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

J. C. Bose

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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single spark for producing a flash of radiation. There used to be, however, some uncertainty from a discharge occasionally failing to be oscillatory. The cause of this uncertainty is ascribed to the deposit of dust on the sparking surface. For greater certainty of action some observers immerse the radiator in oil. The use of oil is under any circumstances troublesome. This is specially so in polarisation experiments, when the radiator has to be placed in different azimuths. I have for these reasons avoided the oil-immersion arrangement, and have tried to secure certainty of oscillatory discharge without this expedient. Attention was specially paid to the coil and the primary break. A radiator has also been constructed which is found to be extremely efficient. It consists of two platinum beads, each 2 mm. in diameter, separated by 0.3 mm. spark-gap. There is no interposed third ball. This radiator, though kept exposed for days without any protecting cover, was yet found to give rise to a succession of effective discharges without a single failure. I even went so far as to pour a stream of dust on the radiator; in spite of this severe treatment, the sparks were found to be quite effective in giving rise to electric oscillation.

The receiver, too, is perfectly certain in its action, and various degrees of sensitiveness may be given to it. In the following experiments, the sensitiveness had to be very greatly enhanced, and this, as alluded to above, was secured by proper adjustments. The secondary disturbances were got rid of by careful screening. But one serious difficulty was encountered at the very outset, in the failure of the polariser to produce *complete* polarisation. In my first experiments on polarisation (the receiver then used not having been very sensitive), polarisers made of wire gratings were found effective. But in my later experiments with still more sensitive receivers, I found that, owing probably to the want of strict parallelism of the wires and the difficulty of *exactly* crossing the analyser and polariser, it was impossible to produce total extinction of the field. I then made a polariser and analyser by cutting parallel slits out of two square pieces of thick copper. When the square pieces were adjusted with coincident edges, the analyser and polariser were either exactly parallel or exactly crossed. This improvement enabled me to carry out successfully some of the more delicate experiments. In the present course of investigation the sensitiveness of the receiver had to be raised to a still higher degree, and it was found that the polariser hitherto found efficient failed to produce complete polarisation, so that even when the polariser and the analyser were exactly crossed the non-polarised portion of radiation was of sufficient intensity to produce strong action on the receiver.

In the paper 'On the Selective Conductivity exhibited by some Polarising Substances' I described a book-form of polariser, when an ordinary book was shown to produce polarisation of the transmitted beam, the vibrations parallel to the pages being absorbed, and those at right angles transmitted in a polarised condition. The advantage of this form of polariser was that the extent to which the rays were polarised depends on the thickness of the polarising medium. The rays could thus be completely polarised by giving the medium a sufficient thickness, this thickness being determined by the intensity of the radiation used and the sensitiveness of the receiver. The necessary thickness of the book-polariser can be materially decreased by making the book consist of alternate leaves of paper and tinfoil. The book was then strongly compressed, and blocks of suitable size cut out to form the polariser and the analyser. Each of these blocks is then enclosed in a brass cell, with two circular openings on opposite sides for the passage of radiation. The size of the polariser I use is 6 × 6 cm., with a thickness of 4.5 cm.; the aperture is 4 cm. in diameter. These polarising cells I find to be quite efficient; when two such cells are crossed, the field is completely extinguished.

The diagram explains the general arrangement of the apparatus, mounted on an optical bench. The spark gap of the radiator is horizontal. The polariser, with the leaves vertical, is placed on a shelf attached to a screen of thick brass plate 35 × 35 cm. In the centre of the plate there is a circular opening 4 cm. in diameter; this aperture may be varied by a series of diaphragms. There is a second similar screen with a shelf for the analyser, which is placed with the leaves horizontal. Behind the analyser is the receiver.

In the space between the brass plates is placed the substance to be examined. Previous tests are made to see whether all disturbing causes have been removed. The sensitiveness of the receiver is occasionally tested by interposing one's finger at 45° between the crossed polariser and analyser; this should, by partially restoring the field, produce strong action, provided the receiver is in a fairly sensitive condition.

Care should be taken that there are no metallic masses between the screens, as reflection from metals is found to produce 'depolarisation', the rays being then elliptically polarised. The substance to be examined should not, for very delicate

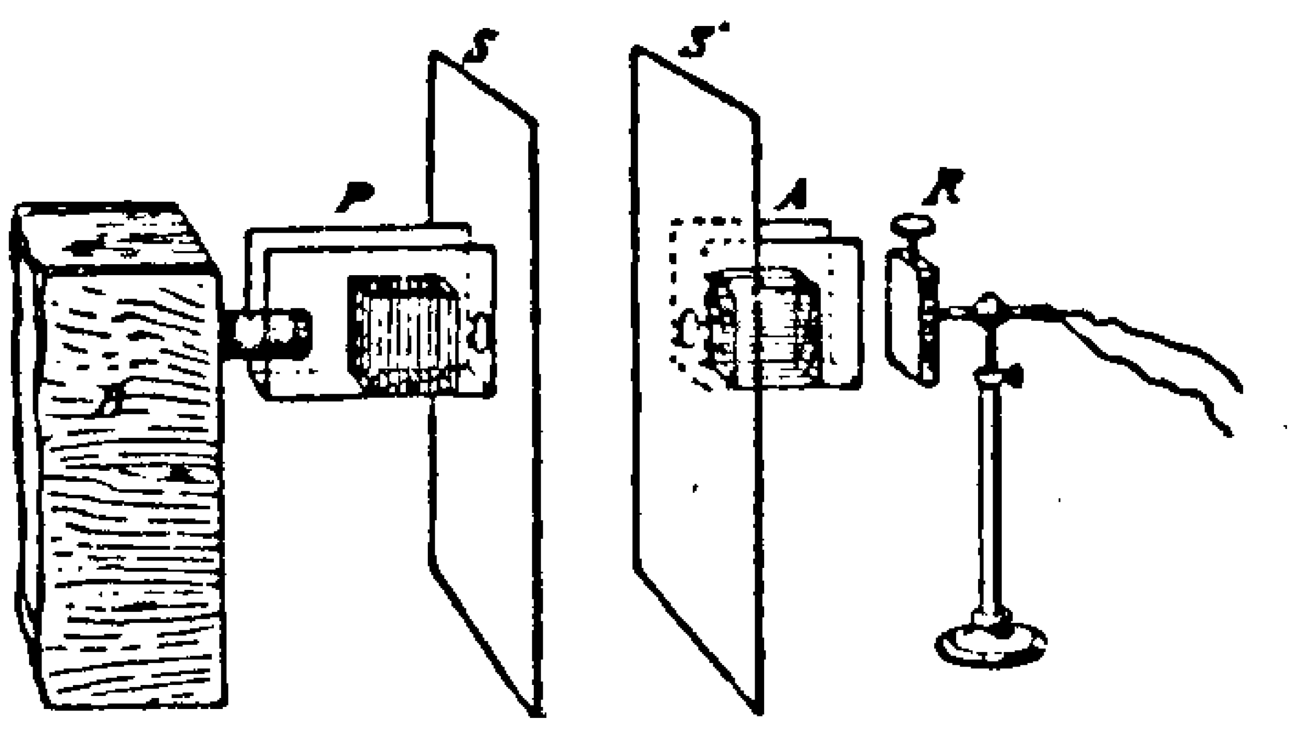

Figure 1. Polarisation apparatus, *B*, the radiating box; *P*, the polariser; *A*, the analyser; *S*, *S'*, the screens; *R*, the receiver.

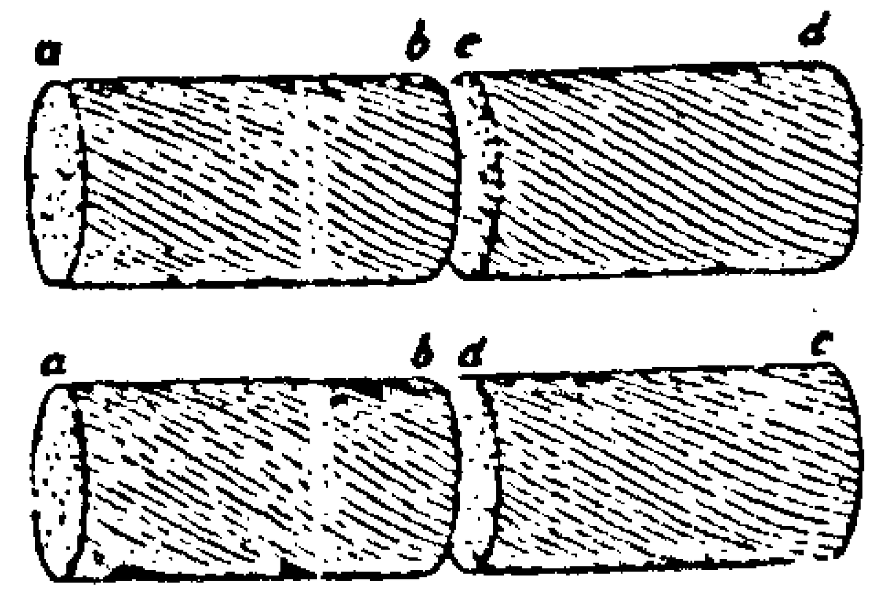

Figure 2. Jute elements.

experiments, be held by the hand, owing to the disturbing action of the fingers. It is preferable to have the substances supported on stirrups made of thin paper. The above are some of the main precautions to be taken in carrying out the following experiments, where the effects to be detected are very small and therefore likely to be masked unless all disturbing causes are carefully excluded.

I have in a previous communication made mention of the double refracting property of fibrous substances like jute. The field is restored when a bundle of jute is placed at 45° between the crossed polariser and analyser. There is, however, no depolarisation effect when the axis of the bundle is parallel to the direction of the ray.

I now took three similar bundles, A, B and C, of parallel fibres of jute 10 cm. in length and 4.5 cm. in diameter. No change was made in the bundle A which was kept as a test one. The bundles B and C were then twisted, B in a right-handed direction and C in a left-handed direction.

The interposition of the untwisted bundle A between the crossed polariser and analyser did not produce any effect, but strong action was produced in the receiver when the bundles, twisted to the right or to the left, were so interposed. It thus appeared as if the twisted structures produced an optical twist of the plane of polarisation.

Further experiments to be described below may be of some interest in connection with the optical rotation produced by liquids. Here two different classes of phenomena may be distinguished:

(1) The rotation induced by magnetic field; this rotation among other things is dependent on the direction and intensity of the magnetic field, and is doubled when the ray is reflected back.

(2) The rotation produced by saccharine and other solutions, when the rotation is equal in all directions and simply proportional to the quantity of active substance traversed by the ray; the rotation in this case is neutralised when the ray is reflected back.

The difficulties in the way of explaining rotation produced by liquids are summarised in the following extract:

'It is, perhaps, not surprising that crystalline substances should, on account of some special molecular arrangement, possess rotatory power, and affect the propagation of light within the mass in a manner depending on the direction of transmission. The loss of this power when the crystalline structure is destroyed, as when quartz is fused, is consequently an event which would be naturally expected, but the possession of it in all directions by fluids and solutions, in which there cannot be any special internal arrangement of the mass of the nature of a crystalline structure, is not a thing which one would have been led to expect beforehand. To Faraday it appeared to be a matter of no ordinary difficulty; it is just possible that the light, in traversing a solution in which the molecules are free to move may, on account of some peculiarity of structure, cause the molecules to take up some special arrangement, so that the fluid becomes as it were polarised by the transmission of the light, in a manner somewhat analogous to that in which a fluid dielectric is polarised in a fluid of electrostatic force.'*

In order to imitate the rotation produced by liquids like sugar solutions, I made small elements or 'molecules' of twisted jute, of two varieties, one kind being twisted to the right (positive) and the other twisted to the left (negative). I now interposed a number of, say, the positive variety, end to end, between the crossed polariser and analyser; this produced a restoration of the field. The same was the case with the negative variety. *I now mixed equal numbers of the two varieties, and there was now no restoration of the field, the rotation produced by one variety being counteracted by the opposite rotation produced by the other.*

To get complete neutralisation, it is necessary that the element should be of the same size, and that the two varieties should be twisted (in opposite directions) to the same amount. The experiment was repeated in the following order, to avoid any uncertainty due to the possible variation of the sensitiveness of the receiver. The receiver is adjusted to a particular sensitiveness, and as long as it is not disturbed by the action of radiation, the sensitiveness remains constant. A mixture of opposite elements is first interposed, the receiver continuing to remain unaffected. From the mixture of positive and negative varieties, one set, say the negative, is now rapidly withdrawn, and an equal number of positive substituted. The receiver which has not been disturbed since its first adjustment is now found to respond, all the elements conspiring to produce rotation in the same direction. It will be seen that the two experiments are carried out under identical conditions.

In the above, we have electro-optic analogues of two varieties of sugar—dextrose and levulose. There is also the production of an apparently inactive variety by the mixture of two active ones.

It is to be noted that there is no polarity in the elements, in the sense we use the term in reference to, say, magnetic molecules. *There is nothing to distinguish, one end of the jute element from the other end; indeed a right-handed element would appear right-handed when looked at from either end.* It thus happens that if the rotation is determined by the direction of the twist, two molecules of the same variety will always conspire whether they are arranged as *ab, cd*, or, to take the extreme case, as *ab, dc* (with the second molecule reversed). The assumption of any particular arrangement of molecules is thus not necessary in explaining the rotation. The average effect produced by a large number of active elements interspersed in an inactive medium will thus be the same in all directions, and proportional to the number of molecules traversed by the ray. *As there is no polarity in the molecule*, a right-handed element will always produce the same kind of rotation, say, to the right of an observer travelling with the ray. The rotation produced when the ray is reversed by reflection will thus be in an opposite direction, and the two rotations will neutralise each other.

But if the molecules exhibit any polarity, that is to say, if the effects produced by the two ends of the same molecule are opposite, the resultant effect produced by a number of such molecules arranged in haphazard directions, will be zero. In order that the effects produced by the molecules may conspire, it is necessary that they should take up a special arrangement like the disposition of molecules in a magnetised rod. It is seen that in this case the rotations of the direct and the reflected rays are in the same direction, and the resultant rotation is therefore doubled. There is some analogy between the action of such polarised molecules and of substances which, when placed in a magnetic field, rotate the plane of polarisation.