15TH ASIAN PHYSICS OLYMPIAD
11 - 18 MAY 2014, SINGAPORE

Experimental Competition
May 15, 2014
0830 - 1330 hrs

Experiment Problem

STUDENT CODE

There are 14 pages including the cover page.

May 15, 2014 (Thursday)

Please first read the following instructions carefully:

1. The time available is 5 hours for the experimental problem.
2. Use only the pen and equipment provided.
3. There is a set of Answer Sheets in which you have to enter your data and results.
4. Write down your **Student Code** in the boxes at the top of each Answer Sheets and additional sheets which you submit.
5. Additional Writing Sheets are provided.
6. If you use any additional Writing Sheets, please write down your **Student Code**, the **Question Number** and the **Page Number** on these additional Writing Sheets.
7. If you use additional Writing Sheets that you do not wish to be marked, put a large '**X**' across the entire sheet.
8. You should use mainly equations, numbers, symbols, graphs, figures and as little text as possible in your answers. Use the symbols defined in the question.
9. At the end of the experiment arrange all sheets in the following order:
    a. Main Answer Sheets
    b. Used Writing Sheets
    c. Writing sheets which are marked with '**X**'
    d. Unused Writing Sheets
    e. The question paper
10. Put all the papers inside the envelope and leave the envelope on your desk.
11. **You are not allowed to take any sheet of paper or any material used in the experiment out of the room.**

Speed of Ultrasonic Sound in Solution

1. Introduction:

Ultrasonic sound waves have many applications in industry, for non-destructive testing, sonar, medical imaging, etc. The acousto-optic effect is extensively used in the study of ultrasonic waves. Acousto-optic devices are now utilized in modulation, signal processing and frequency shifting of light beams. With the availability of lasers, the acousto-optic effect can be readily observed. In addition, development of high frequency piezoelectric transducers can be utilized to generate acousto-optic effects.

In this APhO2014 experiment, we shall embark on a journey to probe the properties of sound travel in selected solutions:

(i) using the acousto-optic effect in the Raman-Nath diffraction regime, and
(ii) by direct visualization of the standing waves.

In addition, we shall also learn that very interesting experiments can be performed by making use of simple and economical items that are easily available.

2. Safety Precautions and General Advice:

(1) Do not stare into the laser beam directly.
(2) The Piezoelectric Transducer should be switched ON **only after being securely placed inside the water in the glass cell**.
(3) Do not dip your hand into the water filled glass cell if the Piezoelectric Transducer is switched ON.
(4) Be careful not to spill the water, especially onto the electrical power socket.
(5) Handle the glass container and the lab-jacks safely.
(6) Do not drink/consume any of the materials provided for the experiment.
(7) Wear the laser safety goggles whenever the laser is ON.
(8) Switch off the laser pointer when it is not in use to avoid unnecessary draining of battery.
(9) Switch off the piezoelectric transducer if it is not in use to avoid the heating of water. The speed of sound in water changes with temperature.
(10) You are provided with a plastic folder to keep your question paper and answer sheets to protect the papers from water.
(11) As there is limited space on the working table, store unused equipment in the box and keep that on the floor.
(12) You are provided with three Glass Cells and you can use a new one when moving from experiment to the next.

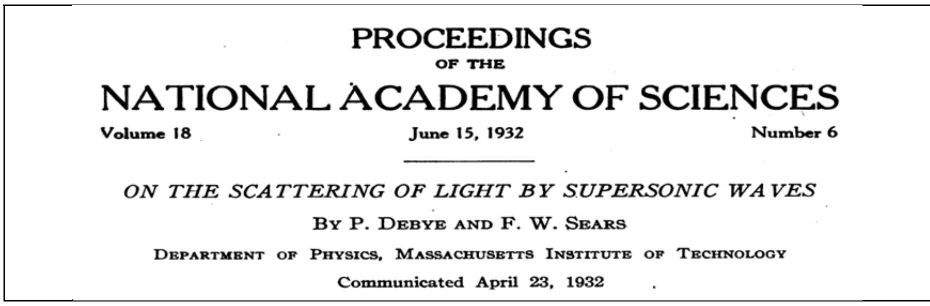
3: Apparatus

(A) Glass Cell for liquids × 3 – for experiments
(B) Aluminium platform for (A) – optional
(C) Piezoelectric Transducer
(D1) Holder for (C) (D2) Adjustable Plate – to be mounted on D1
(E) Laser Pointer with plastic jacket to keep laser ON
(F) Screen Board for mounting Answer Sheets (or Additional Writing Sheets) to mark fringes/patterns
(G) Lab Jacks × 4 – for mounting laser pointer and optical components
(H) Mirror × 2
(I) Lens × 2 (Focal lengths 5.0 cm and 15.0 cm)
(J) Mineral Water 1.5L × 2 & 0.5L × 2
(K) Salt (500 g)
(L) Bottle of solution with unknown concentration of salt in mineral water for Experiment C
(M) Light Corn Syrup 0.51L × 3
(N) Digital Scale
(O) Measuring Container for water
(P) Measuring Tape
(Q) Ruler
(R) Vernier Caliper
(S) Safety Eyewear – laser goggles
(T) 4L Plastic container – for water disposal
(U) Tissue Roll × 2
(V) Spoon
(W) Scissors
(X) Scotch tape and Stick-Tack
(Y) Thermometer inside a plastic case

Figure 1: Images of the apparatus and components required for this experiment problem.

Experiment A

Measurement of the Frequency of Ultrasonic Waves using the Diffraction Method


PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES

Volume 18 June 15, 1932 Number 6

ON THE SCATTERING OF LIGHT BY SUPERSONIC WAVES

By P. Debye and F. W. Sears

Department of Physics, Massachusetts Institute of Technology

Communicated April 23, 1932

When sound waves are travelling in a medium, it gives rise to pressure fluctuations resulting in the variation in the refractive index of the medium. Under the appropriate conditions, sound waves produce a moving periodic refractive index grating in the materials and this grating can be detected optically. This is known as acousto-optic effect. Debye and Sears, in 1932, were one of the first to demonstrate the diffraction of light by this moving periodic refractive index grating. Detailed theoretical treatment was formulated by Raman and Nath in 1935.

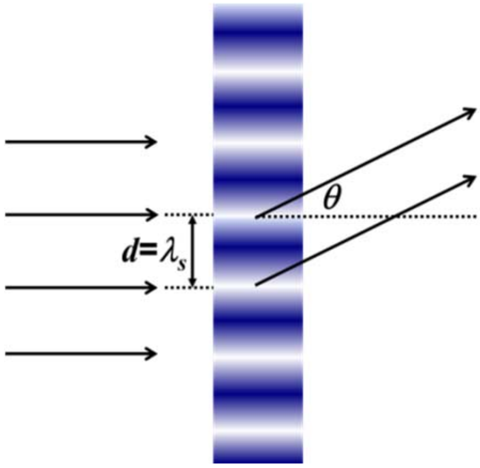


Figure 2: Moving periodic refractive index grating in liquid by ultrasonic waves

As shown in Figure 2, a light beam is diffracted by the moving periodic refractive index grating. The diffracted light follows the grating equation

$$d\sin(\theta) = i\lambda_{medium} \qquad (1)$$

where d is the grating element, θ is the diffraction angle, i is the order of diffraction, and λ_{medium} is the wavelength of the light in the medium.

According to Raman and Nath, the grating element *d* is equal to the <u>wavelength</u>, λ_s, of the ultrasonic wave in the medium as shown in Figure 2.

In this experiment, the diffraction method will be employed to measure the frequency of the ultrasonic waves generated by a Piezoelectric Transducer (C) using the known value of speed of the sound in mineral water. Figure 3 shows the speed of sound in mineral water as a function of temperature.

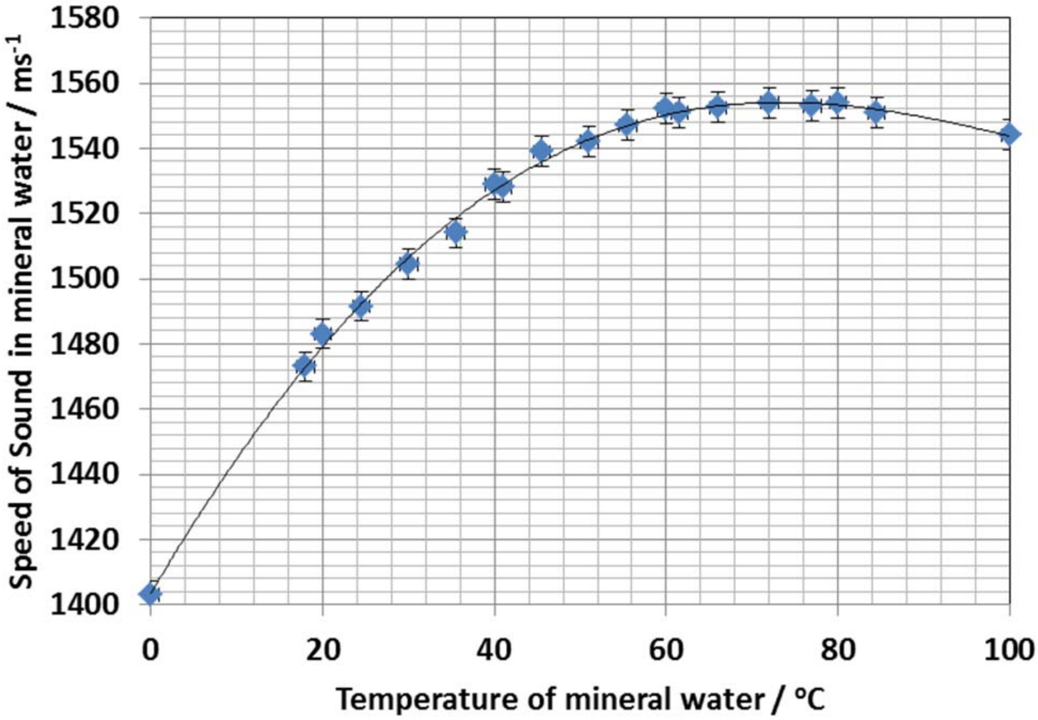


Figure 3: Speed of sound in mineral water as a function of temperature.

The Piezoelectric Transducer (C) is positioned in the circular slot of the Holder (D1) placed in the Glass Cell (A) filled with 1.5L of mineral water. Upon switching on the transducer, a vertical moving periodic refractive index grating is established in water as shown in Figure 4(a). For experiment A, please ensure that the Plate (D2) is positioned above the water level as it is only used to avoid splashing. A laser beam incident perpendicular to the grating results in the formation of the diffraction fringes. At sufficiently large distance from the grating, clearly distinguishable fringes can be formed on the screen (F) for measurement and analysis, as described in Figure 4(b).

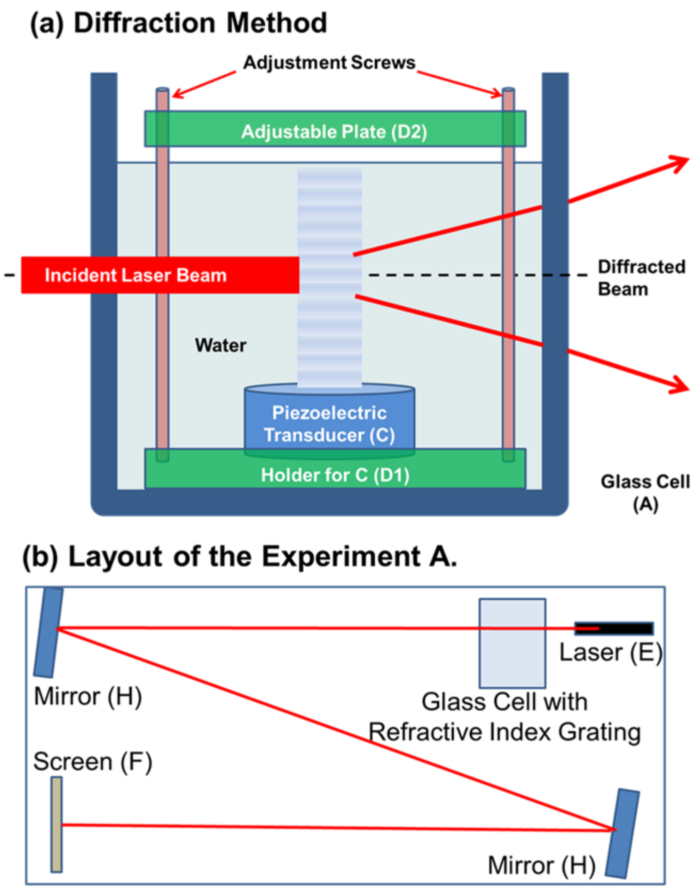


Figure 4: (a) Schematic of the setup for setting up moving periodic refractive index grating (not drawn to scale). (b) Suggested layout for the experimental setup.

The calculation of the frequency of ultrasonic waves generated by the Piezoelectric Transducer in mineral water requires the determination of the wavelength of sound in water, λ_s, first. Using equation (1) and Figure 5, which shows all relevant parameters, answer Question A1.

A1.	An expression for λ_s is given in equation (2) under the small- angle approximation. $$\boxed{\lambda_s = A(m-1)\frac{n_{air}\lambda_{air}}{D_m} \qquad (2)}$$ **<u>Derive an expression for</u>** A in terms of b, g, L, n_w, n_g, and n_{air}. Here λ_s is the wavelength of the ultrasonic wave in water, b is the distance from the center of the grating to the inner wall of the glass cell, g is the thickness of the wall of the glass cell, m is the total number of diffraction fringes counted on screen, n_w, n_g and n_{air} are the refractive indices of water, glass and air, respectively, L is the distance from the wall of the glass container to screen, λ_{air} is the wavelength of laser light in air, and D_m is the spread of m diffraction fringes on the screen.	1.5

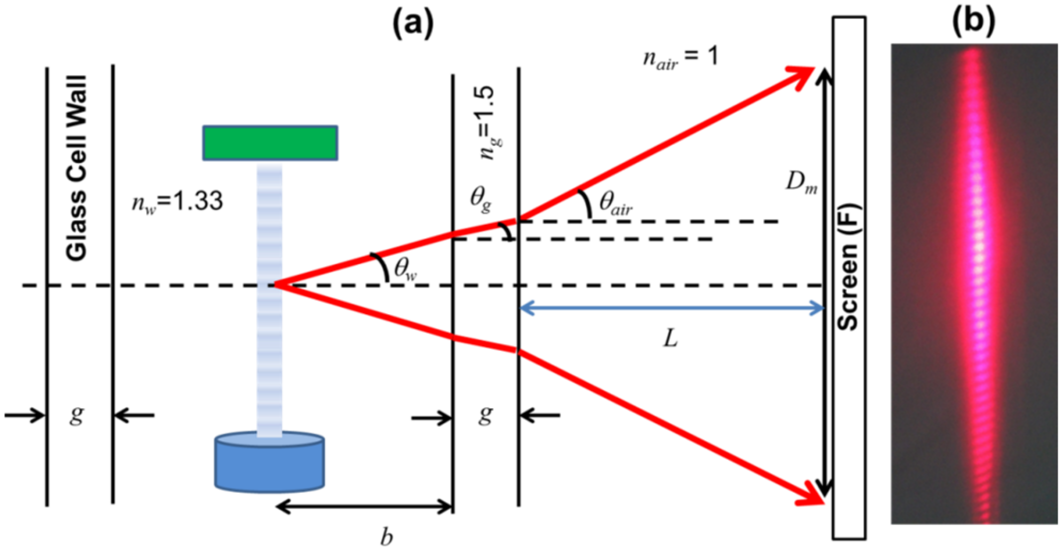


Figure 5: (a) Schematic diagram of the path of the diffracted light beam with the relevant parameters labeled. (b) An example of the fringe pattern seen on the screen.

Now set up the experiment taking hints from the schematics shown in Figure 4 and 5. Do put in effort to generate as many fringes as you can. For this part you are required to mount Answer Sheet A2 on the Screen (F) to record the diffraction fringes. As the laser beam profile may not be perfectly symmetric, you should rotate the laser to get the best possible fringes. Keep your work neat and clean. Since the speed of sound in water depends on the temperature of the water, the temperature should be monitored during the experiment. You are provided with a plastic folder to keep your question paper and answer sheets to protect the papers from water spillage.

A2.	Mark all fringe patterns you measure on the Answer Sheet A2. Write clearly the number of fringes counted, m, and the spread D_m of the fringes. Note down the temperature of the mineral water. Do not forget to note down the relevant experimental parameters, in Answer Sheet A3 as well, needed for calculations.	2.5

Note: Whenever you have completed the marking of the fringes, please switch off the Piezoelectric Transducer (C) and the Laser Pointer (E) while you are working on data analysis and calculations.

For the following questions you may use:
n_w = refractive index of water = 1.333±0.007
n_{air} = refractive index of air = 1.000±0.0003
n_g = refractive index of glass = 1.50±0.05
λ_{air} = the wavelength of laser light in air = 660 ± 3 nm
Figure 3 to determine the speed of sound in mineral water.

Note: For your error analysis, to simplify your calculation, you may neglect the uncertainties in n_w, n_g, n_{air} *and* λ_{air}.

A3.	Measure and record all relevant parameters in Answer Sheet A3 and calculate the wavelength of sound, λ_s, in mineral water.	1.0
A4.	Calculate and record the frequency of ultrasonic waves, f_s, in mineral water.	0.5
A5.	Carry out an error analysis to estimate the uncertainty in f_s.	1.0

Experiment B

Measurement of the Frequency of the Ultrasonic Waves using the Projection Method

In Experiment B a different method, called Projection Method, will be used to measure the frequency of ultrasonic waves in mineral water by directly visualization. To do this a standing wave pattern is setup in mineral water by using the Adjustable Plate (D2) as ultrasonic wave reflector. The superposition of the travelling waves, from the piezoelectric transducer and the adjustable reflector plate, moving in opposite directions generates a standing wave pattern. Figure 6 shows the schematic of projection method setup. As shown in schematic, a Lens (I) is inserted between the Laser (E) and the wall of the Glass Cell (A). The standing wave pattern in the glass cell is then projected onto the screen with a magnification, $M = D_B/p$.

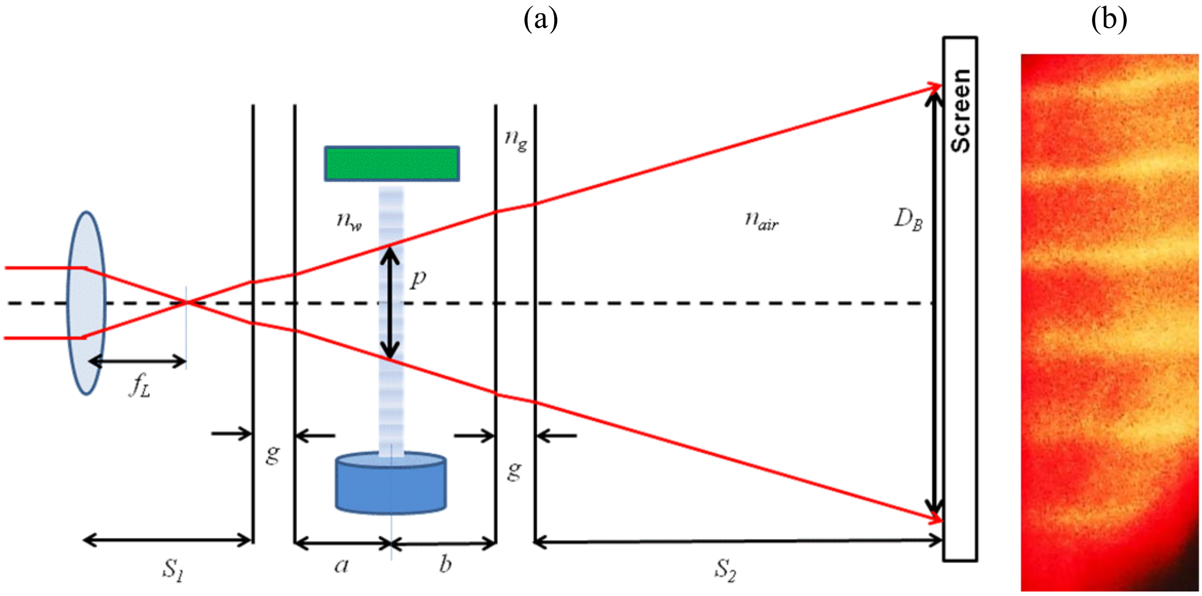


Figure 6: (a) Schematic of the projection method with relevant parameters labelled. (b) An example of the standing wave pattern projected onto the screen.

The magnification, M, of the region p on screen (F) in terms of the parameters shown in Figure 6 is given by equation (3)

$$M = \frac{\left[\frac{(S_1 - f_L)}{n_{air}} + \frac{2g}{n_g} + \frac{(a+b)}{n_w} + \frac{S_2}{n_{air}}\right]}{\left[\frac{(S_1 - f_L)}{n_{air}} + \frac{g}{n_g} + \frac{a}{n_w}\right]} \qquad (3)$$

Here

S_1 is the distance from the center of the lens to the outer wall of the glass cell,
S_2 is the distance from the outer wall of the glass cell to the screen (F),
f_L is the focal length of the lens,
a is the distance from the center of the grating to the left inner wall of the glass cell,
b is the distance from the center of the grating to the right inner wall of the glass cell,

g is the thickness of the wall of the glass cell,
n_w is the refractive index of water,
n_g is the refractive index of glass, and
n_{air} is the refractive index of air.

The bright and dark regions in the projected pattern are related to the nodes and antinodes of the standing wave pattern.

B1.	Assume that the number of bright regions counted within the length D_B on screen is m_B. Use equation (3), to write the expression for λ_s in terms of measurable and given parameters.	1.0

Now set up the experiment taking hints from the schematic shown in Figure 6. For this part you are required to mount Answer Sheet B2 on the Screen (F) to record the projected standing wave pattern.

Some recommendations for the experimental procedure are:
- To obtain a standing ultrasonic wave for the projection method, submerge the adjustable plate (D2) into the water.
- Carefully adjust the leveling screws, to obtain a stable and well defined pattern as shown in Figure 6(b).
- Two lenses of focal lengths 5.0 cm and 15.0 cm are provided. Use **only one** of these lenses for Experiment B.

B2.	Mark the projected standing wave patterns on the Answer Sheet B2. Write clearly the number of bright regions counted, m_B, and the corresponding spread D_B. Note down the temperature of the mineral water. Do not forget to note down the relevant experimental parameters, in Answer Sheet B3 as well, needed for calculations.	2.0

B3.	Measure and record all relevant parameters in the Answer Sheet B3 and calculate the wavelength of sound, λ_s, in mineral water.	1.5

B4.	Calculate and record the frequency of ultrasonic waves, f_s, in mineral water.	0.5

For your error analysis in the next part, to simplify your calculation, you may neglect the uncertainties in n_w, n_g, n_{air} and f_L.

B5.	Carry out an error analysis to estimate the uncertainty in f_s.	1.0

Experiment C

To determine the Salt Concentration of a Solution

In this experiment, you are provided with a bottle (L) labeled as "Unknown Concentration" that contains salt solution with an unknown amount of salt dissolved in mineral water. The aim of Experiment C is to determine the concentration of the salt solution.

The approach in this method is to dissolve increasing and known amounts of salt into 1.5 liters of mineral water in the Glass Cell (A) and subsequently measure the speed of sound in water with the known salt concentration using the frequency of ultrasonic waves determined in Experiment A or B. After dissolving a known amount of salt into the water, measure the speed of sound in the salt solution using **ONLY** one of the two methods described in Experiment A and Experiment B.

You will need to plot a graph of the speed of sound versus the concentration of the salt solution C_s (where C_s is the mass of salt dissolved in water divided by combined mass of water and salt). This shall be your calibration curve.

Then proceed to measure the speed of sound in solution with an unknown amount of salt dissolved in mineral water (L) labeled as "Unknown Concentration" and use your calibration curve to determine the salt concentration in the unknown solution.

Assume that the refractive index of salt solution changes negligibly as salt is added and its value can still be taken as 1.333±0.007.

For Experiment C, make ONLY one measurement corresponding to each of the different salt concentrations.

Remember to switch OFF the Piezoelectric Transducer and the Laser Pointer when they are not in use.

You are required to mount Answer Sheet C1 on the Screen (F) to record the observed pattern.

C1.	Mark the observed patterns on Answer Sheet C1 for each known salt concentration used. Label each recorded pattern with the corresponding salt concentration. Do not forget to note down the relevant experimental parameters, in Answer Sheet C2, needed for calculations. If additional sheets are needed for marking then please use Writing Sheets.	1.0

C2.	Measure and record all relevant parameters in answer sheet and calculate the speed of sound, v_s, in each of the known salt concentrations.	2.0

C3.	Plot the speed of sound, v_s, in solution against the salt concentration, C_s, of the solution. Include error bars, assuming that the percentage error is the same as that obtained in Experiment A or Experiment B, for each data point.	1.0

Now perform the experiment to determine the unknown salt concentration, C_s, of the solution labeled as “Unknown Concentration” (L).

C4.	Mark the observed pattern on Answer Sheet C4 for unknown salt concentration solution. Note down the temperature of the solution. Note down the relevant experimental parameters, in Answer Sheet C4, and calculate the speed of sound, v_s, in this solution.	0.8

C5.	Determine the salt concentration in the unknown solution. Write down your answer along with the uncertainty in the Answer Sheet C5.	0.2

Experiment D

Measurement of Speed of Sound in Corn-Syrup Solution

In this experiment, you are provided with corn-syrup solution (M) which you should pour in one of the new Glass Cells (A).

The speed of sound in corn-syrup solution will be measured **using Diffraction Method illustrated in Experiment A**. However, to calculate the speed of sound the refractive index of corn-syrup needs to be determined first.

Using the resources provided, design and carry out an experiment to determine the refractive index of the corn-syrup.

D1.	Draw a labeled sketch of the experiment you have designed. Carry out this experiment, record relevant parameters need and calculate the refractive index of the corn-syrup.	1.5

Now set up the experiment for the diffraction method of Experiment A to determine the speed of sound in corn-syrup.

D2.	Mark the fringes on the Answer Sheet D2. Measure and note down all relevant parameters needed to calculate the speed, v_s, of sound in corn-syrup solution.	1.0

No error analysis is needed for Experiment D.

----End of Paper----