THE DIFFRACTION OF LIGHT BY TWO ULTRASONIC FIELDS

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

Myron Paul Hagelberg

1956

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By

MYRON PAUL H GOLBERG

AN ABSTRACT

Submitted to the College of Science and Arts of Michigan State University of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Physics

1956

Approved: E. A. Hiedemann

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Abstract

The light in all diffraction orders, except the central one, of an ultrasonic grating will be traveling at an angle to the incident beam. Each of these orders may be considered as an effective source for the second grating. This investigation shows that at low frequencies, the combination lines are symmetric about the primary orders as the theory of C. V. Raman and N. S. Nagendra Nath[1] predicts. At higher frequencies there is an asymmetry about the primary orders due to selective or Bragg reflection. This is in accordance with the theory of Richard C. Extermann[2]. At high frequencies an asymmetry is observed in a direction opposite to the asymmetry produced by Bragg reflection.

References:

1. Raman, C. V. and N. S. N. Nath. The Diffraction of Light by High Frequency Sound Waves. II. Proc. Ind. Acad. Sci. (A)2, 412-20(1935).

2. Extermann, Richard C. Theorie de la diffraction de la lumiere par des ultra-sons. II. Helv. physica Acta 10, 185-217(1937).

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M. Paul Hagelberg

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I. INTRODUCTION

In 1932 P. Debye and F. W. Sears[1] in America and R. Lucas and P. Biquard[2] in France discovered that if a beam of light passes through an ultrasonic field a diffraction pattern is produced which resembles that due to a ruled grating. The grating constant of the ultrasonic grating corresponds to the wavelength of the sound in the medium.

If now one allows the light to be diffracted by a second ultrasonic grating, we may observe a complex pattern of lines, that is, double diffraction. We may consider two cases: The case where the grating constant of one of the ultrasonic gratings is an integral multiple of the grating constant of the other, and the case where the grating constant, and hence the wavelength, of one ultrasonic beam has no particular relation to the grating constant of the other. In the first case diffraction orders due to one of the gratings will coincide with certain of the diffraction lines produced by the other grating. In the second case lines may be observed which are not present in the diffraction patterns due to either of the gratings considered separately; these are known as combination lines.

Double diffraction may be obtained in several ways. A quartz crystal might be excited on two of its odd harmonics. In this way one obtains two ultrasonic fields where the wavelength of one is an integral multiple of the wavelength of the other and where there is a definite phase relation between the two fields. It is possible to obtain double diffraction in this case since the ultrasonic grating has an extension of perhaps two or three centimeters along the light beam. Hence there is ample opportunity for the light to be diffracted by one ultrasonic grating and then to be rediffracted by the other.

Since in a solid one may have shear waves as well as longitudinal waves, double diffraction may be obtained in transparent solids in which an ultrasonic field has been set up. Since the velocities of the shear waves and the longitudinal waves are different there will generally be two ultrasonic gratings with different constants and hence double diffraction.

Double diffraction may also be obtained by using two separate ultrasonic fields produced by two separate transducers. With this arrangement one is free to vary the constants of the two ultrasonic gratings independently and also to vary the intensities of the ultrasonic fields and hence the number of diffraction orders. This makes it possible to obtain a wider variety of patterns. This method differs from the other two also in that the two gratings are not superposed. They were produced in this case in two separate tanks of liquid.

In this study only the latter method, double diffraction produced by two separate ultrasonic fields, shall be considered. This case was first investigated by L. Bergmann and E. Fues[3] and later by M. A. Govinda Rao[4] and by S. Parthasarathy and Harkrishan Singh[5]. As these earlier studies had only been made in a rather limited range of frequencies and sound intensities it appeared desirable to study multiple diffraction effects over a wider range of frequencies.

II. THEORY

Multiple diffraction phenomena have been considered in the C. V. Raman and N. S. Nagendra Nath[6] theory of diffraction of light by ultrasonic waves. Since the ultrasonic grating has a finite extension along the light beam, light which has been diffracted by part of the ultrasonic grating may be rediffracted by succeeding parts of the grating. Each diffraction produces a Doppler shift in the frequency of the light equal to the frequency of the ultrasonic field. In this way Raman and Nath were able to explain the frequency distribution over the subcomponents of a diffraction order.

On the basis of the Raman and Nath diffraction theory, E. Fues[3] obtained a theory of double diffraction by two ultrasonic gratings with different grating constants. K. Nagabhushana Rao[7] obtained the same results by extending the methods of the generalized theory of N. S. Nagendra Nath[8].

In his paper Rao gives for the angle $\theta_{r,s}$ at which diffraction lines may be observed the expression

$$\sin\theta_{r,s} = r\frac{\lambda}{\lambda_1^*} + s\frac{\lambda}{\lambda_2^*} \qquad (1)$$

in which $r, s = 0, \pm 1, \pm 2, \cdots$, λ = wavelength of the light and λ_1^* and λ_2^* are the wavelengths of the first and second ultrasonic beams.

One may see from equation (1) that if the second field is turned off, that is, if $s = 0$, we obtain the expression for the angles at which diffraction lines due to the first grating alone may be observed. When both ultrasonic fields are turned on, the light, after passing through the first grating, will be split into diffraction orders given by the first term on the right in equation (1). Each of the diffraction lines of the first grating will act as an effective light source for the second grating. Now the second term on the right in equation (1) gives the lines produced by diffraction in the second grating, of light in the rth order of the diffraction pattern of the first ultrasonic grating. These are the so-called combination lines.

Equation (1) is obtained under the assumption that $\sin\theta_r + \sin\theta_s = \sin(\theta_r+\theta_s) = \sin\theta_{r,s}$, which is justifiable since the diffraction angles are small. (For example, the angle for the 5th order of a 10 mc/sec. sound field in xylene with $\lambda = 5461$ A is about 1.2 degrees.)

The light in the rth order of the first ultrasonic grating will be traveling at the angle $\theta = \arc \sin\left(r\frac{\lambda}{\lambda_1^*}\right)$ to the incident beam of light and therefore will be obliquely incident upon the second ultrasonic grating. It would be expected that the combination lines corresponding to a given value of r would produce a pattern similar to that produced by diffraction of an obliquely incident beam in a single ultrasonic grating.

The theory of Raman and Nath[6] for the diffraction at oblique incidence predicts that the diffraction patterns will be symmetric about the central order; but, as the angle from the normal increases, the intensity of the diffraction pattern will pass through periodic maxima and minima. The angles at which the maxima occur are given by the expression

$$\sin(\theta + \phi) - \sin\phi = \pm n \frac{\lambda}{\lambda^*} \qquad (2)$$

where ϕ is the angle from the normal and n is an integer greater than or equal to zero.

An extended study of diffraction by an ultrasonic grating, of light which is incident obliquely has been made by Otohiko Nomoto[9,10,11,12]. This study has shown that the predictions of the Raman and Nath theory for oblique incidence are valid at low ultrasonic frequencies. At higher frequencies, however, the diffraction patterns are no longer symmetric about the central order.

This asymmetry is explained by the fact that at higher frequencies the effect becomes one of selective or Bragg reflection. Richard C. Extermann[13] derived a theory for diffraction of light at oblique incidence by considering the ultrasonic field to have a structure similar to that of a crystal. The theory shows that the intensity of the diffraction pattern and the degree of asymmetry have maxima at angles corresponding to the Bragg angles, that is, angles for which $\sin\theta = n\frac{\lambda}{\lambda^*}$ where $n = \pm 1, \pm 2, \cdots$, and that these maxima are very broad.

From these considerations we can expect that at low ultrasonic frequencies the combination lines for a given value of r will be symmetric about that order. At higher ultrasonic frequencies, however, the combination lines for a given r will be selectively reflected toward the central order. The effect will vary gradually from showing predominantly the diffraction of the Raman and Nath theory at low frequencies, through medium frequencies to the predominance of Bragg reflection at high ultrasonic frequencies. Although Bragg reflection may introduce an asymmetry in the combination lines about the order +r, a similar asymmetry occurs for the order -r so that the overall pattern is symmetric about the central order.

Equation (1) also shows that the postions of the diffraction lines will be unaffected by reversing the order of the two ultrasonic gratings. At frequencies for which the Raman and Nath theory is applicable, the intensities should also be the same. At higher frequencies the patterns will not be the same with the gratings reversed since the effect of Bragg reflection will be greater if the higher frequency field is second, introducing a change in the intensity distrobution. This gives a simple means of illustrating the effect of Bragg reflection.

III. EXPERIMENTAL APPARATUS

The Optical Setup

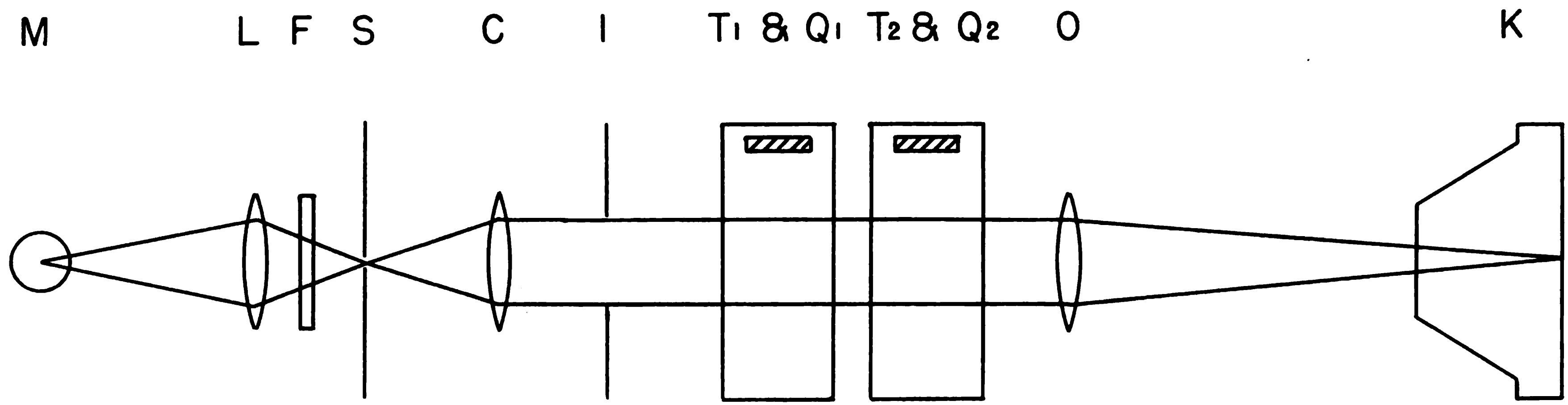
The optical setup which is used in this work differs from the system usually used for observing diffraction phenomena only in that there are two ultrasonic gratings instead of the usual one. See Fig. 1. The source of light is a high pressure mercury arc rated at about 110 watts. The light passes through a filter which transmits only the green line a 5461 A before illuminating the slit which serves as the effective source. The light from the slit is collimated by a 6.5 inch focal length lens; the objective lens is of 20 inch focal length. The camera, a model V Exakta with its lens removed, proved to be a wise choice since its focal plane shutter permits a wide range of exposure times and since it holds a large supply of film.

The Electronic Equipment

The electronic equipment consists of two continuous wave radio frequency transmitters. The output of the transmitters is continuously variable up to about 150 watts. Frequency measurements are made with a Type No. 620-A Heterodyne Frequency Meter and Calibrator, Serial No. 1117, manufactured by the General Radio Co.

Ultrasonic Sources

The sound sources are X-cut quartz transducers either three-fourths inch or one inch square. Since the liquid used is xylene, a non-conductor, the electrodes are aluminum foil glued to the faces of the crystal. The crystal is mounted



M - MERCURY ARC
L - CONDENSER LENS
F - FILTER
S - SLIT
C - COLLIMATING LENS
I - IRIS

T_1 - FIRST TANK
Q_1 - FIRST QUARTZ
T_2 - SECOND TANK
Q_2 - SECOND QUARTZ
O - OBJECTIVE LENS
K - CAMERA

FIG. 1. COMPONENTS OF THE OPTICAL SYSTEM

on a system of rods which permits three degrees of freedom in adjusting its orientation. In the case of the 15 mc/sec. quartz it is necessary to air-back the transducer, since at that frequency it is difficult to obtain a sufficient number of diffraction orders.

IV. EXPERIMENTAL PROCEDURE

The procedure for obtaining a double diffraction pattern begins with the adjustment of the optical system. With the help of the built-in magnifier, the position of the camera is adjusted to give a sharp slit image on the ground glass viewing plate. Closing the iris, thus limiting the cross-section of the incident light beam, helps to increase the sharpness of the slit image. In this work the diameter of the iris is about 5 mm.

Since the resonant frequency of the several transducers is known approximately, the transmitters are tuned to this value. Usually this is sufficient to produce a usable diffraction pattern. In the case of the 15 mc/sec. quartz and for others which are excited on higher odd harmonics, it is necessary to make a finer frequency adjustment. This adjustment is made by varying the frequency until the optimum diffraction is obtained. The criterion in all cases is that there be sufficient diffraction; usually this means that at least the 3rd order be present.

Using each ultrasonic grating alone, the orientation of the crystal is adjusted so that its pattern is symmetric about the central order. After both gratings are adjusted in this way, the double diffraction pattern is observed. The orientation of each grating is very critical; even an asymmetry which can hardly be detected in the individual patterns shows up as a noticeable asymmetry in the double diffraction pattern. When a double diffraction pattern is obtained which is symmetric about the central order, it is photographed. Photographs are also made of the patterns for each of the gratings alone. In addition the frequency of each ultrasonic field is recorded.

V. DATA AND DISCUSSION

In presenting these data the figures are prepared in such a way that the grouping patterns of the double diffraction are made clear. Thin lines are extended from the lines in the photograph of the double diffraction pattern. Superimposed on these, in heavier lines, are the grouping patterns for the double diffraction and for the primary diffractions. In addition to the photographs of the double diffraction pattern, the photographs of the patterns produced by each grating are included since they serve as guides in analysing the double diffraction.

Throughout this study the wavelength of the light is 5461 A and the liquid used xylene in which the velocity of sound is 1340 m/sec. The photographs are not all to the same scale since they were not enlarged by the same factor from the original 35 mm negatives.

Each figure shall be discussed separately in order to point out the effects which are present.

Figure 2: ν_1 = 5.58 mc/sec.

ν_2 = 3.77 mc/sec.

The grouping patterns show that the combination lines are symmetric about each of the diffraction orders of the first grating. The appearance of only the first order combination lines about the second orders of the first grating is due to the low intensity in the primary second orders. The lower intensity of the second primary orders compared to the first primary orders may be seen from the pattern of the first grating alone. These results agree with the Raman and Nath[6] theory.

Figure 3: $\nu_1 = 10.83$ mc/sec.

$\nu_2 = 7.13$ mc/sec.

The grouping patterns show asymmetry in the double diffraction about both the first and second primary orders. The reason that the asymmetry about the second primary order is greater than the asymmetry about the first primary order is that light in the second primary order is incident upon the second grating at an angle very near the third Bragg angle for this grating. That there is asymmetry about the first primary order, which is incident at an angle midway between the first and second Bragg angles of the second grating, shows that the maxima for Bragg reflection are very broad as the theory of Extermann[13] predicts.

Figure 4: a. $\nu_1 = 9.96$ mc/sec.

$\nu_2 = 7.05$ mc/sec.

b. $\nu_1 = 7.05$ mc/sec.

$\nu_2 = 9.96$ mc/sec.

Figure 4-a is obtained by using the higher frequency sound field for the first grating. The gratings are interchanged to obtain figure 4-b but the same sound intensities are used as in figure 4-a. Comparison of the two patterns shows that they are not identical. The second arrangement shows more strongly the effect of Bragg reflection. This agrees with theory since Bragg effects increase with increasing frequency.

Figure 5: $\nu_1 = \nu_2 = 10.00$ mc/sec.

Two ultrasonic fields of the same frequency are adjusted to produce the same diffraction patterns. According to the Raman and Nath theory, the diffraction pattern due to these two gratings together is the same as the diffraction pattern of one field at an amplitude twice as great.

The power to the first transducer is adjusted so that the current through it is 0.75 amperes. With the intensity of the second sound field adjusted to give the same diffraction pattern, a photograph is made of the double diffraction pattern for these two ultrasonic gratings. The current through the first transducer is increased to 1.5 amperes and the pattern for this grating alone is photographed. A comparison of these two patterns in figure 5 shows that they are different. The smaller number of diffraction orders in the double diffraction pattern may be explained by selective reflection. Light in the diffraction orders of the first grating will be incident upon the second grating at precisely the Bragg angles of the second grating: Thus there will be reflection back toward the central order.

Figure 6: a. $\nu_1 = 14.27$ mc/sec.

$\nu_2 = 9.24$ mc/sec.

b. The light is now obliquely incident on the first grating in order to obtain greater intensity in the higher diffraction orders.

The grouping patterns about the first primary order show strong Bragg reflection even though the angle of incidence is quite different from the Bragg angle for the second grating. This is explained by the fact that the Bragg maxima are broad. Figure 6-a shows that for the second primary orders the combination lines toward the outside are stronger than those toward the central order. In figure 6-b this is shown more clearly. This asymmetry is opposite to the asymmetry produced by Bragg reflection. No explanation for this effect can be given from the considerations which have been presented in this paper.

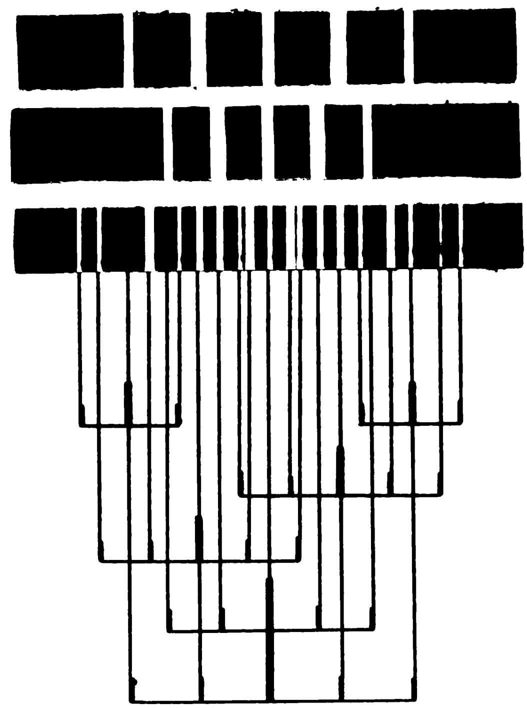


Figure 2: Double Diffraction at Low Ultrasonic Frequencies.
ν_1=5.58 mc/sec.
ν_2=3.77 mc/sec.

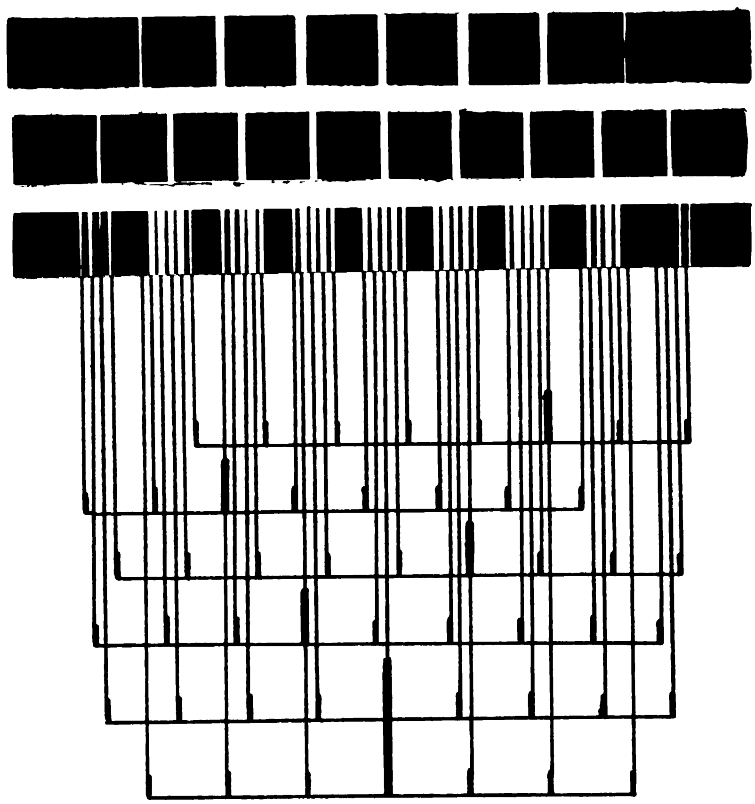
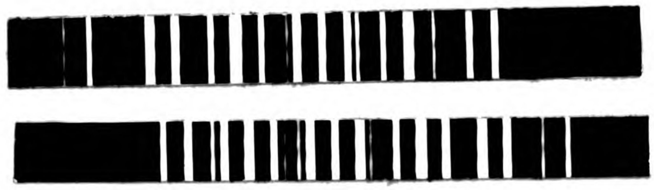


Figure 3: Double Diffraction at Medium Ultrasonic Frequencies.
ν_1 = 10.83 mc/sec.
ν_2 = 7.13 mc/sec.

a.

b.



Comparison of the patterns produced by arrangements a. and b.

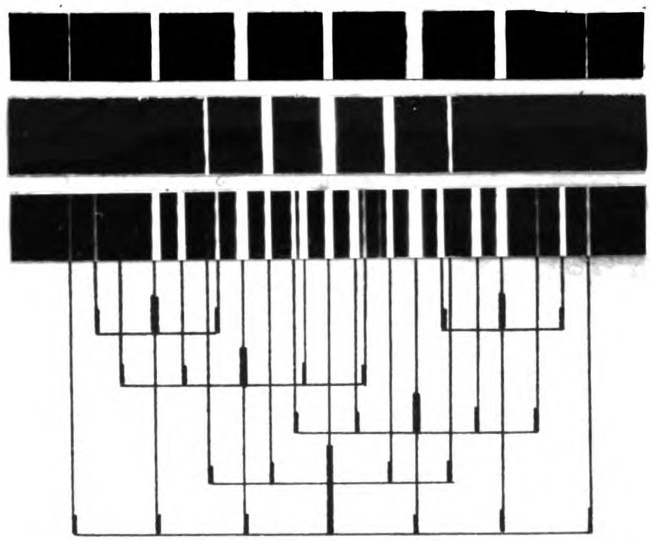


Figure 4-a: $\nu_1 = 9.96$ mc/sec.
$\nu_2 = 7.05$ mc/sec.

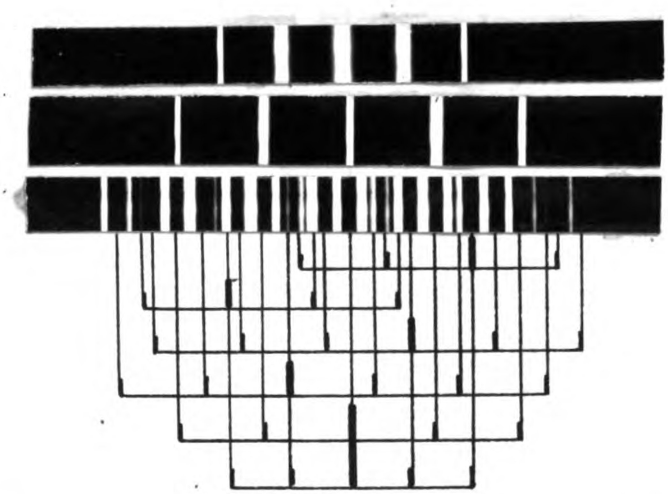


Figure 4-b: The order of the fields is reversed from that of figure 4-a, the intensities remain the same.
$\nu_1 = 7.05$ mc/sec.
$\nu_2 = 9.96$ mc/sec.

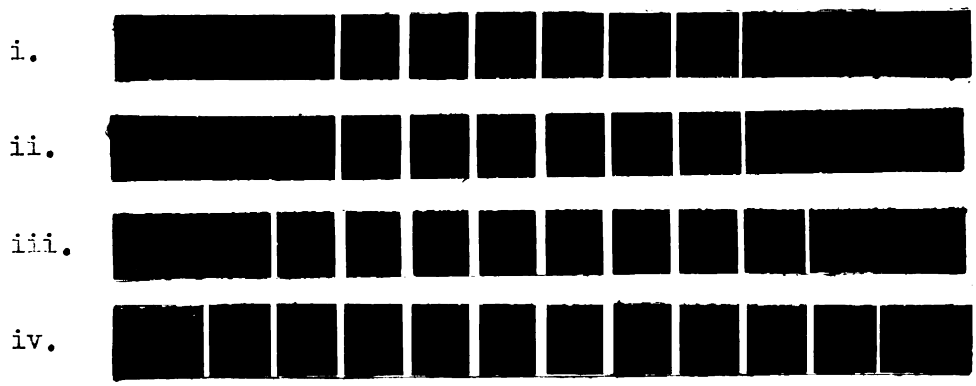


Figure 5: $\nu_1 = \nu_2 = 10.00$ mc/sec.

- i. First grating with transducer current of 0.75 amps.
- ii. Second grating adjusted to give the same pattern as the first.
- iii. Double diffraction pattern of the first and second gratings.
- iv. First grating with transducer current of 1.50 amps.

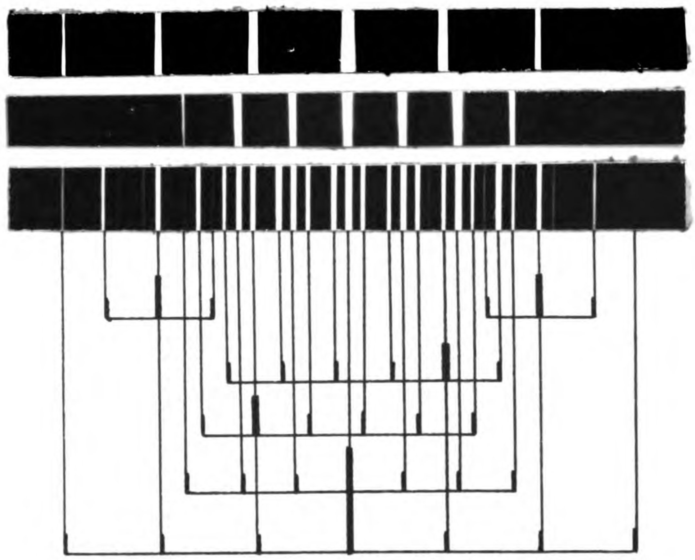


Figure 6-a: Double diffraction at high ultrasonic frequencies.
ν_1=14.27 mc/sec.
ν_2= 9.24 mc/sec.

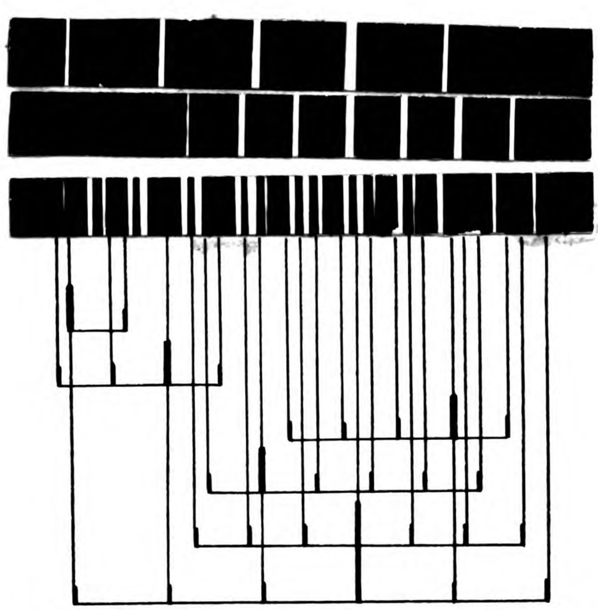


Figure 6-b: The first grating is now at a small angle to the incident light beam in order to obtain the higher diffraction orders.

VI. SUMMARY

The data which are presented in this study illustrate that double diffraction by two ultrasonic gratings can be explained by considering the diffraction orders of the first grating to be effective light sources for diffraction by the second ultrasonic grating. Since the diffraction orders for the first grating will be traveling at an angle to the incident beam, they will be incident obliquely upon the second grating. At low frequencies the effects are in accordance with the Raman and Nath[6] theory for oblique incidence. At higher frequencies selective or Bragg reflection will appear as predicted by the theory of Extermann[13]. At high frequency there occurs an asymmetry in the combination lines so that the diffraction is stronger away from the central order. This is not explained by either theory. Further investigation at high ultrasonic frequencies is necessary to clarify this discrepancy.

VII. BIBLIOGRAPHY

1. Debye, P. and F. W. Sears. On the Scattering of Light by Supersonic Waves. Proc. Nat. Acad. Sci. 18, 400-10(1932).

2. Lucas, R. and P. Biquard. Nouvelles propriétés optiques des liquides soumis à des ondes ultrasonores. C. R. (Paris) 194, 2132-4(1932).

3. Bergmann, L. and E. Fues. Über gleichzeitige Raman-Beugung an mehreren Ultraschallwellen. Z. Physik 109, 1-13(1938).

4. Rao, M. A. Govinda. Diffraction of Light by Superposed Ultrasonic Waves. Proc. Ind. Acad. Sci. 8, 6-10(1938).

5. Parthasarathy, S. and Harkrishan Singh. Diffraction de la lumière par deux faisceaux d'Ultra-sons. Ann. Phys. 9, 382(1954).

6. Raman, C. V. and N. S. N. Nath. The Diffraction of Light by High Frequency Sound Waves. Parts I and II. Proc. Ind. Acad. Sci. (A)2, 406-20(1935), Parts III and IV, ibid. 3, 75-84, 119-125(1936).

7. Rao, K. Nagabhushana. Diffraction of Light by Ultrasonic Waves. Proc. Ind. Acad. Sci. 8, 124-34(1938).

8. Nath, N. S. Nagendra. The Diffraction of Light by High Frequency Sound Waves. Generalised Theory. Proc. Ind. Acad. Sci. (A)4, 222-42(1936).

9. Nomoto, Otohiko. Versuche über die Beugung des Lichtes an Ultraschallwellen. II. Versuche über die Lichtbeugung an Ultraschallwellen bei schiefer Inzidenz des Lichtes. Proc. Phys-Math. Soc. Jap. 3rd Ser. 19, 264-70(1937).

10. Nomoto, Otohiko. Intensitätsverteilung des Lichtes in den an fortschreitenden Ultraschallwellen in Flussigkeiten erzeugten Beugungsspektren. Proc. Phys-Math. Soc. Jap. 3rd Ser. 22, 314-20(1940).

11. Nomoto, Otohiko. Studien über die Beugung von Licht an Ultraschallwellen. I and II. Proc. Phys-Math. Soc. Jap. 3rd Ser. 24, 380-400, 613-39(1942).

12. Nomoto, Otohiko. Diffraction of Light by Ultrasonic Waves at Oblique Incidence. Bull. Kobayasi Inst. Physical Res. 2, 78-85(1952).

13. Extermann, Richard C. Théorie de la diffraction de la lumière par des ultra-sons. II. Helv. physica Acta 10, 185-217(1937).