Scattering of Light by Solid Substances.

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[Plate 12.]

The observations already published on scattering of light by gases and liquids* naturally led on to an examination of the behaviour of solids in this respect. At the first trial it was found that glass scatters very freely, the scattered light being blue, and in many cases almost completely polarised. The observation is so easy that it must almost certainly have been made before, though I have not met with any mention of it. No special arrangements are necessary. If a narrow parallel beam, say 6 mm. diameter, from the condenser of an electric lantern, is allowed to traverse the interior of a block of glass, the scattered light along the track will be conspicuous. This is a ready method of demonstrating the scattering by small particles.

Numerous specimens of plate glass and optical glass have been examined. These all show the scattering, though they differ among themselves in respect of intensity and completeness of polarisation. The depth and purity of the blue colour goes of course with the latter.

A few comparisons were made between the intensities of vibration in the scattered light:

(1) Parallel to direction of primary beam (weak image).

(2) Perpendicular to primary beam (strong image).

The former is given as a percentage of the latter. The result for Chance's crown glass was about 8 per cent., and for ordinary plate glass 3 per cent. The Chance's crown gives a much poorer blue.

These glasses give a degree of polarisation of the same order as the various gases where the scattering is molecular. This however is probably an accidental circumstance. In the case of glasses, the wide difference between different samples suggests that scattering is due in the main to inclusions rather than to the molecules. These inclusions are probably to be regarded as spherical, some of them with a diameter not small compared with the wave-length. In this case the defect of polarisation in glass would be due to the appreciable size of the obstacles, whereas in gases it is due to lack of spherical symmetry.

The remaining experiments on solids have reference to quartz in different varieties and to Iceland spar. It was found that yellow quartz and smoky

* 'Roy. Soc. Proc.,' A, vol. 94, p. 453 (1918); vol. 95, p. 155 (1918).

quartz have the property of scattering light very strongly, the colouring matter being evidently distributed in the crystal in the form of small particles analogous to those found in glass. Preliminary examination of a crystal can often be made by immersing it in a trough of highly refracting liquid such as benzene; but to work satisfactorily, it is necessary to have suitable faces cut and polished, so that the beam can be sent along the axis of the crystal and examined perpendicularly to it. Evidently the scattered light should be analysed parallel and perpendicular to one of the principal planes of the crystal, for if this is not done, double refraction altogether disturbs the relative intensities of the images.

With a crystal of yellow quartz from Madagascar, the polarisation of scattered light was tolerably complete, the weak image having about 0·7 of 1 per cent. of the intensity of the strong one. This is decidedly more perfect polarisation than was obtained with any of the gases examined in the earlier investigation. The stronger image was bluish, but the fainter image was a very rich blue, no doubt the same as the "residual blue" observed by Tyndall in precipitated clouds, when the particles were no longer very small compared with the wave-length.

A sample of slightly smoky quartz from Brazil gave less intense scattering than the above, the scattered light was, however, of a good sky-blue colour. The weak image had about 3 per cent. of the intensity of the strong one.

In these cases the primary beam travels along the axis of the crystal. If, on the other hand, the line of vision is along the axis, then the rotatory property of the crystal intervenes, and (in white light) the two polarisations appear to the eye to be of equal intensity. This, it is not difficult to see, is the natural result of rotatory dispersion by a considerable thickness of crystal, causing several complete rotations.

The rotatory effect is best shown, however, by using a nicol to polarise the incident beam. The cloud of particles then acts as analyser. As the beam advances into the crystal, the plane of polarisation is rotated, so that alternations of light and darkness are observed laterally, corresponding to rotations of 90°. In white light, the rotatory dispersion gives striking coloured bands, reminiscent of interference bands, and like them rapidly losing purity after a few periods, owing to the superposition of different orders. Visually five or six periods can be traced. Photographically several more, see Plate, No. I, which was taken with white light. No. II on the plate was taken with monochromatic violet light (the violet line of a quartz mercury lamp). The bands of higher order do not in this case lose definiteness, though there is a loss of intensity by absorption in the yellowish crystal, and also some variation due to irregular distribution of the scattering particles in the quartz. No. III was photographed on the same scale as No. II, but with yellow light instead of violet. The much longer period will be noticed, due to the comparatively small rotation for this part of the spectrum. Homogeneous yellow light could not be used, as no source available was bright enough for photography with reasonably short exposure. The light of a carbon arc filtered through bichromate solution was employed, and in consequence of the considerable range of wave-lengths present, the maxima in the photograph become less distinct after a few periods.

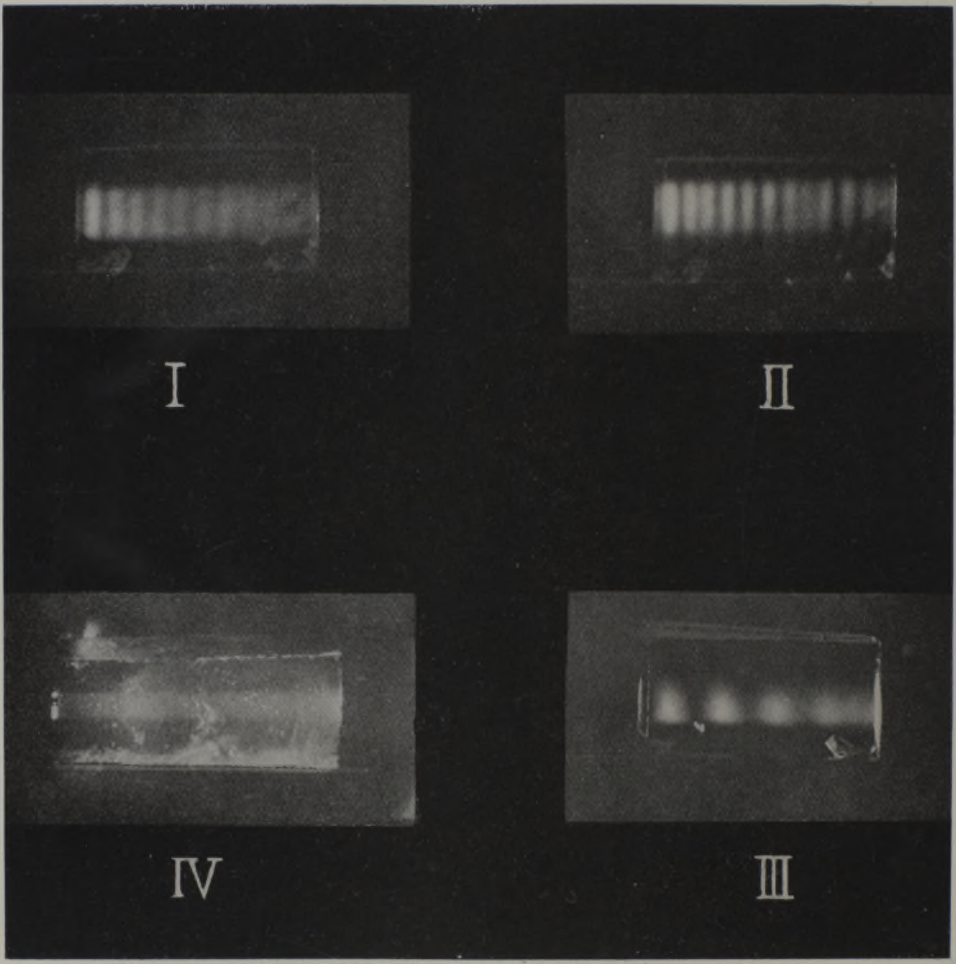
A pretty effect can be got by passing a polarised beam in succession through two crystals, the first right-handed (say) and the second left-handed. The first should be only half the length of the second. In this case, using white light, the bands appear with maximum distinctness when the beam enters the first crystal, becoming fainter along the length of this crystal, from the causes already mentioned. The second crystal, however, reverses the action of the first, and the bands become more distinct again, until the beam has traversed an equal thickness of each, *i.e.*, till it reaches the middle of the second crystal. Here the planes of polarisation for the various colours again coincide, and maximum distinctness is recovered. Beyond this point the bands gradually fade out again. Thus the central white band occurs in the middle of the second crystal, with the coloured bands gradually losing distinctness as we proceed away from it on either side. The appearance is the same as that of the complete interference fringe in white light produced by Fresnel's bi-prism or any equivalent arrangement. On rotating the polariser, the bands in the two crystals travel along the axis in opposite directions.

To get the bands in full intensity, it is important to adjust the crystal so that the light traverses the optic axis pretty accurately.

The experiments on quartz so far described refer to coloured or smoky specimens, which evidently owe their scattering power to the same particles which give rise to the colour or the smokiness. It was of considerable interest to examine the behaviour of clear quartz.

Preliminary examination of a specimen apparently quite colourless, and having only a few internal blemishes, showed that it scattered much less light than any glass, or any specimen of water or liquid ether that has been examined. In fact, scattering has not proved to be visually observable with this specimen. The conditions cannot be made as good for observing a slight scattering as with gases. The few internal blemishes form bright points in the field of view, which distract the eye, and the polished faces diffuse some stray light which spoils the blackness of the background.

It has, however, been possible to detect the scattering by photography.


I
II
IV
III

For this purpose the crystal was covered as far as possible with the composition sold for backing photographic plates, which mitigated reflections and strong light resulting from them. A window was left for the beam to enter along the axis of the crystal, and another for lateral observation. The track of the beam came out well in the photograph (Plate, No. IV), and when a double image prism was mounted in front of the lens, scattered light was only apparent in one of the images, showing that the usual polarisation was present.

Intensity comparisons were made between the total light scattered by clear quartz, and by the other media, by the method formerly described, of altering the lens aperture until photographic intensity was equalised. The results were as follows:—Dust-free air, 1; clear quartz, 8; plate glass, 300; liquid ether, 900.*

I have also observed a scattering strong compared with that of air, in a rhomb of clear Iceland spar. No intensity measurements was made.

It is probable that even in the clearest crystals, the residual scattering is of the same character as that seen in obviously smoky quartz, and is due to inclusions which have no relation to the crystalline structure. Different specimens of apparently clear quartz vary considerably in their scattering power, a fact which can hardly be explained on any other view. The numbers above quoted for quartz and glass are merely illustrative, and refer only to the particular specimens.

The molecules in the crystal are regularly spaced, and at a distance apart small compared with the wave-length of light. So far as they are concerned, the crystal behaves like a diffraction grating with its spacing less than the wave-length. Under these circumstances the secondary disturbances destroy one another by interference, and there is no molecular or atomic scattering. With much shorter waves (X-rays) the well-known diffraction by crystals comes into evidence.

DESCRIPTION OF PLATE.

No. I. Polarised beam along the axis of a yellow quartz crystal. White light.
No. II. Ditto, homogeneous blue light.
No. III. Ditto, yellow light, not highly homogeneous.
No. IV. Unpolarised beam along the axis of a very clear and white quartz crystal.

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* This is the old result for liquid ether, and represents the least scattering I could get, after treating the ether in various ways. I am not satisfied that it is a really definitive result for pure ether. The problem of obtaining such a result is far more difficult for liquids than for gases.