BS 192: Undergraduate Science Laboratory (Physics)

A

Laboratory Report on

ULTRASONIC DIFFRACTION

BY

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Objective:

- Determination of the velocity of ultrasonic wave in liquid using the ultrasonic diffraction apparatus.
- Measurement of the bulk modulus of the given liquid.
- Estimation of the compressibility of the liquid.

Theory:

In this experiment, our main goal is to determine the speed of ultrasonic waves in liquids, as well as the bulk modulus of the liquid and its compressibility factor. We began by examining the setup provided in the lab manual.

The setup consists of a laser diode that emits a concentrated beam of light through a container that responds to electrical signals generated by an RF oscillator. By adjusting the frequency of these electrical signals to match the natural resonance of the crystal, we induce significant vibrations in the liquid. These vibrations create standing waves, causing the layers of the liquid to alternatively compress and rarefy. As a result, the refractive index of these layers changes. When we direct the laser beam to these areas of compression and rarefaction and parallel to the faces of the crystal, we observe diffraction due to the variations in the refractive characteristics of the liquid. As a result of the diffraction, we observe a pattern of bright and dark lines on the pinhole detector. These lines show the interference of diffracted waves. This pattern gives us important information about the liquid, such as its bulk modulus, compressibility, and the speed of ultrasonic waves.

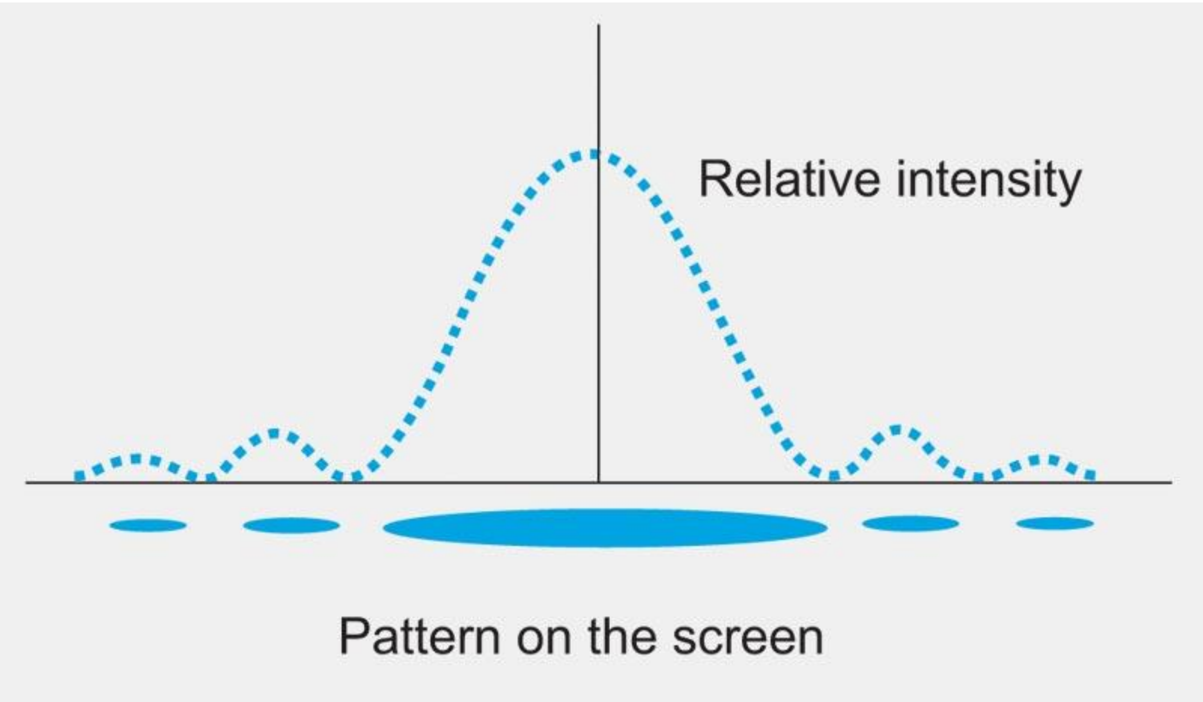


Figure 1

Principle:

In this experiment, an ultrasonic diffraction setup employs laser light to investigate the diffraction behaviour of ultrasonic waves. These waves, generated by an RF oscillator, operate at frequencies beyond the audible range. The RF oscillator induces vibrations, establishing a standing wave within the liquid, causing fluctuations in both density and refractive index. As the laser beam traverses the liquid, it creates a diffraction pattern on a screen, manifesting as fringe patterns. By measuring the diffraction angle (θ), we can approximate the wavelength of sound (Λ) using the formula:

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

The velocity of the waves is subsequently determined by multiplying the wavelength with the oscillator's frequency, denoted as $\mathrm{V} = \Lambda \times v$.

To ascertain the modulus (β) of the liquid, we incorporate its density (ρ) and the velocity of ultrasonic waves; $\beta = \rho \mathrm{V}^2$. The compressibility (K), inversely proportional to the modulus, can be calculated as

$$K = \frac{1}{\beta} = \frac{1}{\rho \mathrm{V}^2}.$$

This experiment yields valuable insights into the behaviour of ultrasonic waves when encountering obstacles. Furthermore, the examination of diffraction patterns enables accurate estimation of liquid characteristics.

Grounded in the principles of wave-particle duality and Huygens' principle, this experiment elucidates the interaction of ultrasonic waves with a crystal and sheds light on the patterns formed through diffraction.

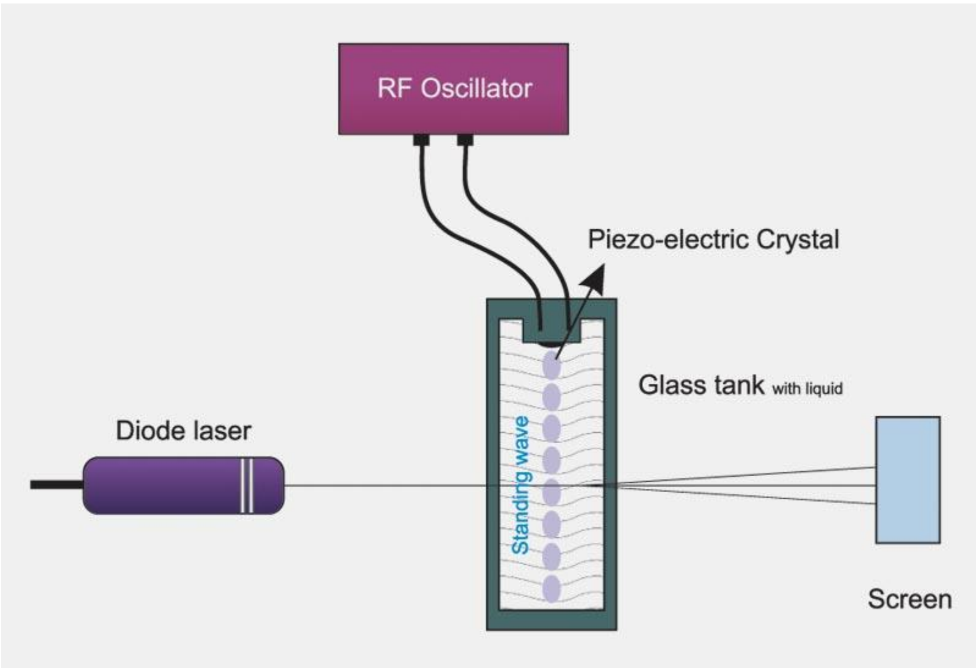


Figure 2

Experimental Details:

Apparatus:

1. Kinetic Laser Mount
2. Diode Laser
3. Power Supply for Laser
4. Glass Tank with Liquid (Distilled Water)
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

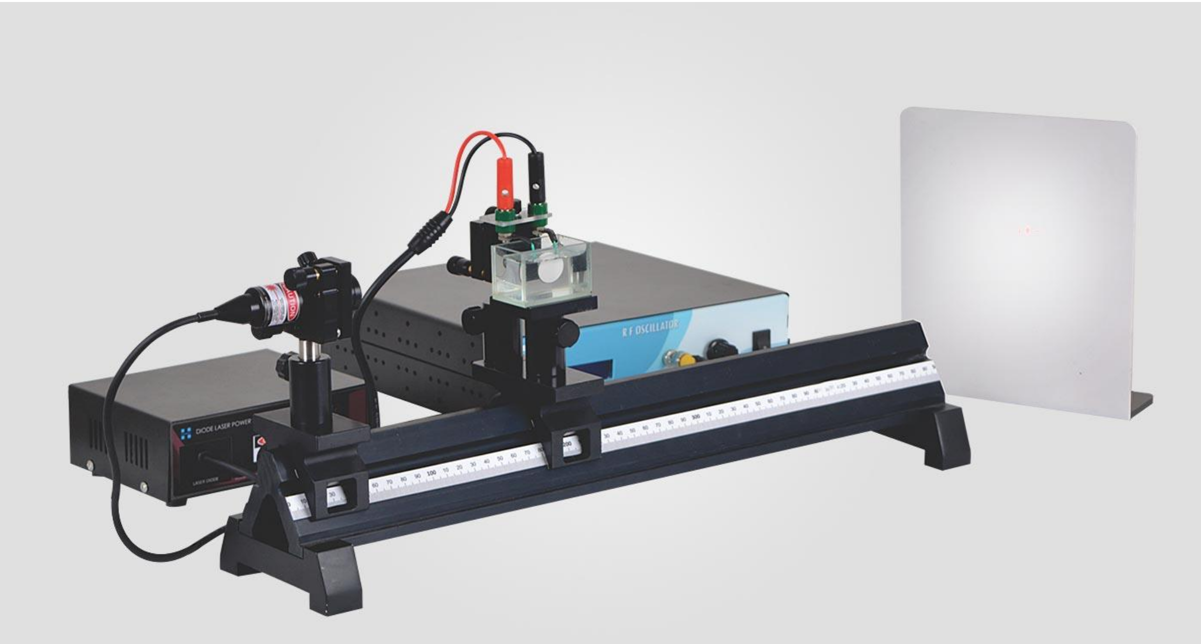


Figure 3

Procedure:

a. Begin by securely positioning the laser mount at one end of the optical bench, ensuring the laser beam points towards the opposite end.

b. Next, place a holder for the glass tank directly in front of the laser. Then, carefully position the glass tank filled with water onto the holder, ensuring that one side of the tank aligns parallel to the laser beam.

c. Submerge the crystal completely in water inside the glass tank and connect it to the Radio Frequency oscillator.

d. Now, place the cell mount at the opposite end of the optical bench. Insert the Pinhole detector into the cell mount and connect the output of the detector to the current measuring device.

e. Activate the laser, RF oscillator, and current measurement device. Adjust the laser beam's direction, so it falls precisely onto the pinhole detector.

f. Fine-tune the oscillator's frequency until a clear fringe pattern appears on the pinhole detector. Look for a bright central fringe within the pattern.

g. If the fringe pattern isn't optimal, ensure that the glass in front of the laser is clean and parallel to the laser beam. Experiment with adjusting the frequency of the RF oscillator and verify the alignment of the pinhole detector with the laser beam.

h. Once the fringe pattern is visible, move the pinhole detector and align its centre with the fringe at one extreme using the micrometre knob of the detector holder.

i. Gradually move the detector along the fringe pattern, recording micrometre and current readings at each successive fringe. Adjust the micrometre carefully, moving it minimally (e.g., by 5 divisions or 0.05 mm) each time.

j. Plot a graph correlating the micrometre readings (distance) with the current readings. From this graph, determine the distance (D) from the central bright fringe to each nth-order fringe.

Precautions:

- Laser radiation predominantly causes injury via thermal effects. So, one should avoid looking directly into the laser beam.
- Care should be taken while handling the crystal oscillator and other components.
- Remove the crystal from the liquid as soon as the experiment is completed. Otherwise, the crystal may get damaged.

Results and Conclusion:

Observations:

Wavelength of the laser $\lambda = 650\ nm$

Least count of the micrometre $= 0.01\ mm$

Distance between the crystal and the detector, $L = 1.25\ m$

Frequency of the crystal, $\nu = 3\ MHz$

Density of water, $\rho = 1000\ kg/m^3$

Length in mm	Current in µA
0	4.8
0.05	5
0.1	5.6
0.15	7
0.2	6.9
0.25	6.2
0.3	6
0.35	5.9
0.4	5.9
0.45	6.5
0.5	7.6
0.55	7.8
0.6	7.9
0.65	9.5
0.7	8.4
0.75	6.9
0.8	7.4
0.85	8.3
0.9	9.4
0.95	14.5
1	19.2
1.05	25.1
1.1	37.3
1.15	47.4
1.2	68.2
1.25	86.6
1.3	101.3
1.35	116.3
1.4	117.8
1.45	113
1.5	93.4
1.55	85.5
1.6	73.5
1.65	68.8
1.7	64.2
1.75	60.8
1.8	59.8
1.85	62.6
1.9	73.1
1.95	94.6
2	130.9
2.05	187.4
2.1	200

04.04.2024

2.15	300
2.2	600
2.25	800
2.3	1200
2.35	1700
2.4	2300
2.45	3200
2.5	3900
2.55	4200
2.6	4500
2.65	4800
2.7	4400
2.75	4200
2.8	3900
2.85	3700
2.9	3500
2.95	2900
3	2400
3.05	2100
3.1	1800
3.15	1600
3.2	1600
3.25	1700
3.3	1800
3.35	2400
3.4	3600
3.45	4600
3.5	6500
3.55	8900
3.6	11900
3.65	15500
3.7	19400
3.75	22300
3.8	24000
3.85	25600
3.9	28200
3.95	28600
4	28800
4.05	28500
4.1	27900
4.15	27200
4.2	26400
4.25	25500
4.3	24000

04.04.2024

6.55	88.9
6.6	91.2
6.65	102.2
6.7	101.4
6.75	94.7
6.8	91.2
6.85	81.3
6.9	69.3
6.95	58.4
7	45.7
7.05	42.2
7.1	37.9
7.15	32.1
7.2	29.7
7.25	25.6
7.3	21.8
7.35	19.2
7.4	14.6
7.45	13.8
7.5	11.8
7.55	11.6
7.6	10.6
7.65	12.7
7.7	8.3
7.75	7.4
7.8	8.2
7.85	7.3
7.9	6.8
7.95	6.4
8	7.2
8.05	7.5
8.1	6.6
8.15	7.3

04.04.2024

4.35	22700
4.4	21200
4.45	18300
4.5	14300
4.55	11500
4.6	7600
4.65	5900
4.7	4100
4.75	3100
4.8	2400
4.85	2100
4.9	1400
4.95	1800
5	2000
5.05	2300
5.1	2700
5.15	3300
5.2	3900
5.25	4400
5.3	4700
5.35	4700
5.4	4600
5.45	4300
5.5	3600
5.55	2900
5.6	2200
5.65	1700
5.7	1400
5.75	1100
5.8	800
5.85	600
5.9	400
5.95	300
6	200
6.05	200
6.1	176.6
6.15	146.4
6.2	121
6.25	108.9
6.3	90.1
6.35	81.4
6.4	77.3
6.45	74.3
6.5	82.9

04.04.2024

Serial No.	Micrometre (in mm)	Current (in µA)
1	0	4.8
2	0.05	5.0
3	0.1	5.6
4	0.15	7.0
5	0.2	6.9
6	0.25	6.2
7	0.3	6.0
8	0.35	5.9
9	0.4	5.9
10	0.45	6.5
11	0.5	7.6
12	0.55	7.8
13	0.6	7.9
14	0.65	9.5
15	0.7	8.4
16	0.75	6.9
17	0.8	7.4
18	0.85	8.3
19	0.9	9.4
20	0.95	14.5
21	1	19.2
22	1.05	25.1
23	1.1	37.3
24	1.15	47.4
25	1.2	68.2
26	1.25	86.6
27	1.3	101.3
28	1.35	116.3
29	1.4	117.8
30	1.45	113
31	1.5	93.4
32	1.55	85.5
33	1.6	73.5
34	1.65	68.8
35	1.7	64.2
36	1.75	60.8
37	1.8	59.8

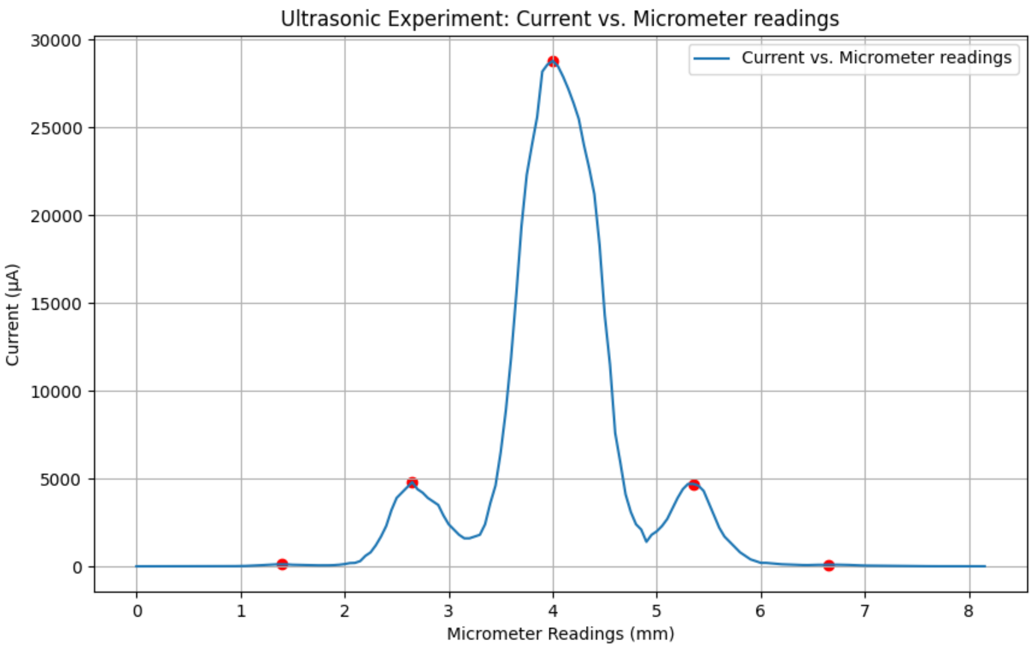
38	1.85	62.6
39	1.9	73.1
40	1.95	94.6
41	2	130.9
42	2.05	187.4
43	2.1	200
44	2.15	300
45	2.2	600
46	2.25	800
47	2.3	1200
48	2.35	1700
49	2.4	2300
50	2.45	3200
51	2.5	3900
52	2.55	4200
53	2.6	4500
54	2.65	4800
55	2.7	4400
56	2.75	4200
57	2.8	3900
58	2.85	3700
59	2.9	3500
60	2.95	2900
61	3	2400
62	3.05	2100
63	3.1	1800
64	3.15	1600
65	3.2	1600
66	3.25	1700
67	3.3	1800
68	3.35	2400
69	3.4	3600
70	3.45	4600
71	3.5	6500
72	3.55	8900
73	3.6	11900
74	3.65	15500
75	3.7	19400
76	3.75	22300

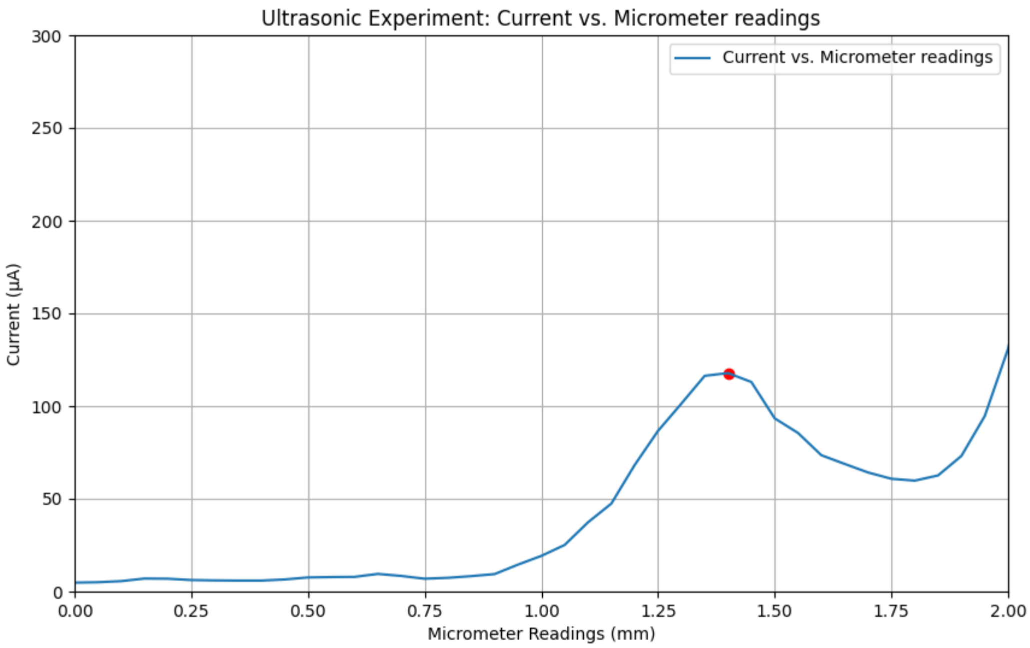
77	3.8	24000
78	3.85	25600
79	3.9	28200
80	3.95	28600
81	4	28800
82	4.05	28500
83	4.1	27900
84	4.15	27200
85	4.2	26400
86	4.25	25500
87	4.3	24000
88	4.35	22700
89	4.4	21200
90	4.45	18300
91	4.5	14300
92	4.55	11500
93	4.6	7600
94	4.65	5900
95	4.7	4100
96	4.75	3100
97	4.8	2400
98	4.85	2100
99	4.9	1400
100	4.95	1800
101	5.00	2000
102	5.05	2300
103	5.10	2700
104	5.15	3300
105	5.20	3900
106	5.25	4400
107	5.30	4700
108	5.35	4700
109	5.40	4600
110	5.45	4300
111	5.50	3600
112	5.55	2900
113	5.60	2200
114	5.65	1700
115	5.70	1400

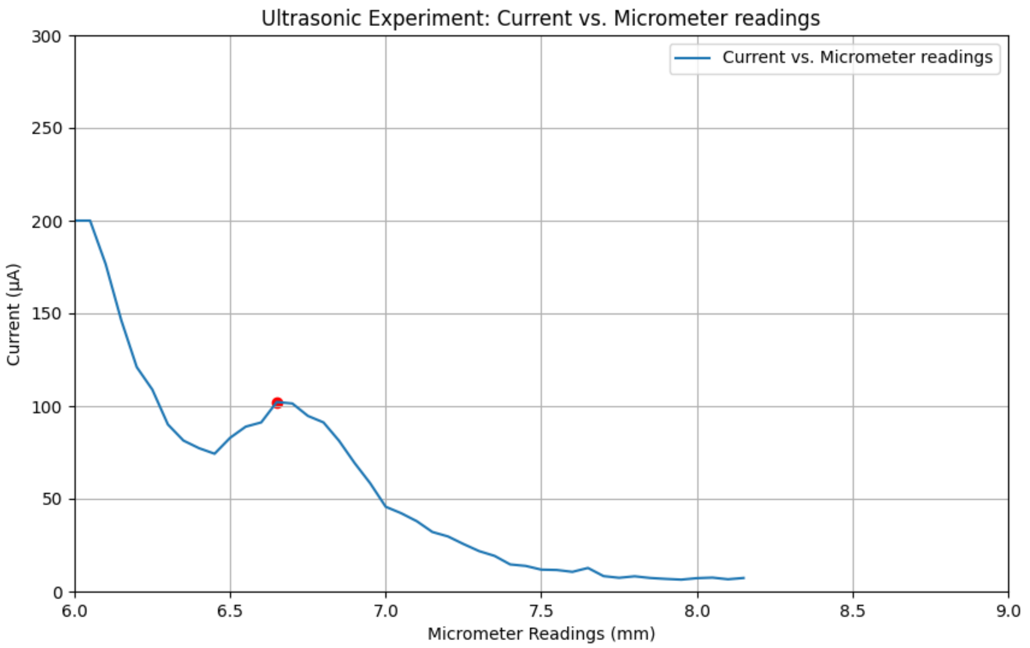
116	5.75	1100
117	5.80	800
118	5.85	600
119	5.90	400
120	5.95	300
121	6.00	200
122	6.05	200
123	6.10	176.6
124	6.15	146.4
125	6.20	121
126	6.25	108.9
127	6.30	90.1
128	6.35	81.4
129	6.40	77.3
130	6.45	74.3
131	6.50	82.9
132	6.55	88.9
133	6.60	91.2
134	6.65	102.2
135	6.70	101.4
136	6.75	94.7
137	6.80	91.2
138	6.85	81.3
139	6.90	69.3
140	6.95	58.4
141	7.00	45.7
142	7.05	42.2
143	7.10	37.9
144	7.15	32.1
145	7.20	29.7
146	7.25	25.6
147	7.30	21.8
148	7.35	19.2
149	7.40	14.6
150	7.45	13.8
151	7.50	11.8
152	7.55	11.6
153	7.60	10.6
154	7.65	12.7

155	7.70	8.3
156	7.75	7.4
157	7.80	8.2
158	7.85	7.3
159	7.90	6.8
160	7.95	6.4
161	8.00	7.2
162	8.05	7.5
163	8.10	6.6
164	8.15	7.3

Graphs:







Note: Due to small peaks for 2nd Maxima on both sides and its non-visibility in the main graphs, separate graphs are plotted. The Peaks are marked in Red.

Tables:

Location and magnitude of peaks:

Order of Fringe (n)	Micrometre Reading (in mm)	Current (in μA)
2^{nd} order Bright	1.40	117.8
1^{st} order Bright	2.65	4800
0^{th} or central Bright	4.00	2880
1^{st} central Bright	5.35	4700
2^{nd} order Bright	6.65	102.2

Distance of left and right fringes:

Order(n)	Distance of left and right fringes from the central spot (D_1 and D_2 respectively) (in mm)	Average value ($\frac{D_1+D_2}{2}$) (in mm)
2	|1.4-4|=2.6; |4-6.65|=2.65	2.62
1	|4-2.65|=1.35; |4-5.35|=1.35	1.35
0	|20-20|=0	0

Calculation of V:

Order(n)	Distance from the central spot (D) (in mm)	Angle of diffraction $\theta = \tan^{-1}(\frac{D}{L})$ (in radians)	$\Lambda = \frac{n\lambda}{\sin\theta}$ (in m)	$V = \Lambda \times \nu$ (in m/s)
2	2.62	2.70×10^{-3}	4.81×10^{-4}	1444
1	1.35	1.39×10^{-3}	4.67×10^{-4}	1401
0	-	-	-	-

∴ Average Velocity of sound ($\overline{V}$) = $\frac{1444+1401}{2}$ = 1422.5 m/s

∴ Bulk Modulus of the liquid (distilled water) (β) = $\rho\overline{V}^{\,2} = 1000 \times (1422.5)^2 = 2.02 \times 10^9$ Pa

∴ Adiabatic Compressibility of the liquid = K = $\frac{1}{\rho\overline{V}^{\,2}}$ = 4.95×10^{-8} Pa^{-1}

Results:

- The velocity of ultrasonic sound wave= 1422.5 m/s
- Bulk Modulus of the given liquid = 2.02×10^9 Pa
- Adiabatic Compressibility of the given liquid = 4.95×10^{-8} Pa^{-1}

Error Analysis:

$$\Delta\bar{V} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(V_i - \bar{V})^2}$$

Velocity (in m/s)	Mean Value ($\bar{V}$) (in m/s)	(V_i-$\bar{V}$)^2 (in (m/s)^2)	Standard Deviation $\Delta\bar{V}$ (in m/s)
1444	1422.5	462.25	$\sqrt{\frac{462.25 + 462.25}{2}}$ = 21.5
1401		462.25	

$$\therefore \Delta\bar{V} = 21.5$$

The percentage error of ($\bar{V}$) can be calculated as:

$$\%\, error = \frac{\Delta\bar{V}}{\bar{V}} \times 100$$

$$\%\, error = \frac{21.5}{1422.5} \times 100$$

$$\boldsymbol{\%\, error = 1.49\, \%}$$

Therefore, the speed of sound is:

$$V = \bar{V} \pm \Delta\bar{V}$$

$$\boldsymbol{V = 1422 \pm 22\ m/s}$$

The error analysis for bulk modulus and Compressibility

We know that the Bulk Modulus (β) is given by,

$$\beta = \rho V^2$$

Taking ln on both sides of the equation we get,

$$\ln \beta = \ln(\rho) + 2 \times \ln(V)$$

Taking derivatives on both sides:

$$\frac{d\beta}{\beta} = \frac{d\rho}{\rho} + 2\frac{dV}{V}$$

Since ρ is constant, $\frac{d\rho}{\rho} = 0$

$$\frac{d\beta}{\beta} = 2\frac{dV}{V} = .0298$$

% error in bulk modulus = 2.98 %

$\Delta\beta = 0.6 \times 10^8$ Pa

% error in compressibility is the same as Bulk modulus = 2.98 %

$\Delta K = 0.03 \times 10^{-8}$ Pa^{-1}

Final Precise Readings:

∴ Speed of sound calculated is $\boldsymbol{V = 1422 \pm 22\ m/s}$

Percentage error in V is 1.49 %

∴ Bulk Modulus calculated is $\boldsymbol{\beta} = (\mathbf{20} \pm 1) \times\ \mathbf{10}^{8}\ \mathbf{Pa}$

Percentage error in β is 2.98 %

∴ Adiabatic Compressibility calculated is **K = (4.95 $\pm$ 0.03) × $\mathbf{10^{-8}\ Pa^{-1}}$**

Percentage error in K is 2.98 %

Sources of Error:

- There might have been slight error in measurement of distance between crystal oscillators and detector, due to parallax error.
- The distilled water may have had some impurities, leading to slight variation in the speed of ultrasonic waves.
- The light from the optical lamp present near the apparatus may have interfered with the laser and affected the detector output due to fluctuations in brightness of the dark room.
- The laser may not have been perfectly parallel to the quartz crystal leading to lesser order fringes spotted on the detector. Or it could have been de-aligned during the experiment.

Conclusion:

The experiment helps us study ultrasound and the nature of diffraction waves. By performing the experiment carefully and doing the required calculations, we estimated the value of speed of sound (V) in water to be $(\mathbf{1422} \pm \mathbf{22})\ \boldsymbol{m/s}$, which accounts for an error of 1.49 % of the calculated value of speed of sound. Using this value we calculated the Bulk Modulus (β) of water to be $(\mathbf{20} \pm \mathbf{1}) \times\ \mathbf{10^{8}\ Pa}$ which accounts for an error of 2.98 % and Compressibility (K) which is the inverse of Bulk Modulus comes out to be **(4.95 $\pm$ 0.03) × $\mathbf{10^{-8}\ Pa^{-1}}$** which accounts for an error of 2.98 %.

Thus, in short, this experiment helps us in knowing the properties of the wave and the medium. The future use case of this experiment may be Nanotechnology, Microscopy, Aerospace industry, medical imaging, and industrial usage too.

Author Contributions:

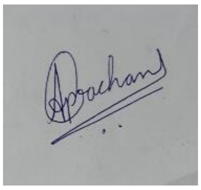
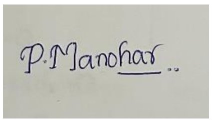
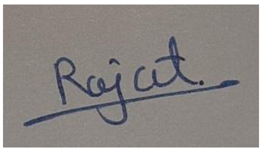
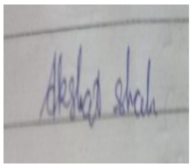
Name	Roll Number	Contribution	Signature
Prachand Aditya Prashant	23110250	• Results • Calculations • Observation Table	
Pulakurthi Manohar	23110259	• Apparatus • Safety Precautions	
Rajat Kabra	23110268	• Introduction • Mechanism • Procedure	
Rishank Soni	23110277	• Author Contributions • Results • Calculations	
Shah Akshat Saurin	23110293	• Conclusion	

Image Sources

References:

- https://www.holmarc.com/images/ultra_acousto_screen3.jpg
- https://www.holmarc.com/images/ultra_acousto_screen2.jpg
- https://www.holmarc.com/images/ultra_acousto_screen1.jpg