OBLIQUE SCATTERING OF LIGHT IN GASES AND LIQUIDS

By A. S. Ganesan

Abstract

Oblique scattering of sunlight in gases and liquids.—(1) *Theoretical variation with angle.* The scattered light is assumed to consist of an unpolarized part whose intensity is the same in all directions and a polarized part whose intensity varies as $(1+\cos^2\varphi)$. This leads to simple equations for the ratio of the two components and for the total intensity for various angles, which are found to agree within 5 per cent with the (2) *experimental results for carbon dioxide and for dust-free toluene, benzene and ether.* The observed ratios of the intensity for $\varphi=45°$ to that for $\varphi=90°$, are 1.91, 1.79, 1.71 and 2.12 respectively; the observed ratios of the components for $\varphi=90°$ are .102, .52, .48 and .084 respectively. For *carbon disulphide* the observed ratio is .704.

1. Study of Oblique Scattering in Gases

The scattering in gases at ordinary pressures is rather feeble, so that unless sufficient precautions are taken, visual determinations of the intensity or of the state of polarization are easily liable to serious errors. To obtain reliable results, two points must be particularly attended to. The incident beam must be very intense and secondly, the back-ground against which the track is viewed must be perfectly black. For this purpose the following arrangements were employed.

Sunlight reflected from a large plate-glass mirror was concentrated by the objective of an astronomical telescope of 18 cm diameter and 200 cm focal length, and then focussed by a second lens of about 20 cm focal length at the centre of the cross tube containing the gas under examination. A very intense illuminating beam was thus secured which enabled the intensity and state of polarization to be quantitatively determined by visual photometry.

To study the scattering at different angles a set of 5 cross tubes were made up of zinc sheet with their arms inclined at angles of 30°, 45°, 60°, 75° and 90° respectively. The ends A, B and C (Fig. 1) were fitted with plane, clear glass windows. At D a glass plate was fixed at 45°, blackened on both sides so that no light was reflected back towards the observer. This end was further wrapped up with dark cloth. An ideal background for these experiments would be Rayleigh's black glass horn, but the arrangement described above was more easily set up and was found to serve the purpose sufficiently. The cross tubes employed had 8 cm diameter and each arm was of about 20 cm length. They were completely blackened inside and made air tight. To cut off superfluous light, apertures about 3 cm in diameter were placed along the four arms. Two side tubes served to let in and let out the gas. The condensed beam of light was passed along the arm *AB* and the track was viewed through the observation window *C* against the background. For quantitative work the observer's eyes must be shielded from all extraneous light. For this purpose the observer locates himself in a canvas cage covered outside by dark cloth, in one of the walls of which is a perforation into which protrudes the observation window *C* of the cross tube. After remaining some

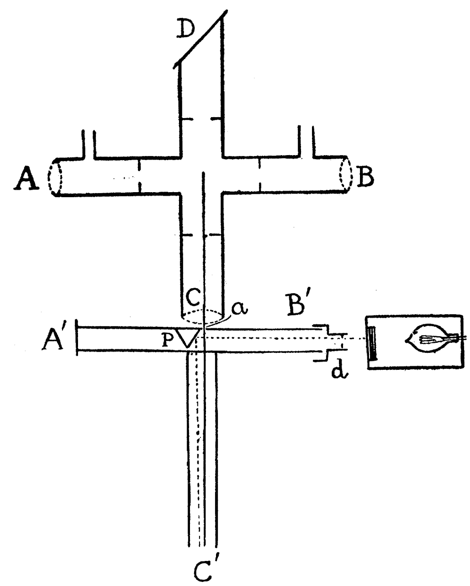

Fig. 1

little time in the cage, even the feeble track of scattering by hydrogen gas is seen as a conspicuous phenomenon. For the purpose of the present study, it was thought sufficient to confine attention to the case of one gas, namely carbon-dioxide, as this shows comparatively intense scattering and exhibits markedly imperfect polarization in the transverse scattering.

The tube was first exhausted and then dust-free carbon-dioxide was passed through it in a continuous stream. The state of the polarization was measured by a double-image prism and nicol. A rectangular aperture punched in a piece of black paper was placed in front of the observation window and the double-image prism adjusted to give two images of this aperture illuminated by the scattered light and polarized respectively in vertical and horizontal planes. The two positions of the nicol placed behind the prism were found for which the two images were of equal brightness. If 2θ be the angle between these two positions of the nicol, the ratio of the intensities of the two components is given by $\tan^2\theta$.

The intensity of the scattered light in different directions was measured by comparing the track with a standard source of light. The light from a 50 c.p. Osram lamp filtered through blue glasses of sufficient thickness to secure a color-match with the blue of molecular scattering, was passed through an adjustable aperture (an iris diaphram of an ordinary camera was found very suitable) on to the face of the photometric wedge which consisted of a strip of white filter-paper held at an angle. Fig. 1 shows the arrangement.

$A'B'C'$ is a hollow wooden T piece of about 5 cm square cross-section, the two arms being each 30 cm long. At B' is fixed the adjustable diaphram. The photometric wedge P is fixed at the centre of the cross arm adjacent to the small aperture a which is placed against the face C of the cross tube through which the track is viewed. The T piece is completely blackened inside. By adjusting the diaphram the two spots (the aperture illuminated by the track, and the white patch illuminated by the blue light from the lamp) are made of equal brightness.

TABLE I

Polarization of light scattered by carbon dioxide

Ratio of components			Ratio of components		
ϕ	Obs.	Calc.	ϕ	Obs.	Calc.
30°	75.9 %	77.6%	105°	17.3%	16.2%
45°	55.6	55.1	120°	32.5	32.6
60°	30.0	32.6	135°	52.6	55.1
75°	16.0	16.2	150°	79.4	77.6
90°	10.18				

TABLE II

Intensity of light scattered by carbon dioxide

ϕ	Observed	Calculated
90°	1	
60°	1.34	1.38
45°	1.91	1.98

The calculated values given in the above two tables are obtained as explained in section 3 of this paper.

2. Study of Oblique Scattering in Liquids

The study of scattering in liquids is made in the same manner as in the case of gases. Here the track being more intense the experimental difficulties are less. The liquids are contained in large glass bulbs. They are made dustfree by repeated slow distillations in vacuo using the form of apparatus devised by W. H. Martin.[1] The bulb is completely blackened except for three windows for the ingress and egress of light and for making the observations. Sunlight reflected from a mirror is focussed by means of a short-focus lens at the centre of the bulb. A rectangular aperture is placed in front of the bulb, and as before the polarization is measured by means of the double image prism and nicol. The bulb is placed at the center of a graduated circle while the combination of the double image prism and nicol moves along the graduations, thus enabling measurements to be taken at various angles.

To measure the intensity, two beams of light reflected by two similar mirrors and focussed by two lenses of the same focal length are made to cross at the centre of the bulb one above the other. They are viewed in a direction perpendicular to one of the tracks. In the path of the two beams apertures are placed and by adjusting them the two tracks are made equal. The intensities are inversely proportional to the areas of the apertures. By altering the angle between the two crossing beams the intensity can be measured in different directions. Care is taken to reflect the sunlight from the mirrors at nearly the same angles. In the case of benzene which was contained in a cylindrical bottle, the intensities of the crossed beams were directly compared by means of a rotating sector photometer which yielded very satisfactory results.

The following tables give the results obtained with carbon disulphide, toluene, benzene and ether, all Merck's extra pure quality and made absolutely dust free.

TABLE III

Observed and calculated ratios of two polarized components for light scattered by various liquids in various directions, in percent.

ϕ	Carbon disulphide		Toluene		Benzene		Ether	
	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.
40°			81.7	80.2	82.2	78.5	63.7	62.2
50°	84	82.6	73.4	71.9	75.8	69.5	47.2	46.3
60°	79.2	77.8	63.7	64.1	61.5	61.0	32.3	31.3
70°	75.6	73.9	56.4	57.8	56.8	54.1	19.6	19.2
80°	73.0	71.3	53.2	53.6	50.1	49.6	11.6	11.2
90°	70.4		52.2		48.0		8.44	
100°	70.9	71.3	52.4	53.6	48.7	49.6	10.3	11.2
110°	73.0	73.9	55.2	57.8	54.4	54.1	18.6	19.2
120°	76.6	77.8	61.5	64.1	60.2	61.0	30.7	31.3
130°	81.1	82.6	69.9	71.9	68.4	69.5	50.9	46.3

[1] Martin, Journal of Physical Chemistry, 1919

TABLE IV

Intensity of light scattered by various liquids in different directions

ϕ	Toluene Obs.	Toluene Calc.	Benzene Obs.	Benzene Calc.	Ether Obs.	Ether Calc.
90	1		1		1	
60	1.377	1.246	1.321	1.257	1.423	1.399
45	1.788	1.636	1.708	1.663	2.120	2.011
30	2.557	2.471	2.626	2.527	3.312	3.267

In the case of benzene the observed values with the rotating sector photometer were 1.200, 1.612 and 2.472 respectively in the three directions. The calculated values in the above tables are obtained after the manner explained in the following section.

3. THEORY OF OBLIQUE SCATTERING IN FLUIDS

The imperfect polarisation of the transversely scattered light by gases has been explained by Lord Rayleigh, Born and others as due to molecular anisotropy. A complete mathematical theory has been developed by Ramanathan[2] which includes the case of both gases and liquids on the assumption that the *orientation* of the molecules is at random. For our present purpose, the matter may be dealt with on a purely geometrical basis, and a simple formula may be obtained in the following way. When the incident light is unpolarised we may consider the scattered light as consisting of two parts, one consisting of polarised light whose intensity varies according to the law $(1+\cos^2\phi)$, and a second part consisting of unpolarised light whose intensity is the same whatever be the direction in which the light is viewed. Resolving the vibrations corresponding to these in perpendicular directions and denoting the intensities corresponding to the unpolarised and polarised parts by A and B respectively, we have in the transverse direction the ratio between the weak and strong components given by

$$r = A/(A+B).$$

In any other direction ϕ this ratio is given by

$$r_\phi = (A+B\cos^2\phi)/(A+B) = r\sin^2\phi + \cos^2\phi \qquad (1)$$

The values given in Tables I and III are obtained with this formula.

As regards the intensity, that of the polarised part is given by $B(1+\cos^2\phi)$ and adding to this the intensity due to the unpolarised light which is $2A$, (since both the horizontal and vertical components are to be

[2] Ramanathan, Proc. Indian Assoc. Cult. Sci., **8**, I, pp. 1-24

taken), we have the ratio of the intensity in a direction ϕ to the intensity in the transverse direction given by

$$\frac{2A+B(1+\cos^2\phi)}{2A+B}=1+\frac{1-r}{1+r}\cos^2\phi.$$

A correction is to be applied to this for the thickness of the layer of the fluid contributing to the luminosity. In a direction ϕ the ratio of this thickness to the thickness in the normal direction is cosec ϕ so that finally we have

$$I_\phi=\left[1+\frac{1-r}{1-r}\cos^2\phi\right]\operatorname{cosec}\phi. \tag{2}$$

The calculated results in Tables III and IV are obtained with this formula. It will be seen that the agreement is generally satisfactory.

In conclusion I have to thank Prof. Raman for the great interest he took during the course of the experiments and for his valuable suggestions.

210, Bowbazaar Street,
Calcutta, India,
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