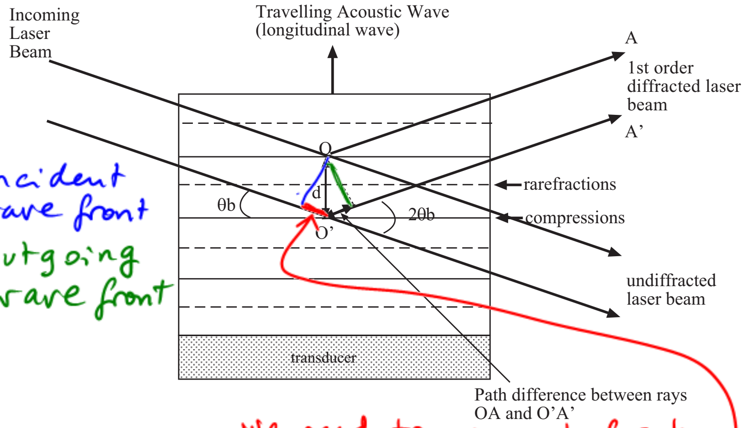
Lab 9: The Acousto-Optic Effect



incident wave front

outgoing wave front

we need to account for the added path before scattering too

Figure 1: Satisfying the Bragg condition.

1 Introduction

Refer to Appendix D for photos of the apparatus

This lab will allow you to acquire experience with an acousto-optic modulator (AOM). AOMs are used as diffraction gratings for light. The diffraction grating is created only when the Bragg condition is satisfied. In the first part of the experiment, you will learn how to align the AOM to satisfy the Bragg condition, and then use the results to measure the speed of sound in the AOM crystal. In the second part, you will understand how an AOM can be used to produce optical pulses by turning a CW Laser on and off. This will allow you to measure the speed of sound in the AOM crystal using an independent method.

EXERCISES 1-6 PERTAIN TO THE EXPERIMENTAL SECTIONS.

2 Background

An Acousto-Optics Modulator (AOM) is used to amplitude modulate and shift the frequency of a laser beam. An AOM uses the interaction of travelling acoustic waves with the laser beam to produce these effects. AOMs consist of a tuned LC circuit, a transducer and a crystal. AOMs find widespread use in scanners and printers.

Acoustic waves are pressure waves, or longitudinal waves. The "crests" and "troughs" of such waves consist of compressions and rarefractions, which modulate the index of refraction. A radio frequency (RF) source excites a transducer glued to the AOM crystal. The transducer produces acoustic waves in the crystal. The index of refraction of light in the crystal is related to the pressure. The changes in pressure along the longitudinal wave leads to a periodic variation in the index of refraction of the AOM crystal. This periodicity has a wavelength equal to the wavelength of sound in the crystal. The changing index of refraction can be used to diffract a laser beam if the **Bragg condition** is satisfied. The Bragg condition is satisfied only when the following equation holds,

$$m\lambda = \cancel{d \sin\theta_b} \;\; 2d \sin\vartheta_b \qquad (1)$$

Here, λ is the wavelength of the laser beam, d is the wavelength of the acoustic wave, m is the order of diffraction and b is the **Bragg angle.** Equation 1 can easily be satisfied by adjusting, the angle between the acoustic waves in the crystal and the incoming laser beam.

The diffraction of the laser beam will only be observed when the incident light beam is diffracted from the acoustic wave in the crystal at the Bragg angle, θ_b as shown in figure 1.

From figure 1 we see that the path difference between rays OA and O'A' is $d\cos(\frac{\pi}{2} - \theta_b)$. If the path difference is an integral multiple of the laser wavelength the Bragg condition is satisfied. Therefore,

$$d\cos(\frac{\pi}{2} - \theta_b) = m\lambda \qquad (2)$$

This equation simplifies to equation 1, since $\cos(\frac{\pi}{2} - \theta_b) = \sin\theta_b$. Therefore, if the crystal is oriented at the correct angle relative to the incoming laser beam, the Bragg condition (equation 1) will be satisfied. This will result in a diffracted beam as shown in figure 1. Since, d represents the wavelength of the sound wave in the AOM crystal,

$$V_s = df \qquad (3)$$

where, f is the radio frequency applied to the transducer and V_s is the speed of the sound wave in the crystal. Substituting equation 3 into equation 1,

$$\sin\theta_b = \frac{m\lambda f}{V_s} \qquad (4)$$

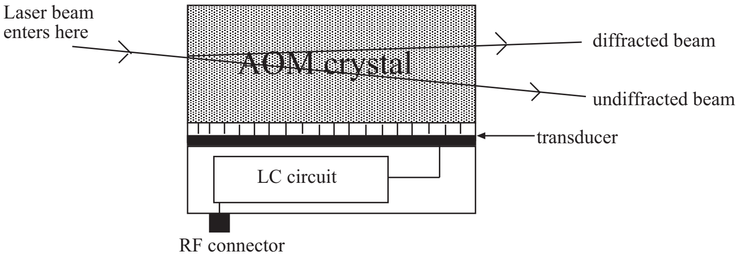


Figure 2: AOM (Acousto-Optic Modulator) setup.

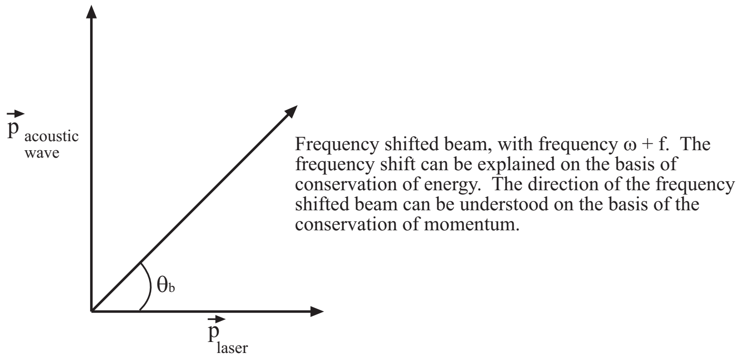


Figure 3: Frequency shift of diffracted laser beam (conservation of momentum).

When θ is small, $\sin\theta \approx \theta$ and equation 4 can be simplified as,

$$\theta_b = \frac{m\lambda f}{V_s} \tag{5}$$

The diffracted beam is frequency shifted from the incident laser beam by an amount equal to the RF frequency, f. By changing the orientation of the AOM with respect to the incident beam, the diffracted beam can be produced at frequencies $f_L + f$ or $f_L - f$. Here, f_L is the laser frequency. The frequency shift is due to conservation of momentum of the interaction between the laser beam and the acoustic wave.

3 Apparatus

- Oscillator ZOS-50
- Amplifier (for AOM) model #: ZHL-1-2W
- 15V Power Supply for RF amplifier
- Convex lens
- 12V Power Supply - hp 6212A (to power oscillator)
- 24V Power Supply - LodeStar DC (to power amplifier)
- Variable Power Supply (Range 1-15V)
- He-Ne Laser
- Cardboard Screens-to block off stray laser beams
- 3-mirrors
- 3-mirror holders
- 1-photodiode
- Pulse Generator
- Digital Storage Oscilloscope
- AOM(Acoustic-Optic Modulator) attached to a kinematic base
- Mixer (with L, X and R ports)
- 5-3" and 2-2" postholders and posts
- 7-bases (3 big bases and 4 small bases)
- 7-BNC cables
- 2-BNC splitters/tees
- 1-Optical Table
- 1-Meter Stick
- 3/16" Allen key

WARNING!!: KEEP TRACK OF YOUR LASER BEAM AT ALL TIMES. NEVER POINT THE BEAM AT PEOPLE, OR LOOK IN THE APERTURE OF THE LASER OR BE AT EYELEVEL WITH THE BEAM.

KEEP EYES AWAY FROM DIRECT OR REFLECTED LASER BEAMS. OTHERWISE SERIOUS EYE DAMAGE WILL OCCUR.

YOU SHOULD BE AWARE OF WHERE THE LASER BEAMS STRIKE OPTICAL COMPONENTS. REFLECTIONS FROM OPTICAL COMPONENTS SHOULD BE BLOCKED BY USING PIECES OF CARDBOARD THAT ARE PROVIDED. BE PARTICULARLY CAREFUL WHEN YOU INSERT OR REMOVE LENSES INTO A LASER BEAM.

DO NOT TOUCH THE OPTICAL SURFACES OF LENSES AND MIRRORS. IF THE SURFACES ARE UNCLEAN, PLEASE BRING IT TO THE ATTENTION OF THE TA IMMEDIATELY.

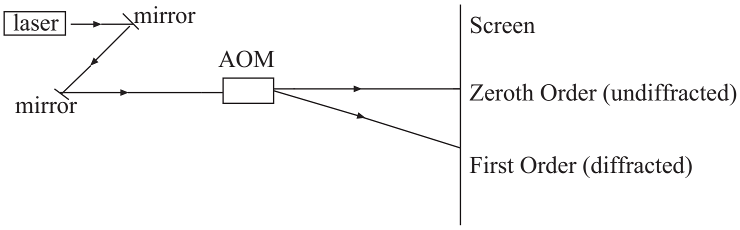


Figure 4: Optical Setup.

USE THE TRANSPARENT LENS TISSUES TO DETECT THE BEAMS.

MAKE SURE ALL MOUNTS ARE SECURELY FASTENED ON THE OPTICAL TABLE.

4 Experiment I: Measuring the speed of sound, V_s by measuring the Bragg angle

In this experiment you will use a He-Ne laser and an AOM to study the acousto-optic effect. You will determine the speed of sound in the crystal by measuring the Bragg angle as a function of the RF frequency.

Use bases, postholders, and posts to mount the mirrors, laser and AOM on the optical table as shown in figure 4.

Mount the AOM so the AOM crystal aperture is about 12 cm above the table. Turn on the He-Ne laser. Adjust the laser and mirror mounts so that the laser beam is at the same height as the AOM aperture. To do this, mark the height of the beam using a piece of cardboard. Next use this cardboard to check the height of the beam as it travels from one mirror to the next and then through the AOM. If the beam is not leveled everywhere on the path use the two adjusting screws on each mirror mount to adjust the height. Turn the laser off.

Connect the oscillator, amplifier and power supplies as shown in figure 5.

CAUTION: DISCUSS THE CONNECTIONS WITH THE TA BEFORE PROCEEDING.

IN PARTICULAR, MAKE SURE THAT THE AMPLIFIER POWER SUPPLY DOES NOT EXCEED 24V.

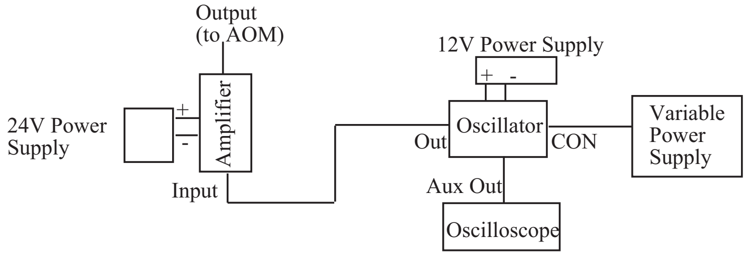


Figure 5: Connecting the oscillator and amplifier to the AOM. Note that the negative terminal for the two floating power supplies is connected to the ground terminal (which is at 0 Volts) by a jumper cable.

THE OSCILLATOR POWER SUPPLY SHOULD NOT EXCEED 12 V.

THE RANGE OF THE VARIABLE POWER SUPPLY SHOULD BE 1 - 15V.

THE OUTPUT OF THE RF AMPLIFIER SHOULD NEVER BE CONNECTED TO THE OSCILLOSCOPE.

The following list of instructions highlights what needs to be done to connect the circuit,

- Connect the AUX OUT of the oscillator to Channel 1 of the oscilloscope.
- Next turn the 12Vpower supply on and trigger the oscilloscope on Ch.1. To choose the trigger mode on the oscilloscope, press the **trigger menu** button and then use the buttons beside the screen to select Ch.1 as the **source**. Then use the trigger knob to locate the signal. A sinusoidal signal should appear on the oscilloscope screen.
- Next, turn the variable power supply on and vary the voltage until the frequency of the signal is at about 40 MHz. Do not exceed a voltage of 15V on the variable power supply. This is the **center frequency** of the AOM. Use the **measure** button on the oscilloscope to view the measure menu. Then use the first button on the side of the screen to select **type**, and then the second button to select **frequency** measure for **Ch.1**.
- Connect the output of the amplifier to the input of AOM and then turn on the 24 V supply to the amplifier as indicated in figure 4.
- Connect the OUT of the oscillator to the input of the amplifier.

- Next turn the laser on and rotate the AOM slowly until the diffracted beam is observed on the screen. Adjust the mirrors to maximize the intensity of the diffracted beam. Then, lock the AOM in position. The screen should be placed at least 1m away from the output of the AOM.

- Measure the distance from the center of the AOM aperture to the undiffracted beam on the screen. Then measure the distance on the screen between the undiffracted and the 1st order diffracted beams.

- Verify that the diffracted beam turns off when the input to the amplifier is disconnected.

Exercise 1: From your measurements, find the angle between the undiffracted and the 1st order diffracted beams. Does this angle represent θ_b or $2\theta_b$? Hint: see figures 1 and 2. Estimate the error in your measurement.

Vary the frequency of the oscillator by adjusting the voltage on the variable power supply. Measure the frequency using the oscilloscope, and then measure the angle between the undiffracted and 1st order diffracted beams.

Note: If the diffraction pattern is lost once the frequency is changed, slowly re-adjust the AOM to satisfy the Bragg condition.

Repeat the above step for other frequencies. The AOM has a radio frequency **bandwidth** of 20 MHz centered at the resonance frequency of 40 MHz. Any frequency less than 30 MHz or greater than 50 MHz does not interact efficiently with the AOM crystal and the diffraction pattern is hard to observe. Tabulate your measurements along with the experimental errors.

Exercise 2: Plot a graph of θ_b vs. frequency. Find the speed of sound in the crystal from your graph and the error in this measurement. The wavelength of the He-Ne laser is 632.8nm. The speed of sound in the crystal is characteristic of this crystal. Once the speed is known, the type of crystal can be identified. The AOM used in this experiment has a Lead Molybdate ($PbMoO_4$) crystal.

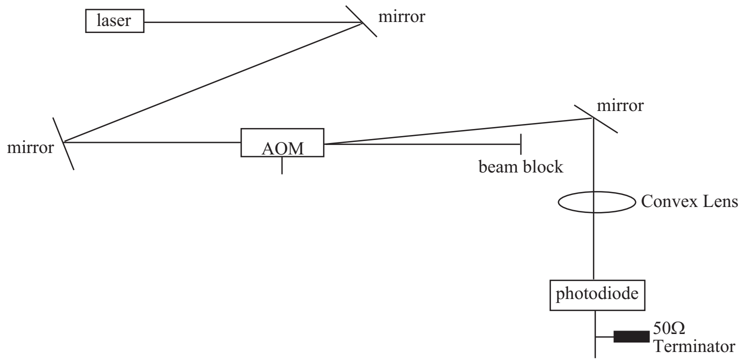


Figure 6: Experiment 2 optical Setup. Note: the AOM and the photodiode are connected to the circuit components as shown in figure 8.

5 Experiment II: Measuring the delay time between a RF pulse and an optical pulse to measure the speed of sound.

AOMs can also be used to create optical pulses. An **optical pulse** is produced when a sound wave of finite duration crosses a light beam. When the finite sound wave is on, the radio frequency from the oscillator creates the diffraction grating in the AOM crystal, but when the RF source is off, the light beam is not diffracted. A photodiode can be placed in front of the path of the 1st order diffracted beam to detect the optical pulse. The photodiode observes a signal when the sound pulse crosses the laser beam.

The RF pulse used to produce an optical pulse can be generated using an RF mixer. The mixer multiplies the signal from the oscillator with a short pulse from a pulse generator. The pulse generator can be adjusted to achieve the desirable pulse amplitude and pulse width. The optical pulses can be observed on a photodiode, and recorded on an oscilloscope.

Without altering the optical setup from experiment 1, add another mirror to reflect only the 1st order diffracted beam as shown in figure 6. Turn on the laser and adjust the AOM to observe the diffraction at the central frequency of the AOM. Use a beam block to stop the undiffracted beam from reaching the photodiode. Adjust the third mirror to reflect the first order diffracted beam onto the surface of the photodiode. Make sure that the beam is hitting the sensitive part of the photodiode. Introduce the convex lens so that the laser beam is focussed on the photodiode. Now turn off the laser.

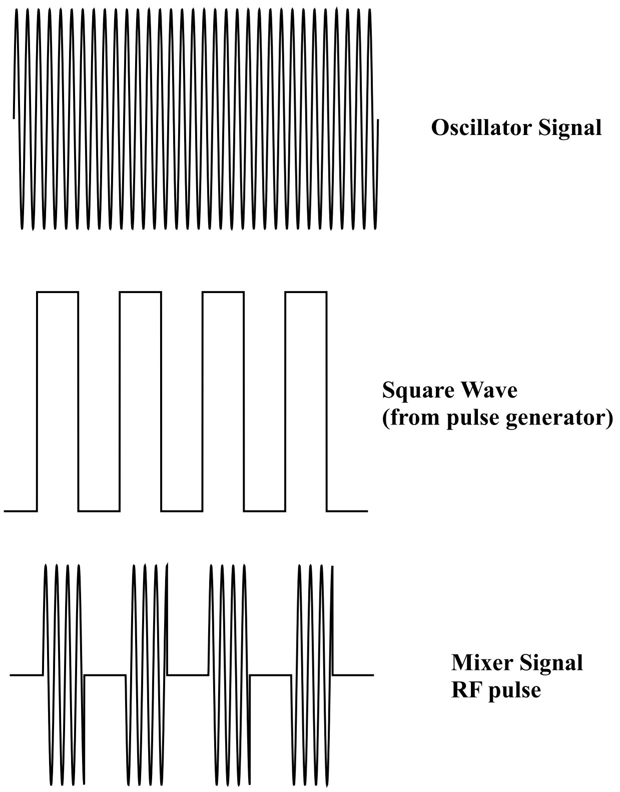


Figure 7: A Radio Frequency (RF) pulse.

Turn the pulse generator on and press the **run** mode button. The **run** mode of the pulse generator produces a square wave pulse. The square wave button **should not** be pushed in.

Use a BNC splitter to split the signal from the pulse generator and trigger the oscilloscope with this pulse on channel 1. Connect the other end of the BNC splitter to the **X** port of the mixer (the BNC splitter is used to observe the square pulse from the pulse generator directly and also sent to the mixer producing the RF pulse). Next, connect the **OUT** of the oscillator to the **L** port of the mixer.

Connect the **R** port of the mixer to channel 2 of the oscilloscope and observe the RF pulse. The mixer essentially multiplies the oscillator signal with the square pulse wave from the pulse generator (see figure 7). When the RF pulse is amplified and connected to the AOM, it will turn on at very nearly the same time as the pulse from the pulse generator. This is because time delays caused by the coaxial cables and the amplifier are negligible.

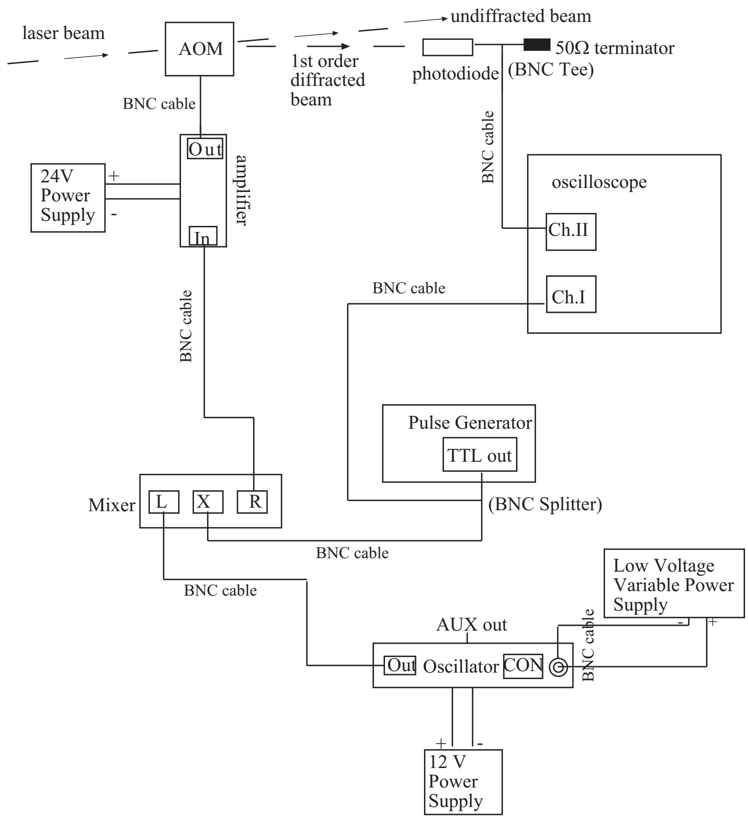


Figure 8: Circuit for creating optical pulses. Note that the negative terminal for the three floating power supplies is connected to the ground terminal (which is at 0 Volts) by a jumper cable.

Disconnect the R port of the mixer from the oscilloscope and connect it to the input of the amplifier as shown in figure 8. The amplified RF pulse will produce the optical pulses when the amplifier is connected to the AOM. Adjust the knobs on the pulse generator so that the pulse width is roughly $1\mu s$. Turn on the laser. Next, connect the output of the photodiode to the input of the oscilloscope using a 50Ω terminator and a BNC tee as shown in figure 8. Turn on the photodiode, and observe the optical pulse on the oscilloscope. The optical pulse from the photodiode will be delayed with respect to the pulse from the pulse generator as shown in figure 9. You can average the optical pulse on the scope to increase the signal to noise ratio. This can be done by pressing the **acquire** button and then choosing the **average** option.

Exercise 3: Explain the reason for the observed time delay.

Exercise 4: The time between the turn on of the pulse from the pulse generator and the turn on of the optical pulse from the photodiode is called the **delay time**. Measure the delay time observed on the oscilloscope. Sketch the image observed on the oscilloscope.

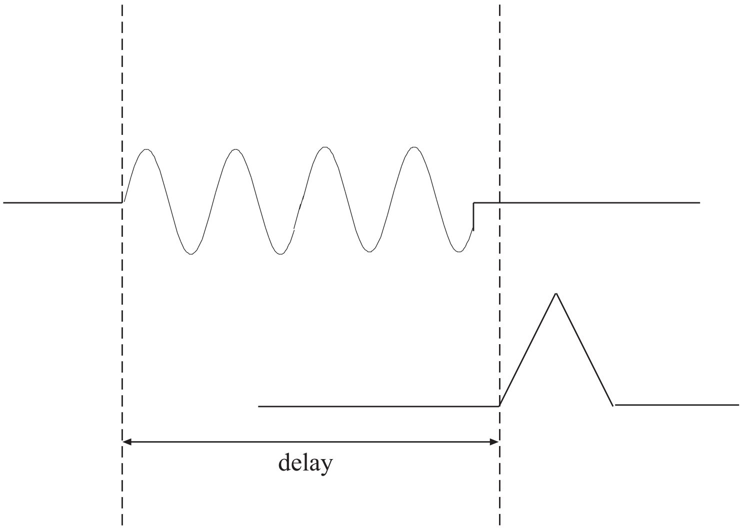


Figure 9: Delay time between RF pulse and optical pulse.

Exercise 5: Measure the distance between the transducer and where the laser beam hits the crystal. Combine this measurement with the delay time and calculate the speed of sound, V_s and the uncertainty in its value. How does this value compare with the measurement in the first part of the experiment?

Exercise 6: Measure the rise time of the optical pulse. Use this to estimate the size of the Laser beam passing though the AOM.

Note: Once you have completed the experiment, please remove all optical elements and the detector from their mounts and place them on the optical table.

Your lab report should include:

Answers to exercises 1-6 with relevant data tables, graphs, figures and qualitative comments.

Refer to Appendix C for Maple worksheets.