DIFFRACTION OF LIGHT BY ULTRASONIC WAVES.

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Received May 7, 1986.

(Communicated by Sir C. V. Raman, Kt., F.R.S., N.L.)

Part L Effect of Oblique Incidence.

In a series of interesting papers, Sir C. V. Raman and N. S. Nagendra Nath have developed a theory for the diffraction of light by high frequency sound waves, the essential idea being the diffraction of the corrugated form of the transmitted wave-front of light. Their theory has been able to explain many of the experimental results of R. Bär and of Debye and Sears. In Part II of their theory they have very satisfactorily explained the curious phenomenon of the wandering of the intensities of the various orders observed first by Debye and Sears on tilting the trough containing the liquid. Their theory also explains the disappearance of the diffraction effects at greater angles of obliquity. The standpoint developed by them in Parts IV and V of their series, based on the wave-equation governing the propagation of light in a medium filled with sound waves explains the asymmetry in the diffraction pattern. In this paper the author presents detailed results of investigation with regard to the asymmetry observed in the diffraction spectra.

The asymmetry in the diffraction spectra was observed, simultaneously and independently by Lucas and Biquard, and by Debye and Sears in their earliest papers, and later by the author while carrying out determinations of ultrasonic velocities in various organic liquids. It has been recently investigated in detail by Bär also.

Results.

The experimental arrangement was the one followed earlier and described in previous papers.

It was found by the author that when the quartz crystal, set up to excite vibrations in the liquid, is inclined to the incident parallel beam, then an asymmetry in the diffraction spectra was observed.

Fig. 1 shows the arrangement. \( \theta \) represents the angle through which the quartz plate \( Q \) is turned in the direction shown by the arrow, and is
given in Fig. 2, in minutes of arc. P is the ground-glass plate on which are received the diffraction spectra. The upper portion is the right side (say +) where the greater number of orders is observed when the tilt is as shown in the diagram.

It is necessary to make exact determinations of the angle of inclination for obtaining the relationship between the nature of asymmetry in the spectra and the angle of inclination. This can be useful to test further the theory relating to the diffraction spectra.

To the centre of the ebonite piece carrying the quartz crystal, of $20 \times 20 \times 2$ mms., a straight rigid steel rod of 310 mms. in length was firmly attached by sealing wax. The free-end of the rod, which was sharp and pointed, moved over a vertical scale, divided into millimeters, so that any small inclination could be read off accurately.

A series of photographs of the spectra were taken at different inclinations of the quartz, with the parallel position marked zero. The frequency employed was $7.37 \times 10^6$ c./s., while only the spectra for 5461 Å of the mercury arc were photographed.

We describe below, the positions, number and intensities of the different orders, as seen visually, at various angles of inclination. Fig. 2 bears this out amply. The intensities are not accurate but should be taken as indicative of the progress of changes accompanying the inclination.

The liquid, benzene, was contained in a tall vessel 12" high with plane plates serving as walls. Progressive waves were employed throughout.

For incident light parallel to the sound wave-front, the position indicated by 0 in the figure (Fig. 2), the number of orders is equal on either side, with symmetrical distribution of intensity. At a small angle of even 6', the fifth order on the right (say +) has begun to brighten up, almost double.
in intensity, while it is evident that other orders on the same side are brighter than the corresponding ones on the left (say − ). The + 1 order is more intense than − 1, + 2 more intense than − 2, and so on, each to each in the same spectrum. The difference in intensities, of + 3 and − 3 orders, for inclination marked 22′, is remarkable.

The plate was slowly turned and kept at a position corresponding to the maximum number of orders that could be obtained on the + side. The quartz plate has made an angle of 22′. It should be remarked here that the total number of diffraction spectra remains what it was for symmetrical distribution, but with this difference, that the number and the intensity distribution are not the same as before. One could very easily see visually in the above experiment that the + 1 order increases in intensity to a maximum and then falls gradually for increasing angle of the light beam to the sound wave-front. The displacement in the spectra corresponding to the maximum number of orders on the + side, was two orders; that is, the + side had increased by two, while the − side had lost two. The pattern is asymmetrical.

On still further increasing the angle to 28′, one could see that the asymmetry was maintained while progressively about the same number of orders disappeared from either side of the zero order. Even at such a large angle as 72′, the + 2 order is definitely more intense than the − 2 order and it is only at 94′ and greater angle that something like symmetry is brought about. At still greater angles, one sees only the first order spectrum getting fainter and fainter—so that finally at an inclination of 25′, even the first order has almost disappeared.

We give below the visual estimate of intensities for different orders at four inclinations only. The intensities are only relative but indicate the progressive changes accompanying the tilting of the quartz plate.

**Table I.**

<table>
<thead>
<tr>
<th>Angle of Inclination</th>
<th>−Order</th>
<th></th>
<th></th>
<th>+Order</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>8</td>
<td>20</td>
<td>20</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>6′</td>
<td>1</td>
<td>6</td>
<td>20</td>
<td>25</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>22′</td>
<td>1</td>
<td>3</td>
<td>25</td>
<td>30</td>
<td>20</td>
<td>6</td>
</tr>
<tr>
<td>28′</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>15</td>
<td>8</td>
<td>1</td>
</tr>
</tbody>
</table>
An exactly similar set of changes occurred when the quartz plate was turned in the opposite direction, but now the greater number of orders was observed on the — side of the zero order, as against the + side as observed previously.

**Part II. A Case of Overlapping Resonance.**

While the author was experimenting, he observed a curious phenomenon. At one stage in the setting of the variable condenser, he obtained one kind of diffraction spectra, and not far from it, not more than 40° in the setting of the variable condenser, another set of spectra, with distances for the first orders in the ratio 2 : 3. At some intermediate position between the two, the two first orders were obtained simultaneously on the ground-glass plate; while turning of the condenser either way, increased the intensity of one kind or the other, depending on the direction it was turned, with consequent diminution of the other kind. This was quite unexpected, and therefore the electrical wave-length for the two resonances were determined by means of a wave-meter, to determine the exact frequency with which the quartz was oscillating.

These frequencies were again checked in the following way. Since the liquid used was benzene, we know with fair accuracy the velocity of sound in it, and from a knowledge of the angles $\theta_1$ and $\theta_2$ which the first order of each kind produces, it is easy to calculate the wave-length of sound in the medium and hence the frequency of oscillation of the quartz plate.

The quartz plate used was of dimensions 20 x 20 x 1 mms.

The following table gives the results obtained in the case of overlapped resonance.

**TABLE II.**

<table>
<thead>
<tr>
<th>No.</th>
<th>Wave-length of sound in benzene in mms.</th>
<th>Frequency from previous column in c/s.</th>
<th>Frequency by wave-meter reading in c/s.</th>
<th>Frequency at the resonance point in c/s.</th>
<th>Number of the harmonic of the crystal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.000 mms.</td>
<td>6.46 x 10^6</td>
<td>6.45 x 10^6</td>
<td>6.75 x 10^6</td>
<td>5/2 $n$</td>
</tr>
<tr>
<td>2</td>
<td>2.045 mms.</td>
<td>9.69 x 10^6</td>
<td>9.70 x 10^6</td>
<td>9.45 x 10^6</td>
<td>7/2 $n$</td>
</tr>
</tbody>
</table>

It is evident, therefore, that the crystal is vibrating at the $\frac{5}{2}$th and $\frac{7}{2}$th harmonic of the crystal, simultaneously.

We know that in liquids the resonances are broad and the present result is a case of superposition of the base of the two resonances, occurring
near to each other. This is clear if we closely notice what happens if the condenser is turned either way. Along the reading common to both, one of the spectra should get brighter depending upon the fact how much of the curve of the other it overlaps, and then finally should reach the pure resonance of \( \frac{2}{3}n \) or \( \frac{2}{3}n \) where \( n \) is the fundamental of the quartz. This was realised completely in the experiment.

Fig. 3 is a photograph of the overlapped resonance, while Fig. 4 gives the true graphical representation of facts.

![Resonance Curves](image)

\[ \text{Resonance Curves} \]

\[ \text{Diffraction Spectra} \]

\[ \text{Fig. 4.} \]

It will be worth recording here that L. Bergmann observed and proved by these optical methods, the simultaneous existence of fundamentals and harmonics, and any two harmonics, and it has not been known whether such \( \frac{2}{3}n \) and \( \frac{2}{3}n \) are possible of excitation. It is a fact known to all in the field of radio communication that transmitters are capable, in addition to the fundamental frequency, of sending harmonics, but always with the fundamental, though feebly.

Fig. 5 reproduces the diffraction spectra due to standing waves in \( p \)-Xylene at \( 7.32 \times 10^6 \) c/s. Others have reported previously, notable among them being Oyama, on the production of a large number of diffraction orders due to ultrasonic waves. The number of orders observed by the author is 16 and it will be interesting to account for such a large number and also their intensities by the Raman-Nath theory as developed in Part III. Further work is being continued in this direction.

The author thanks Professor Sir C. V. Raman for the interest he took in the work.

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* Oyama’s 30 orders really correspond to 15 orders; he probably means 30 lines, which will be \( \pm 15 \) and \( -15 \) orders. Nobody seems to have obtained even as great many as 20 orders of diffraction spectra. 16 appears to be the maximum.
Diffraction spectra at small angles between the incident light beam and the sound wave-front.

FIG. 2.

FIG. 3.

FIG. 5.

In p-Xylene
Summary.

A detailed relationship between the angle of inclination of the oscillating quartz, and the diffraction spectra produced by it at these angles, is given. It is explicable on the basis of the Raman-Nath theory for the diffraction of light by high-frequency sound waves. The paper includes the case of overlapped resonance, the resonances occurring at $\frac{n}{5}$ and $\frac{4}{5} n$, independent of each other.

REFERENCES.

5. R. Bär, in a proof sent to Sir C. V. Raman.