. M. F. will be found very simple and effective.

When the Polariser and the Analyser are properly constructed, and the two exactly crossed, no radiation can reach the sensitive surface, and the galvanometer will remain unaffected. The field is then said to be dark. Any slight rotation of either the Polariser or the Analyser partially restores the field, and the galvanometer spot of light then sweeps across the scale.

Method of Experiment

The spark gap of the Radiator is adjusted in a vertical line. The wires of the Polariser are horizontal, and the transmitted electric ray is plane-polarised, its plane of vibration being vertical. The Analyser is now adjusted in a crossed position; on producing a flash of radiation by a single break of the primary, there is no effect on the galvanometer. The crystal to be examined is now interposed with its principal plane inclined at 45°C to the horizon.

Rhombohedral system

(1) *Beryl.*—The first piece experimented

on was a large crystal of Beryl. It is a hexagonal prism with basal planes. The specimen examined has each face 11 × 5 cm. The three axes lying in the same plane are inclined at 60° to each other, the fourth axis, which is also the optical axis, is at right angles to the plane containing the other three. The crystal was optically opaque.

On interposing this block with its principal plane inclined at 45°, the galvanometer spot flew off the scale. The crystal had thus produced the well-known depolarising action. The crystal was now turned round till its principal plane coincided with the vibration plane of the Polariser. There was now no action on the galvanometer. On continuing the rotation, the galvanometer at once responded. The spot became quiescent a second time, when the principal plane coincided with the plane of vibration of the Analyser.

The crystal was now placed with its optical axis parallel to the direction of the incident ray. There was now no action on the galvanometer. Rotation of the crystal round this axis did not produce any effect on the galvanometer. The field continued to be dark.

The piece of Beryl used in the above experiment was unusually large. But in the following experiments the crystals were quite small.

(2) *Apatite.*—In repeating the experiment with this crystal, strongly marked double refraction effect was exhibited.

(3) *Nemalite.*—This is a fibrous variety of Brucite, silky in appearance. In its chemical composition it is a hydrate of magnesia. This specimen exhibited a very strong depolarisation effect with a thickness of less than one cm.

Rhombic system

Barytes.—A piece of this crystal was found to be strongly double-refracting.

Triclinic system

Microcline.—This is a greenish blue crystal of the double oblique type. It exhibited polarisation effect in a remarkable degree.

Regular system

Rock Salt.—A large piece of this crystal did not produce any effect. This is what was expected.

Having satisfied myself of the fact that systems of crystals, other than regular, produce double refraction and consequent polarisation of the electrical ray, I tried the action of electric radiation on crystals ordinarily used in optical apparatus.

I got a fairly large piece of black Tourmaline. On interposing this with its plane inclined at 45°, there was prompt movement of the spot of light. There was no galvanometric indication when the principal plane of the Tourmaline coincided with the vibration planes of either the Polariser or the Analyser.

With ordinary light, a piece of Tourmaline of *sufficient* thickness absorbs the ordinary, but transmits the extraordinary ray. With the piece of Tourmaline used in the last experiment, I found both the rays transmitted, but, it seemed to me, with unequal intensities. In other words, one ray suffers greater absorption than the other. It seems probable that with greater thickness of crystal one ray would be completely absorbed. I found other crystals behaving more or less in the same way. I reserve for another communication particulars of experiments bearing on this subject.

Lastly, I tried an experiment with a crystal of Iceland Spar taken out of a polarising apparatus. With this I got distinct depolarising action.

Summary.—Crystals which do not belong to the Regular System, polarise the electric ray just in the same way as they do a ray of ordinary light. Theoretically, all crystals, with the exception of those belonging to the Regular System, ought to polarise light. But this could not hitherto be verified in the case of opaque crystals. There is now no such difficulty with the electric ray, for all crystals are transparent to it. As a matter of fact, all the above experiments, with one exception, were performed with specimens opaque to light, and it was an interesting phenomenon to observe the restoration of the extinguished electric radiation, itself invisible, by the interposition of what appears to the eye to be a perfectly opaque block of crystal, between the crossed gratings.

The rotation of plane of polarisation of electric waves by a twisted structure

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In my previous papers I have given accounts of the double refraction and polarisation of electric waves produced by various crystals and other substances, and also by strained dielectrics. An account was there given of the polarisation apparatus with which the effects were studied. In the present investigation effects had to be studied which were exceedingly feeble. The apparatus had, therefore, to be made of extreme sensitiveness; but the secondary disturbances became at the same time more pronounced, and the great difficulty experienced was in avoiding them.

In one of my communications I alluded to the fact that the secondary disturbances are to a great extent reduced when the radiators are made small. The advantage of a large radiator is the comparative ease with which the receiver can be adjusted to respond to the waves, but this advantage is more than counter-balanced by the increased difficulty with the stray radiation and other disturbances. On the other hand, with small radiators, the difficulty is in the proper adjustment of the receiver. It then becomes necessary to have very exact adjustments of the receiver, both as regards the pressure to which the sensitive spirals are subjected and the E. M. F. acting on the circuit. It is only after some practice that the peculiarity of each receiver is properly understood, when it becomes easy to make the necessary adjustments by which the receiver becomes quite certain in action. For various reasons the radiation emitted by small radiators are more favourable for 'accurate work'.

In order that the surface of the radiator should be little affected by the disintegrating action of the sparks, I use a

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