# Ultrasonic Diffraction Experiment

BS192: Undergraduate Science Laboratory (Physics)

**Group 7 (Wednesday)**

**Lab No. 4, Experiment No. 5**

**A laboratory report by**

**Aksh Kishor Solanki (24110023)**

**Akshat Vishal Wandalkar (24110024)**

**Akshay (24110025)**

**Akshit Chhabra (24110026)**

**Akul Gupta (24110027)**

**Indian Institute of Technology, Gandhinagar**

Experiment No. 5

# Ultrasonic Diffraction Experiment

## I. Aim:

To determine the velocity of ultrasonic waves in liquid using an ultrasonic diffraction apparatus. Further, measure the bulk modulus of the given liquid and estimate the compressibility of the liquid.

## II. Apparatus:

1. Laser Mount
2. Diode Laser
3. Power Supply for Laser
4. Glass Tank with Liquid
5. Glass Tank Holder
6. Crystal with Mount
7. RF Oscillator
8. Optical Rail (1500 mm)
9. Cell mount with linear translation stage and Pinhole detector
10. Output measurement unit

## III. Theory:

Ultrasonic waves are generated by a transducer. They propagate through the liquid medium, get reflected at the bottom of the cell, which is a flat glass plate and lead to the formation of stationary or standing waves due to interference between incident and reflected waves. The velocity ($v$) of these ultrasonic waves in the liquid can be calculated using the formula,

$$v = f \times \Lambda$$

Where $f$ is the frequency of the crystal oscillator, and $\Lambda$ is the wavelength of the ultrasonic wave.

The wavelength $\Lambda$ can be further expressed as:

$$\Lambda = (n \times \lambda) / sin(\theta)$$

Where n is the order of diffraction, $\lambda$ is the wavelength of the laser used and $\theta$ is the angle of diffraction. The angle of diffraction can be obtained by the equation,

$$\theta = (D/L)$$

Where $D$ is the order length and $L$ is the distance between the detector and the crystal oscillator.

The bulk modulus $\beta$ of the liquid is related to the density $\varrho$ and the velocity $v$ of the ultrasonic wave by,

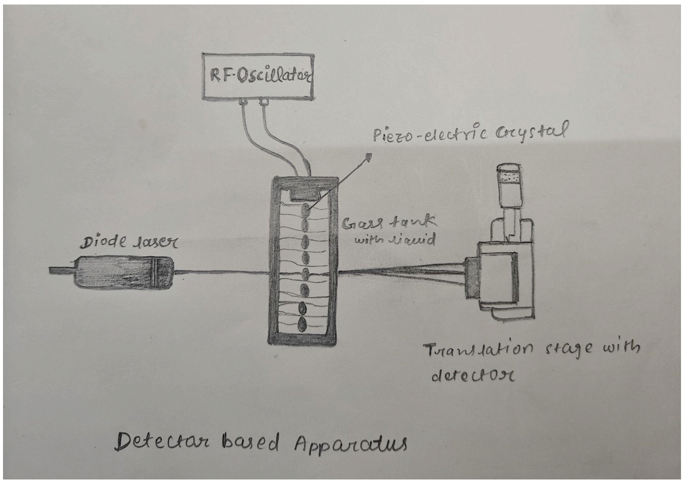
$$\beta = \varrho \times v^2$$

The adiabatic compressibility κ of the liquid can be calculated by using the relation

$$\kappa = 1 / \beta = 1 / (\varrho \times v^2)$$

## IV. Procedure:

1. Clean all the glass equipment and fix the laser mount on the optical rail.
2. Fill the glass tank with liquid and place it on the tank holder on the optical rail.
3. Place the laser on the mount properly.
4. Fix the crystal on the mount such that it is fully submerged in the liquid and connect it to the RF oscillator.
5. Set up the cell mount with the translation part on the rail. Insert the pinhole detector into the mount and connect the output probe to the measurement device.
6. Switch on the laser and output measurement device. Align the crystal and laser so that the laser beam is parallel to the face of the crystal. Adjust the setup provided on the laser mount to position the laser beam to create standing waves.
7. Keep the laser spot falling on the detector stage and adjust the frequency of the oscillator until you get a very good fringe pattern on both sides of the central bright spot. Utilize the micrometer-driven stage to move the detector to the edges of the diffraction pattern.
8. Scan the pattern at close intervals. Each time note the micrometer reading and corresponding output of the detector.
9. Plot a graph (Distance Vs detector current). Note the distance from the central bright spot to nth order spot.



V. Results and Discussion

| | Micrometer Reading *(mm)* | Detector Output ($\mu m$) | | Micrometer Reading *(mm)* | Detector Output ($\mu m$) | | Micrometer Reading *(mm)* | Detector Output ($\mu m$) |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1.3 | 24 | 1.15 | 3.8 | 47 | 2.3 | 50.2 |
| 2 | 0.05 | 1.4 | 25 | 1.2 | 4 | 48 | 2.35 | 50.7 |
| 3 | 0.1 | 1.4 | 26 | 1.25 | 4.4 | 49 | 2.4 | 45.6 |
| 4 | 0.15 | 1.4 | 27 | 1.3 | 4.6 | 50 | 2.45 | 45.2 |
| 5 | 0.2 | 1.4 | 28 | 1.35 | 4.8 | 51 | 2.5 | 44.3 |
| 6 | 0.25 | 1.7 | 29 | 1.4 | 5.5 | 52 | 2.55 | 44.1 |
| 7 | 0.3 | 1.8 | 30 | 1.45 | 6.7 | 53 | 2.6 | 44 |
| 8 | 0.35 | 2 | 31 | 1.5 | 8.1 | 54 | 2.65 | 43.7 |
| 9 | 0.4 | 2.2 | 32 | 1.55 | 12.4 | 55 | 2.7 | 43.2 |
| 10 | 0.45 | 2.5 | 33 | 1.6 | 14.6 | 56 | 2.75 | 41.9 |
| 11 | 0.5 | 3.1 | 34 | 1.65 | 14.9 | 57 | 2.8 | 44.5 |
| 12 | 0.55 | 3.9 | 35 | 1.7 | 14.8 | 58 | 2.85 | 44.8 |
| 13 | 0.6 | 4 | 36 | 1.75 | 16.2 | 59 | 2.9 | 42.8 |
| 14 | 0.65 | 4 | 37 | 1.8 | 18.7 | 60 | 2.95 | 45.2 |
| 15 | 0.7 | 4.2 | 38 | 1.85 | 21.7 | 61 | 3 | 55.4 |
| 16 | 0.75 | 4.5 | 39 | 1.9 | 21.9 | 62 | 3.05 | 63.4 |
| 17 | 0.8 | 4.2 | 40 | 1.95 | 23.5 | 63 | 3.1 | 75.3 |
| 18 | 0.85 | 3.8 | 41 | 2 | 28.7 | 64 | 3.15 | 83.6 |
| 19 | 0.9 | 3.7 | 42 | 2.05 | 35.3 | 65 | 3.2 | 98.6 |
| 20 | 0.95 | 3.8 | 43 | 2.1 | 37.8 | 66 | 3.25 | 112.7 |
| 21 | 1 | 4 | 44 | 2.15 | 39.2 | 67 | 3.3 | 117.6 |
| 22 | 1.05 | 3.9 | 45 | 2.2 | 43.4 | 68 | 3.35 | 138.4 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 23 | 1.1 | 3.9 | 46 | 2.25 | 46.2 | 69 | 3.4 | 157.3 |
| 70 | 3.45 | 166.9 | 95 | 4.7 | 700 | 120 | 5.95 | 2100 |
| 71 | 3.5 | 183.2 | 96 | 4.75 | 900 | 121 | 6 | 2000 |
| 72 | 3.55 | 500 | 97 | 4.8 | 1000 | 122 | 6.05 | 1800 |
| 73 | 3.6 | 500 | 98 | 4.85 | 1100 | 123 | 6.1 | 1900 |
| 74 | 3.65 | 500 | 99 | 4.9 | 1200 | 124 | 6.15 | 2000 |
| 75 | 3.7 | 600 | 100 | 4.95 | 1500 | 125 | 6.2 | 2000 |
| 76 | 3.75 | 600 | 101 | 5 | 1600 | 126 | 6.25 | 2000 |
| 77 | 3.8 | 700 | 102 | 5.05 | 1700 | 127 | 6.3 | 2100 |
| 78 | 3.85 | 800 | 103 | 5.1 | 1900 | 128 | 6.35 | 2600 |
| 79 | 3.9 | 800 | 104 | 5.15 | 2000 | 129 | 6.4 | 2700 |
| 80 | 3.95 | 800 | 105 | 5.2 | 2200 | 130 | 6.45 | 2800 |
| 81 | 4 | 700 | 106 | 5.25 | 2300 | 131 | 6.5 | 3000 |
| 82 | 4.05 | 700 | 107 | 5.3 | 2400 | 132 | 6.55 | 3600 |
| 83 | 4.1 | 600 | 108 | 5.35 | 2500 | 133 | 6.6 | 3700 |
| 84 | 4.15 | 600 | 109 | 5.4 | 2700 | 134 | 6.65 | 3800 |
| 85 | 4.2 | 600 | 110 | 5.45 | 3000 | 135 | 6.7 | 4000 |
| 86 | 4.25 | 600 | 111 | 5.5 | 3200 | 136 | 6.75 | 4500 |
| 87 | 4.3 | 600 | 112 | 5.55 | 3000 | 137 | 6.8 | 5000 |
| 88 | 4.35 | 600 | 113 | 5.6 | 2800 | 138 | 6.85 | 5300 |
| 89 | 4.4 | 600 | 114 | 5.65 | 2600 | 139 | 6.9 | 5500 |
| 90 | 4.45 | 500 | 115 | 5.7 | 2500 | 140 | 6.95 | 5800 |
| 91 | 4.5 | 500 | 116 | 5.75 | 2400 | 141 | 7 | 6600 |
| 92 | 4.55 | 600 | 117 | 5.8 | 2400 | 142 | 7.05 | 7500 |
| 93 | 4.6 | 600 | 118 | 5.85 | 2300 | 143 | 7.1 | 7400 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 94 | 4.65 | 600 | 119 | 5.9 | 2200 | 144 | 7.15 | 7100 |
| 145 | 7.2 | 6600 | 170 | 8.45 | 2400 | 195 | 9.7 | 700 |
| 146 | 7.25 | 6000 | 171 | 8.5 | 2500 | 196 | 9.75 | 700 |
| 147 | 7.3 | 5600 | 172 | 8.55 | 2800 | 197 | 9.8 | 600 |
| 148 | 7.35 | 5400 | 173 | 8.6 | 3100 | 198 | 9.85 | 600 |
| 149 | 7.4 | 5300 | 174 | 8.65 | 3300 | 199 | 9.9 | 600 |
| 150 | 7.45 | 4800 | 175 | 8.7 | 3300 | 200 | 9.95 | 600 |
| 151 | 7.5 | 4500 | 176 | 8.75 | 3100 | 201 | 10 | 600 |
| 152 | 7.55 | 4100 | 177 | 8.8 | 2800 | 202 | 10.05 | 600 |
| 153 | 7.6 | 3800 | 178 | 8.85 | 2500 | 203 | 10.1 | 700 |
| 154 | 7.65 | 3600 | 179 | 8.9 | 2400 | 204 | 10.15 | 700 |
| 155 | 7.7 | 3400 | 180 | 8.95 | 2300 | 205 | 10.2 | 800 |
| 156 | 7.75 | 3300 | 181 | 9 | 2100 | 206 | 10.25 | 700 |
| 157 | 7.8 | 3100 | 182 | 9.05 | 1800 | 207 | 10.3 | 700 |
| 158 | 7.85 | 2700 | 183 | 9.1 | 1700 | 208 | 10.35 | 600 |
| 159 | 7.9 | 2500 | 184 | 9.15 | 1600 | 209 | 10.4 | 600 |
| 160 | 7.95 | 2500 | 185 | 9.2 | 1500 | 210 | 10.45 | 600 |
| 161 | 8 | 2300 | 186 | 9.25 | 1400 | 211 | 10.5 | 600 |
| 162 | 8.05 | 2100 | 187 | 9.3 | 1300 | 212 | 10.55 | 500 |
| 163 | 8.1 | 2100 | 188 | 9.35 | 1300 | 213 | 10.6 | 400 |
| 164 | 8.15 | 2100 | 189 | 9.4 | 1100 | 214 | 10.65 | 400 |
| 165 | 8.2 | 2100 | 190 | 9.45 | 1000 | 215 | 10.7 | 400 |
| 166 | 8.25 | 2000 | 191 | 9.5 | 900 | 216 | 10.75 | 198.4 |
| 167 | 8.3 | 2100 | 192 | 9.55 | 800 | 217 | 10.8 | 186.4 |
| 168 | 8.35 | 2300 | 193 | 9.6 | 700 | 218 | 10.85 | 169.2 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 169 | 8.4 | 2300 | 194 | 9.65 | 700 | 219 | 10.9 | 163.5 |
| 220 | 10.95 | 163.2 | 232 | 11.55 | 46.7 | | | |
| 221 | 11 | 138.1 | 233 | 11.6 | 47.3 | | | |
| 222 | 11.05 | 113.2 | 234 | 11.65 | 49.5 | | | |
| 223 | 11.1 | 105.5 | 235 | 11.7 | 51.4 | | | |
| 224 | 11.15 | 98.6 | 236 | 11.75 | 51.9 | | | |
| 225 | 11.2 | 91.8 | 237 | 11.8 | 55.2 | | | |
| 226 | 11.25 | 78.1 | 238 | 11.85 | 54.3 | | | |
| 227 | 11.3 | 69.3 | 239 | 11.9 | 50.1 | | | |
| 228 | 11.35 | 62.5 | 240 | 11.95 | 47.6 | | | |
| 229 | 11.4 | 57.1 | 241 | 12 | 45.2 | | | |
| 230 | 11.45 | 50.3 | | | | | | |
| 231 | 11.5 | 48.4 | | | | | | |

- $1^{st}$ Order of Diffraction

Average of the differences between the 1st order peek values (*D*) = 1.575 m$m$

Distance between the crystal and the detector (*L*) = $1100mm$

To calculate the wavelength of sound Λ, we use

$$\Lambda = \frac{n\lambda}{sin\theta}$$

where,
n = order of diffraction
λ = wavelength of laser used
$\sin\theta = \ \theta = \frac{D}{L} \ = \ 0.001432$

In our case, we are observing the $1^{st}$ order diffraction, so $n \ = \ 1$
Also, we are using a laser of $\lambda = \ 650 \ nm$

Using these values,

$$\Lambda = 0.000454\, m$$

Now, we can calculate the speed of the wave using:

$$v = \Lambda f$$

where,

f (frequency of the wave) = 3 $MHz = 3 \times 10^6 Hz$

$$v = 1361.90\, m/s$$

And the bulk modulus, compressibility of water are:

$$\beta = \rho v^2$$

$$\beta = 1.854 \times 10^9\, Pa\ or\ 1.854\, GPa$$

$$k = \frac{1}{\beta}$$

$$k = 5.393 \times 10^{-8}\, Pa^{-1}$$

- 2nd Order of Diffraction

Average of the differences between the 2nd order peek values ($D$) = 3.15 m$m$

Distance between the crystal and the detector ($L$) = $1100mm$

To calculate the wavelength of sound Λ, we use

$$\Lambda = \frac{n\lambda}{sin\theta}$$

where,

n = order of diffraction

λ = wavelength of laser used

$\sin\theta = \theta = \frac{D}{L} = 0.002863$

In our case, we are observing the $1^{st}$ order diffraction, so $n = 2$

Also, we are using a laser of $\lambda = 650\, nm$

Using these values,

$$\Lambda = 0.000454\, m$$

Now, we can calculate the speed of the wave using:

$$v = \Lambda f$$

where,

f (frequency of the wave) = 3 $MHz = 3 \times 10^6 Hz$

$$v = 1361.90\, m/s$$

And the bulk modulus of water is:

$$\beta = \rho v^2$$

$$\beta = 1.854 \times 10^9\ Pa\ or\ 1.854\ GPa$$
$$k = \frac{1}{\beta}$$
$$k = 5.393 \times 10^{-8}\ Pa^{-1}$$

## VI. Error Analysis

Using the equation,

$$\Lambda = \frac{n\lambda}{sin\theta}$$

We can take log on both sides and differentiate to get the error formula,

$$\Delta v = v \times \left(\frac{\Delta f}{f} + \frac{\Delta \lambda}{\lambda} + cos^2(\theta) \times \left(\frac{\Delta D}{D} + \frac{\Delta L}{L}\right)\right)$$

Taking the errors as least count of the instruments,

$\Delta f = 0.01\ MHz$
$\Delta \lambda = 0\ nm$
$\Delta D = 0.01\ mm$
$\Delta L = 1 mm$

Plugging in the values into the derived formula,

$$\Delta v = 9.88\ m/s$$

Similarly,

$$\frac{\Delta \beta}{\beta} = \frac{\Delta \rho}{\rho} + 2\frac{\Delta v}{v}$$

Taking error in density to be zero,

$$\Delta \beta = 0.01 \times 10^9 Pa$$

For compressibility,

$$\frac{\Delta K}{K} = \frac{\Delta \beta}{\beta}$$
$$\Delta K = 4.22 \times 10^{-9} Pa^{-1}$$

**Possible sources of error:**

- **Alignment errors –** Incorrect positioning of the transmitter, receiver, or sample.
- **Temperature variations –** Affecting the speed of sound and diffraction pattern.
- **Electrical noise** – Interference from surrounding electronic devices.
- **Air gaps or coupling issues –** Poor contact between the transducer and the medium**.**
- **Multiple reflections –** Unwanted echoes distorting measurements.

## Conclusion

In conclusion, the ultrasonic diffraction experiment helped us understand wave behavior and measure the velocity of sound in a medium. We calculated the velocity as **1361.9 m/s**, with a percentage error of **0.73%**, which is fairly low. The accuracy of our results depended on proper alignment, minimizing interference, and ensuring good contact between the transducers and the medium. While there were some sources of error, careful setup and better control of conditions could improve the results. Overall, the experiment was a great way to explore the principles of wave diffraction and ultrasonic measurement.

# VIII. Author Contributions:

| **Name** | **Roll number** | **Contribution** | **Signature** |
|---|---|---|---|
| Aksh Kishor Solanki | 24110023 | Creation of pre-report | |
| Akshat Vishal Wandalkar | 24110024 | Error analysis and possible sources of erors | |
| Akshay | 24110025 | Proofreading of reports and elimination of errors, drawing diagrams | |
| Akshit Chhabra | 24110026 | Results and discussion in the lap report, operation of equipment | |
| Akul Gupta | 24110027 | Documenting data during the experiment, sketching of graphs | |