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IX. *On the Polarization of the Chemical Rays of Light.*  
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IT has been long known that the invisible rays of the solar light, which manifest their presence by inducing chemical action, are possessed of some of the properties of the luminous rays. Their capability of being reflected and refracted must have been observed at the time of their discovery; and Dr. Thomas Young proved that they were capable of producing the phænomena of interference, by allowing the rays beyond the violet extremity of the spectrum to fall on paper covered with chloride of silver, after having been transmitted through glasses showing Newton's rings. The same phænomenon was also exhibited directly by M. Arago, who made use of Fresnel's experiment for the purpose of demonstrating it.

On the 21st December 1812, M. J. E. Bérard read a paper before the French Institute, "*Sur les propriétés des différentes espèces de rayons qu'on peut séparer au moyen du prisme de la lumière solaire,*" which was published in the "*Mémoires d'Arcueil,*" vol. iii.; and in this memoir, after investigating several properties of the chemical rays, he relates the following experiment:—"I received the chemical rays directed into the plane of the meridian, on an unsilvered glass, under an incidence of  $35^{\circ} 6'$ . The rays reflected by the first glass were received upon a second under the same incidence. I found that when this was turned towards the south, the muriate of silver exposed to the invisible rays, which it reflected, was darkened in less than half an hour; whereas, when it was turned towards the west, the muriate of silver exposed in the place where the rays ought to have been reflected, was not darkened, although it was left exposed for two hours." From this experiment he deduces that the chemical rays can be polarized like white light, when they are reflected by surfaces of glass under a certain angle, and that this angle appears to be very nearly the same for the two kinds of rays. "It is," he says, "consequently to be presumed that the chemical rays can undergo double refraction in traversing certain diaphanous bodies, and, lastly, we may say that they enjoy the same physical properties as light in general."

An experiment similar to M. Bérard's will be found detailed in the following paper, although I was not aware of there being any such on record, till informed of it by the kindness

\* Communicated by the Author; having been read before the Royal Society of Edinburgh, December 21, 1840: a communication on the same subject had been previously made to the Literary and Philosophical Society of Liverpool, November 2, 1840.

of Professor Forbes, after my paper had been read. In a communication which I have recently received from him, he also says, "In spring 1839 I tried the experiment of letting the picture formed by polarized light passing through calc spar fall upon sensitive paper, then newly discovered:—whether from the fault of the paper, I know not, but on my first trial I obtained no kind of effect, and my attention being occupied with other matters, I never repeated it: but at Birmingham, in August 1839, being requested to give some account of the Daguerreotype, which I had seen in Paris, I mentioned the experiment, and pointed out its valuable application to fix with unerring accuracy phænomena of diffraction and polarization, which different eyes have seen differently, and which, regarded as the test of theories, would thus be preserved with unimpeachable fidelity for examination at leisure by every eye."

With these few preliminary remarks I shall proceed to the paper itself.

Liverpool, 22d March, 1841.

In the course of last summer it occurred to me that the invisible chemical rays of light might be subject to the laws of polarization, and early in the month of July I instituted a series of experiments to determine the point. In all investigations of this nature it is of importance that the solar light should continue for a certain time of nearly the same intensity; but during the summer the sky was so frequently overcast that a very few days only could be devoted to the subject, and for a considerable part of the autumn the sun's altitude has been too low. For these reasons I have been unable to pursue the investigation so far as I could have wished, but I have nevertheless obtained a sufficient number of results to establish the principal facts, and I have thought it better to bring these forward at the present time than to allow the subject to lie over for the several months which must intervene before I can again resume it.

I have succeeded in polarizing the chemical rays:—1st, as they proceed directly from the sun; 2nd, as they exist at the extreme violet end of the spectrum; 3rd, as they fall from the sky; and by three different processes,—double refraction, reflexion, and repeated single refraction. I shall describe in succession these processes, with the apparatus used.

1. *Polarization of the Chemical Rays by double Refraction.*

The first important fact in regard to the chemical rays is, that they are susceptible of double refraction, in the same manner as the luminous rays are. To prove this, a prism of cal-

careous spar, one and three quarters of an inch in length and one inch in the side, and polished at each end, was employed. It was inclosed in a case having an aperture at one extremity, the other extremity being open. The extreme violet rays of the solar spectrum were allowed to pass through the aperture and to fall on a piece of photogenic paper. Two very faint images were formed, and in a minute or two these produced corresponding dark impressions on the paper. A similar result was also obtained when the direct sun's rays were employed. By this apparatus two impressions of equal intensity, each half an inch long and one-eighth of an inch broad, were obtained; but on extending the experiments I soon found that a polarized beam of greater size than it could give was necessary; I therefore substituted a plate of Iceland spar an inch square and  $\frac{3}{16}$ ths of an inch thick, and in order to increase the divergence of the rays, one of the planes was ground to an angle of  $63^\circ$  with the obtuse edge, and both planes were then polished. A plate of Iceland spar thus prepared, has the property of separating the two rays so much, that when inserted into an aperture admitting a sun-beam into a darkened room, it gives two images of polarized light, each one inch in diameter and about an inch apart, on a screen placed at the distance of eight feet from the aperture.

These images, when received on sensitive paper, both produced considerable effect; but the extraordinary more than the ordinary, and it was therefore chosen for the purpose of experiment.

An analyzing apparatus, consisting of six thin plates of mica, was placed obliquely in the course of the polarized ray, so as to form with its axis an angle of about  $25^\circ$ . The instrument was turned round until the plane of the mica plates coincided with the plane of polarization of the ray. When this was done the light was almost extinguished, and was allowed to fall on a piece of photogenic paper. After the lapse of five minutes no effect whatever was produced on the paper. The mica plates were then turned round  $90^\circ$ , until their plane was at right angles with the plane of polarization. The light was greatly increased in intensity, and in one minute the paper was tinged, in three minutes a good deal so, and in five minutes it was pretty dark. This experiment proves that the plane of polarization of the chemical rays is coincident with that of the luminous rays of the sun's light.

Instead of the mica plates employed in the last experiment, I next used the long prism of Iceland spar already mentioned. The polarized beam was transmitted along it, and the prism turned on its axis until one of the rays was extinguished: a

piece of sensitive paper received a dark image from the unextinguished ray; but the extinguished ray produced no effect whatever.

A film of mica was then placed in the course of the polarized beam before it passed through the prism, and the extinguished ray immediately reappeared: the two rays were allowed to fall on sensitive paper, and both produced tints of equal intensity.

This experiment was repeated with a film of selenite instead of the mica: one of the rays was coloured of a yellowish, the other of a purple tint: on being received on photogenic paper both the images gave dark impressions, but the purple image produced more effect than the other.

The experiment was again repeated with a film of selenite, which gave a pink colour to one ray and a green colour to the other; and in this instance both images gave tints of equal depth to the paper. These experiments go to prove that the chemical rays, when polarized, are acted upon by thin crystallized plates, in a manner similar to that in which the luminous rays are influenced.

I was next desirous of ascertaining whether any phænomena resembling the coloured rings seen round the axes of crystals in polarized light were presented by the chemical rays when polarized, and for this purpose I employed an apparatus consisting of a tube two inches long and three-fourths of an inch in diameter: at one extremity of it was placed a double convex lens, having a focus of one and a quarter inch: within the tube, and at the distance of half an inch from the lens, was placed a section of a calcareous spar rhomb, such as is used for showing the coloured rings. At the other extremity of the tube was placed an oblique analyzing bundle of three mica plates, or one of Nicol's improved prisms, and the apparatus was so disposed that the polarized sunbeam was allowed to fall on the lens, and thence through the tube upon a screen placed close to it. An image of the coloured rings and black cross was thus obtained, and by turning the tube  $90^\circ$  upon its axis, the rings with the white cross appeared; while in this position a piece of photogenic paper was used to receive the image, and a reversed impression of the rings and cross was obtained; to wit, the place where the white cross had been was dark, the centre light, with a complete black ring round it, and segments of other rings exterior to it. The tube was next turned  $90^\circ$  upon its axis, so as to show an image of the rings with the black cross; sensitive paper was again employed, and another reversed impression obtained; to wit, the position of the black cross was white, the centre and inter-

spaces dark, with segments of two or three darker circles on them.

I have also used a section of rock crystal for the purpose of obtaining impressions of its rings, and to determine whether phenomena were presented similar to those of circular polarization. The result, however, owing to the unsettled state of the weather, was not so satisfactory as I could have desired, and I have therefore left this part of the subject for a more favourable opportunity.

The next step in the investigation was to determine whether similar phenomena were presented at the violet extremity of the spectrum. For this purpose I employed a glass prism to decompose the polarized sunbeam used in the preceding experiments. A polarized spectrum was thus formed, at the extreme violet end of which most of the experiments were repeated. The extreme violet ray was allowed to pass through the prism of calcareous spar, and received on photogenic paper; one image of violet light, extremely feeble, was all that was visible. The action of the chemical ray was, however, intense, for in a minute or two a deep dark spot marked the position of the *unextinguished* ray, while no effect whatever was produced by the *extinguished* ray. A film of mica was now introduced into the course of the violet ray; two faint luminous images appeared, and two dark impressions were obtained. These experiments were again repeated beyond the extreme violet ray. That part of the spectrum which traversed the prism of calcareous spar gave no luminous image, but the result was the same; to wit, the *unextinguished* chemical ray gave a dark impression on sensitive paper, and the *extinguished* ray none; and when a film of mica was used, two dark impressions of both rays were obtained.

The experiments with the rings were also tried; but although the impressions were visible, they were by no means so distinct as those obtained from the direct sun-light, a circumstance which is partly to be attributed to the great difficulty of keeping the axis of the apparatus employed in the axis of the polarized ray. The sun's motion has to be compensated by the movement of the hand; and these experiments are on this account of difficult performance, unless a heliostate, or some similar contrivance, be used to keep the sunbeam precisely in the same direction during the required time.

## 2. *Polarization of the Chemical Rays by Reflexion.*

I have now stated the principal results at which I have arrived in the polarization of the chemical rays by double refrac-

tion, and shall next proceed to detail experiments which go to prove that these rays can be polarized by reflexion. The apparatus made use of consists of a mirror composed of nine plates of parallel glass, by which a beam of polarized light can be thrown upon an analyzing plate of thick flint glass, so mounted that its angle of position can be changed, and its plane of reflexion made to revolve round the polarized beam. The image of the sun, after having been reflected from the mirror at the polarizing angle, was thrown upon the analyzing plate, the plane of which had previously been turned at right angles to the plane of primitive polarization. From this plate the ray was received upon a piece of photogenic paper, and in three minutes a very faint impression was obtained. The apparatus being still in the same position, another piece of paper, cut from the same sheet, was substituted for that used in the last experiment, and the ray was depolarized by interposing a plate of mica between the mirrors; in three minutes the paper received a dark impression, thus affording another illustration of the effect of crystallized plates on the polarized chemical rays.

Another piece of paper, also cut from the same sheet, was made use of, but the analyzing plate was turned  $90^\circ$  upon its axis before the ray reflected from it was allowed to fall on the paper, and in three minutes an impression was obtained equal in intensity to that produced in the last experiment.

These three experiments, which occupied little more than ten minutes in their performance, were executed at a time when the sun's rays were of equal intensity, and the paper used was also of equal sensibility; and they afford an additional proof of the similarity of effect produced by polarizing forces on the chemical and luminous rays.

### *3. Polarization of the Chemical Rays by repeated single Refraction.*

To exhibit this phenomenon I prepared two bundles of mica plates, nine in each bundle. These were arranged diagonally in a tube, one half of which could be turned round within the other. The tube was turned so that the planes of both bundles were at right angles, and the sun's rays were transmitted through it so as to fall on sensitive paper. In a few minutes little or no effect was produced, but on turning the planes round so as to coincide, an immediate darkening of the paper took place.

I next employed this method to polarize the chemical emanations proceeding from the sky alone; but as it was necessary in this case to have simultaneous results to obviate the

effects of varying intensity, two sets of experiments were carried on at the same time. A piece of thin window glass was chosen, out of which sixteen plates, one and a half inch long and one inch broad, were cut. These were arranged diagonally in four bundles, and placed in two tubes; two of the bundles having their planes coincident in one tube, and the other two with their planes at right angles in the other tube. The tubes were placed close to each other in a perpendicular position in the open air, so that the light from the sky could pass directly through them upon two pieces of photogenic paper, cut from the same sheet, and placed so as to receive the chemical emanations. In this position they were left for two hours in a tolerably clear day; and although the chemical rays had to pass through the same number of plates in both instances, the impressions received by the paper differed much in intensity, that under the tube containing the two bundles with the planes at right angles being much less affected than the other. The explanation of this phænomenon is that all those chemical emanations which were polarized by the repeated refraction of the first bundle of glass plates did not pass through the second bundle when their planes were at right angles, and consequently produced no effect on the paper; but, on the contrary, they passed readily through the second bundle, when its plane coincided with that of the first, and produced their characteristic darkening effect. The phænomena are in fact similar to those observed with the luminous rays under the same circumstances.

Such, then, are the results at which I have as yet arrived in this interesting branch of physical research, and they appear to prove that the third great division of the solar emanations, like the luminous and calorific, are capable of being acted upon by polarizing forces, and that thus they are all subject to the same beautiful laws.

Before concluding this communication I may state, that the photogenic paper employed in the experiments was prepared in the usual way with chloride of silver, but that it would be more satisfactory to use small Daguerreotype plates, particularly in obtaining impressions of organized or crystalline structures by the solar microscope. To effect this, a pair of short polarizing prisms, made according to Mr. Nicol's improved plan, may be adapted to the microscope, one being placed so as to polarize the sun's light before it falls on the object, and the other to analyze the beam immediately after it has passed the object-glass. A sensitive surface placed so as to receive the image thus formed would take a corresponding impression of the structure.