XX.—*On the Polarisation of Light by Rough and White Surfaces.* By Sir DAVID BREWSTER, K.H., D.C.L., F.R.S.

(Read 2d March 1863.)

The laws of the polarisation of light when reflected from the surfaces of solids and fluids, and when refracted and transmitted by translucent and transparent bodies, have been successfully investigated; but no experiments, I believe, have been made on the polarisation of light by rough or unpolished surfaces, such as ground glass, painted surfaces, pounded glass, snow, white powders, and solids and fluids reflecting white light from their interior. When studying the polarisation of the atmosphere, and anxious to discover the cause of its partial polarisation, and of the three neutral points or spots, in which there is no polarisation, I investigated the action of rough surfaces upon light, under the conviction that the sky or atmosphere was a rough surface like any aggregation of white or coloured particles. Had the atmosphere been specular like water or any body with a polished surface, the image of the sun would have been seen in it by reflexion, but being composed of aerial and aqueous molecules, it must reflect the sun's rays like pounded glass, or any white or coloured powders.

The results of this inquiry, which I now submit to the Society, are such as I anticipated, and afford an explanation not only of the partial polarisation produced by the atmosphere, but of each of the three neutral points, which, it will be shown, can be produced artificially by the combination of rays polarised by the reflexion and refraction of any rough or molecular surface.

The experiments by which these results were obtained were made chiefly with rectangular plates of glass, 9 inches by 7, of various degrees of roughness, some with only one side, and others with both sides rough. These plates, some of which are now on the table, were made at the Smethwick Glass Works, near Birmingham, and were kindly presented to me by Messrs CHANCE and BROTHERS, the proprietors of that great establishment.

The angle of complete polarisation for light reflected from the polished surface of this glass is about $56\frac{1}{2}^{\circ}$, and the polarisation is a maximum at this angle, diminishing on one side to 0° of incidence, and on the other to 90° . When the light thus polarised is examined by the band polariscope, the bands are nowhere interrupted, and therefore there can be no neutral point, the polarisation of the bands being everywhere positive or vertical.

In order to observe the effect of a single rough surface, such as that of glass ground with the finest emery, I blackened with melted wax the polished surface of a plate which was ground only on one side, in order to prevent the light scattered by the ground surface from being reflected at the second surface. When this single rough surface reflected the light of a gas flame, it polarised it almost completely at nearly the polarising angle of $56\frac{1}{2}^\circ$, and there is no interruption or neutral point in the bands of the polariscope. The Rotation, therefore, or measure of polarisation, is nearly 45° .

If this single rough surface is placed at an open window when the sun is not shining, and reflects the light of the sky or clouds, the light is only partially polarised, and the degree of polarisation R is only 19° . In the open air it is much less with in the room the polarisation increases as the glass recedes from the window. In the open air it is a maximum when the plane of reflexion passes through the sun and the observer. The rotation is then 15° , and it diminishes with the distance of the plane of reflexion from the plane passing through the sun and the observer.*

When the second or polished surface is not blackened, it reflects the light scattered by the ground surface, and the maximum polarisation of the rough surface is greatly diminished. The rotation is 16° with a gas burner very near, and 20° when the flame is still nearer. The polarisation is diminished by holding a lighted candle on one side of the plane of reflexion.

With a similar plate having a rougher surface, the degree of the polarisation of the sun's rays directly reflected was $16\frac{1}{2}^\circ$ close to a south window. Before noon the angle of maximum polarisation was 44° , and at noon, with a brighter sun, it was 40° .

Fig. 1.

When the whole light of the sky fell upon the rough surface MN, the rotation was 21° . When AB was covered up the rotation was diminished, and when CD was covered up the rotation was increased.

When both the surfaces of the plate of glass are rough, the polarisation is a maximum, at an angle greater than the normal polarising angle, or $56\frac{1}{2}^\circ$, and the degree of polarisation is about 20° .

In making similar experiments with ivory, bone, porcelain, white or coloured surfaces painted in oil, paper, parchment, silk, linen, and cotton cloths, milk, flour, and other white powders, &c., I found *that the polarisation was partial* in all of them, the normal or complete polarisation being reduced by its combination with the oppositely polarised rays produced by refraction.

In all these experiments the partial polarisation was positive or vertical from

* The roughness of the glass surface used in the preceding experiments is such, that a gas flame, distant $5\frac{1}{2}$ feet, ceases to be visible at an angle of incidence of $79^\circ 50'$.

an incidence of 90° up to an incidence of 0° , as far as it could be observed, owing to the impossibility of examining the bands where they were reflected at or near a perpendicular incidence. In order to meet this difficulty, I adopted the following mode of observation:—

The rough or white surface MN being placed vertically, was illuminated with the flame of a gas burner, or a moderator lamp, placed at F. The observer at E, or in any direction between F and N, observes the condition of the bands of the polariscope when they are placed parallel to MN.

Fig. 2.

If we now take a single rough surface of plate-glass *blackened* on its polished side, and place it at MN, we shall observe a neutral point about H, the polariscope bands being *negative* or *horizontal*, with a *white* centre on the M side of H, and *positive* or *vertical*, with a *black* centre on the N side of H. This neutral point is obviously produced by the equal and opposite action of light polarised by reflexion and refraction. As these two lights, proceeding from light incident at H, proceed from F, they cannot reach the eye at E by the ordinary law of reflexion. They are portions, therefore, of oppositely polarised rays scattered in every direction by the rough surface of the glass.

If we take the same plate of glass with its surface *not blackened*, and place it at MN, we shall find the neutral point at G.

If we invert this plate, so that its polished side is uppermost, the neutral point is advanced to A, all the bands on the M side of A being, as before, *negative*, and those on the N side of A *positive*,—a result proving that the intensity of the negative bands had been *increased* and the positive ones *diminished*.

Conceiving that this effect was produced by the light scattered by the rough surface being polarised *negatively* by the refraction of the polished surface, I took the plate with the blackened side, and laid upon its surface a plate of transparent glass, in order to imitate the action of the unpolished surface in the preceding experiment. The neutral point which, by the action of the single rough surface, was at H, was now advanced to A by the refractive polarisation of the two surfaces of the transparent plate. When this plate was placed at *mn* parallel to MN, the very same effect was produced. By inclining *mn*, the neutral point was advanced from A to *a*, still farther, by increasing the inclination, and still farther, by using several plates, the plane of refraction or incidence being parallel to a plane passing through FGA.

If we turn the plate or plates at *mn* round 90° , keeping the same inclination

to the incident rays from MN, the neutral points will return to their respective places *a*, A, G, H, the refractive polarisation of the plate or plates reducing the negative bands between M and the neutral points, and increasing the positive bands between the neutral points and N.

Hence, we have a method of determining whether the polarisation of the bands is positive or negative, when they are so faint or indistinct that we cannot see whether the central band is black or white. When they become *less intense*, or perhaps disappear, by viewing them through one or more plates of glass at *mn*, having their planes of reflexion parallel to the plane passing through FA, they are *positive*. When they become *more intense* they are *negative*.

The place of any neutral point may be advanced from H to G, or from G to A and *a*, by placing a sheet of *white* paper behind the rough surfaced plate MN, or by one or more plates of glass with rough surfaces, each plate advancing it farther. A sheet of paper advances it farther than *four* surfaces of ground glass. The rays scattered by the paper are negatively polarised by refraction at their emergence from the Plate MN, and, by increasing the intensity of the negative bands, shifts the neutral point towards N.

We have already seen that a single rough surface of glass blackened behind has its neutral point about H, and when not blackened about G. A plate with both sides rough carries the neutral point towards A, and two and more such plates still farther. The smoothest ground plates carry the neutral point farther than the roughest towards M.

In the prosecution of this subject, I submitted to examination the following substances :—

Calcareous spar ground.	Linen cloth, white.	Swan's down.
Marble white.	Cotton cloth, white.	Snow.
Painted board.	Cashmere, white.	Pearl oyster shell.
Ivory.	Paper of all colours.	Pounded sugar.
Ivory artificial.	Parchment.	Pounded glass.
Bone.	White kid leather.	Rochelle salts.
Porcelain.	Pith of the sola.	Soda.
White fir wood planed,	Rice paper.	Magnesia.
Yellow fir wood planed.	Cotton wool.	Milk.
Silk, white.	Ermine.	White shell.
Satin, white.		

In all these substances I found a neutral point in the mixture of the positively and negatively polarised rays which they reflect. In many of them the neutral point was on the A side of G, or when the angle of incidence was less than 90°, while in others it was on the H side, or when the angle of incidence was negative and greater than 0°, but on the other side of the perpendicular FG.

As in ground glass, one or more plates of glass inclined to the reflected ray, as previously described, brought the neutral point, in almost all these substances, to the A or N side of G.

When the substance was more or less glazed, the neutral point was on the A side of G, the glazed surface acting exactly like the polished surface of a plate of ground glass when placed next the light. This effect is finely seen in milk, where the fluid surface increases the negative or refracted light as in the glass plate.

I attempted to determine for several of these substances the angle of maximum polarisation, the intensity of the partial polarisation, and the place of the neutral point; but I found it very difficult, owing to the magnitude of the flame which was necessary to show the bands when very faint, and to its proximity to the reflecting surface, which was necessary from the same cause.

In white unglazed *paper* for example, in the sun's light on the 1st of February 1841, at 11^h A.M., the polarising angle was about 71° , and the degree of polarisation, or $R=18\frac{1}{4}^\circ$. On the 2d February the polarising angle was $69\frac{1}{2}^\circ$, and $R=18\frac{1}{4}^\circ$ at 10^h 40^m A.M.

In almost all the substances which I have examined, I have observed a neutral point only at angles of incidence below the maximum polarising angle, and beyond G, fig. 2; but it is obvious that there must be another at some angle above the maximum polarising angle, excepting in substances where the light polarised by refraction is too feeble to neutralise the light polarised by reflexion. I have observed this second neutral point only in one case, but with a sufficiently strong light it will doubtless be seen in many substances.

In all the preceding experiments, the substances employed have been opaque, or with such rough surfaces, that objects cannot be seen through them. I was therefore desirous of ascertaining if neutral points were produced when the surfaces which polarise the light were perfectly transparent, having some analogy with the strata of the atmosphere of different densities. With this view I used a pile of transparent plates with twenty surfaces, and I found a neutral point distinctly visible, both above and below the angle of complete polarisation. I obtained the same result at an angle less than that of complete polarisation, with a large plate of mica split by an intense heat into so many films that it had the metallic lustre of silver.

The results now submitted to the Society could hardly have been anticipated from theoretical considerations. The laws of polarisation for light, normally reflected and refracted by polished surfaces, are not applicable to those which are rough, or to bodies which reflect light from their interior; and in the case of piles of polished glass-plates, the most distinguished philosophers, ARAGO, YOUNG, and Sir JOHN HERSCHEL, would have considered the light which the plates reflected, as they did that which they transmitted, as consisting of polarised light, accompanied with a portion of common light, a combination incapable of producing neutral points.

The most important application of the preceding experiments is to the polarisation of the atmosphere. ARAGO, BABINET, and others, in their theory of the neutral points, and of the partial polarisation of the atmosphere, took no account of the rays which are polarised by refraction, whenever light is polarised by reflexion, and they referred these abnormal phenomena to a horizontal secondary reflexion from the atmosphere itself, modifying, and, in three neutral points, extinguishing the light polarised by reflexion. Whether or not such a secondary reflexion exists, or is adequate, if it does, to account for these phenomena, are questions which will be considered in another paper on the polarisation of the atmosphere. But however ingenious may be the hypothesis, it has no support either from experiment or observation. The reduction of complete to partial polarisation, by the opposite action of light polarised by reflexion and light polarised by refraction, and the production of neutral points where these two lights are equal, whenever light is incident on surfaces, which, like the atmosphere, disperse and polarise it, is next to an ocular proof of the true laws of atmospherical polarisation.

It is not one of the least wonders of terrestrial physics, that the blue atmosphere which overhangs us, exhibits in the light which it polarises phenomena somewhat analogous to those of crystals with two axes of double refraction.