# Acousto-Optics

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[1] *Cohort A - Thu 9-1 class*
[2] *Word count: XXXX words*
(Dated: 14:05 Monday 17th March, 2025)

I would have a succinct (1-2 sentence statement) of the aim in here. And then I would also have a succinct (1-2 sentence statement) of the key conclusion. That is all, keep it simple, it's so a reader can quickly get at your two key points.

## INTRODUCTION

The study of Acousto-Optics began with the problem of light scattering resulting from thermal fluctuations in a body resulting from a superposition of sound waves (Brillouin 1922). Light passed through a small slit into a crystal filled with various liquids such as benzene, carbon tetrachloride or glycerine. Using a radio-frequency oscillator, vibrations excited supersonic waves traveling through the liquid as the light entered the medium in a perpendicular direction to the supersonic waves. Early observations involved noticing the number of orders visible on the right and left of the central image were different for every case except the one where the light rays are passing exactly parallel to the planes of the supersonic waves. The number of orders that were observed was found to be dependent on the amplitude of the supersonic oscillations (Debye and Sears 1932). The spacing between the observed orders was found to be dependent only on the frequency of the oscillations.

A simple explanation for these observations points out that the supersonic waves traveling through the crystal periodically varies the refractive index of light along the direction perpendicular to the sound wave fronts, causing the light to diffract similar to a phase grating, as seen in Figure 1, (Raman and Nath 1935). Experimentally, the following relationship was obtained,

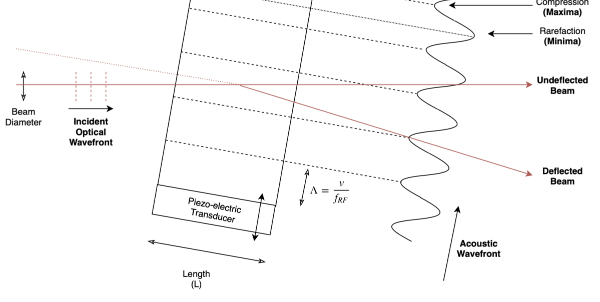



FIG. 1: Diagram showing density fluctuations in medium. The refractive index value varied with the acoustic wave i.e higher refractive indicies occured in areas of compressions and lower indicies in areas of rarefractions of the acoustic wave.

$$\sin\theta = \pm\frac{n\lambda}{\Lambda}. \tag{1}$$

where $\theta$ is the angle between the central beam and the nth order beam, $\lambda$ is the wavelength of light and $\Lambda$ is the wavelength of the sound wave.

There are two distinct regimes in acousto-optics, related to the 'thickness' of the diffraction grating induced by the supersonic waves. The Raman-Nath regime is observed when the grating is considered to be thin. The resultant diffraction pattern will display a number of diffraction maxima symmetrically arranged in a row around the central maxima. This diffraction pattern can be observed at any small angle. These two regimes are found in Figure 2 Conversely, the Bragg regime can only be observed at the Bragg angle of light incidence ($\theta_B$)Note1 which can be determined by the ratio, (A.V. Zakharov and Voloshinov 2014),

$$|\sin\theta_B| = \frac{K}{2k} \tag{2}$$

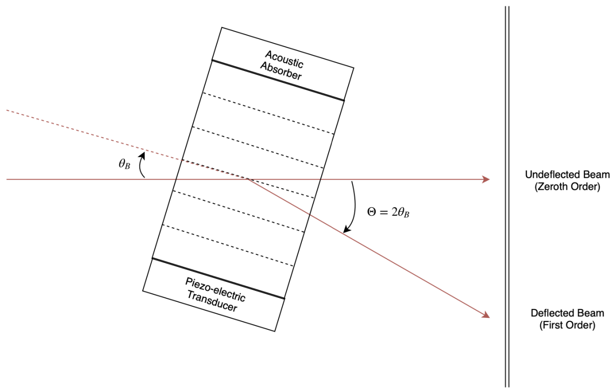
where k and K are the wave numbers of the light and sound waves respectively. The Klein-Cook parameter, $Q$, follows from this, traditionally defined as,(Jing Gao and Zhu 2021),

$$Q = \frac{K^2 L}{n_0 k \cos\theta} \approx \frac{K^2 L}{k} = \frac{2\pi\lambda L}{\Lambda}, \tag{3}$$

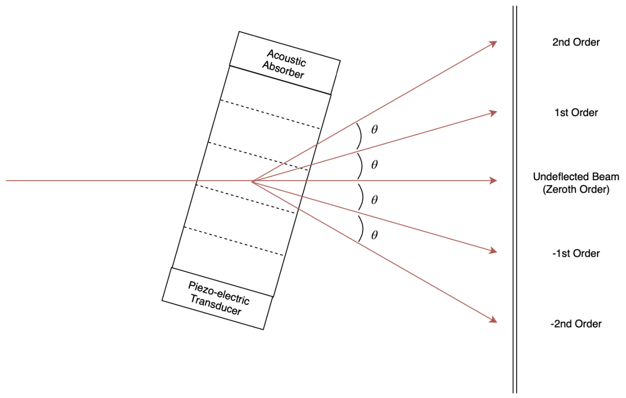
where L denotes the width of the crystal medium. This parameter quantiatively defines these two regimes, Raman-Nath observations are said to be in the domain of $Q \ll 1$ whereas the Bragg regime lies in the range of $Q \gg 1$.

## AIM

Verify observations of previous experiments and investigate the behaviour of the acousto-optic deflector and modulator to achieve a greater understanding of the devices and to understand the difference between Bragg and Raman-Nath Diffraction.




(a) Bragg diffraction




(b) Raman-Nath diffraction

FIG. 2: Diagram of the two diffraction regimes.

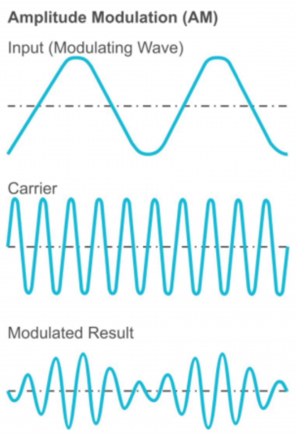



FIG. 3: The modulating wave is created by a superposition of an input modulating wave with a carrier wave.

## METHOD

### Instruments

In this experiment, we used an AO Deflector made of Dense Flint Glass and an AO modulator made of Lead Molybdate. Both devices are capable of sending acoustic waves through their respective mediums however we will be using the deflector for the Bragg regime and the modulator for the Raman-Nath regime. The light is said to be modulated when its intensity varies proportional to the peak of the modulating signal.

The modulating signal is created by combining an input modulating wave from a signal generator with a carrier wave of relatively higher frequency as seen in Figure 3.

### Theory

We will rewrite Equation 1 to obtain a relationship between the Bragg Angle and the frequency of the modulating sound waves,

$$\sin\Theta = \frac{\lambda}{\Lambda} \tag{4}$$

where $\Theta$ is the angle between the zeroth and first diffracted order beams. Substituting in the velocity of sound wave and the Bragg's angle,

$$\sin 2\theta_B = \frac{f_{\mathrm{RF}}\lambda}{v}. \tag{5}$$

We can use the small angle approximation here,

$$\sin 2\theta_B \approx 2\theta_B. \tag{6}$$

We can write,

$$2\theta_B = \frac{f_{\mathrm{RF}}\lambda}{v} \tag{7}$$

$$\theta_B = \frac{\lambda}{2v} f_{\mathrm{RF}}. \tag{8}$$

### Bragg Angle

To determine the Bragg Angle for a 70MHz signal, the deflector was slowly rotated until a maximum intensity on the screen could be observed. The distance between the left maxima to the central beam was measured to be 1.80±0.05 cm. Similarly the right maxima to the central maxima was measured to be $1.85 \pm 0.05$ cm. The average distance, $d$, is then $1.83 \pm 0.07$ cm. The distance of the deflector, $L$, was measured to be $159.0 \pm 0.1$ cm. The Bragg Angle is then,

$$\theta_B = \tan^{-1}(\frac{d}{L}) \tag{9}$$

$$= 0.0115 \pm 0.0004 \text{ rad} \tag{10}$$

$$= 11.5 \pm 0.4 \text{ mrad}. \tag{11}$$

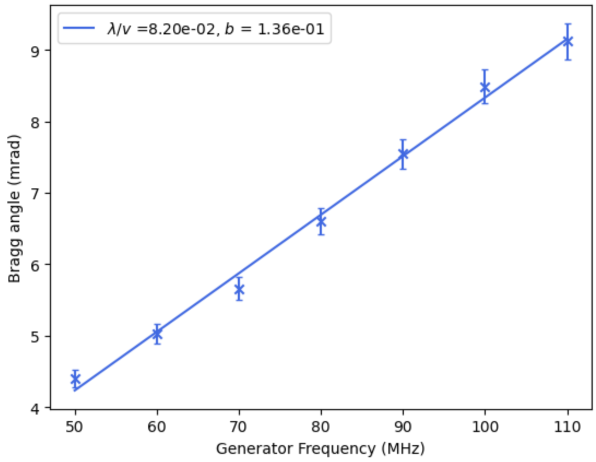



FIG. 4: Linear function of the measured Bragg angle as the frequency in the deflector was increased slowly from 50MHz to 110MHz.

This represents a 0.8% error from the specification provided by the deflector manual, citing the beam separation for a 70MHz signal to be 11.4 mrad. Therefore our value agrees with the predetermined specifications.

## RESULTS & ANALYSIS

### Bragg Regime

The velocity of the acoustic wave in the deflector was calcuated using Equation 8. Referring to 4, and applying the appropriate scaling factors,

$$\frac{\lambda}{2v} = 8.20 \times 10^{-2} \times \frac{10^{-3}}{10^{6}} \tag{12}$$

$$v_{\text{sound}} = \frac{633 \times 10^{-9}}{2 \times 8.20 \times 10^{-11}} \tag{13}$$

$$= 3859.8 \pm 134 \text{ ms}^{-1} \tag{14}$$

We also found that the polarisation of incident light on the deflector influenced the intensity of the diffracted light. The intensity of the diffracted beams followed Malus' Law, as seen in Figure 5,

$$I = I_0 \cos^2 \theta, \tag{15}$$

indicating that the only factor affecting the intensity of the diffracted beams was the intensity and the polarisation of the incident beam. The deflector and acoustic waves were purely changing the phase of the light, not its intensity behaviour in any significant way other than a simple offset.

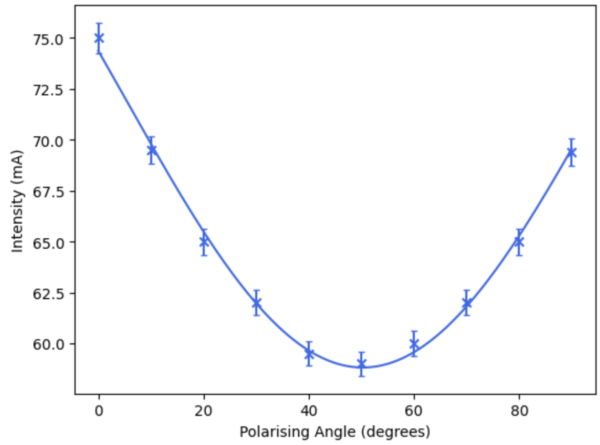



FIG. 5: Parabolic function displaying the relationship between the diffracted intensity and the polarisation of the incident light.

### Raman-Nath Regime

## DISCUSSION

If you would like this as a section, feel free. This might be a place to distil your analysis down to some key points or make an argument with that analysis.

## CONCLUSIONS

You should finish with a succinct (1-2 sentence) statement of your key finding. It should be similar to (or even match) the conclusion you state in your abstract.

## ACKNOWLEDGEMENTS

Chocolate is awesome, so are weekends.

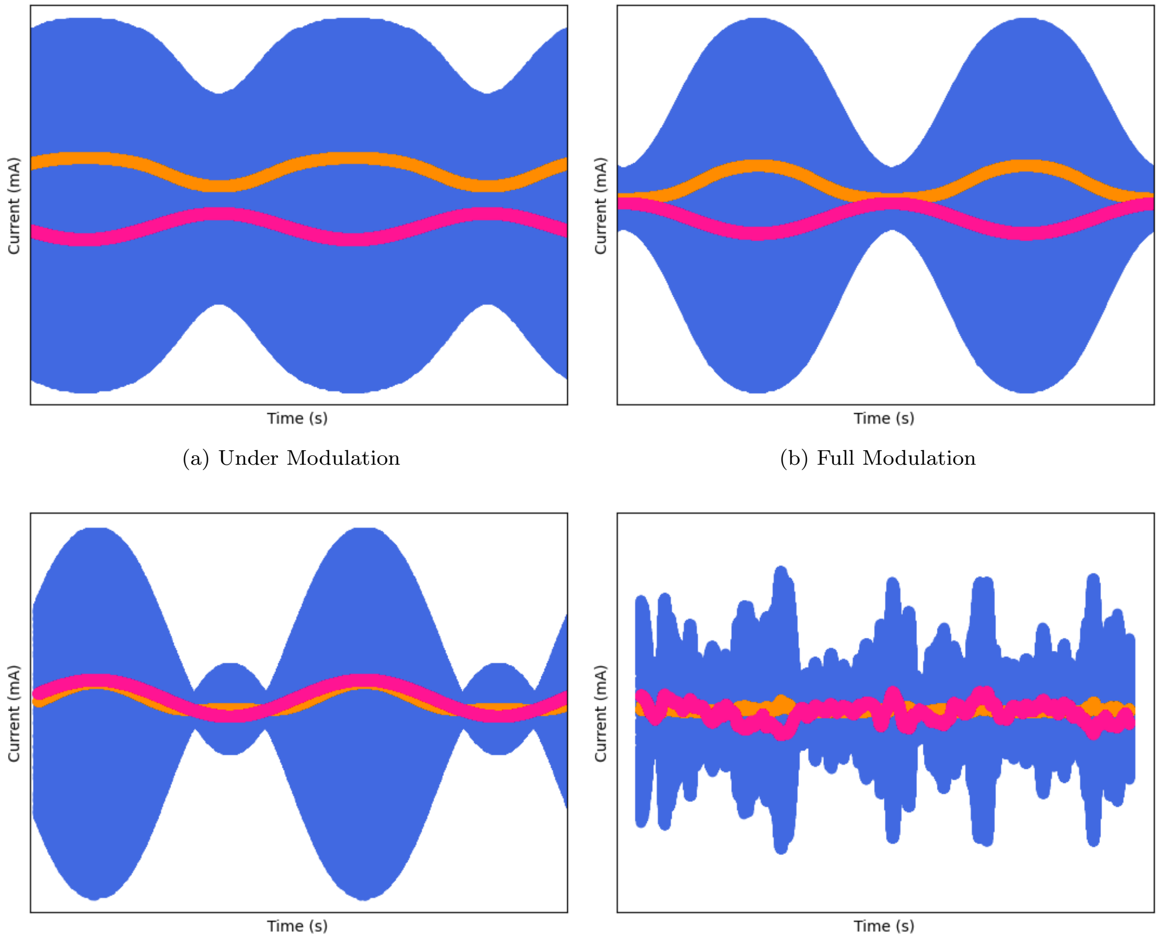
## APPENDIX

### Bragg Angle

From a geometric perspective, the Bragg angle occurs when the deflected angle is the same as the angle of incidence on the plane of the sound wave as seen in Figure 8. The total path difference at the points of constructive interference are then

$$\sin \theta_i + \sin \theta_d = \frac{m\lambda}{\Lambda}. \tag{16}$$

As the medium is continuous and not made up of discrete planes, the only point that be viewed is when $m = 1$, so,




(a) Under Modulation

(b) Full Modulation

(c) High Modulation

(d) Modulating with rap song 'Tweaker'

FIG. 6: o

$$2\sin\theta_B = \frac{\lambda}{\Lambda} \tag{17}$$

$$\sin\theta_B = \frac{\lambda}{2\Lambda} \tag{18}$$

## QUESTIONS

### Describe the acousto-optic principle

The fundamental phenonemon of acousto-optics is the interaction between light and sound waves, specifically how sound waves can deflect light, change its frequency and modulate its phase and amplitude. The study of acousto-optic effects involve the investigation of various diffraction patterns caused by the presence of sound waves in the medium of light, leading to the refractive index at different parts of the medium to vary, ultimately producing a diffraction pattern.

### Distinguish the difference between Bragg and Raman-Nath diffraction

The main difference in the Bragg and Raman-Nath diffraction patterns is the location of the peaks and troughs as well as the ratio of intensity between these points on the pattern. We observe that the intensity pattern follows a sinusoidal curve with its peaks corresponding to Bragg angles, which are related to the wavelength of the light and sound waves. Raman-Nath diffraction occurs when the observed intensity of the peaks diminish in a ratio of the square of Bessel functions.

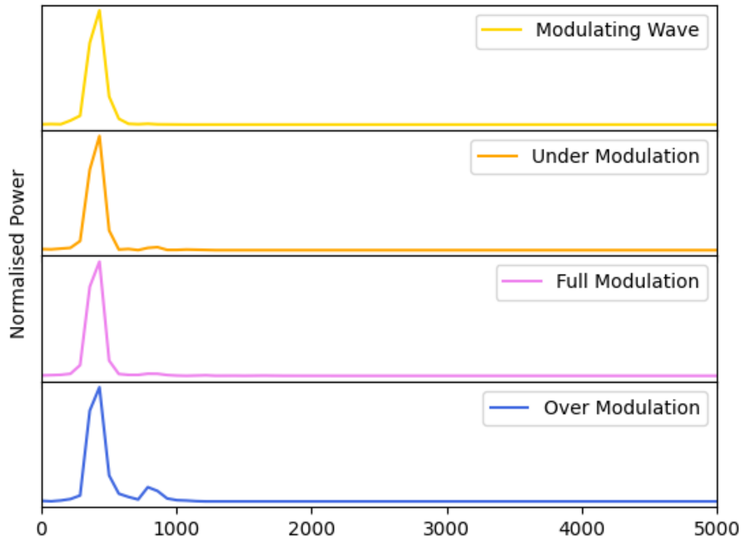



FIG. 7: hello

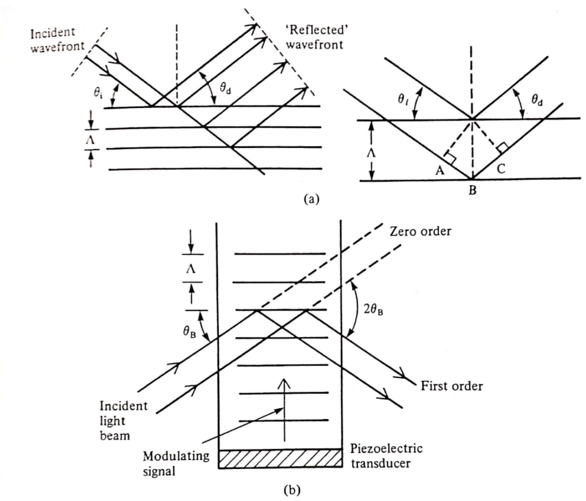



FIG. 8: Geometric diagram showing ray tracing of light. Bragg deflection occurs when the angle of incident is equal to the angle of the deflected beam

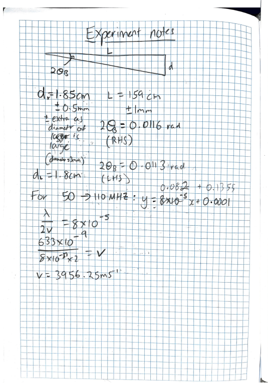
**Show that the deflector is in Bragg regime and Raman-Nath is in diffraction regime using the Q-Factor (refer to references for unknown parameters)**

**What determines the intensity of the diffracted beams?**

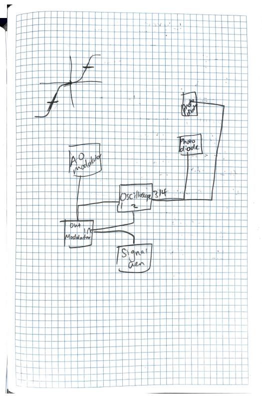
**Give some applications for AO and deflectors and modulators**

**LAB BOOK**

L. Brillouin, Annales de Physique **9** (1922).
P. Debye and F. Sears, National Academy of Sciences **6** (1932).
C. Raman and N. N. Nath, Proc. Indian Acad Sci **3** (1935).
A geometrical approach can be found in the Appendix.
N. P. A.V. Zakharov and V. Voloshinov, Bulletin of the Russian Academy of Sciences **78** (2014).
G. H. Jing Gao and J. Zhu, Optica Applicata **51** (2021).




(a)

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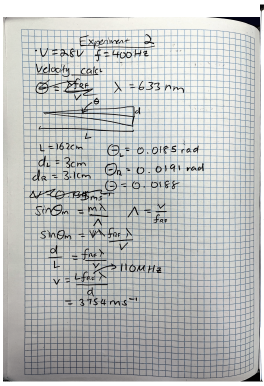


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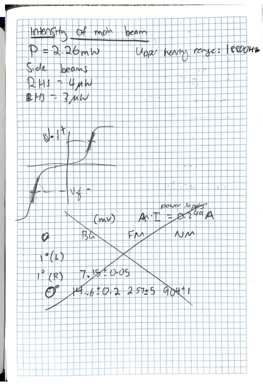
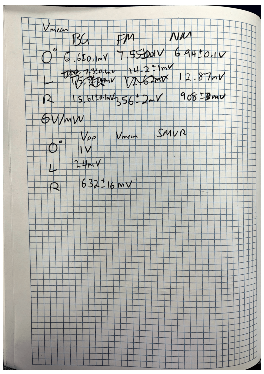



(d)




(e)

FIG. 9: Overall caption for the combined figure.