CONTENTS

HEAT

EXPERIMENT No. 1

Object : To determine the coefficient of apparent expansion of a liquid (water) with a weight thermometer.

Apparatus required : Weight thermometer, balance with weight box, thermometer, beaker containing water, arrangement of heating.

Formula used :

The coefficient of apparent expansion of a liquid γ_a is given by the formula

$$\boxed{\gamma_a = \frac{m}{M.t}}$$

$$= \frac{\text{mass of the liquid expelled}}{\text{mass of the remaining liquid} \times \text{rise in temperature}}$$

Description of the apparatus :

Neglecting the increase in size of vessel, the increase which we get in the volume of a liquid is the apparent expansion. The coefficient of apparent expansion is obtained by dividing the change in volume by the original volume and rise in temperature. To determine it experimentally, a weight thermometer is used as shown in fig. (1). It is simply a cylindrical glass bulb having a neck drawn into a fine capillary tube. The neck may either have a single bend of 60° or have two bends, each of 90°. This is called a weight thermometer because it can be used for the evaluation of temperatures by measuring the changes in the weight of liquid filling the whole of the thermometer.

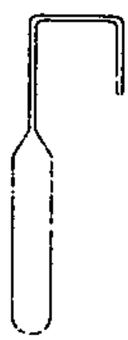

Fig. (1)

Procedure:

(i) Take a clean and dry weight thermometer and weigh it in a chemical balance.

(ii) Fill the thermometer with water by the process of alternate heating and cooling. For this purpose, take water in a beaker and dip the capillary part of thermometer inside it. Heat the bulb of the thermometer so that few air bubbles escape through water. Now cool it with the capillary part kept inside water. Some liquid will enter inside the bulb. By continuing this process again and again the thermometer will be completely filled with water. Here care should be taken that no air bubble remains inside thermometer. Allow to cool it to the room temperature with its capillary part inside water.

(iii) When it has acquired the room temperature, take it out of water and wipe with a filter paper any liquid adhering to it. Weight the thermometer and determine the mass of the liquid contained in it at room temperature.

(iv) Next immerse the thermometer into a bath of boiling water. With its neck-projecting outside, keep the bulb immersed for sufficiently long time till no more drops of water expelled outside. Take out the thermometer and dry its outer surface. Cool it to room temperature and again weigh it. Find out the mass of the remaining water in the bulb and thus mass of the liquid expelled.

(v) Note the room temperature t_1 as well as the temperature t_2 of bath. From these readings, calculate the value of the coefficient of apparent expansion of water.

Observations :

S.No.	Determination	Quantity
1	Mass of the empty wt. thermometer	... gm.
2	Mass of the empty wt. therm. +water at t_1 °C	... gm.
3	Mass of the empty wt. therm. +water at t_2 °C	... gm.
4	Room temperature t_1.	... °C
5	Temperature of boiling water t_2	... °C
6	Rise in temperature t, $(t_2 - t_1)$	... °C
7	Mass of expelled water, m .	... gm.
8	Mass of the remaining water, M	... gm.

Calculations :

$$\gamma_a^* = \frac{\text{mass of the water expelled, } m}{\text{mass of remaining water } M \times \text{rise in temperture, t}}$$

$= \ldots$ per °C.

Result. The coefficient of apparent expansion of water between the range of temperature from ... °C to ... °C = ... per °C

Standard value. = ... per °C

Percentage error = ... %.

Precautions and Sources of Error :

(i) The process of filling the weight thermometer should be slow and the last stages of filling it requires skill and practice too.

(ii) No air bubble should remain inside the weight thermometer, when it has been filled completely.

(iii) The weight thermometer should not be weighed while it is hot.

(iv) The weight thermometer should be held by its neck with a cotton loop or pad.

(v) The weighing of m and M should be accurately done with a chemical balance as the accuracy of the result depends upon these factors.

Viva-Voce

Q. 1. *What is the coefficient of apparent expansion ? Is there any coefficient of real expansion ? If so, why there are two coefficients of expansion ?*

Ans. *Coefficient of apparent expansion.* It is defined as the apparent increase in volume per unit volume of a liquid at 0°C when its temperture rises through 1°C.

Coefficient of real expansion. It is defined as the real increase in volume per unit volume of a liquid at 0°C when its temperature rises through 1°C.

Why are two coefficients of expansion in case of liquids ?

A vessel is required to hold a liquid. Therefore when liquid is heated, vessel also expands. Therefore measured increase in volume of the liquid is apparent increase in volume. The real increase in the volume of the liquid is equal to the sum of the apparent increase in the volume of the liquid and increase in the volume of containing vessel.

Q. 2. *What is the unit of coefficient of expansion ?*

Ans. per °C.

Q. 3. *Why is it called a weight thermometer ?*

Ans. It is called so because temperature through which the liquid is heated can be obtained in terms of the weights of the liquid expelled and left behind after heating.

* In order to find out the coefficient of real expansion γ_r of water following formula is used :

$$\gamma_r = \gamma_a + \gamma_g$$

where γ_g is cubical expansion of the material of weight thermometer.

Q. 4. *Is it better than a dilatometer (volume thermometer) ?*

Ans. Yes, because weight can always be measured with more accuracy than volume.

Q. 5. *What is the precaution while weighing the filled thermometer ?*

Ans. There should be no loss of liquid during weighing.

Q. 6. *What is the most important quantity to be measured in this experiment ?*

Ans. Mass of water expelled, m, which is a small quantity, is to be measured accurately.

Q. 7. *What if a bubble remains ?*

Ans. Expansion of air is large. Therefore when the liquid is heated, bubble will expand and drives away large amount of liquid. This gives rise to unnecessary expansion. Mesurements also become erratic.

Q. 8. *Will the dissolved impurities have any affect on the expansion of a liquid ?*

Ans. Coefficient of expansion increases.

Q. 9. *Do all liquids expand on heating or is there any exception ?*

Ans. Water below 4°C, when heated, contracts instead of expanding.

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EXPERIMENT No. 2

Object : To determine the coefficient of real expansion of a liquid (water) by upthrust method.

Apparatus required : A chemical balance with weight box, glass bulb, thin thread, thermometer, beaker and a small bench.

Formula used :

The coefficient of real expansion γ_r is given by

$$\boxed{\gamma_r = \frac{W_1 - W_2}{W_2\,(t_2 - t_1)} + \frac{W_1}{W_2} \cdot \gamma_g}$$

where W_1 = loss in the weight of sinker at t_1 °C

W_2 = loss in the weight of sinker at t_2 °C

γ_g = coefficient of cubical expansion of the sinker (glass)

Description of the apparatus :

The apparatus is shown in fig. (1). One end of a long thread is attached to the left pan of a chemical balance whose other end carries a glass bulb as a sinker. This form of sinker is used in order that it may quickly attain the temperature of the liquid in which it is placed. The sinker is immersed in a beaker of water which can be heated to a desired temperature. The beaker contains a sensitive thermometer to record the temperature of water and a stirrer. The thread used should be very thin to avoid the surface tension effect to the thread where it enters inside water.

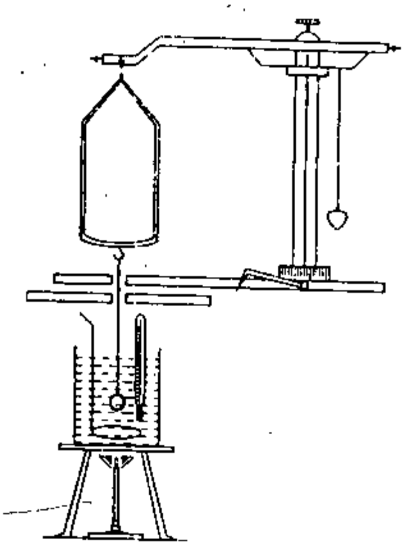

Fig. (1)

Procedure :

(i) Make a suitable arrangement as shown in fig. (1) and find the mass of the sinker in air.

(ii) Heat the water to a high temperature say 85°C. Bring the beaker of hot water under the bulb. Here it should be remembered that the bulb should be heavy enough to sink in water otherwise, before starting the experiment, fill it with lead shots.

Suspend a thermometer and stir the water to ensure the uniformity of temperature.

(iii) Adjust the weights on the right pan of the balance such that the sinker (glass bulb) is slightly heavier than the weights. Due to the decrease in density of cooling water, a stage will come when the pointer of the balance passes through the zero position. At this particular position record the temperature of water. The weights which had been placed in the balance give the weight of sinker in water at that recorded temperature.

(iv) As described above record a series of weighing of the sinker for different temperatures.

Observations :

Room temperature = ...°C

S. No.	Weight of sinker in air, M gm.	Weight of sinker in water, gm.	Corresponding temperature, °C	Loss in weight at these tempertures, gm.
1	...	...	...	...
2	...	...	...	...
3	...	...	...	...
4	...	...	...	...
5	...	...	...	...

The coefficient of cubical expression for glass = ... per °C (from table)

Conclusion :

Set I [for temperature difference = ... °C]

$$\gamma_r = \frac{W_1 - W_2}{W_2(t_2 - t_1)} + \frac{W_1}{W_2}\gamma_g$$

$$= \ldots \text{ per } ^\circ\text{C}.$$

Make similar calculations for other temperature differences.

Result. The coefficients of real expansion of water for different temperature ranges are given below :

Temperature interval	Coefficient of real expansion	Standard result from table	% error
...	...	...	...
...	...	...	...
...	...	...	...

Precautions and Sources of Error :

(i) If the weight of sinker is not enough to sink inside the water then the glass bulb should be loaded with lead shots.

(ii) The bulb of the thermometer should be placed near the sinker.

(iii) The thread carrying the sinker should be very thin.

(iv) Water should be stirred so that the temperature may be same everywhere.

(v) The hot water should not be near the boiling point otherwise the vapours will wet the upper thread.

(vi) The initial temperature of hot water is not required but the temperature should be recorded only when the balance is obtained.

Viva-Voce

Refer to questions 1, 2 of Exp. No. 1.

Q. 1. ***What is the principle involved in thrust method ?***

Ans. It is Archimedes' principle, *i.e.*, when a body is immersed in a liquid, it suffers an apparent loss of weight equal to the weight of the liquid displaced.

EXPERIMENT No. 3

Object : To determine the latent heat of steam of Joly's steam calorimeter.

Apparatus used. Joly's steam calorimeter, chemical balance, thermometer, a small copper piece, a piece of fine copper wire and boiler.

Formula used :

The latent heat L of the steam is given by

$$\boxed{L = \frac{(m_1 + m_2)\, s(\theta_2 - \theta_1)}{M}}$$

where m_1 = mass of the copper piece,

m_2 = mass of the copper pan,

s = specific heat of copper,

$(\theta_2 - \theta_1)$ = rise in temperature,

M = mass of steam condensed on pan and the copper piece.

Description of apparatus. Joly's steam calorimeter is shown in fig. (1). A copper pan is suspended inside the steam chamber by means of fine copper wire attached to one arm of a chemical balance. Steam from a boiler enters at one end in the chamber and leaves at the other end. A sensitive thermometer is inserted inside it through a hole to record the temperature of the inside. Inclined shades KK are provided at the top to prevent water drops from falling upon pan. The hole where the suspension wire leaves the steam chamber is lined with Plaster of Paris to absorb the water condensed over wire. A further precaution is taken by placing an electrically heated coil P around the wire.

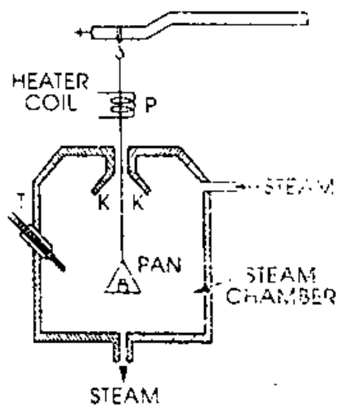

Fig. (1)

Procedure :

(i) Suspend the pan from the left arm of a chemical balance by means of copper wire such that it hangs in the middle without touching the hole in the lid. Insert the thermometer at its proper place.

(ii) Counter-poise the empty scale pan and then put the small solid copper piece and again find the mass of the two together. The difference of the two gives the mass of copper piece. Note down the temperature θ_1 of the jacket.

(iii) Allow the steam to rush in the chamber from a boiler and switch on the current to flow in the spiral such that it becomes red hot. The steam will be condensed on the pan and copper piece which disturbs the equilibrium of the balance. Restore the equilibrium by adding suitable weights in the other pan of the balance. When the weights become constant practically for enough time, note down the additional mass M. This gives the mass of the steam condensed on the pan and copper piece.

(iv) Note down the temperature θ_2 of the steam Jacket.

(v) Calculate the latent heat of steam by using the formula.

Observations :

1. Mass of the copper pan = ... gm.
2. Mass of the copper pan + solid = ... gm.
3. Initial temperature of the Jacket, θ_1 = ... °C.
4. Mass of copper pan + solid + steam condensed = ... gm
5. Final temperature of steam (Jacket), θ_2 = ... °C.
6. Specific heat s of copper (from table) = ...

Calculations. Mass of the copper piece (solid) m_1 = ... gm.

Mass of the copper pan m_2 = ... gm..

Mass of the steam condensed M = ...gm.

$$L = \frac{(m_1 + m_2)\, s\, (\theta_2 - \theta)}{M}$$
$$= \ldots \text{ cal. per gm.}$$

Result. Latent heat of the steam as determined with the help of Joly's calorimeter = ... cals. per gm.

Standard result. = ... cal. per gm.

Percentage error = ... %

Precautions and Sources of Error :

1. The copper wire carrying the pan should not touch the hole of steam Jacket.
2. The current should be switched on only when the steam is allowed to pass in the middle of the steam Jacket.
3. Suspension wire should be thin.
4. The pan should be in the middle of the steam Jacket.
5. The temperature of steam chamber should be recorded when it becomes steady.
6. M does not represent actually the correct weight of the steam condensed on the pan and solid because the first weighing is done in air while the other in the steam.

Viva-Voce

Q. 1. *Define latent heat of fusion and latent heat of vaporisation.*

Ans. *Latent heat of fusion.* It is the amount of heat required to convert unit mass of ice at 0°C into water. It is 80 cal/gm.

Latent heat of vapourisation. It is the amount of heat required to convert unit mass of water at 100°C into steam, or the same amount of heat is given out by unit mass of steam at 100°C on condensing into water at the same temperature. It is 540 cal/gm.

Q. 2. *Why latent heat of vapourisation is more than that of fusion ?*

Ans. Latent heat is utilised in breaking the bonds between the molecules of substance. In case of fusion less energy is required to decrease the binding force of solid in order to become liquid. But in case of vapourisation, molecules are set free so that more energy will be required in this case.

Q. 3. *Why the top of the chamber is of conical shape ?*

Ans. Any drop of water, formed due to condensation, on its inner surface may not drop on the pan and is drained away quickly.

Q. 4. *Is it an accurate method ?*

Ans. Weighing is an accurate process, good results can be obtained if due precautions are taken.

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EXPERIMENT No. 4

Object : To determine the mechanical equivalent of heat (J) with the help of Joule's calorimeter.

Apparatus used. Step down transformer, rheostat, Joules calorimeter, and ammeter, a voltmeter, a sensitive thermometer, physical balance, weight box, plug key and connecting wires.

Formula used :

The mechanical equivalent of heat is given by

$$\boxed{J = \frac{V\, i\, t\, 10^7}{(M + W)(\theta_2 - \theta_1)}}$$

where V = potential difference across the coil of the calorimeter,
i = strength of current passing in the coil,

t = time for which the current is passed,

M = mass of the water contained in the calorimeter

W = water equivalent of calorimeter,

= mass of calorimeter with stirrer × specific heat of the material of calorimeter (copper).

θ_1 = initial temperature of water.

θ_2 = final temperature of water.

Procedure :

(i) Weigh the empty calorimeter with stirrer in the balance and again by filling it with two thirds of water. The difference of the two readings will give the mass M of water taken.

(ii) Make the electrical connections as shown in figure (1).

(iii) Note down the initial temperature θ_1 of water in the calorimeter with the help of sensitive thermometer.

(iv) Switch on the current with key and immediately start the stop watch. Note down the potential difference across the coil with the help of voltmeter connected in parallel and the strength of the current with the help of ammeter connected in series. This potential difference should be maintained constant with the help of rheostat R_h. Keep the water stirring with stirrer.

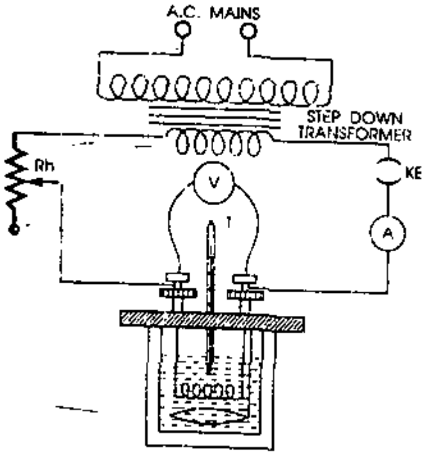

Fig. (1)

(v) When the temperature has risen about 5°, switch off the current and note down the total time for which current is passed. Note down the final temperature θ_2'.

(vi) Allow the temperature to fall for the same time of experiment and note down this temperature also. Let this temperature be θ_3. Add half of the temperature $\left(\frac{\theta_2' - \theta_3}{2}\right)$ in the final temperature θ_2' that will give the final temperature θ_2.

(vii) Calculate the value of J using the above formula.

Observations :

(A)

S. No.	Determination	Magnitude	Derived quantities
1	Mass of the calorimeter + stirrer	... gm.	mass of the water M = ... gm
2	Mass of the calorimeter + stirrer + water	... gm.	
3	Initial temperature of water θ_1	... °C	
4	Initial reading of stop watch	... sec.	
5	Reading of voltmeter	... volt.	Time taken for experiment, t = ... sec.
6	Reading of ammeter	... amp.	
7	Final reading of stop watch	... sec.	Final temperature $\theta = \theta_2' + (\theta_2' - \theta_3)/2$ = ...°C
8	Final temperature of water θ_2'	... °C	Sp. heat of the material of the calorimeter = ... (from table of constants)
9	Last temperature after cooling for the same time θ_3	... °C	

Calculations :

Water equivalent $W = \ldots$ gms.

Now $$J = \frac{V\,i\,t\,10^7}{(M+W)(\theta_2 - \theta_1)}$$

$= \ldots$ erg/cal.

Result. The value of the mechanical equivalent of heat

$= \ldots$ erg. per cal.

Standard Result $= \ldots$ erg per cal.

Percentage error $= \ldots$ %.

Sources of Error and Precautions :

(i) Potential difference across the coil should not be greater than 5 volts.

(ii) The coil should not touch the calorimeter.

(iii) Potential difference should be kept constant throughout the experiment.

(iv) Sensitive thermometer should be used to record the temperatures.

(v) The final temperature should be corrected for radiation loss.

(vi) Ammeter and voltmeter should be properly connected.

ADDITIONAL EXPERIMENT

Object : To calibrate a given energy meter with Joule's calorimeter.

Theory : The energy consumed in the calorimeter is given by

$$\boxed{E' = \frac{J\,(M+W)\,(\theta_2 - \theta_1)}{3600 \times 1000 \times 10^7} \text{ K. W. H.}} \quad \ldots \text{(i)}$$

where J = mechanical equivalent of heat.

M = mass of water.

W = water equivalent of calorimeter.

θ_1 = initial temperature of water.

θ_2 = final temperature of water.

Energy consumed in energy meter is given by

$$E = \frac{n}{N} \text{ K. W. H.} \quad \ldots \text{(ii)}$$

where n = rotations made by the disc of energy meter,

N = rotations made by energy meter corresponding to 1 K.W.H. energy.

Procedure :

(i) Weigh the empty calorimeter with stirrer in the chemical balance and again by filling it with two thirds of water. The difference of two readings will give the mass M of the water used.

(ii) Set up the electrical connections as shown in fig. (2).

(iii) Note down the initial temperature of water θ_1.

(iv) Switch on the current to flow in the circuit and simultaneously start the stop watch. Count the number of rotations of the disc of energy meter. Pass the current for 15 minutes and then switch off the current. Note down the final temperature θ_2' of water.

(v) Find the true temperature by applying the radiation correction.

(vi) Note down the number of rotations N of the disc of the energy meter for consumption of 1 K.W.H.

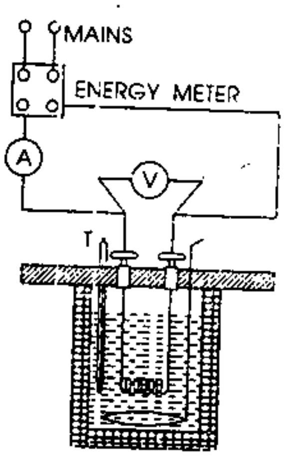

Fig. (2)

Observations :

(A) (i) Number of rotations corresponding to 1 K.W.H. energy $N = \ldots$

(ii) Number of rotations of disc in the experiment $n = \ldots$

(B)

S. No.	Determination	Magnitude	Derived quantities
1	Mass of the calorimeter + stirrer	... gm.	mass of the water M = ... gm
2	Mass of the calorimeter + stirrer + water	... gm.	
3	Initial temperature of water θ_1	... °C	
4	Initial reading of stop watch	... sec.	
5	Reading of voltmeter	... volt.	Time taken for experiment, t = ... sec.
6	Reading of ammeter	... amp.	
7	Final reading of stop watch	... sec.	Final temperature $\theta = \theta_2' + (\theta_2' - \theta_3)/2$ = ...°C
8	Final temperature of water θ_2'	... °C	Sp. heat of the material of the calorimeter = ... (from table of constants)
9	Last temperature after cooling for the same time θ_3	... °C	

Calculations :

$$E' = \frac{J(M+W)(\theta_2 - \theta_1)}{3600 \times 1000 \times 10^7} \text{ K.W.H.}$$

$$= \ldots\ldots\ldots\ldots$$

$$E = \frac{n}{N}$$

$$= \ldots\ldots\ldots\ldots$$

Result. Percentage error in the reading of energymeter

$$e = \frac{E - E'}{E} \times 100$$

$$= \ldots \%$$

Viva-Voce

Q. 1. *If q charge is carried against a potential difference of V volts then how much work is done ?*

Ans. qV joules if q is in coulombs and V in volts.

Q. 2. *But you are using V i t.*

Ans. Since $q = it$.

Q. 3. *How ammeter and voltmeter are connected in an electrical circuit?*

Ans. Voltmeter is connected in parallel while ammeter is connected in series.

Q. 4. *Do you apply correction for radiation loss ?*

Ans. Yes. We allow the temperature to fall for the same time of experiment and add half of the fall of temperature in the final temperature.

Q. 5. *Why is the work done when electric current passes through a conductor ?*

Ans. The electrons, constituting current on flow, experience resistance to their flow in the interatomic space of the conductor. To overcome this resistance work is done which appears in the form of heat in the conductor.

Q. 6. *Upon what factors does the amount of this work depend and why?*

Ans. It depends upon (i) the number of electrons flowing, i.e., the strength of the current, (ii) the resistance overcome and (iii) the time for which the current is passed.

Q. 7. *Which effect of current does not depend on the direction of current?*

Ans. Heating effect of the current.

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EXPERIMENT No. 5

Object : To determine the coefficient of thermal conductivity of a metal, by using Searle's apparatus.

Apparatus used. Searle's conductivity apparatus, four sensitive thermometers, constant pressure water flow arrangement, measuring flask, stop watch and arrangement for generating steam.

Formula used :

The coefficient of thermal conductivity K for a material is given by the formula

$$\boxed{K = \frac{md\,(\theta_3 - \theta_4)}{A\,(\theta_1 - \theta_2)}}$$

where A = Area of cross section of the rod,

$= \pi r^2$ where r is the radius of the rod, if of cylindrical shape.

θ_1, θ_2 = steady temperatures at the two fixed points of the rod in steady state.

d = distance between the two points or the distance between two thermometers.

m = mass of water collected per second.

θ_3, θ_4 = steady temperatures of water at exit and at entrance respectively.

Description of the apparatus :

The Searle's apparatus is shown in figure (1). The metal under consideration is taken in the form of cylindrical tube AB. The end A is placed in a chamber through which steam is passed from a boiler while the other end is cooled by circulating cold water from constant pressure waterflow arrangement. The flow of water is adjusted so that water comes drop by drop from the exit side. The temperature of incoming and outflowing water is noted with the help of two sensitive thermometers introduced at the points M and N. The temperature at two other points S and L along the length of the rod is also determined by placing two thermometers in the two holes. To make good thermal contact with rods, few drops of mercury are poured in each hole. The apparatus is covered with felt so as to minimise loss of heat from its sides and is contained in a wooden box.

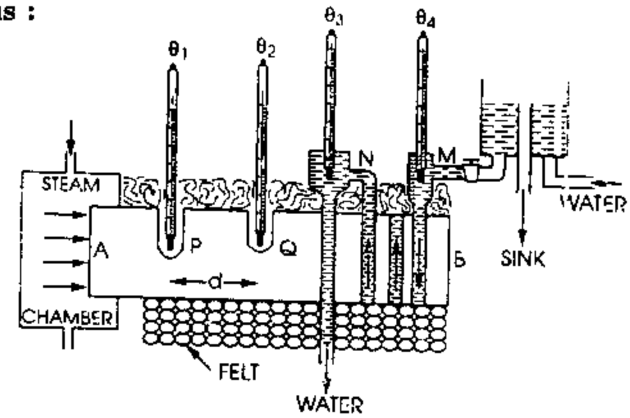

Fig. (1)

Procedure :

(i) Pass a steady current of steam from the boiler into the steam chamber to heat the end A. Allow the water to flow in the tubes on the end B from a constant pressure water flow arrangement and adjust it such that water comes drop by drop from the outlet.

(ii) Insert the various thermometers in their respective places.

(iii) Attain a steady state, i.e. the reading of temperature of any thermometer should be constant and there should not be any further increase in temperature.

(iv) After the steady state is attained, collect water in a clean graduated cylinder and note the time with the help of an accurate stop watch and calculate the mass of water flowing per second.

(v) Repeat the above procedure for a number of times.
(vi) Measure the distance d between the two fixed points.
(vii) Determine the diameter of the rod. Calculate value of K using the above derived formula.

Observations :

(1) The distance d between the points along the bar where θ_1 and θ_2 are measured = ... cms.

(2) Determination of the diameter of the bar.

Least count of the vernier callipers = ... cms.
Zero error of the vernier callipers = ± ... cms.

S. No.	Reading along any direction-O			Reading along a perpendicular direction D			Uncorrected diameter (a+b)/2 cm.	Mean Uncorrected cm.	Mean corrected diameter	Mean radius cm.
	M.S. reading	V.S. reading	Totol X cm.	M.S. reading	V.S. reading	Totol Y cm.				
1.	...	...	...	...	...	...				
2.	...	...	...	...	...	...				
3.	...	...	...	...	...	...	...	...	...	...
4.	...	...	...	...	...	...				
5.	...	...	...	...	...	...				

(3) Table for ascertaining the steady temperatures :

S. No.	Time in minutes	Thermometer reading			
		θ_1°C	θ_2°C	θ_3°C	θ_4°C
1	1	x_1	...	...	...
2	2	...	x_2	...	...
3	3	...	...	x_3	...
4	4	...	...	...	x_4
5	5	...	...	...	...
6	6	...	...	...	...
7	7	x_5	...	...	...
8	...	...	x_6	...	...
	...	...	...	x_7	...
9	...	...	...	...	...
...	...	...	...	...	...
10	...	...	...	...	x_8
11	...	x_5	x_6	x_7	x_8

Note : Start noting the time when steady state is nearly reached.

(4) Mass of water collected for ... seconds = ... gm.
... seconds = ... gm.
... seconds = ... gm.

Hence mean value of mass of water collected per second m = ... gm.
Steady state temperatures from the above table :

θ_1 = ... °C.
θ_2 = ... °C.
θ_3 = ... °C.
θ_4 = ... °C.

Calculations. We know that

$$K = \frac{m(\theta_3 - \theta_4)d}{\pi r^2(\theta_1 - \theta_2)} \text{cal/cm/°C/sec.} \quad = \text{... cal/cm/°C/sec.}$$

Result. The thermal conductivity of = ... cal./cm./°C/sec.

Standard result. Standard value of thermal conductivity of ... = ... cal./cm./°C/sec.

Precautions and Sources of Error :

(i) Water should flow from a constant pressure flow arrangement.

(ii) A number of determinations of the rate of flow of water should be made and their mean value should be substituted in the formula.

(iii) The diameter should be determined accurately.

(iv) The success of the experiment depends upon the attainment of steady state and hence it should be attained very accurately.

(v) Water should be collected only when the steady state is attained.

Permissible error : $$K = \frac{m(\theta_3 - \theta_4)\, d}{\pi r^2(\theta_1 - \theta_2)}$$

Taking log and differentiating, we have

$$\frac{\delta K}{K} = \frac{\delta m}{m} + \frac{2\delta r}{r} + \frac{\delta(\theta_3 - \theta_4)}{(\theta_3 - \theta_4)} + \frac{\delta(\theta_1 - \theta_2)}{(\theta_1 - \theta_2)}$$
$$= \ldots$$

Maximum permissible error = ...%.

Viva-Voce

Q. 1. ***Define coefficient of thermal conductivity.***

Ans. It is the quantity of heat flowing per second through unit area of cross section of an element of the material, of unit thickness, when the difference of temperature between its faces is unity.

Q. 2. ***What is the unit of it ?***

Ans. Calorie/cm/°C/sec.

Q. 3. ***How the heat is transmitted in this experiment ?***

Ans. By conduction.

Q. 4. ***When do you record the temperatures ?***

Ans. When steady state is reached.

Q. 5. ***What is steady state ?***

Ans. In steady state the temperauture of each point of rod becomes constant, i.e., it does not rise further. The heat transmitted from one section to another does not raise their temperature but a part of it is radiated and rest transmitted to next section.

In steady state the temperature of a point on the rod is a function of its distance from the hot end and does not depend on time.

Q. 6. ***Why do you cover the experimental rod with felt ?***

Ans. As the felt is of low conductivity, it prevents radial flow of heat.

Q. 7. ***Why do you want to avoid radial flow of heat ?***

Ans. Formula used is based on normal flow of heat.

Q. 8. ***Is this method suitable for bad conductors ? If no, why ?***

Ans. No, because in case of bad conductors, heat conducted will be very small and temperature differences will not be worth recording.

Q. 9. ***Why is the experimental bar thick in Searle's apparatus ?***

Ans. So that the proportion of heat escaping from sides will be small compared to that conducted by its cross section.

Q. 10. ***Why is the rod of circular cross-section ?***

Ans. Circular cross-section has maximum area for a given parameter and hence such a cross-section will conduct the maximum amount of heat down the rod.

Q. 11. ***What should be the thermal conductivity of a perfect conductor of heat ?***

Ans. Infinite.

Q. 12. ***Name some good conductor of heat which is good conductor of electricity as well.***

Ans. Silver.

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EXPERIMENT No. 6

Object : To determine the thermal conductivity of a nonmetallic solid (bad conductor) by Lee's disc method.

Apparatus used. Lee's apparatus, two sensitive thermometers and stop watch.

Formula used :

The coefficient of thermal conductivity K is given by the formula,

$$\boxed{K = \frac{msd}{\pi r^2(\theta_1 - \theta_2)} \left(\frac{d\theta}{dt}\right)_{\theta = \theta_2}}.$$

where m = mass of the disc placed over the experimental disc or slab.

s = specific heat of the material of the disc,

d = thickness of experimental disc,

r = radius of the experimental disc,

θ_1, θ_2 = steady temperatures of the two surfaces of the experimental disc,

$\frac{d\theta}{dt}$ = rate of radiation of the two surfaces of the experimental disc.

Description of apparatus :

The Lee's method is shown in fig. (1). In Lee's arrangement, a hallow metallic box A known as steam chamber is suspended from a stand in such a way that the upper surface is horizontal. Steam is passed from one end which comes out from the other end. The experimental disc C is placed on the steam chamber. Another disc B of brass well polished is also placed over C such that C is pressed between the steam chamber and brass disc. The steam chamber A and disc B are provided with two thermometers T_1 and T_2 to note the temperatures θ_1 and θ_2 of steam and slab B respectively.

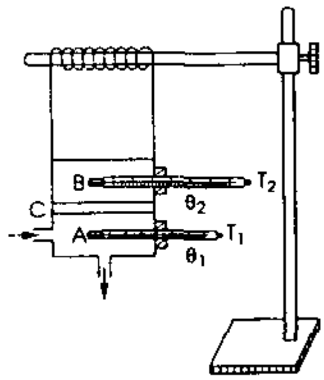

Fig. (1)

Procedures :

(i) Note down the mass of the brass disc B as quoted over it.

(ii) Note the radius r and thickness d of the experimental disc C as quoted over it. If r and d are not quoted over the disc C, measure these quantities.

(iii) Insert the two thermometers T_1 and T_2 in the steam chamber A and brass disc B respectively and set the arrangement as shown in fig. (1).

(iv) Allow the steam to pass in the steam chamber.

(v) Obtain a steady state and note down the readings of the two thermometers.

(vi) To measure $\left[\frac{d\theta}{dt}\right]$ the experimental disc C is removed and the disc B is directly placed on the steam chamber to increase its temperature by 10°C above θ_2. The disc B is then suspended separately and allowed to cool. Its temperature is noted at regular intervals of time.

(vii) A graph is plotted between temperature and time, which comes out to be a curved line and from the tangent to curve at the temperature θ_2, the rate of fall of temperature $\left[\frac{d\theta}{dt}\right]$ as θ_2 is found.

Observations :

(i) Radius r of the experimental disc = ... cm.

(ii) Thickness d of the experimental disc = ... cm.
(iii) Mass of the brass disc B = ... gm.
(iv) Specific heat s of brass = ...
(v) Table for ascertaining the steady state :

S. No.	Time in minutes	Reading of thermometer T_1 θ_1 °C	Reading of thermometer, T_2 θ_2 °C
1	0	x_1	...
2	1	...	x_2
3	2	x_3	...
4	3	...	x_4
...	4	x_5	...
...	...	...	x_6
...	...	x_5	...
...	...	...	x_6
...	...	x_5	....
...	...	...	x_6

Note : The reading should be started when the steady state is nearly attained.

Steady state temperatures from the above observations :

(a) θ_1 = ... °C

(b) θ_2 = ...°C

(vi) Table for the measurement of $\left[\frac{d\theta}{dt}\right]$ at θ_2.

S.No.	Time Taken			Temperature
	Min.	Sec.	Total sec.	
1	...	10	10	...
2	...	20	20	...
3	...	30	30	...
4	...	40	40	...
5	...	50	50	...
6	1	00	60	...
7	1	10	70	...
8	1	20	80	...
9	1	30	90	...
10	1	40	100	...

Calculations :

Draw a graph between time and temperature for the disc B as shown in fig. (2).

Find the value of $\left[\frac{d\theta}{dt}\right]$ at θ_2.

Now find out the value of K using following formula

$$K = \frac{msd}{\pi r^2(\theta_1 - \theta_2)}\left[\frac{d\theta}{dt}\right]_{\theta_2}$$

= ... cal/cm./°C/sec.

Result : The coefficient of thermal conductivity K of the given non-metallic (...) solid = ... cal/cm./°C/sec.

Standard result : Standard value of K for ... = ...cal./cm./°C/sec.

Precautions and Sources of Error :

(i) Observations for d and r of the experimental disc should be taken before starting the experiment.

(ii) The steady state should be obtained very accurately.

(iii) The experimental disc should be thin.

(vi) The value of $\left[\frac{d\theta}{dt}\right]$ from the graph should be obtained at the temperature θ_2.

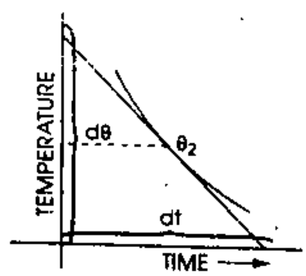

Fig. (2)

Permissible error :

$$K = \frac{msd}{\pi r^2 (\theta_1 - \theta_2)}\left[\frac{d\theta}{dt}\right]$$

Taking log, and differentiating, we have

$$\frac{\delta K}{K} = \frac{\delta m}{m} + \frac{\delta d}{d} + \frac{2\delta r}{r} + \frac{\delta(\theta_1 - \theta_2)}{(\theta_1 - \theta_2)} + \frac{\delta d\theta}{d\theta} + \frac{\delta dt}{dt} = \ldots$$

Maximum permissible error = ... %.

Viva-Voce

Q. 1. ***Why is the experimental material taken in the form of disc ?***

Ans. A thin disc is taken because its area of cross section is large, while thickness is small. It increases the quantity of heat conducted across its faces.

Q. 2. ***Why the two discs, between which the disc of bad conductor is pressed, are taken of metal ?***

Ans. It ensures the normal flow of heat from one face of experimental disc to another.

Q. 3. ***What is principle involved in this method ?***

Ans. In steady state, temperature of lower metal plate becomes constant and then the heat lost by it to the surroundings is just made up the heat gained by it through the experimental disc of bad conductor.

Q. 4. ***At what temperature, do you find rate of radiation ?***

Ans. At steady state temperature.

Q. 5. ***Can this method be used in case of good conductors ?***

Ans. No. because the two sides of the experimental disc will atonce acquire the same temperature.

Q. 6. ***Can this method be used in case of liquids ?***

Ans. With liquids, the difficulty is that the convection currents are easily set up and transfer more heat than the conduction actually does. To overcome this difficulty, liquid should be heated at the top and should be taken in the form of thin film.

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EXPERIMENT No. 7

Object : To determine the thermal conductivity of rubber in the form of a tube.

Apparatus required. Calorimeter, balance with weight box, stop watch, thermometer, steam boiler, graduated cylinder, rubber tubing, wooden screen and vernier microscope.

Formula used :

The coefficient of thermal conductivity K of rubber in the form of a tube is given by the formula,

$$\boxed{K = \frac{(m + w)(\theta_4 - \theta_3) \times 2.3026 \times \log_{10} r_2/r_1}{2\pi\, l.t\left[\theta_{\text{steam}} - \left(\frac{\theta_4 + \theta_3}{2}\right)\right]}}$$

where m = mass of the water taken in the calorimeter,

w = water equivalent of calorimeter and its contents,

= mass of calorimeter with stirrer × specific heat of material of calorimeter (copper),

Practical Physics-II

EXPERIMENT No. 8

Object : To determine the coefficient of thermal conductivity of glass in the form of a tube

Apparatus required. The given glass tube, a wider tube to serve as a steam Jacket, constant level water arrangement, two sensitive thermometers, boiler, graduated jar, stop watch and microscope.

Formula used.

The coefficient of thermal conductivity K of glass in the form of a tube is given by

$$\boxed{K = \frac{m(\theta_2 - \theta_1)\, 2.3026 \times \log_{10} r_2/r_1}{2\pi\, l\, .\, t\left[\theta_{steam} - \dfrac{(\theta_2 + \theta_1)}{2}\right]}}$$

where m = mass of the water collected in time t,

l = length of the tube within the steam jacket,

r_1, r_2 = internal and external radii of the tube,

θ_1, θ_2 = temperature of inflowing and out-flowing water,

θ_{steam} = temperature of the steam.

Description of the apparatus :

The thermal conductivity of glass in the form of a thick walled tube can be easily determined by accomplishing the radial heat flow with continuous flow calorimeter. The experimental arrangement is shown in figure (1).

AB is a long glass tube with thin walls and is held inside the wider jacket J through which steam can be allowed to pass. The glass tube at the ends is joined with two wider tubes CC which are provided with inlet I and outlet O for cold water. A spiral wire is placed inside AB in order that the water may be in good contact with the inner surface of the tube. Water is allowed to flow through the tube AB. Thermometers T_1 and T_2 are provided to measure the temperature of incoming and outflowing water respectively.

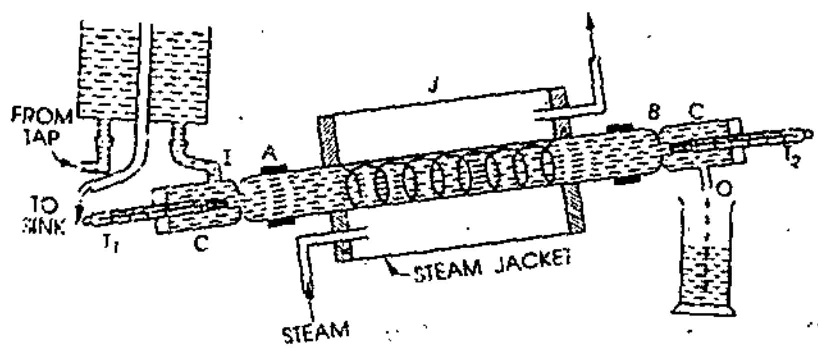

Fig. (1)

Procedure :

(i) Set up the arrangement as shown in fig. (1). *Allow a steady stream of water to flow through the glass tube.*

(ii) Allow the steam to flow through the steam jacket J and obtain a steady state, i.e. there should be no variation of the temperatures recorded by the two thermometers T_1 and T_2.

(iii) Collect the water in a clean graduated cylinder from the outlet O and note the time with the help of a stop watch. The operation is repeated for several times.

(iv) Note the length of the tube inside the jacket.

(v) Measure the internal and external radii r_1 and r_2 with the help of micrsocope.

(vi) Calculate the value of K with the help of the formula derived above.

Observations :

(A) Reading for the determination of m, t, θ_1 and θ_2.

S. No.	Mass of water collected, m	Time taken t	(m/t)	Mean	Steady temp. θ_1°C	Steady temp. θ_2°C	θ_{steam}
1	...	...	...				
2	...	...	...				
3	...	...	...	...	...	...	...
4	...	...	...				

(B) Length of the glass tube exposed to steam, l = ... cms.

(C) Internal radius (r_1) = ... cm.

External radius (r_2) = ... cm.

Table for the internal and external radii r_1 and r_2 :

L.C. of microscope = ... cm.

S. No.	Internal radius r_1					External radius r_2				
	Reading at one inner end (a)	Reading at other inner end (b)	Diameter (a~b)	Mean diameter	r_1 cm.	Reading at one outer end (c)	Reading at other outer end (d)	Diameter (c~d)	Mean diameter	Radius r_2 cm.
1	...	...	...			...	...	...		
2	...	...	...	...	...	...	...	...	...	...
3	...	...	...			...	...	...		

Radius

Calculations :

$$K = \frac{\frac{m}{t}(\theta_2 - \theta_1)\, 2.3026 \times \log_{10} r_2/r_1}{2\pi l \cdot \left[\theta_{steam} - \frac{(\theta_2 + \theta_1)}{2}\right]}$$

= ... C. G. S. units.

Result. The thermal conductivity of glass = ... cal per sec. per sq. cm. per unit. temperature gradient.

Standard result. 0.0025 units.

Percentage error = ...%.

Precautions and Sources of Error :

(i) The tube should be inclined a little as shown in the figure. In this case the water will flow up and the tube will always remain full of water.

(ii) Steady state should be observed strictly.

(iii) Water should flow from a constant pressure flow arrangement.

(iv) A number of determination of the rate of flow of water should be made and their mean value should be substituted in the formula.

(v) The diameters should be determined accurately.

Viva-Voce

Q. 1. ***Why is the spiral placed inside the tube ?***

Ans. The water comes in good thermal contact with the inner walls of the tube due to the spiral. Thus heat is connected evenly to the water through glass walls.

Q. 2. ***Why the tube is kept inclined with outlet side up ?***

Ans. Water flows out after coming in contact with complete inside surface of glass tube.

Q. 3. ***Would you keep the rate of flow of water slow or fast ?***

Ans. Slow so as to have measurable difference of temperature at the two ends (inlet and outlet).

Q. 4. ***How much length of the tube should be accounted ?***

Ans. That which is exposed to steam.

Q. 5. ***What is the effect of temperature on thermal conductivity ?***

Ans. The conductivity of pure metals generally decreases with the rise in temperature. For liquids, it increases in case of water while decreases in case of oils as the temperature rises.

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EXPERIMENT No. 9

Object : To determine Planck's constant, h, by measuring radiation in a fixed spectral range.

Apparatus required. All that are required in experiment No. 15 on Stefan's law (6 volt battery; D.C. voltmeter 0-10V; D.C. Ammeter 0-1 amp; Electric bulb with tungsten filament of 6V, 6w; rheostat 100 ohm). A battery; Ballistic galvanometer; one tapping key; one way key; Photo cell; Filter for green light; (Electric bulb will serve as light source for photocell) convex lens to focus the radiation after the filter on to the cathode of photocell.

Formula used. Planck's constant is given by

$$\boxed{h = \frac{2.303\,\lambda k}{c}\,\frac{\Delta(\log_{10}\theta)}{\Delta(1/T)}.}$$

where c = velocity of light

λ = effective wavelength used

k = Boltzmann constant

θ = deflection of galvanometer on scale corrsponding to bulb filament temperature T in K

Procedure :

It is to be performed in two steps :

***(A) First Step* :** It is for the determination of temperature in kelvin of bulb filament (bulb serves as light source, we need its temperature) at different current, I, values. The method is described in Expt. No. 15 on Stefan's law. From the observations (see table-2 of Expt. No. 15) of Expt No. 15 draw I-T (current-temperature) graph for the filament used.

***(B) Second Step* :** We use this bulb as light source in the experiment to find Planck's constant.

(i) Draw the circuit diagram as shown in fig. 1.

(ii) Send a current (I) across filament of the bulb. It will start glowing.

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* But if for further currents deflection, θ, reaches a large value which may go out of scale then by shutter reduce this θ to $\theta' = \theta/2$, half the true value but record in the table $2\theta'$ i.e. true value of deflection.

Now do not disturb shutter opening and double the value of deflection for all further currents as mentioned earlier, 2 being called as multiplying factor.

(iii) Pass the radiation through green filter and adjust the shutter to control the flux of radiation falling on the cathode of photocell. The deflection of ballistic galvanometer should remain well within the limits of scale. Note the deflection, θ. Do not change shutter opening for next readings*.

(iv) Now increase the filament current, I and take other values of deflection, θ.

(v) Corresponding to different filament currents used in the experiment, find values of temperature, T, in K, from I-T graph drawn in First Step.

(vi) Then plot a graph between $\log_{10}\theta$ and $(1/T)$ which will be a straight line, the slope of which gives the value of

$$[\log_{10}\theta/(1/T)].$$

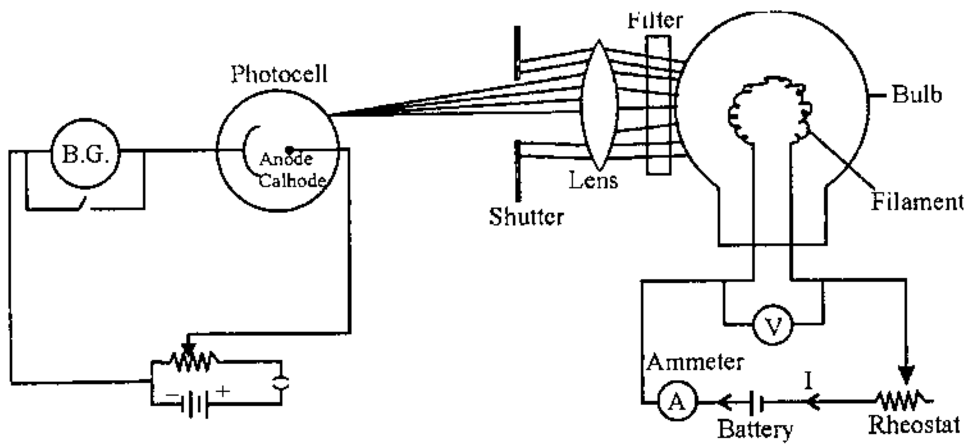

Fig. (1)

Observations :

Part (A) : All tables of Expt. No. 15 on Stefan's law. Draw I–T graph.

Part (B) : with Fig. (1).

Reading of voltmeter V, volt	Reading of Ammeter, filament current, I, amp.	Correspounding temperature, T, from I-T graph of Part-A	Deflection, θ cm
...	...	...	...
...	...	...	...
...	...	...	...
...	...	...	...

Calculation : From graph fig. (2)

$$\frac{\Delta \log_{10}\theta}{\Delta(1/T)} = \frac{AB}{BC}$$

$$k = 1.4 \times 10^{-16} \text{ erg/K}$$

$$c = 3 \times 10^{10} \text{ cm/sec.}$$

$$\lambda = 5.5 \times 10^{-5} \text{ cm. (green)}$$

$$h = \frac{2.303\,\lambda k}{c} \cdot \frac{AB}{BC} = \ldots \text{ erg . sec.} = \ldots \text{ joule.sec.}$$

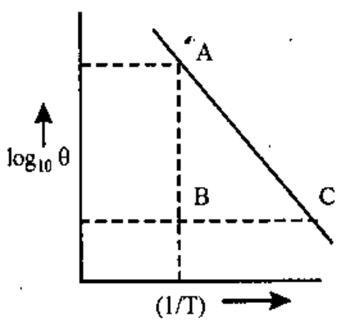

Fig. (2)

Result : Value of Planck's constant, $h = \ldots$ joule.sec

Standard result : $h = 6.625 \times 10^{-34}$ Joule.sec.

Source of Error and Precautions :

1. Photocell may not have a linear response for large variations of intensity and therefore use of shutter to limit the flux of radiation reaching the photocell is necessary. Multiplying factor for all observations should remain same. i.e. shutter is adjusted once in the whole experiment if precaution is taken at the initial reading.

2. It is better to do the experiment with more filters so that observations are taken over a wider spectral range. It can be inferred then, for what values of λ, result closely agree with standard value of Planck's constant.

EXPERIMENT No. 10

Object : To determine the critical temperature and critical pressure of a gas.

Apparatus required. A hard glass tube (cylindrical bulb) in which liquid under test is filled. A manometer and a thermostat.

About the apparatus. Apparatus is shown in fig. (1). B is a sealed cylindrical bulb containing the liquid under test. The bulb is connected to a manometer M containing air at the closed end. The bulb is surrounded by a thermostat T by means of which the bulb can be kept at any temperature.

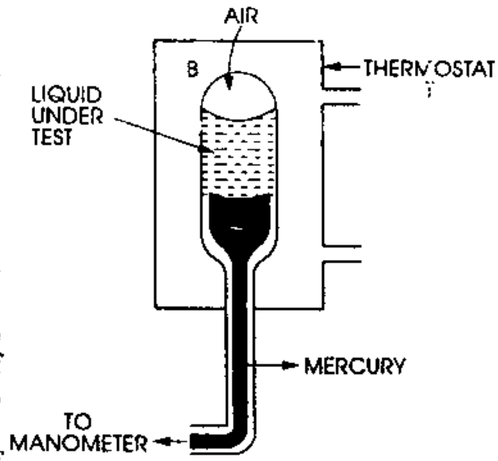

Fig. (1)

Procedure.

(i) Raise the temperature of the bulb, B, with the help of thermostat till the meniscus of the liquid disappears. Note this temperature. Let it be T_1.

(ii) Now lower the temperature of the bulb, B, by thermostat till the meniscus of the liquid just reappears. Note this temperature. Let it be T_2.

(iii) Keep the bulb at the mean of temperatures T_1 and T_2; note the corresponding pressure in manometer. This is critical pressure, p_c.

Observations.

(i) Temperature at which meniscus disappears, $T_1 = \ldots$ °C

(ii) Temperature at which meniscus just reappears, $T_2 = \ldots$ °C

(iii) Pressure in manometer $p_c = \ldots$ ohm.

Calculations and Result :

(i) Critical temperature. $T_c = \dfrac{T_1 + T_2}{2} = \ldots$ °C $= \ldots$ K

(ii) Critical pressure, $p_c = \ldots$ atm.

Precautions.

Appearance or disappearance of the liquid meniscus should be noted carefully. It happens sometimes that liquid menisus is not quite visible even below critical temperature.

Viva-Voce

Q. 1. *Define critical constant ?*

Ans. The three critical constants of the gas are :

(i) *Critical temperature* : The maximum temperature at which a gas can be liquefied by pressure alone is called critical temperature.

(ii) *Critical pressure* : The pressure required to liquefy the gas at critical temperature is called critical pressure.

(iii) *Critical volume* : The volume occupied by one gram mole of the gas at critical pressure and critical temperature is called critical volume.

Q. 2. *What is that temperature at which the density of the gas or the vapour becomes equal to that of its liquid ?*

Ans. It is critical temperature.

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EXPERIMENT No. 11

Object : To measure temperature with the help of Jolly's constant volume air thermometer.

Apparatus required. Jolly's constant volume air thermometer.

Formula used. *Temperature is given by*

$$\boxed{t = \frac{h_t - h_0}{h_{100} - h_0} \times 100^\circ C}$$

where h_t = difference in the levels of mercury when bulb is placed in a bath whose temperature, t, is to be measured.

h_0 = difference in the levels of mercury when bulb is placed in melting ice.

h_{100} = difference in the levels of mercury when bulb is placed in steam.

About the Apparatus :

Constant volume air thermometer is shown in fig. 1. It consists a spherical bulb, A, that is connected to another cylindrical bulb BC through a narrow horizontal tube having three way stop cock, S. S can open into bulb BC or tube *G*.

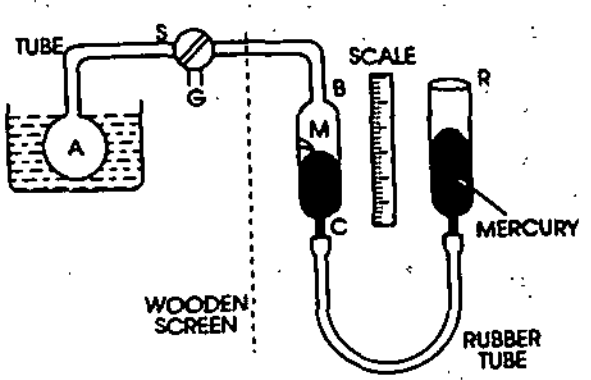

Fig. (1)

Bulb BC is connected to a mercury reservoir, R through rubber tube, and a centimeter scale is adjusted between them, so that the difference in mercury levels in the two limbs can be read directly.

Bulb BC also carries a fixed pointer *M* inside it. Mercury in this bulb is always adjusted so as to touch the tip of pointer *M*. This ensures that volume of air in bulb A is constant. Mercury equal to one seventh of the volume of bulb A is placed in bulb A *in order to compensate for expansion of bulb.*

Procedure :

Bulb *A* is dried and then filled with dry air and mercury in bulb BC is adjusted by *moving R to touch the tip of the pointer M.*

(i) Bulb A is placed in a melting ice for sufficient time so that air inside *A* is at 0°C. Mercury in bulb BC is adjusted to touch the tip of pointer *M*. Note the difference in the mercury *levels of bulb BC and reservoir R. This is* h_0.

(ii) Place the bulb now in steam for a long time and again note the difference in the mercury levels in BC and *R* after the mercury level in BC has been adjusted to touch the tip of pointer *M*. This is h_{100}.

(iii) Now place the bulb in the bath whose temperature is to be measured. After keeping for sufficiently long time, adjust mercury level in BC to touch the tip of pointer, *M*. Note the difference in the mercury levels in BC and R. This is h_t.

Observations :

(i) $h_0 = \ldots$ cm.

(ii) $h_{100} = \ldots$ cm.

of the eyepiece. The telescope can be clamped to the main body of the instrument and can be moved slightly by tangent screw. The telescope is attached to the main scale and when it rotates, the graduated scale rotates with it. The inclination of telescope is adjusted by two screws provided at the lower surface.

Adjustments :

Before using the spectrometer, the following adjustments must be made.

(a) The axis of the telescope and that of the collimator must intersect the principal vertical axis of rotation of the telescope.

This adjustment is done by the manufacturer and can only be tested in the laboratory. For this purpose a pin is mounted vertically in the centre of prism table and observing its image in the telescope tube without eyepiece and for a wide slit in the collimator. If the image appears in the middle, then the adjustment is perfect otherwise the image is made in the centre by using the screws supporting the telescope and collimator till the pin appears in the middle.

(b) Prism table should be levelled.

(i) The prism table is levelled with the help of three screws supporting the prism table. A spirit level is placed along a line joining the screws and the two screws are moved till the air bubble appears in the middle. Now place the spirit level along a line perpendicular to the previous line and adjust the third screw such that again the air bubble appears in the middle. Here one thing should be remembered that the first two screws should not be touched this time. The prism table is now levelled.

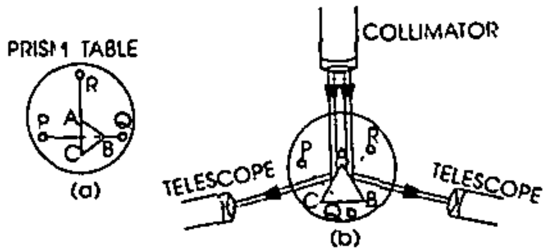

Fig. (2)

(ii) The second method (which is generally used in optical levelling of the prism table) : In this method the prism is placed on the prism table with its refracting edge at the centre of the prism table and one of its polished surface perpendicular to the line joining the two levelling screws P and Q as shown in fig. (2)a.

Now rotate the prism table in such a way that refracting edges AB and AC face towards the collimator and light falling on the prism is usually reflected on both the sides as shown in fig. (2) b.

The telescope is moved to one side to receive the light reflected from the face AB and the levelling screws P and Q are adjusted to obtain the image in the centre of the field of view.

Again the telescope is moved to the other side to receive the light reflected from the face AC and the remaining third screw R is adjusted till the image becomes in the central field of view of the telescope.

The procedure is repeated till the two images from both the reflecting faces are seen in the central field of view of the telescope. The prism table is now levelled.

(c) Telescope and collimator are adjusted for parallel light by Schuster's method.

First of all the prism is placed on the prism table and then adjusted approximately for minimum deviation position. The spectrum is now seen through the telescope. The prism table is rotated slightly away from this position towards collimator and the telescope is brought in view. The collimator is well focussed on the spectrum. Again rotate the prism table on the other side of minimum deviation position, *i.e.*, towards telescope and focus the telescope for the best image of the spectrum. The process of focussing the collimator and telescope is continued till the slight rotation of the prism table does not make the image to go out of focus. This means that both collimator and telescope are now individually set for parallel rays.

Procedure :

(A) Measurement of the angle of the prism.

(i) Determine the least count of the spectrometer.

(ii) Place the prism on the prism table with its refracting angle A towards the collimator and with its refracting edge A at the centre as shown in the fig. (3). In this case some of the light falling on each face will be reflected and can be received with the help of the telescope.

(iii) The telescope is moved to one side to receive the light reflected from the face AB and the crosswires are focssed on the image of the slit. The reading of the two verniers are taken.

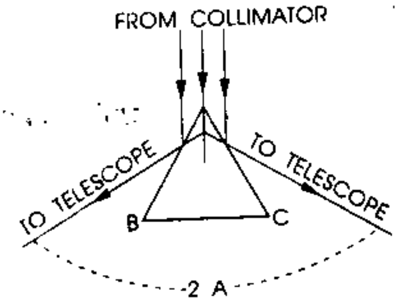

Fig. (3)

(iv) The telescope is moved in other side to receive the light reflected from the face AC and again the crosswires are focussed on the image of the slit. The readings of two verniers are noted.

(v) The angle through which the telescope is moved or the difference in the two positions gives twice the refracting angle A of the prism. Therefore, half of this angle gives the refracting angle of the prism.

(B) Measurement of the angle of minimum deviation :

(i) Place the prism so that its centre coincides with the centre of the prism table and light falls on one of the polished faces and emerges out of the other polished face, after refraction. In this position the spectrum of light is obtained.

(ii) The spectrum is seen through the telescope and the telescope is adjusted for minimum deviation position for a particular colour (wavelength) in the following way:

Set up telescope at a particular colour and rotate the prism table in one direction, of course the telescope should be moved in such way to keep the spectral line in view. By doing so a position will come where the spectral line recede in the opposite direction although the rotation of the table is continued in the same direction. The particular position where the spectral line begins to recede in opposite direction is the minimum deviation position for that colour. Note the readings of two verniers.

(iii) Remove the prism table and bring the telescope in the line of the collimator. See the slit directly through telescope and coincide the image of slit with vertical crosswire. Note the readings of two verniers.

(iv) The difference in minimum deviation position and direct slit position gives the angle of minimum deviation for that colour.

(v) The same procedure is repeated to obtain the angles of minimum deviation for other colours.

Observations :

(i) Value of the one division of the main scale = 0·5 deg.
Total number of vernier divisions = 30
Least count of the vernier = 0·5/30 = 1 minute

(ii) Table for the angle (A) of the prism :

S. No.	Vernier	Telescope reading for reflection from first face			Telescope reading for reflection from second face			Difference a − b = 2A deg.	Mean value of 2A deg.	A deg.	Mean A deg.
		M.S. reading	V.S. reading	Total (a) deg.	M.S. reading	V.S. reading	Total (b) deg.				
1.	V_1	...	...	...	...	...	...	...	...	...	
	V_2	...	...	...	...	...	...	...			
2.	V_1	...	...	...	...	...	...	...	...	...	...
	V_2	...	...	...	...	...	...	...			
3.	V_1	...	...	...	...	...	...	...	...	...	
	V_2	...	...	...	...	...	...	...			

(iii) Table for angle of minimum deviation (δ_m).

S. No.	Colour	Vernier	Dispersed image. Telescope in minimum deviation position			Telescope reading for direct image			Difference a ~ b deg.	Mean deviation δ_m deg.
			M.S. reading	V.S. reading	Total a deg.	M.S. reading	V.S. reading	Total b deg.		
1.	Violet	V_1	...	...	...	...	...	...	...	...
		V_2	...	...	...	...	...	...	...	
2.	Blue	V_1	...	...	...	...	...	...	...	...
		V_2	...	...	...	...	...	...	...	
3.	Green	V_1	...	...	...	...	...	...	...	...
		V_2	...	...	...	...	...	...	...	
4.	Yellow	V_1	...	...	...	...	...	...	...	...
		V_2	...	...	...	...	...	...	...	

Calculations :

Angle of minimum deviation for violet :

$$\mu \text{ for violet} = \frac{\sin\left(\frac{A+\delta m_1}{2}\right)}{\sin(A/2)}$$

$$= \ldots\ldots\ldots$$

Angle of minimum deviation for blue :

$$\mu \textbf{ for blue} = \frac{\sin\left(\frac{A+\delta m_2}{2}\right)}{\sin(A/2)}$$

$$= \ldots\ldots$$

Similarly find the value of μ for other colours.

Result : Refractive index of the material of the prism :

S. No.	Colour	Calculated μ	Standard μ	% Error
1.	Violet	...	...	...
2.	Blue	...	...	...
3.	...	...	...	...
4.	...	...	...	...
5.	...	...	...	...

Precautions and Sources of Error :

(i) The telescope and collimator should be individually set for parallel rays.

(ii) Slit should be as narrow as possible.

(iii) While taking observations, the telescope and prism table should be clamped with the help of clamping screws.

(iv) Both verniers should be read.

(v) The prism should be properly placed on the prism table for the measurement of angle of the prism as well as for the angle of minimum deviation.

Theroretical Error :

Refractive index of the material of the prism is given by the expression

$$\mu = \frac{\sin\left(\frac{A+\delta m}{2}\right)}{\sin(A/2)}$$

Taking logarithms of both sides and differentiating,

$$\frac{\delta\mu}{\mu} = \frac{\cos\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A+\delta_m}{2}\right)} \frac{\delta(A+\delta_m)}{2} + \frac{\cos\left(\frac{A}{2}\right)}{\sin\left(\frac{A}{2}\right)} \frac{\delta(A)}{2}$$

$$\frac{\delta\mu}{\mu} = \cot\left(\frac{A+\delta_m}{2}\right)\frac{\delta(A+\delta_m)}{2} + \cot\left(\frac{A}{2}\right)\delta\left(\frac{A}{2}\right)$$

Now
$$\left.\begin{aligned}\delta A &= 2' \\ \delta(\delta_m) &= 2'\end{aligned}\right\}$$

because the least count of the spectrometer = 1" and there are two verniers.

Hence
$$\frac{\delta(A+\delta_m)}{2} = 2' \quad \text{and} \quad \delta\left(\frac{A}{2}\right) = 1'$$

$$\frac{\delta\mu}{\mu} = \cot\left(\frac{A+\delta_m}{2}\right)2' + \cot\left(\frac{A}{2}\right)1'$$

$$= \frac{\pi}{60 \times 180}\left\{2\cot\left(\frac{A+\delta_m}{2}\right) + \cot\left(\frac{A}{2}\right)\right\}$$

$$= \ldots\ldots$$

$$= \ldots\ldots\%.$$

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EXPERIMENT No. 13

Object : To determine the dispersive power of the material of the prism for violet and yellow colours of mercury light with the help of a spectrometer.

Apparatus required : Spectrometer, prism, mercury source and reading lens.

Formula used :

The dispersive power, ω, of the material of the prism is given by the formula

$$\boxed{\omega = \frac{\mu_v - \mu_y}{\mu - 1}}$$

where μ_v = refractive index of the material of the prism for violet colour,
μ_y = refractive index of the material of the prism for yellow colour,

and $\mu = \dfrac{\mu_v + \mu_y}{2}$

The refractive index of the prism is given by

$$\boxed{\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}}$$

where A = Angle of the prism,
δ_m = Angle of minimum deviation.

Procedure : The procedure is as follows :

(i) Adjustment of the spectrometer.
(ii) Measurement of angle of prism A.
(iii) Measurement of angle of minimum deviation δ_m for violet and yellow colours.

For details see Experiment No. 1.

Observations : Make the tables, similar to those in Experiment No. 1.

Calculations :

Find out the value of μ_v and μ_y using the relation,

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

$$\mu_v = \ldots\ldots$$

$$\mu_y = \ldots\ldots$$

$$\mu = \frac{\mu_v + \mu_y}{2} = \ldots$$

and $$\omega = \frac{\mu_v - \mu_y}{\mu - 1}$$

Result : The dispersive power of the given prism,

= ......

Precautions and Sources of error :

Same as in the experiment No. 1.

Viva-Voce

Q. 1. *What do you mean by dispersive power ? Define it.*

Ans. The dispersive power of a material is its ability to disperse the various components of the incident light. For any two colours, it is defined as the ratio of angular dispersion to the mean deviation, *i.e.*

$$\omega = \frac{\delta_v - \delta_r}{\delta_y}.$$

Q. 2. *On what factors, the dispersive power depends ?*

Ans. It depends upon (i) material, and (ii) wavelength of colours.

Q. 3. *Out of the prism of flint and crown glasses, which one will you prefer to use?*

Ans. We shall prefer a prism of flint glass because it gives greater dispersion.

Q. 4. *What is a normal spectrum ?*

Ans. A spectrum in which angular separation between two wavelengths is directly proportional to difference of the wavelengths is called a normal spectrum.

Q. 5. *Do you think that a prismatic spectrum is a normal one ?*

Ans. No.

Q. 6. *Can you find out the dispersive power of a prism with sodium light ?*

Ans. No. This is a monochromatic source of light.

Q. 7. *How many types of spectra you know ?*

Ans. There are two main types of spectra (i) emission spectra and (ii) absorption spectra.

Q. 8. *What type of spectra do you expect to get from (i) an incandescent filament lamp (ii) sun light (iii) mercury lamp ?*

Ans. (i) continuous spectrum, (ii) band spectrum, and (iii) line spectrum.

Q. 9. *How do you classify emission spectrum ?*

Ans. (i) Continuous spectrum, given by a candle or electric bulb.

(ii) Band spectrum, given by elements of compound in molecular state.

(iii) Line spectrum, given by sodium or mercury spectrum.

Q. 10. *What is difference between a telescope and a microscope ?*

Ans. Telescope is used to see the magnified image of a distinct object. Its objective has large aperture and large focal-length. The microscope is used to see the magnified image of very near object. Its objective has small focal-length and aperture.

Q. 11. *Without touching can you differentiate between microscope and telescope ?*

Ans. The objective of microscope has small aperture while the telescope has a large aperture.

Q. 12. ***What is that which you are adjusting in focussing the collimator and telescope for parallel rays ?***

Ans. In case of collimator, we adjust the distance between collimating lens and slit while in case of telescope the distance between cross wires from the objective lens is adjusted.

Q. 13. ***What are these distances equal to when both the adjustments are complete?***

Ans. The slit becomes at the focus of collimating lens in collimator and cross wires become at the focus of objective lens in telescope.

Q. 14. ***How can telescope and collimator be adjusted together ?***

Ans. (i) The prism is set in minimum deviation for yellow colour.

(ii) Prism is rotated towards telescope and telescope is adjusted to get a well defined spectrum.

(iii) Now the prism is rotated towards collimator and the collimator is adjusted to get well defined spectrum.

(iv) The process is repeated till the spectrum is well focussed. This is known as Schuster's method.

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EXPERIMENT No. 14

Object : To determine the angle between crystal surface by spectrometer.

Apparatus required : Spectrometer, crystal and source.

Procedure : When the crystal is of bigger size, *i.e.* of the size of the prism, the angles between the crystal surfaces can be determined with the help of spectrometer. The procedure is as follows :

(i) The spectrometer is adjusted as described in Experiment No. 1.

(ii) The crystal is placed on the prism table with one of the edges facing towards the collimator.

(iii) The light falling on each surface will be reflected and can be received with the help of telescope. The telescope is moved to one side to receive the light reflected from one surface and the cross wires are focussed on the image of the slit. The reading of the two verniers are taken.

(iv) The telescope is moved on other side to receive the light reflected from the other surface and again the cross wires are focussed on the image of the slit. The reading of the two verniers are noted.

(v) The angle through which the telescope is moved or the difference in the two positions gives twice the angle between the crystal surfaces. Half of the angle gives the angle α between the two crystal surfaces.

(vi) Proceed similarly for other pair of surfaces.

Viva-Voce

See the Viva-Voce of Experiment No. 1 and 2.

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EXPERIMENT No. 15

Object : To determine the refractive indices μ_o and μ_e of calcite (or quartz) for the ordinary and extraordinary rays using spectrometer and sodium light.

Apparatus required : Specrometer, prism, calcite or quartz prism with its optic axis parallel to the refracting edge, sodium lamp, reading lens.

Formula used :

The refractive indices μ_o and μ_e of calcite crystal for the ordinary and extra-ordinary rays are given by the formula,

$$\boxed{\mu_o = \frac{\sin\left(\frac{A + \delta_{m_0}}{2}\right)}{\sin\left(\frac{A}{2}\right)}}$$

and
$$\boxed{\mu_e = \frac{\sin\left(\frac{A + \delta_{m_e}}{2}\right)}{\sin\left(\frac{A}{2}\right)}}$$

where A = Angle of prism.

δ_{m_o} = Angle of minimum deviation for ordinary ray.

δ_{m_e} = Angle of minimum deviation for extra-ordinary ray.

Theory : Calcite or quartz crystal is doubly refracting and therefore if an object is viewed through such crystal two images of the object are seen; one corresponding to ordinary ray and the other corresponding to extra-ordinary ray. It is observed experimentally that O ray end E-ray are plane polarised with their planes of polarisation mutually perpendicular. In such a crystal, the velocity of O-ray is the same in all directions but that of E-ray is different in different directions. However, the velocity of both the rays is same along the optic axis. In a direction perpendicular to the optic axis, difference in their velocities is maximum. Therefore there are two principal refractive indices of the medium of doubly refracting crystal μ_o and μ_e for O and E-rays respectively travelling perpendicular to the optic axis.

The crystal, under consideration, is cut in the form of prism with optic axis parallel to the refraction edge. When a ray of light enters into the prism, it splits into ordinary and extra ordinary rays. Because O-ray and E-ray, inside the prism, are travelling perpendicular to the optic axis; the basic condition for the determination of μ_e is satisfied.

Since the two rays are refracted through the prism at minimum deviation like ordinary unpolarised rays, one can apply the same formulae as used in Experiment No. 1.

Procedure :

After refraction through the prism, in this experiment, the two images of the slit will appear (corresponding to O and E-rays). Find the angle of minimum deviation for two images separately. It can be seen that for calcite $\delta_{m_o} > \delta_{m_e}$ and for quartz prism $\delta_{m_o} < \delta_{m_r}$.

Proceed as follows :

(1) Adjust the spectrometer as in Experiment No. 1.

(2) Measure the angle of prism A as found in Expt. No. 1.

(3) Measure angle of minimum deviations for the two images separately (after setting the prism in minimum deviation position) as described in Expt. No. 1.

Observation : Make tables similar to those in Expt. No. 1.

Calculations :

$$\mu_o = \frac{\sin\left(\frac{A+\delta_{m_0}}{2}\right)}{\sin\left(\frac{A}{2}\right)} = \ldots\ldots$$

$$\mu_e = \frac{\sin\left(\frac{A+\delta_{m_e}}{2}\right)}{\sin\left(\frac{A}{2}\right)} = \ldots\ldots$$

Result : The refractive indices of calcite (or quartz)

for ordinary ray = ...

for extraordinary ray = ...

Sources of error and Precautions : Same as in Expt. No. 1.

Viva-Voce

Q. 1. *What is the material of the prism ?*

Ans. The material of the prism is either calcite or quartz.

Q. 2. *Why do you observe two beams ?*

Ans. Calcite or quartz is a doubly refracting material.

Q. 3. *What is the geometry of a calcite crystal ?*

Ans. It is a colourless, transparent crystal. Chemically it is hydrated calcium carbonate ($CaCO_3$). It belongs to rhombo-hedral class of hexagonal system. The six faces are parallelogram each having angles of 101° 55′ and 78° 5′. There are two opposite corners where the three angles are obtuse. These corners are known as blunt corners.

Q. 4. *What is an optic axis ?*

Ans. A line passing through any one of the blunt corners and making equal angles with the three faces, locate the direction of optic axis.

Q. 5. *What is the phenomenon of double refraction ?*

Ans. When an ordinary ray of light is passed through a calcite crystal, the refracted light is split upto two refracted rays. The one which obeys the ordinary laws of refraction is known as ordinary ray. The other which does not obey the laws of refraction is known as extra-ordinary ray. This phenomenon is known as double refraction.

Q. 6. *Why do you, often, use sodium lamp in the laboratory ?*

Ans. Sodium lamp is a convenient source of monochromatic light.

Q. 7. *Do you know any other monochromatic source of light ?*

Ans. Red line of cadmium is also monochromatic source.

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EXPERIMENT No. 16

Object : To determine (i) λ, the wavelength of sodium yellow light and (ii) $(\lambda_1 - \lambda_2)$, the difference between the wavelengths of two sodium D-lines, with the help of Michelson interferometer.

Apparatus used : Michelson interferometer, sodium lamp, condensing lens and a pin.

Formula used :

(i) The wavelength λ of sodium light is given by

$$\boxed{\lambda = \frac{2\,(x_2 - x_1)}{N}} \qquad \ldots (1)$$

where $x_1 =$ initial position of mirror M_1 of Michelson interferomeer.

$x_2 =$ final position of mirror M_1 of Michelson interferometer

i.e., $(x_2 - x_1) =$ distance moved by mirror M_1.

$N =$ number of fringes appeared at the centre of field corresponding to distance $(x_2 - x_1)$.

(ii) The difference of two wavelengths of sodium lines $(\lambda_2 - \lambda_1)$ is given by

$$\boxed{(\lambda_2 - \lambda_1) = \frac{\lambda_{av}^2}{2x}} \qquad \ldots (2)$$

where $\lambda_{av}^2 = \lambda_1 \lambda_2 = (\text{mean of } \lambda_1 \text{ and } \lambda_2)^2$

$x =$ distance between the two indistinct positions of mirror M_1.

Description of apparatus :

Michelson interferometer is shown in fig. 1. It consists of two excellent optically plane, highly polished plane mirrors M_1 and M_2 which are right angles to each other. There are two optically flat glass plates G_1 and G_2 of the same thickness and of the same material placed parallel to each other. These plates are also inclined at an angle 45° with mirrors M_1 and M_2. The face of G_1 towards G_2 is semi-silvered. The mirror M_1 is mounted on a carriage which can be moved forward or backward. The motion is controlled by a very fine micrometer screw (capable of reading upto 10^{-5} cm.). The mirrors M_1 and M_2 are provided with three levelling screws at their backs. With the help of these screws the mirrors can be tilted about horizontal and vertical axes so that they can be made exactly perpendicular to each other. T is a telescope which receives the reflected lights from mirrors M_1 and M_2.

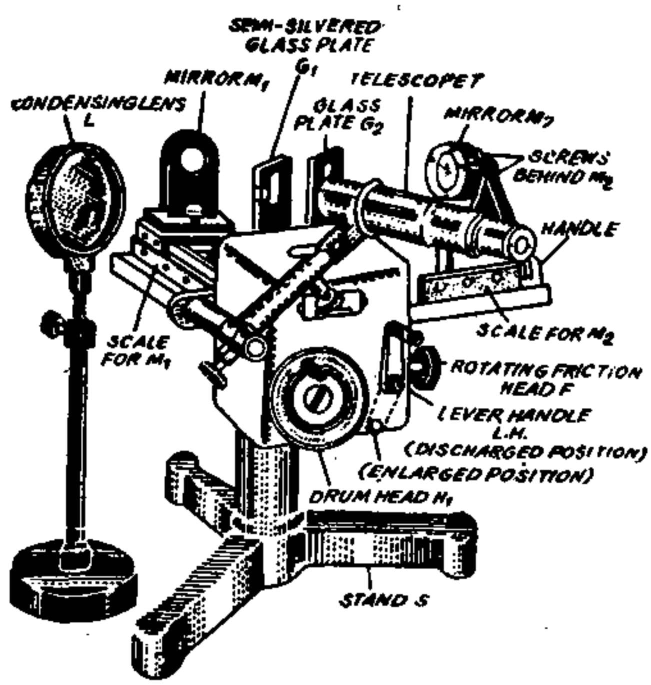

Fig. (1)

Adjustment of the interferometer : In order to obtain the circular fringes, the following adjustments are made :

(i) The distance $G_1 M_1$ is made nearly equal to $G_2 M_2$ with the help of drum head H_1 *i.e.,* movable mirror M_1 is moved by turning the drum head until the two distances are nearly equal.

(ii) Light coming from sodium lamp is rendered parallel by condensing lens L. Now a pin is introduced between condensing lens L and glass plate G_1. On looking through the telescope (being towards glass plate G_1 for receiving the emergent light from M_1), four images R_1, R_2, R_3 and R_4 are observed as shown in fig. (2). The images R_3 and R_4 are brighter while R_1 and R_2 are fainter. By adjusting the screws behind the mirror M_2, the brighter images R_3 and R_4 are made to coincide.

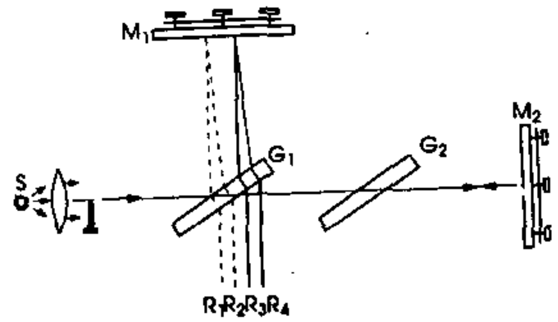

Fig. (2)

(iii) The pin is now removed. Usually localised fringes appear in the field of view. To obtain the circular fringes, the mirror M_2 is further tilted with the help of screws attached behind it in such a way that the spacing between the fringes increases. After a slight adjustment circular fringes appear in the centre of the field of view. If the centre of the fringes is not at the centre of field of view, then it is also adjusted by screws.

(iv) By moving the eye in linear or lateral direction, the fringes should not converge or diverge. If they do so, then again by a final tilt of mirror M_2 the fringes are made sationary.

Procedure : (1) For the wavelength of monochromatic light :

(i) The position of mirror M_1 is adjusted by turning drum head H_1 so that a bright spot of circular fringes appears at the centre of field of view. The micrometer reading is noted.

(ii) The mirror M_1 is moved away so that a good number of fringes (say 25) appear at the centre of the field. The micrometer screw reading is again noted.

(iii) The procedure is repeated to take 20 readings. In each reading, say, 25 fringes appearing.

(2) For difference of wavelengths :

(i) The interferometer is adjusted for circular fringes. The mirror M_1 is moved till there is maximum indistinctness of the fringe pattern. The micrometer screw reading is noted.

(ii) By further movement of mirror M_1, the fringe pattern becomes clear. Again the mirror is moved until the next position of maximum indistinctness is obtained. The micrometer reading is noted.

(iii) The procedure is repeated for a number of consecutive positions of maximum indistinctness.

Observations :

(1) Table for wavelength of monochromatic light.

Leastcount of rough micrometer screw = 0·001 cm.

Leastcount of fine micrometer screw = 10^{-5} cm.

S. No.	No. of fringes appeared	Position of mirror M_1				Difference x for 200 fringes (cm.) (200 x)	Mean difference x (cm.)
		Main scale reading (cm.)	R.M.S. reading (cm.)	F.M.S. reading (cm.)	Total (cm.)		
1	0	...	...	...	...	...	
2	25	...	...	...	...	...	
3	50	...	...	...	...	...	
4	75	...	...	...	...	...	...
:	...	...	...	...	...	...	
:	...	...	...	...	...	...	
20	400	...	...	...	...	...	

(2) Table for difference of wavelengths $(\lambda_1 - \lambda_2)$.

S. No.	Position of mirror M_1 for maximum indistinctness				Difference between 5 consecutive positions 5 (x') (cm.)	Mean 5 x' (cm.)	Mean x' (cm.)
	Main scale reading (cm.)	R.M.S. reading (cm.)	F.M.S. reading (cm.)	Total (cm.)			
1	...	...	...	...	...		
2	...	...	...	...	...		
3	...	...	...	...	...		
4	...	...	...	...	...	...	...
:	:	:	:	:	:		
:	:	:	:	:	:		
:	:	:	:	:	:		
:	:	:	:	:	:		
10	...	...	...	...	...		

Calculations :

(1) $$\lambda = \frac{2x}{N} = \frac{2\,(\ldots)}{200} = \ldots \text{ cm.}$$

(2) $$\lambda_1 - \lambda_2 = \frac{\lambda_{av}^2}{2x'} = \frac{(5893 \times 10^{-8})^2}{2\,(\ldots)} = \ldots\text{cm.}$$

where $\lambda_{av} = 5893 \times 10^{-8}$ cm.

Result : (1) The wavelength of sodium light = ... Å

(2) The difference of wavelengths = ... Å

Precautions and Sources of Error :

(1) Glass plate G_1, G_2 and mirrors M_1, M_2 should not be touched or cleaned.

(2) The micrometer screw should be handled carefully.

(3) The screws behind mirror M_2 should be rotated through a very small angle.

(4) There should not be linear or lateral displacement of circular fringes when viewed by eye.

(5) In the position of maximum indistinctness, the fringes should almost disappear.

(6) There should be no disturbance near the experiment.

Viva-Voce

Q. 1. ***What do you mean by interferometer ?***

Ans. Interferometer is a device used to determine the wavelength of light utilising the phenomenon of interference.

Q. 2. ***Are two mirrors simply plane mirrors ?***

Ans. They are excellently optically plane and highly silver polished plane mirrors.

Q. 3. ***What type of glass plates are G_1 and G_2 and how are they mounted?***

Ans. The two plates are optically flat glass plates of same thickness and of the same material. They are parallel to each other and inclined at an angle 45° with the two mirrors. G_1 is semisilvered at the face towards G_2 and G_2, is known as compensating plate.

Q. 4. ***What shapes of fringes do you get ?***

Ans. The fringes may be straight, circular, parabolic etc. depending upon the path difference between the two rays and angle between the two mirrors.

Q. 5. ***How do you get circular fringes ?***

Ans. The circular fringes are obtained when the two mirrors are exactly perpendicular to each other (or they encloses an air film of uniform thickness). The screws provided at the back of mirror M_2 are adjusted for this purpose.

Q. 6. ***Where the circular fringes are formed ?***

Ans. They are formed at infinity and that is why a telescope is used to receive them.

Q. 7. ***What will you observe with white light source ?***

Ans. With white light source, we observe a central white fringe and some coloured fringes placed symmetrical on both sides of central fringe.

Q. 8. ***What are localised fringes ?***

Ans. When the two mirrors are not exactly perpendicular to each other then either straight or parabolic fringes are observed. These are known as localised fringes.

Q. 9. ***When the mirror is moved through a distance $\lambda/2$, how many fringes appear or disappear ?***

Ans. One.

Q. 10. ***Can you measure the difference of two wavelengths with Michelson's interferometer ?***

Ans. Yes. By moving the mirror M_1, the positions of two consecutive maxmum indistinctness are observed. If x be the distance between them, then

$$\lambda_1 - \lambda_2 = \lambda_{av}^2/2x.$$

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EXPERIMENT No. 17

Object : To determine the separation between the plates of a Fabry Perot Etalon.

Apparatus required : Fabry-Perot Etalon spectrometer, condensing lens, reading lamp, sodium lamp.

Formula used :

The condition of maxima in Fabry-Perot Etalon is given by

$$\boxed{2d \cos \theta_n = n \lambda}$$

or

$$\boxed{d = \frac{n}{\cos \theta_n} \frac{\lambda}{2}}$$

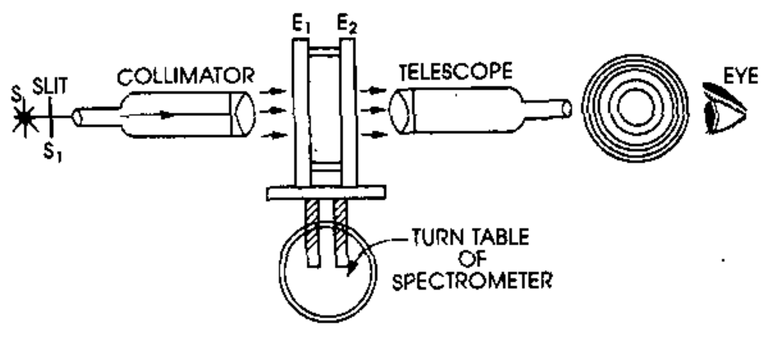
where $d =$ separation between the plates

$n =$ order of interference

$\theta =$ angle of incidence

$\lambda =$ wavelength of light used (5890 Å).

Experimental arrangement and adjustment : The experimental arrangement is shown in fig. (1). In figure, S is a broad source of monochromatic light and S is an adjustable slit. Etalon E_1, E_2 is placed on the turn table of an ordinary



spectrometer. The collimator, collimates the beam which suffers multiple reflections in the air film of Etalon. The transmitted light is collected by telescope. When viewed through the telescope, circular fringes are observed. Sometimes the fringes are not very clear. To obtain a clear fringe pattern, the following adjustment is made : The spectrometer is turned in such a way that light directly from the source falls on the etalon *i.e.* collimator removed from the light path. An oily paper with a fine pin hole is placed in front of the source. Now circular fringes are clearly observed through telescope.

Procedure :

(1) The fringe pattern is brought at the centre of the field of view by adjusting the levelling screws provided at the base of the etalon.

(2) The turn table is fixed and the telescope is moved towards right of the fringe pattern. The cross wire of the telescope is made tangential to the first dark ring and the turn table reading is noted. By moving the telescope, the procedure is repeated for successive dark fringes till the clearly visible fringe is reached.

(3) Procedure no. 2 is repeated towards the left side of fringe pattern.

(4) The angular diameters $2\theta_n$ of the rings are measured as shown in the table on next page.

Observations :

Least count of spectrometer = ...

Table for plotting $\cos\theta_n$ against n.

Ring Number	Angular diameter $2\theta_n$				Difference		Mean $2\theta_n$	θ_n	$\cos\theta_n$
	Reading on left		Reading on right		$c \sim a$ $2\theta_n$	$d \sim b$ $2\theta_n$			
	1st scale (a)	2nd scale (b)	1st scale (c)	2nd scale (d)					
1	...	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...	...	...
5	...	...	...	...	...	...	...	...	...
:	...	...	...	...	...	...	...	...	...
:	...	...	...	...	...	...	...	...	...
20	...	...	...	...	...	...	...	...	...

Calculations : A graph is plotted between $\cos\theta_n$ as a function of n. The graph is shown in fig. (2).

From graph

$$\frac{n}{\cos\theta_n} = \frac{BC}{AB}$$

$$\therefore \quad d = \frac{BC}{AB} \times \frac{\lambda}{2}$$

Here

$$\lambda = 5893 \times 10^{-8} \text{ cm.}$$

Hence the value of d can be calculated.

Result : The thickness of the etalon = ... cm.

Precautions and sources of error :

(i) The centre of the fringe pattern should be made at the centre of field of view.

(ii) While taking readings, the turn table should be fixed.

(iii) Before measuring the diameters of the rings, the telescope should be properly adjusted.

(iv) Cross wire should be focussed tangentially.

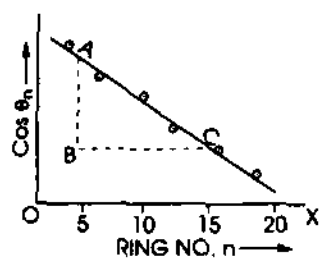


Fig. (2)

Viva-Voce

Q. 1. ***What is a Fabry-Perot etalon ?***

Ans. This is a multiple beam high resolution interferometer designed by Fabry and Perot.

Q. 2. ***What is its construction ?***

Ans. This consists of two semi-silvered (inner side) optically plane and parallel glass plates which are separated at a fixed distance.

Q. 3. ***What is the shape of fringes ?***

Ans. The fringes are circular which are widely separated at the centre while crowded for larger radii.

Q. 4. ***What is the difference between these fringes and those obtained in Michelson's interferometer ?***

Ans. These fringes are much narrower, sharper and brighter than those of Micheloson's interferometer.

Q. 5. ***Where are these fringes formed ?***

Ans. They are formed at infinity.

Q. 6. ***What do you mean by sharpness of fringes ?***

Ans. The sharpness of fringes defines that how rapidly the intensity diminishes on either side of maximum.

Q. 7. ***What is half width of a ring ?***

Ans. This is the total width of a fringe at those points where the intensity has fallen to half the maximum intensity.

Q. 8. ***On what factors the sharpness of maxima depend ?***

Ans. The sharpness depends upon half fringe width, smaller is the half fringe width, sharper is the maxima. Moreover half fringe width decreases as reflection coefficient increases.

Q. 9. ***Instead of spectrometer, can you use a Michelson's interferometer arrangement of Fabry Perot Etalon ?***

Ans. Yes. In this case, mirror M_1 of Michelson's interferometer is removed and Fabry Perot Etalon is mounted on the carriage so that required separation between the two plates may be adjusted.

Q. 10. ***Can you measure the difference of two wavelengths with the help of above arrangement ?***

Ans. Yes. As in case of Michelsons interferometer.

❑❑❑

EXPERIMENT No. 18

Object : To determine the wavelength of prominent lines of mercury by plane diffraction grating.

Apparatus required : A diffraction grating, spectrometer, mercury lamp, prism, reading lens.

Formula used :

The wavelength λ of any spectral lines can be calculated by the formula

$$(a + b) \sin \theta = n\lambda$$

or

$$\boxed{\lambda = \frac{(a + b) \sin \theta}{n}}$$

where $(a + b)$ = grating element.

EXPERIMENT No. (18-1)

Object : To determine the dispersive power of a plane transmission diffraction grating.

Apparatus required : Spectrometer, sodium lamp, grating and reading lens.

Formula used : The dispersive power of a grating $d\theta/d\lambda$ is given by

$$\boxed{\frac{d\theta}{d\lambda} = \frac{n}{(a+b)\cos\theta}}$$

where $(a + b)$ = grating element

n = order of spectrum

θ = angle of diffraction.

Adjustments :

(A) Adjustment of the spectrometer : As described in experiment on Refraction and Dispersion of Light, Expt No. 1 Page 1L.

(B) Grating is adjusted normal to the axis of collimator : See experiment No. 14.

(C) The slit is adjusted parallel to the lines of grating : See experiment No. 14.

Procedure :

For the determination of angle of diffraction, the following procedure is adopted:

(i) Rotate the telescope to the left side of direct image and adjust the specral lines D_1 and D_2 one by one on the cross wire in first order. Note down the readings of both verniers for D_1 and D_2.

(ii) Rotate the telescope further to obtain the second order spectrum. Adjust the cross wire on the spectral lines D_1 and D_2 one by one in second order. Note down the readings of both verniers for D_1 and D_2.

(iii) Now rotate the telescope to the right of direct image and repeat the above procedure for first order as well as for second order.

(iv) Find the difference of same kind of verniers for the spectral lines in first order and then in the second order. The angle is twice the angle of diffraction. Half of this angle will be the angle of diffraction. In this way the angles of diffraction for D_1 and D_2 in first order and in second order are known.

Observations :

No. of rulings per inch on the grating, N = ...

Least count of the spectrometer = ...

Reading of telescope for direct image = ...

Reading of circular scale when reflected image is obtained on the cross wire = ...

Reading after rotating the prism table through 45° = ...

Table for determination of angle of diffraction.

Order of Spectrum	Kind of Verniers	Specification of the line	Spectrum on left side Reading of Telescope			Spectrum on right side Reading of Telescope			$2\theta = a - b$	Mean θ	$d\theta$	$\cos\theta$
			M.S. reading	V.S. reading	Total a deg.	M.S. reading	V.S. reading	Total b deg.				
First	V_1	D_1	...	...	...	...	...	...	...	...	...	...
	V_2		...	...	...	...	...	...	...			
	V_1	D_2	...	...	...	...	...	...	...	...	...	...
	V_2		...	...	...	...	...	...	...			
Second	V_1	D_1	...	...	...	...	...	...	...	...	...	...
	V_2		...	...	...	...	...	...	...			
	V_1	D_2	...	...	...	...	...	...	...	...	...	...
	V_2		...	...	...	...	...	...	...			

Calculations : Grating element

$$(a+b) = \frac{2.54}{N} = \text{......} \text{ per cm.}$$

For Ist order, $$\frac{d\theta}{d\lambda} = \frac{1}{(a+b)\cos\theta} = \text{......}$$

Also $$\frac{d\theta}{d\lambda} = \frac{\theta_2 - \theta_1}{\lambda_2 - \lambda_1} = \text{......}$$

For second order $$\frac{d\theta}{d\lambda} = \frac{2}{(a+b)\cos\theta} = \text{......}$$

Also $$\frac{d\theta}{d\lambda} = \frac{\theta_2 - \theta_1}{\lambda_2 - \lambda_1} = \text{......}$$

Result : The dispersive power of grating in first order = ... and the second order = ...

The theoretical and experimental values are approximately equal.

Viva-Voce

Q. 1. ***What do you mean by diffraction of light ?***

Ans. When light falls on an obstacle or small aperture whose size is comparable with the wavelength of light, there is a departure from straight line propagation, the light bends round the corners of obstacle or aperture. This bending of light is called diffraction.

Q. 2. ***What is difference between interference and diffraction ?***

Ans. Interference of light takes place due to the superposition of two waves coming from two different coherent sources while diffraction is due to the mutual interference of secondary wavelets originating from the various points of the wavefront which are not blocked off by the obstacle.

Q. 3. ***What is a diffraction grating ?***

Ans. An arrangement consisting of a large number of parallel slits of same width and separated by equal opaque spaces is known as diffraction grating.

Q. 4. ***What are the requisities of a good grating ?***

Ans. The lines should be exactly parallel, uniform, equidistant and of equal width.

Q. 5. ***What is grating element ?***

Ans. The distance between the centres of two successive slit is called grating element. This is denoted by $(a+b)$ where a is width of transparent part and b is width of opaque part.

Q. 6. ***How many orders do you get here ? Why ?***

Ans. We know that $(n)_{max} = \frac{a+b}{\lambda}$. The grating which we are using have 15,000 lines per inch. Hence

$$(a+b) = \frac{2.54}{15{,}000}, \quad \lambda = 5893 \times 10^{-8} \text{ cm.}$$

$$\therefore \quad (n)_{max} = \frac{2.54}{15{,}000 \times 5893 \times 10^{-8}} = 2.875 < 3$$

Thus we get only two orders.

Q. 7. ***What is main difference between a prism spectrum and a grating spectrum?***

Ans. In grating spectrum red colour is deviated most and violet least while this order is reversed in prism spectrum.

Q. 8. ***Why is the prism spectrum more intense than the grating spectrum?***

Ans. In case of a prism, the light is concentrated in one spectrum while in case of grating, the incident light is diffracted into spectra of various orders; moreover, most of the light is concentrated in direct image where no spectrum is formed.

Q. 9. *What is dispersive power of grating ?*

Ans. The rate of change of angle of diffraction with wavelength is defined as the dispersive power of grating. This is expressed as

$$\frac{d\theta}{d\lambda} = \frac{n}{(a+b)\cos\theta}$$

Dispersive power is more for higher orders.

Q. 10. *On what factors does the dispersive power of a grating depend?*

Ans. The dispersive power depends upon (i) grating element, (ii) angle of diffraction and (iii) order of spectrum.

Q. 11. *What will happen if the width of clear space and ruled space is made equal?*

Ans. Even order spectra (2, 4, 6, 8 . . . . . etc.) will be absent.

EXPERIMENT No. 19

Object : To determine the wavelength of monochromatic light by diffraction at a straight edge.

Apparatus required : Optical bench, a straight edge (say a razor blade) slit, stand and travelling microscope.

Description of apparatus and theory :

The experimental arrangement is shown in fig. (1).

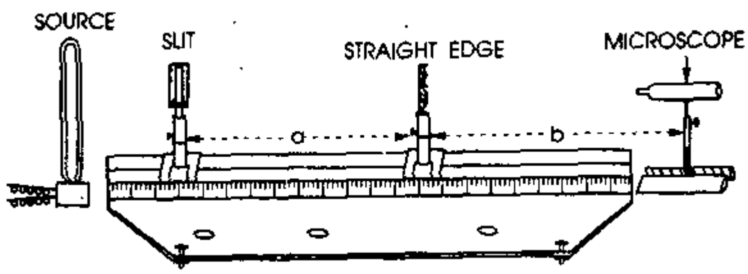


Fig. (1)

The optical bench used in the experiment consists of a heavy iron base supported on four levelling screws. There is a graduated scale along one of its arms. The bench is provided with three uprights which can be clamped anywhere and their position can be read by means of vernier attached to it. Each of the uprights is subjected to the following motions :

(i) motion along bench,
(ii) transverse motion,
(iii) rotation about the axis of upright.

The straight edge is set up in one of stands on an optical bench, parallel to the length of the slit which is illuminated by monochromatic light. The fringes are observed with the help of travelling microscope.

For first maximum,

$$x_1 = \sqrt{\left\{\frac{b(a+b)\lambda}{a}\right\}}$$

and for nth maximum,

$$x_n = \sqrt{\left\{\frac{b(a+b)(2n-1)\lambda}{a}\right\}}$$

Subtracting, we get

$$x_n - x_1 = \sqrt{\left\{\frac{b(a+b)\lambda}{a}\right\}}\,[\sqrt{(2n-1)} - 1]$$

or $$(x_n - x_1)^2 = \frac{b\,(a+b)\,\lambda}{a}\;[\sqrt{(2n-1)} - 1]^2$$

or $$\lambda = \frac{(x_n - x_1)^2\,a}{(a+b)\,b\,[\sqrt{(2n-1)} - 1]^2}$$

Using the above formula λ can be calculated.

Procedure :

The experiment is divided into the following two parts :

(i) Obtaining perfect fringes.

(ii) Measurement of $(x_n - x_1)$.

(i) Adjustment for getting perfect fringes :

In order to secure well defined fringes in the field of view of eyepiece, the following adjustments are made :

(a) the optical bench should be levelled,

(b) the eyepiece should be focussed on the cross wires,

(c) axis of the slit should be made vertical,

(d) slit, straight edge and micrometer eyepiece should be adjusted to the same height.

(e) the edge of the razor blade and the slit are made parallel, and

(f) the lateral shift is removed.

Procedure for the various adjustments :

(a) Level the bed of the optical bench with the help of spirit level and levelling screws.

(b) Point the micrometer eyepiece towards a white wall. By moving the tube containing the eye lens in or out focus the eyepiece on the cross-wire till they are distinctly visible. Set one of them vertical by rotating the eyepiece as a whole.

(c) Illuminate the slit with the help of sodium lamp. Now see the slit in the micrometer eyepiece and rotate the slit in its own plane with the help of tangent screw, till it becomes vertical.

(d) The upright carrying the straight edge is placed as close to the slit as possible. The edge of the razor blade is made vertical approximately with the help of tangent screw attached with it. See the diffracted images of the slit and adjust the height of slit and razor blade so to obtain the maximum length of the images of the slit. Adjust the height of the micrometer eyepiece such that images of the slit are visible in the centre of the field of view of the eyepiece.

(e) Put the upright carrying the micrometer eyepiece near the straight edge. Fringes will be visible in the field of view. They are made clear by gradually narrowing the slit.

In case the fringes are not sharp, rotate the edge of the razor blade in its own plane with the help of tangent screw till the fringes are sharp. In this case slit and the edge of razor blade will be parallel to each other.

(f) The lateral shift will exist so long as the line joining the slit and the edge of the razor blade is not parallel to the bed of the bench.

In order to adjust the system for no lateral shift, the eyepiece is moved away from the straight edge. In this case the fringes will move to the right or left, but with the help of the base screw provided with straight edge it is moved at right angle to the bench in a direction to bring the fringes back to their original position.

Now move the eyepiece towards the straight edge and same adjustment is made with the help of eyepiece.

Using the process again and again, the lateral shift is removed.

(ii) Measurement of $x_n - x_1$:

(i) Find out the least count of the microscope and adjust it on the first maximum. Note down this reading.

(ii) Now adjust the microscope on a clearly visible maximum and again note down its position.

(iii) The distance between slit and straight edge (a) is noted.

(iv) The distance between straight edge and microscope (b) is also noted.

Observations :

(i) Distance between slit and straight edge (a) = ... cm.

Distance between straight edge and microscope (b) = ... cm.

(ii) Table for the determination of $(x_n - x_1)$.

Least count of the microscope = ... cm.

S. No.	Microscope reading for x_1			x_1	Microscope reading for x_n			x_n	n	$(x_n - x_1)$ cm.
	M.S. readng	V.S reading	Total cm.		M.S. readng	V.S reading	Total cm.			
1	...	...	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...	...	...	...
5	...	...	...	...	...	...	...	...	...	...

Calculations : The wavelength of monochromatic light is given by

$$\lambda = \frac{(x_n - x_1)^2 \, a}{(a+b)\,(b)\,[\sqrt{(2n-1)} - 1]^2}$$

Result : The wavelength of the monochromatic light

= ...... Å

Standard Result : = ... Å

Percentage Error : = ... %.

Sources of Error and Precautions :

(i) The straight edge should be parallel to the slit.

(ii) Make the slit as narrow as possible until the fringes are most clear.

(iii) The cross wire of the microscope should be well focussed on the fringes.

(iv) Distance (a) and (b) should be measured accurately.

Viva-Voce

Q. 1. ***What thing do you use for straight edge ?***

Ans. We use razor blade as straight edge.

Q. 2. ***Where do you place the razor blade ?***

Ans. We place the razor blade on the bench of biprism experiment between slit and eyepiece.

Q. 3. ***What are two kinds of diffraction ?***

Ans. (i) Fresnel's diffraction, in this class the source and screen are placed at finite distances from diffracting system.

(ii) Fraunhofer diffraction, in this class the source and screen are placed at infinity or effectively at infinity by using convex lenses.

Q. 4. ***Give example of Fresnel's diffraction and Fraunhofer diffraction.***

Ans. The diffraction by straight edge comes under Fresnel's class while diffraction by grating is the example of Fraunhofer class.

Q. 5. ***What is the nature of fringes observed in this experiment ?***

Ans. Inside the geometrical shadow, the intensity of light falls off rapidly without any maxima and minima while outside the geometrical shadow there are diffraction bands of diminishing intensity.

Q. 6. ***What type of source are you using in this experiment ?***

Ans. Monochromatic source of light.

Q. 7. ***What will happen if the source is not monochromatic ?***

Ans. The bands will be coloured, the blue bands appearing near the edge.

Q. 8. ***What is the importance of this experiment in regard to the wave theory of light ?***

Ans. As the shadow cast by straight edge is not sharp, so the propagation is not rectilinear.

❑❑❑

EXPERIMENT No. 20

Object : To determine the resolving power of a telescope.

Apparatus required : Telescope with a rectangular adjustable slit, a black cardboard with narrow white strips on it, travelling microscope and metre scale.

Formula used :

The theoretical and practical resolving powers are given by

$$\text{Theoretical resolving power} = \frac{\lambda}{a}$$

and

$$\text{Practical resolving power} = \frac{d}{D}$$

where λ = mean wavelength of light employed,

a = width of the rectangular slit for just resolution of two objects.

d = separation between two objects.

D = distance of the objects from the objective of the telescope.

Hence $$\frac{\lambda}{a} = \frac{d}{D}.$$

Theory of the experiment :

Rayleigh's criterion of resolution : According to Rayleigh's criterion, two equally bright sources can be just resolved by any optical system when their distance apart is such that in the diffraction pattern, the maximum due to one falls on the minimum due to the other.

Resolving power of Telescope : The resolving power of a telescope may be defined as the inverse of the least angle subtended at the objective by two distant point objects which can be just distinguished as separate in its focal plane.

Let a beam of monochromatic light starting from a distant object O (not shown) be incident normally on a rectangular aperture AB fitted infront of the telescope objective. Let AQ represents the incident wavefront which is brought to a focus F and observed magnified by means of eyepiece. The intensity pattern at F is shown by thick curved line.

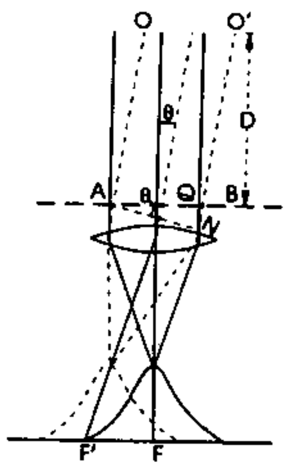


Fig. (1)

Consider again an object O' towards the right of O whose pattern is formed towards left of the F. The pattern is formed at F' as shown by dotted curve. The wave front due to the incident light is shown by AN. According to the Rayleigh criterion, the two objects can only be resolved when the maximum due to one falls on the minimum due to the other as shown in fig. (1).

As the aperture is rectangular the minimum due to one will fall on the maximum due to the other when $QN = \lambda$. The angle between the two wavefronts, is,

$$\theta = \frac{AQ}{AN} = \frac{\lambda}{a}$$

where a is the aperture and θ is the angle subtended by two objects OO' at the objective of telescope.

Again $$\theta = \frac{OO'}{D} = \frac{d}{D} = \frac{\lambda}{a},$$

where d is the distance between two objects and D is their distance from the objective of telescope.

Procedure :

(i) Mount the telescope on a stand such that its axis lies horizontal and the rectangular lines marked on cardboard or glass on the another stand such that they are vertical. Place the two stands at a suitable distance (say about 5 or 6 ft.) fig. (2).

(ii) Illuminate the object with source of light.

Now open the slit with the help of micrometer screw and move the telescope in the horizontal direction such that the images of two vertical sources are in the field of view of the eyepiece.

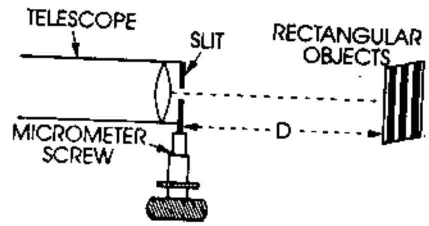


Fig. (2)

(ii) Gradually reduce the width of the slit till the two images just cease to appear as two. Note down the reading of the micrometer. Again close the slit completely and note down the micrometer reading. The difference of the two readings gives the width of the slit (a) just sufficient to resolve the two images.

Or

If the slit is not provided with micrometer arrangement, the slit is gradually reduced till the two images cease to appear two. Take the slit and measure its width with the help of travelling microscope.

(iv) Measure the width (d) of white or black rectangular strips with the help of travelling microscope.

(v) Measure the distance between the object and the slit which gives D.

(vi) The experiment is repeated for different values of D.

Observations :

(i) Mean value of $\lambda = 5000 \times 10^{-8}$ cm.

(ii) Table for width (a) of slit when micrometer arrangement is attached.

Least count of screw of micrometer = ... cm.

S. No.	Slit reading						Width of the slit a = (X ~ Y)	Theoretical resolving power (λ/a)	Distance D cm.
	Slit when images cease			When slit is closed					
	M.S. reading	V.S. reading	Total X cm	M.S. reading	V.S. reading	Total Y cm.			
1	...	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...	...	...

Table for the width of slit (a). When micrometer arrangement is not used.

Least count of microscope = ... cm.

S. No.	Distance D	Microscope reading						a = Y − X cm.
		ONE END			OTHER END			
		M.S.	V.S.	Total X cm	M.S.	V.S.	Total Y cm	
1	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...	...

(ii) Table for the distance between two Objects (d)

Least count of microcope = ... cm.

Micrometer reading						d = Y − X cm.
ONE END			OTHER END			
M.S.	V.S.	Total X	M.S.	V.S.	Total Y	
...	...	...	...	...	...	...

Result : A comparison of theoretical and practical resolving powers of the telescope is shown in the table.

Theoretical and Practical Resolving Powers :

Distance	Theoretical (λ/a) resolving power	Practical (d/D) resolving power
...	...	...
...	...	...
...	...	...

Precautions and Sources of Error :

(i) The axis of telescope should be horizontal.
(ii) The rectangular object drawn on the card-board should be vertical.
(iii) Backlash error in the micrometer screw should be avoided.
(iv) The plane of the slit should be parallel to the objects.
(v) The width a should be measured carefully.
(vi) The minimum width of slit for resolution should be adjusted very carefully.
(vii) The distance D should be measured from the slit of the telescope to the card-board.

Viva-Voce

Q. 1. ***What do you mean by resolving power of a telescope ?***

Ans. The resolving power of a telescope is defined as the reciprocal of the smallest angle subtended at the objective by two distinct points which can be just seen as separate through the telescope.

Q. 2. ***On what factors does the resolving power depend ?***

Ans. The resolving power of a telescope is given by

$$\frac{1}{d\theta} = \frac{d}{1 \cdot 22\, \lambda}$$

Resolving power is directly proportional to d *i.e.*, a telescope with objective of large diameter has higher resolving power and inversely proportional to λ.

Q. 3. ***Define the magnifying power of the telescope.***

Ans. The magnifying power of a telescope is defined as the ratio of angle subtended at the eye by the final image to the angle subtended at the eye by object when viewed at its actual distance.

Q. 4. ***What is Rayleigh criterion of resolution ?***

Ans. According to Rayleigh criterion, two point sources are resolvable by an optical instrument when the central maximum in the dffraction pattern of one falls over the first minimum in the diffraction pattern of the other and vice versa.

Q. 5. ***Why have the objectives of telescopes large apertures ?***

Ans. The resolving power is increased.

Q. 6. ***What is the resolving power of a normal eye ?***

Ans. The resolving power of normal eye is about one minute.

Q. 7. ***What does indicate the term 200 inch written on a telescope ?***

Ans. This indicates that the diameter of the objective of a telescope is 200 inches.

Q. 8. ***What will be the resolving power of this telescope ?***

Ans. It is about 1/40th of a second for sunlight.

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EXPERIMENT No. 21

Object : To determine the resolving power of a grating.

Apparatus used : Plane diffraction grating, spectrometer, mercury lamp, prism, a rectangular aperture of adjustable width, reading lens.

Formula used :

The resolving power $\lambda/d\lambda$ of a plane diffraction grating is given by

$$\boxed{\frac{\lambda}{d\lambda} = N_0\, n,}$$

where $d\lambda$ is the smallest wavelength difference between the two spectral lines, which are just resolved by the grating.

$N_0 =$ Total number of lines in the exposed width of the grating in just resolution position, and

$n =$ order of the spectrum.

Procedure :

(1) The spectrometer adjustments are made as described under the spectrometer head in the general section on refraction and dispersion of light.

(2) Procedure (B) of expt. no. 9 is then adopted for normal incidence setting of the grating on the prism table.

(3) The slit should be adjusted parallel to the ruling of the grating [procedure (c) of expt. no. 14].

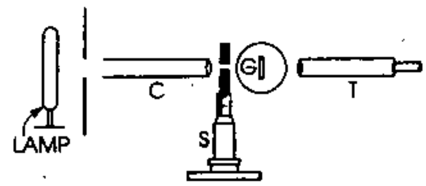

Fig. (1)

(4) Mount the rectangular aperture of adjustable width on the prism table infront of the grating or on the collimating lens of the collimator such that its axis is parallel to the slit.

(5) Now keep the aperture fully opened and turn the telescope to the left to the direct image of slit till two yellow lines of first order of mercury spectrum are seen in the field of view.

(6) Gradually reduce the width of the aperture till the two spectral lines just cease to appear to as separate. Measure this width of the aperture with the help of a travelling microscope.

(7) Again put the aperture in the same position and open it fully. Now turn the telescope to the right of the direct slit image till the two yellow lines of the Ist order of Hg spectrum are seen, and again reduce the width of the aperture till the two lines cease to appear as separate. Again measure this width of aperture by microscope. Take mean of the widths measured this time and that measured in observation 6.

(8) Repeat the same procedure for two yellow lines in the second order.

(9) Note the number of lines ruled per cm. on the grating.

Observations :

(1) No. of lines per cm. of the grating,

$$\text{(grating element)} = \frac{2 \cdot 54}{N}$$

$$= \ldots \text{ per cm.}$$

where N is the number of rulings per inch on the grating.

(2) Table for the measurement of rectangular aperture for just resolution:

S. No.	Side	*Microscope reading* when its cross wire is set at		Exposed width of the aperture for just resolution $(x \sim y)$	Mean aperture width $(x \sim y)$	No. of lines of grating in this width N_0	Order of spectrum n
		One end of the aperture x cm.	Other end of the aperture y cm.				
1	Left Side	...	...	...	...	...	1
2	Right Side	...	...	...			
3	Left Side	...	...	...	...	...	2
4	Right Side	...	...	...			

Calculations :

(1) The difference in wavelengths of the two yellow lines of Hg spectrum,

$$= 5790 - 5770$$
$$= 20 \text{ A.U.}$$

(2) Mean wavelength,

$$\lambda = \frac{\lambda_1 + \lambda_2}{2}$$
$$= \frac{5770 + 5790}{2}$$
$$= 5780 \text{ A.U.}$$

(3) Therefore theoretical resolving power,

$$\frac{\lambda}{d\lambda} = \frac{5780}{20}$$
$$= 289$$

(4) We have calculated already that the number of lines per cm. of grating = 2·54/N. Therefore :

Order of spectrum $= n$	No. of lines in mean width $x \sim y = N_0$	Product $N_0 \cdot n$	$\lambda/d\lambda$	Difference
1	$\frac{2 \cdot 54}{N} \times (x \sim y)$ $= \ldots$	...	...	...
2	$\frac{2 \cdot 54}{N} \times (x \sim y)$ $= \ldots$	...	...	...

Result : Comparison of theoretical and practical resolving power is shown in the table.

Sources of Error and Precautions :

Same as in experiment No. 18.

Viva-Voce

Q. 1. ***What do you mean by resolving power of grating ?***

Ans. The resolving power of grating is defined as the capacity to form separate diffraction maxima of two wavelengths which are very close to each other.

Q. 2. ***How the resolving power of a grating is measured ?***

Ans. This is measured by $\lambda/d\lambda$. The value is $N_0 n$, where n is order of spectrum and N_0 the number of lines on grating.

Q. 3. ***Upon what factors does the resolving power of a grating depend ?***

Ans. The resolving power depends upon the total number of rulings N in the grating and the order of spectrum.

Q. 4. Does the ...

Practical Physics-II

$$i = \frac{180 - \alpha}{2}$$

For $\alpha = 10°$, $i = \frac{180 - 10}{2} = 85°$

and $\mu = \frac{\sin i}{\sin r}$ or $r = \sin^{-1}\left(\frac{\sin i}{\mu}\right)$

(iv) The angle of incidence is varied in steps of 10° by turning the teles... and angle θ is measured for all values of i.

Observations and Calculations :

(1) Table for the angle of prism (A)

S. No.	Position of telescope for the image of slit from one face		Position of telescope for the image of slit from other face		Difference 2A			M...
	Vernier V_1	Vernier V_2	Vernier V_1	Vernier V_2	V_1	V_2	Mean	
1	...	...	...	...	...	...	...	
2	...	...	...	...	...	...	...	
3	...	...	...	...	...	...	...	

(2) Table for the angle of minimum deviation (δ_m)

S. No.	Position of telescope for the minimum deviation		Position of telescope for direct image of the slit		Difference			M...
	Vernier V_1 (a)	Vernier V_2 (b)	Vernier V_1 (c)	Vernier V_2 (d)	V_1 $(a - c)$	V_2 $(b - d)$	Mean	
1	...	...	...	...	...	...	...	
2	...	...	...	...	...	...	...	
3	...	...	...	...	...	...	...	

Angle of the prism $A = \ldots$

$$\therefore \quad \mu = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin(A/2)} = \ldots \quad \text{and } \phi = \tan^{-1}\mu = \ldots$$

(3) Readings for setting the plane of vibration of incident light at 45° with the plane of incidence.

(i) Position of telescope on veriner V_1 for direct image of slit

$= \ldots$

(ii) The angle through which the telescope is rotated

$= (180 - 2\phi) = \ldots$

(iii) New position of telescope on vernier = ...

(iv) Reading of analyser for minimum intensity $\beta = \ldots$

(v) Reading of polariser for minimum intensity = ...

(vi) Reading of polariser after rotation of 45° = ...

(4) Table for finding θ for different values of i.

S. No.	Angle of rotation of telescope α	Reading of analyser for minimum intensity β'	Initial reading of analyser	...$-\beta$)	tan...
1	10°			...	...
2	20°	...		...	...
3	30°	...		...	...
4	40°	...		...	...
5	50°	...	...	...	...
6	60°	...		...	...
7	70°	...		...	...
8	80°	...		...	
9	90°	...			

(5) **Table for calculation of [$- \cos(i-r)/\cos(i+r)$]**

S. No.	Angle of incidence $i = \left(\frac{180° - \alpha}{2}\right)°$	Angle of refraction $r = \sin^{-1}\left(\frac{\sin i}{\mu}\right)$	$(i-r)$	$(i+r)$	$-\frac{\cos(i-r)}{\cos(i+r)}$
1	...	...	...	...	...
2	...	...	...	...	...
3	...	...	...	...	...
4	...	...	...	...	...
5	...	...	...	...	...
6	...	...	...	...	...
7	...	...	...	...	...
8	...	...	...	...	...
9	...	...	...	...	...

A graph is plotted between $\tan\theta$ and corresponding values of $-\frac{\cos(i-r)}{\cos(i+r)}$. The graph comes out to be a straight line inclined at an angle 45° to the axes as shown in fig. (3).

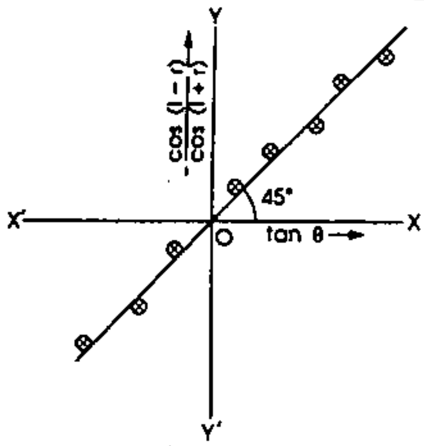

Fig. (3)

Result : The graph between $\tan\theta$ and $-[\cos(i-r)/\cos(i+r)]$ is a straight line passing through origin and inclined at an angle 45° with the axes. This shows the verification of Fresnel's formulae for reflection.

Sources of Error and Precautions :

(1) Spectrometer should be adjusted properly.

(2) The reflecting face of the prism should be clean.

(3) The angle θ should be measured for several values of i at interval of 10°.

(4) To find the value of θ, the analyser is set several times to minimise the intensity inside telescope and then mean value should be recorded.

(5) The setting of polariser should not be disturbed throughout the part third of the experiment.

□□□

EXPERIMENT No. 23

bject : To determine the radii of curvature of the surfaces of a convergent lens nd hence to calculate its refractive index.

pparatus used : Convergent lens, pin, stand, clean mercury shallow dish, and rew gauge.

rmula used : The radius of curvature of the lens is given by

$$\boxed{R = \frac{uf}{f - v}}$$

ere u = distance of the pin from the lens,

f = focal length of the lens.

The refractive index of the material of the lens is calculated from the following rmula

$$\boxed{\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)}$$

where R_1 = radius of curvature of first surface of lens

R_2 = radius of curvature of second surface of lens.

Procedure :

(i) The thickness t of the lens is measured with the help of screw gauge.

(ii) The focal length of the lens is determined by *u-v method on the optical* bench. The focal length may also be calculated with the arrangement shown in fig. (1). The lens is put on a plane mirror and *a pin is mounted* on a vertical stand. The pin is moved up or down and adjusted such that there is no parallax between the pin and its image *formed by the lens*. The distance of the pin from the plane mirror give the focal lenth of the lens.

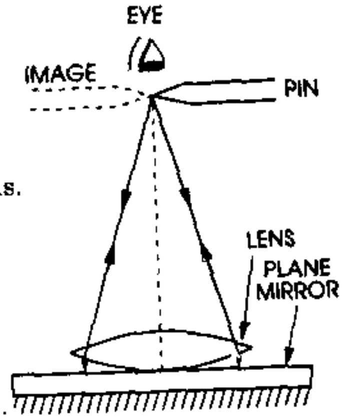

Fig. (1)

(iii) The lens is floated on the mercury contained in a dish. The pin is mounted on the vertical stand such that its tip is vertically above the centre of the lens as shown in fig. (2). The position of the pin is again adjusted till there is no parallax between the pin and its image. The distance d of the pin from the upper surface of the lens is measured. To obtain the value of u, half of the thickness of lens is added in d.

(iv) The lens is inverted and procedure (iii) is again repeated to know d for the second surface of the lens.

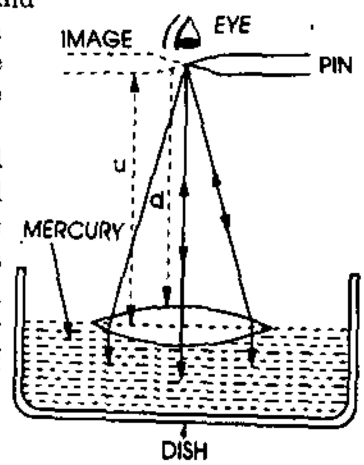

Fig. (2)

Observations :

(1) Thickness of the lens by screw gauge t = ... cm.

(2) Focal length of the convex lens of f = ... cm.

(3) Table for R_1 and R_2

Surface of the lens	distance d of pin from the top of the lens cm.	$u = d + \frac{t}{2}$	$R = \frac{uf}{f-u}$	Mean cm.
First surface	...	...	...	
	...	...	...	R_1 = ...
	...	...	...	
Second surface	...	...	...	
	...	...	...	R_2 = ...
	...	...	...	

Calculations : $R_1 = \frac{u_1 f}{f - u_1}$ = ... cm. ; $R_2 = \frac{u_2 f}{f - u_2}$ = ... cm.

Further, $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = (\mu - 1)\left(\frac{R_1 + R_2}{R_1 R_2}\right)$.

$$\mu = \left[\frac{f(R_1 R_2)}{(R_1 + R_2)}\right] = ...$$

Result : The refractive index of the material of the given lens = ...

Sources of Error and Precautions :

(i) Mercury taken should be pure.

(ii) Parallax should be removed very carefully.

(iii) Surfaces of the lens should be clean.

(iv) Half of the thickness of lens should be added in d to obtain the value u.

(v) Focal length should be measured accurately.

EXPERIMENT No. 24

Object : To determine the refractive index of the material of a concave lens.

Apparatus used : Optical bench, Pins, concave lens, metre scale, plane mirror, spherometer.

Formula used : The refractive index μ of the material of a concave lens is given by

$$\boxed{\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)}$$

where, f = focal length of the concave lens

R_1 = radius of curvature of first surface

R_2 = radius of curvature of second surface.

The radius of curvature R is given by

$$\boxed{R = \frac{l^2}{6h} + \frac{h}{2}}$$

where l = distance between the two legs of the spherometer

h = difference of readings of the spherometer when it is placed on the lens as well as when placed on plane surface.

Procedure.

(A) Determination of the focal length of concave lens.

(i) The given convex lens is mounted on one of the uprights of optical bench. A bright vertical pin O (mounted on the upright of optical bench) is placed at a certain distance from concave lens as shown in fig. (1).

(ii) The image of O is viewed through the lens from the other side. Another pin I is placed on the object side. The pin I is moved and adjusted such that there is no parallax between the image of O and pin I. Then I is the position of the image of O.

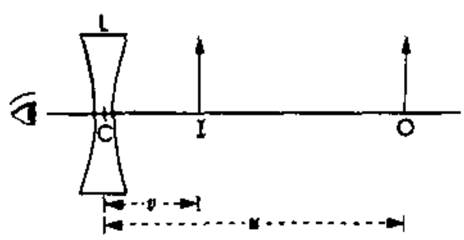

Fig. (1)

(iii) The positions of C, I and O are noted.

(iv) The experiment is repeated three or four times.

(B) Determination of radius of *curvature.*

(i) Determine the least count of the sphermometer.

(ii) The spherometer is placed on the plane surface and the screw is lowered until it just touches the surface. Note down the reading of spherometer.

(iii) Next, the spherometer is placed on one curved surface of the lens and the screw is lowered until it just touches the surface. The spherometer reading is noted.

(iv) Procedure (iii) is repeated for the second curved surface of the concave lens.

(v) Press the legs of the spherometer on a sheet of plane paper. Complete an equilateral traingle with the impressions of legs. Measure the sides of the triangle with meter scale. The average of the lengths of the three sides gives l.

Observations :

(A) Table for focal length f.

S. No.	Position of lens a cm	Position of object b cm.	Position of image pin c cm.	u = b ~ a cm.	v = c ~ a cm	$f = \frac{uv}{v-u}$	Mean f cm,
1	...	...	...	...	...	...	
2	...	...	...	...	...	...	...
3	...	...	...	...	...	...	
4	...	...	...	...	...	...	

(B) Table for h

Least count of screw gange = $\frac{\text{Pitch of the screw}}{\text{Number of divisions on circ}}$

= ... cm.

S. No.	Spherometer reading on			h_1 $(b-a)$ cm	h_2 $(c-a)$ cm		h_2
	Plane surface a cm	Ist surface of lens b cm.	2nd surface of lens c cm				
1.	...	...	...	...	...		
2.	...	...	...	...	...	...	...
3.	...	...	...	...	...		
4.	...	...	...	...	...		

(c) Average length of legs of spherometer l = ... cm.

Calculations :

Focal length of concave lens $f = \frac{uv}{v-u}$ = ... cm.

Radius of first surface $R_1 = \frac{l^2}{6h_1} + \frac{h_1^2}{2}$ = ... cm.

Radius of the second surface

$$R_2 = \frac{l^2}{6h_2} + \frac{h_2}{2} = \ldots \text{ cm.}$$

Further

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

$$= (\mu - 1)\left(\frac{R_1 + R_2}{R_1 R_2}\right)$$

or

$$\mu = \left[1 + \frac{R_1 R_2}{f(R_1 R_2)}\right] = \ldots$$

Result : The refractive index of concave lens = ...

Precautions and Sources of Error :

(i) Optical bench should be levelled.

(ii) Object pin and image pin heights should be upto the centre of concave lens.

(iii) Radius of curvature of both the surfaces should be determined.

(iv) Spherometer readings should be taken carefully.

(v) At least three or four readings should be taken for the determination of focal-length of the lens.

□□□

EXPERIMENT No. 25

Object : To determine the refractive index of a liquid using Pulfrich refractometer

Apparatus used : Pulfrich refractometer, glass cell, liquid, source of light, righ angled prims.

Formula used : *The refractive index of liquid is given by*

$$\boxed{m = \sqrt{(\mu_0^2 - \sin^2 i)}}$$

where μ_0 = refractive index of the material of the prism.

i = minimum angle of emergence.

Description of apparatus :

Pulfrich refractometer is shown in fig. (1). It consists of a right angled having it two faces perfectly plane. The liquid whose refractive in determined is taken in a glass cell B and placed on prism A. Light is incident in a direction parallel to the horizontal surface so that light entering prism A is incident as the critical angle C with the normal. Finally it emerges from the prism at an angle i. The emergent lgiht is viewed with the help of telescope T which can be moved on a graduated circular scale.

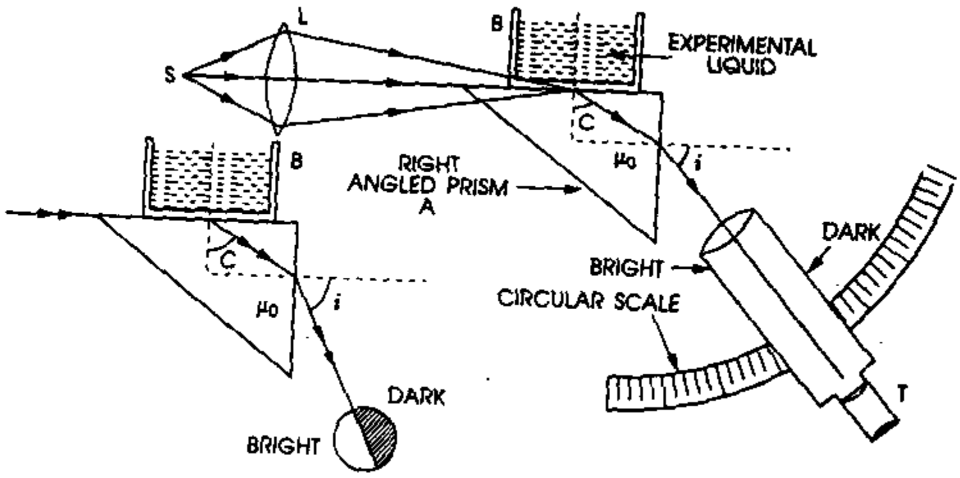

Fig. (1)

Procedrue :

(i) The glass cell is cleaned and experimental liquid is filled in it. This is properly placed at its place in the apparatus.

(ii) The source of light is switched on and the light is allowed to incident on the prism-cell system.

(iii) The emergent light from the prism is viewed by telescope T. The telescope is moved on the circular scale. One side of field of view appears dark while the other side appears bright.

The telescope is adjusted so that the cross wire lies on the dark edge of the field of view. This gives the position of the minimum angle of emergence i.

(iv) The experiment is repeated for three or four times to obtain the minimum angle of emergence. Then mean i is calculated.

Note. In modern instruments, the circular scale is calibrated in terms of the refractive index. So the readings can be read directly from the scale. In some cases, a table is provided with the instruments which gives the value of μ corresponding to i.

Observations :

(1) Refractive index of the material of the prism, $\mu_0 = \ldots$

(2) Table for the minimum angle i of emergence

S. No.	Minimum angle of emergence, i deg.	Mean, i deg.	Sin i
1	...		
2	...	...	...
3	...		
4	...		

Calculations : $\mu = \sqrt{\mu_0^2 - \sin^2 i} = \ldots$

Result : The refractive index of given liquid = ...

Precautions and sources of errror.

(1) There should be no air bubble in the liquid.

(2) The glass cell should be clean.

(3) The field of view should be judged correctly.

(4) The position of the cross-wire should be set on field of view carefully.

(5) A number of readings of the measurement of i should be taken.

UNIVERSAL PHYSICAL C NTS

(1) Elementary Charge = $e = 1.602 \times 10^{-19}$ C
(2) Electron rest mass : $m_e = 9.110 \times 10^{-3}$ kg.
(3) Proton rest mass : $m_p = 1.6735 \times 10^{-27}$ kg
(4) Neutron rest mass : $m_n = 1.675 \times 10^{-27}$ kg.
(5) Atomic mass unit : 1 amu = 1.661×10^{-27} kg.
(6) Planck constant : $h = 6.626 \times 10^{-34}$ J.s
: $h' = h/2\pi = 1.055 \times 10^{-34}$ J.s.
(7) Boltzmann constant : $k = 1.381 \times 10^{-23}$ J.K^{-1}
(8) Stefan-Boltzmann constant : $\sigma = 5.670 \times 10^{-8}$ W.m^{-2}.K^{-4}
(9) Wien's displacement law constant ; $b = 2.898 \times 10^{-3}$ m.K
(10) Speed of light in vacuum : $c = 2.998 \times 10^{23}$ m.s^{-1}
(11) Avogadro number : $N_A = 6.022 \times 10^{23}$ per mole.
(12) Bohr magneton : $\mu_B = 9.274 \times 10^{-24}$ A.m^2
(13) Nuclear magneton : $\mu_n = 5.051 \times 10^{-27}$ A.m^2
(14) First Bohr radius : $a_0 = 5.292 \times 10^{-11}$ m.
(15) Classical electron radius : $\gamma_e = 2.818 \times 10^{15}$ m.
(16) Standard volume of ideal gas : $V_0 = 22.414 \times 10^{-3}$ m^3/mole
(17) Gravitational constant : $G = 6.673 \times 10^{-11}$ N.m^2.kg^{-2}
(18) Standard acceleration of free fall : $g = 9.807$ m.s^{-2}
(19) Faraday constant : $F = 9.649 \times 10^4$ C.mole^{-1}
(20) Rydberg constant : $R'_\infty = 1.098 \times 10^7$ per m
(21) Fine structure constant : $\alpha = 7.297 \times 10^{-3}$
(22) First radiation constant : $C_1 = 4.993 \times 10^{-24}$ J.m
(23) Second radiation constant : $C_2 = 1.439 \times 10^{-2}$ m.K
(24) Electron rest energy : $m_e c^2 = 0.511$ MeV
(25) Proton rest energy : $m_p c^2 = 938.259$ MeV
(26) Neutron rest energy : $m_n c^2 = 939.553$ MeV
(27) Ratio : $h/2e = 2.068 \times 10^{-15}$ Wb (weber)
Ratio : $h/e = 4.136 \times 10^{-5}$ J-s/C
Ratio : $h/2m_e = 3.637 \times 10^{-4}$ J-s/kg
Ratio : $h/m_e = 7.274 \times 10^{-4}$ J-s/kg
(28) Normal atomspheric pressure : $P_0 = 1.013 \times 10^5$ N/m^2
(29) Charge to mass ratio of the electron :
$e/m_e = 1.759 \times 10^{11}$ *C/kg.*
(30) Compton wavelengths of the electron, proton, neutron respectively :
(a) $\lambda_e = 2.426 \times 10^{-12}$ m
(b) $\lambda_p = 1.321 \times 10^{-15}$ m
(c) $\lambda_n = 1.320 \times 10^{-5}$ m.
(31) Magnetic moments of electron and proton respectively :
(a) $\mu_e = 9.285 \times 10^{-24}$ A.m^2
(b) $\mu_p = 1.411 \times 10^{-26}$ A.m^2.
The respective ratios μ_e and μ_p with μ_B may be computed.

Densities

At ordinary temperature (17° – 23°)

Substance	Density × 10³ kg/m³	Substance	Density × 10³kg/m³
Metals and alloys		Liquids	
Aluminium	2.7	Alcohol	0.80
Iron. Pure	7.88	Benzene	0.88
Wrought	7.85	Ether	0.74
Cast	7.6	Glycerine	1.26
Steel	7.7	Lubricating oil	0.91
Brass	8.4-8.7	Mercury	13.60
Chromium	6.92	Aniline	1.02
Copper	8.89	Ether	0.736
Gold	19.3	Turpentine	0.87
Antimony	6.62		
Bismuth	9.78		
Silver	10.5		
Mica	2.6-3.2		
Platinum	21.45		
Tungsten	19.3		
Tin	7.3		
Lead	11.34		
Magnesium	1.74		
Nickle	8.8		
Selenium	4.8	Gases :	
Germanium	5.3		
Bronze	8.8-8.9	Air	0.00129
Constantan	8.88	Carbon dioxide	0.00198
Manganin	8.50	Hydrogen	0.00609
Asbestos	2.0-2.8	Steam-(100°C)	0.00091
Cork	0.22-0.26	Helium	0.000179
Glass Crown	2.0		
Flint	4.0		
Zinc	7.1		

Acceleration due to Gravity :

Place	g	Place	g
Pole	9.8222	Allahabad	9.7895
Equator	9.7803	Gorakhpur	9.7905
Delhi	9.7915	Gwalior	9.7897
Meerut	9.7915	Indore	9.7860
DehraDun	9.7907	Jaipur	9.7852
Lucknow	9.7900	Ajmer	9.7890
Kanpur	9.7901	Bombay	9.7865
Varanasi	9.7899	Calcutta	9.7878
Agra	9.7606	Madras	9.7828
Aligarh	9.7808		

Elastic constants :

Substance	Young's Modulus Y Newton/ $m^2 \times 10^{11}$	Modulus of rigidity η Newton/$m^2 \times 10^{11}$	Poisson's ratio σ
Aluminum	0.69—0.72	0.25—0.27	0.33—0.35
Brass	0.9—1.0	0.34—0.23	0.39—0.40
Copper	1.1—1.29	0.34—0.46	0.25—0.35
Iron Wrought	1.9—2.2	0.77—0.83	0.27—0.29
Cast	1.0—1.3	0.35—0.53	0.24—0.31
Steel Cast	1.9—2.1	0.74—0.76	—
Mild	2.1—2.3	0.80—0.89	0.25—0.31
Zinc	0.8—1.1	0.39—0.38	0.23—0.31
Glass Crown	0.6—0.78	0.26—0.32	0.25—0.27
Flint	0.5—0.6	0.2—0.25	0.21—0.26

Viscosity of water :

Temperature °C	Viscosity (Poise)	Temperature °C	Viscosity (Poise)
0	0.01793	60	0.00469
10	0.01311	70	0.00406
20	0.01000	80	0.00356
30	0.00800	90	0.00316
40	0.00657	100	0.00284
50	0.00550		

Surface tension of water :

Temperature °C	Surface tension Newton $/m \times 10^{-2}$	Temperature °C	Surface tension Newton$/m \times 10^{-2}$
0	7.5	60	6.56
10	7.35	70	6.38
20	7.21	80	6.20
30	7.06	90	6.02
40	6.89		
50	6.73	100	5.82

Velocity of sound (meter/sec) :

Substance	Velocity	Substance	Velocity
Solid		Liquid :	
Aluminium	5100	Alcohol	1275
Brass	3400	Mercury	1407
Copper	3560	Water	1447
Glass	5000	Gases :	
Iron	5130	Air	331.1
Steel	4990	Hydrogen	1262
		Nitrogen	338
		Oxygen	316

Refractive index of substances at 15°C for D-line of sodium relative to air :

Substance	μ	Substance	μ
Solids :		Liquids :	
Glass crown	1.50	Aniline	1.590
Glass flint	1.55	Benzene	1.504
Diamond	2.417	Chloroform	1.53
Mica	1,56—1.69	Glycerine	1.449
Sugar	1.56	Sulphuric acid	1.47
Quartz	1.544	Turpentine	1.43
		Water	1.333

Wavelength of spectral lines (A. U.)

Hydrogen :	Mercury :	Neon :
6562.784	4047 V	5765 y
4861.327	4078 V	5853 y
4340.466	4358 V	5882 o
4101.736	4916 bg	6507 r
Sodium :	4960 g	
5890 D_1	5461 g	Cadmium :
5896 D_2	5770 y	6438
Helium :	5791 y	5085
3889		4799
4026		4678
4471		4662
5876		

Specific rotation :

Optically active substance	Solvent	Specific rotation
Cane sugar	Water	+ 66.5°
Glucose	Water	+ 52°
Fructose	Water	– 91°
Camphor	Alcohol	+ 41°
Turpentine	Pure	– 37°
Nicotine	Pure	– 122°

Thermal constants : (C.G.S. units)

Substance	Melting point, °C	Boiling point, °C	Specific heat	Latent heat	Thermal Conductivity
Aluminium	658	1800	.22	92.4	.504
Bismuth	269	1560	.03	13.4	.0194
Copper	1084	2360	.093	43	.918
Gold	1063	2360	.032	16	.7
Ice	0	100	.5	79	.005
Iron (wrought)	1530	2450	.12	49	.144
Lead	327	1755	.031	5	.083
Platinum	1774	4300	.032	27	.166
Silver	961	2152	.056	22	.974
Tungsten	3387	4830	.03	...	.35
Steel	1400	...	.11	...	.115
Benzene	5.5	80.2	.34	95	3.3
Water	0	100	1.00	539	14.7
Mercury	–38.9	357	0.033	68	...
Ether	–132	34.6	.56	88	3.1

Magnetic elements :

Station	Dip	H oersted	Station	Dip	H oersted
Agra	40° 41'	.348	Gorakhpur	39° 40'	.358
Aligarh	41° 50'	.346	Jaipur	40° 30'	.347
Allahabad	37° 10'	.353	Kanpur	38° 39'	.363
Delhi	42° 52'	.345	Khurja	42° 10'	.343
Meerut	43° 30'	.339	Lucknow	40° 00'	.354
Varanasi	37° 10'	.364	Bareilly	42° 20'	.344
Dehra Dun	45° 50'	.332	Bombay	25° 30'	.376
Gwalior	39° 00'	.353	Calcutta	31° 30'	.382

Wire resistances :

S.W.G. No.	Diameter m.m.	Resistance (ohm/meter)		
		Copper	Constantan	Manganin
10	3.25	0.0021	0.057	0.051
12	2.64	0.0032	0.086	0.077
14	2.03	0.0054	0.146	0.131
16	1.63	0.0083	0.228	0.205
18	1.22	0.0148	0.495	0.361
20	0.914	0.0260	0.722	0.645
22	0.711	0.0235	1.20	1.07
24	0.559	0.070	1.93	1.73
26	0.457	0.105	0.89	2.58
28	0.374	0.155	4.27	3.82

30	0.315	0.222	6.08	5.45
32	0.274	0.293	8.02	7.18
34	0.234	0.404	11,1	9.9
36	0.193	0.590	16.2	14.5
38	0.152	0.950	26.2	23.2
40	0.122	1.48	40.6	36.3

Specific resistance and Temperature coefficient of resistance :

Substance	Composition	Sp. resistance ohm × cm × 10^{-6}	Temperature coefficient of resistance per °C × 10^{-4}
Constantan	60% Cu, 40% Zn	49.0	–0.4 to + 0.1
Silver		1.64	36.0
German silver	62% Cu, 15% Ni 22% Zn	26.6	2.3 to 6.0
Copper		1.78	42.8
Nichrome	80% Ni, 20% Cr	110.0	1.7
Mercury		99.8	9.0
Brass	70% Cu, 30% Zn	6.6	10.0
Platinum	...	11.0	37.0
Manganin	84% Cu, 4% Ni 12% Mn	43.0	0.02 to 0.5

Electro-chemical equivalent :

Element	Atomic weight	Valency	E.C.E. gm/coulomb
Aluminium	26.97	3	0.0000935
Oxygen	16.00	2	0.0000829
Silver	107.88	1	0.0011180
Copper	63.57	2	0.0003294
Zinc	65.38	2	0.0003383
Gold	197.20	3	0.0006809
Nickle	58.69	2	0.0000304
Hydrogen	1.007	1	0.0000105

Thermo E.M.F. :

Thermocouple	Thermo e.m.f.
Copper-constantan	41.8 Microvolt/°C
Copper-iron	8.6 Microvolt/°C
Antimony-Bismuth	113 Microvolt/°C

Internal resistance and E.M.F. of cells :

Cell	Internal resistance (ohm)	E.M.F. (volts)
Cadmium	900 Ω (very high)	1.0183 volt at 20°C
Daniel	3—4 Ω (fairly constant)	1.08
Leclanche	High, increases with usage	1.46
Alkali accumulator	Low	1.35
Lead accumulator	Very Low	2.1

COMMON LOGARITHMS $\log_{10} x$

x	0	1	2	3	4	5	6	7	8	9	Δ_m	1	2	3	4	5	6	7	8	9
											+	ADD								
10	.0000	0043	0086	0128	0170	0212					42	4	8	13	17	21	25	29	34	38
						0212	0253	0294	0334	0374	40	4	8	12	16	20	24	28	32	36
11	.0414	0453	0492	0531	0569	0607					39	4	8	12	16	19	23	27	31	35
						0607	0645	0682	0719	0755	37	4	7	11	15	19	22	26	30	33
12	.0792	0828	0864	0899	0934	0969					35	4	7	11	14	18	21	25	28	32
						0969	1004	1038	1072	1106	34	3	7	10	14	17	20	24	27	31
13	.1139	1173	1206	1239	1271	1303					33	3	7	10	13	16	20	23	26	30
						1303	1335	1367	1399	1430	32	3	6	10	13	16	19	22	26	29
14	.1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	30	3	6	9	12	15	18	21	24	27
15	.1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	28	3	6	8	11	14	17	20	22	25
16	.2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	26	3	5	8	10	13	16	18	21	23
17	.2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	25	2	5	7	10	12	15	17	20	22
18	.2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	24	2	5	7	10	12	14	17	19	22
19	.2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	22	2	4	7	9	11	13	15	18	20
20	.3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	21	2	4	6	8	11	13	15	17	19
21	.3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	20	2	4	6	8	10	12	14	16	18
22	.3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	19	2	4	6	8	10	11	13	15	17
23	.3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	18	2	4	5	7	9	11	13	14	16
24	.3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	18	2	4	5	7	9	11	13	14	16
25	.3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	17	2	3	5	7	9	10	12	14	15
26	.4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	16	2	3	5	6	8	10	11	13	14
27	.4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	16	2	3	5	6	8	10	11	13	14
28	.4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	15	2	3	5	6	8	9	11	12	14
29	.4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	15	1	3	4	6	7	9	10	12	13
30	.4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	14	1	3	4	6	7	8	10	11	13
31	.4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	14	1	3	4	6	7	8	10	11	13
32	.5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	13	1	3	4	5	7	8	9	10	12
33	.5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	13	1	3	4	5	6	8	9	10	12
34	.5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	13	1	3	4	5	6	8	9	10	12
35	.5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	12	1	2	4	5	6	7	8	10	11
36	.5563	5573	5587	5599	5611	5623	5635	5647	5668	5670	12	1	2	4	5	6	7	8	10	11
37	.5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	12	1	2	4	5	6	7	8	10	11
38	.5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	11	1	2	3	4	6	7	8	9	10
39	.5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	11	1	2	3	4	6	7	8	9	10
40	.6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	11	1	2	3	4	8	7	8	9	10
41	.6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	10	1	2	3	4	8	6	7	8	9
42	.6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	10	1	2	3	4	8	6	7	8	9
43	.6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	10	1	2	3	4	8	6	7	8	9
44	.6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	10	1	2	3	4	8	6	7	8	9
45	.6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	10	1	2	3	4	8	6	7	8	9
46	.6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	9	1	2	3	4	8	5	6	7	8
47	.6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	9	1	2	3	4	8	5	6	7	8
48	.6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	9	1	2	3	4	4	5	6	7	8
49	.6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	9	1	2	3	4	4	5	6	7	8

No	log			No.	log
$\pi = 3.14159$	0.49715	$\ln x = \log_e x = (1/M) \log_{10} x$	$(1/M) = 2.30259$		0.36222
$e = 2.71828$	0.43429	$\log_x = \log_{10} x = M \log_e x$	$M = 0.43429$		1.63778

p	1	2	3	4	5	6	7	8	9	10
$\log e^p$	0.4343	0.8686	1.3029	1.7372	2.1715	2.6058	3.0401	3.4754	3.9087	4.3429
$\log e^{-p}$	1.5657	1.1314	2.6971	2.2628	3.8285	3.3942	4.9599	4.5256	4.0913	5.6571

COMMON LOGARITHMS $\log_{10} x$

x	0	1	2	3	4	5	6	7	8	9	Δ_m	1	2	3	4	5	6	7	8	9
											+	ADD								
50	.6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	9	1	2	3	4	4	5	6	7	8
51	.7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	8	1	2	2	3	4	5	6	6	7
52	.7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	8	1	2	2	3	4	5	6	6	7
53	.7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	8	1	2	2	3	4	5	6	6	7
54	.7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	8	1	2	2	3	4	5	6	6	7
55	.7404	7412	7419	7427	7433	7443	7451	7459	7466	7474	8	1	2	2	3	4	5	6	6	7
56	.7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	8	1	2	2	3	4	5	6	6	7
57	.7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	8	1	2	2	3	4	5	6	6	7
58	.7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	8	1	2	2	3	4	5	6	6	7
59	.7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	7	1	1	2	3	4	4	5	6	6
60	.7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	7	1	1	2	3	4	4	5	6	6
61	.7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	7	1	1	2	3	4	4	5	6	6
62	.7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	7	1	1	2	3	3	4	5	6	6
63	.7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	7	1	1	2	3	3	4	5	6	6
64	.8062	8069	8075	8082	8089	8096	8101	8109	8116	8182	7	1	1	2	3	3	4	5	6	6
65	.8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	7	1	1	2	3	3	4	5	6	6
66	.8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	7	1	1	2	3	3	4	5	6	6
67	.8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	6	1	1	2	2	3	4	4	5	5
68	.8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	6	1	1	2	2	3	4	4	5	5
69	.8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	6	1	1	2	2	3	4	4	5	5
70	.8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	6	1	1	2	2	3	4	4	5	5
71	.8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	6	1	1	2	2	3	4	4	5	5
72	.8573	8579	8585	8691	8597	8603	8609	8615	8621	8627	6	1	1	2	2	3	4	4	5	5
73	.8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	6	1	1	2	2	3	4	4	5	5
74	.8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	6	1	1	2	2	3	4	4	5	5
75	.8751	8756	8762	9768	8774	8779	8785	8791	8797	8802	6	1	1	2	2	3	4	4	5	5
76	.8808	8814	8820	8825	8831	8837	8842	8843	8854	8859	6	1	1	2	2	3	4	4	5	5
77	.8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	6	1	1	2	2	3	4	4	5	5
78	.8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	6	1	1	2	2	3	4	4	5	5
79	.8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	6	1	1	2	2	3	4	4	5	5
80	.9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	5	1	1	2	2	3	3	4	4	5
81	.9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	5	1	1	2	2	3	3	4	4	5
82	.9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	5	1	1	2	2	3	3	4	4	5
83	.9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	5	1	1	2	2	3	3	4	4	5
84	.9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	5	1	1	2	2	3	3	4	4	5
85	.9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	5	1	1	2	2	3	3	4	4	5
86	.9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	5	1	1	2	2	3	3	4	4	5
87	.9395	9400	9305	9410	9415	9420	9425	9430	9435	9440	5	0	1	1	2	2	3	3	4	4
88	.9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	5	0	1	1	2	2	3	3	4	4
89	.9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	5	0	1	1	2	2	3	3	4	4
90	.9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	5	0	1	1	2	2	3	3	4	4
91	.9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	5	0	1	1	2	2	3	3	4	4
92	.9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	5	0	1	1	2	2	3	3	4	4
93	.9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	5	0	1	1	2	2	3	3	4	4
94	.9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	5	0	1	1	2	2	3	3	4	4
95	.9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	5	0	1	1	2	2	3	3	4	4
96	.9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	4	0	1	1	2	2	2	3	3	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	4	0	1	1	2	2	2	3	3	4
98	.9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	4	0	1	1	2	2	2	3	3	4
99	.9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	4	0	1	1	2	2	2	3	3	4

ANTILOGARITHMS 10^x

x	0	1	2	3	4	5	6	7	8	9	Δ_m	1	2	3	4	5	6	7	8	9
											+	ADD								
.00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	2	0	0	1	1	1	1	1	2	2
.01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	2	0	0	1	1	1	1	1	2	2
.02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	2	0	0	1	1	1	1	1	2	2
.03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	2	0	0	1	1	1	1	1	2	2
.04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	3	0	1	1	1	1	2	2	2	3
.05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	3	0	1	1	1	1	2	2	2	3
.06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	3	0	1	1	1	1	2	2	2	3
.07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	3	0	1	1	1	1	2	2	2	3
.08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	3	0	1	1	1	1	2	2	2	3
.09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	3	0	1	1	1	1	2	2	2	3
.10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	3	0	1	1	1	1	2	2	2	3
.11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	3	0	1	1	1	2	2	2	2	3
.12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	3	0	1	1	1	2	2	2	2	3
.13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	3	0	1	1	1	2	2	2	2	3
.14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	3	0	1	1	1	2	2	2	2	3
.15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	3	0	1	1	1	2	2	2	2	3
.16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	3	0	1	1	1	2	2	2	2	3
.17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	4	0	1	1	2	2	2	3	3	4
.18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	4	0	1	1	2	2	2	3	3	4
.19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	4	0	1	1	2	2	2	3	3	4
.20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	4	0	1	1	2	2	2	3	3	4
.21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	4	0	1	1	2	2	2	3	3	4
.22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	4	0	1	1	2	2	2	3	3	4
.23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	4	0	1	1	2	2	2	3	3	4
.24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	4	0	1	1	2	2	2	3	3	4
.25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	4	0	1	1	2	2	2	3	3	4
.26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	4	0	1	1	2	2	2	3	3	4
.27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	4	0	1	1	2	2	2	3	3	4
.28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	4	0	1	1	2	2	2	3	3	4
.29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	4	0	1	1	2	2	2	3	3	4
.30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	5	0	1	1	2	2	3	3	4	4
.31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	5	0	1	1	2	2	3	3	4	4
.32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	5	0	1	1	2	2	3	3	4	4
.33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	5	1	1	2	2	3	3	4	4	5
.34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	5	1	1	2	2	3	3	4	4	5
.35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	5	1	1	2	2	3	3	4	4	5
.36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	5	1	1	2	2	3	3	4	4	5
.37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	6	1	1	2	2	3	4	4	5	5
.38	2399	2404	2410	2415	2421	2427	2432	2338	2443	2449	6	1	1	2	2	3	4	4	5	5
.39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	6	1	1	2	2	3	4	4	5	5
.40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	6	1	1	2	2	3	4	4	5	5
.41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	6	1	1	2	2	3	4	4	5	5
.42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	6	1	1	2	2	3	4	4	5	5
.43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	6	1	1	2	2	3	4	4	5	5
.44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	6	1	1	2	2	3	4	4	5	5
.45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	7	1	1	2	3	3	4	5	6	6
.46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	7	1	1	2	3	3	4	5	6	6
.47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	7	1	1	2	3	3	4	5	6	6
.48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	7	1	1	2	3	4	4	5	6	6
.49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	7	1	1	2	3	4	4	5	6	6

ANTILOGARITHMS 10^x

x	0	1	2	3	4	5	6	7	8	9	Δ_m +	1	2	3	4	5	6	7	8	9
												ADD								
.50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	7	1	1	2	3	4	4	5	6	6
.51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	8	1	2	2	3	4	5	6	6	7
.52	3311	3319	3327	3334	3342	3550	3357	3365	3373	3381	8	1	2	2	3	4	5	6	6	7
.53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	8	1	2	2	3	4	5	6	6	7
.54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	8	1	2	2	3	4	5	6	6	7
.55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	8	1	2	2	3	4	5	6	6	7
.56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	8	1	2	2	3	4	5	6	6	7
.57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	9	1	2	3	4	4	5	6	7	8
.58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	9	1	2	3	4	4	5	6	7	8
.59	3890	3899	3908	3917	3926	3926	3945	3954	3863	3972	9	1	2	3	4	5	5	6	7	8
.60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	9	1	2	3	4	5	5	6	7	8
.61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	10	1	2	3	4	5	6	7	8	9
.62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	10	1	2	3	4	5	6	7	8	9
.63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	10	1	2	3	4	5	6	7	8	9
64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	10	1	2	3	4	5	6	7	8	9
.65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	10	1	2	3	4	5	6	7	8	9
.66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	11	1	2	3	4	5	7	8	9	10
.67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	11	1	2	3	4	5	7	8	9	10
.68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4883	11	1	2	3	4	6	7	8	9	10
.69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000 -	11	1	2	3	4	6	7	8	9	10
.70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	12	1	2	4	5	6	7	8	10	11
.71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	12	1	2	4	5	6	7	8	10	11
.72	5248	560	5272	5284	5297	5309	5321	5335	5346	5358	12	1	2	4	5	6	7	8	10	11
.73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	12	1	2	4	5	6	7	8	10	11
.74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	13	1	3	4	5	6	8	9	10	12
.75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	13	1	3	4	5	7	8	9	10	12
.76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	13	1	3	4	5	7	8	9	10	12
.77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	14	1	3	4	6	7	8	10	11	13
.78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	14	1	3	4	6	7	8	10	11	13
.79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	14	1	3	4	6	7	8	10	11	13
.80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	15	1	3	4	6	7	9	10	12	13
.81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	15	2	3	5	6	8	9	11	12	14
.82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	15	2	3	5	6	8	9	11	12	14
.83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	16	2	3	5	6	8	10	11	13	14
.84	6918	6934	6950	6996	6982	6998	7015	7731	7047	7063	16	2	3	5	6	8	10	11	13	14
.85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	16	2	3	5	6	8	10	11	13	14
.86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	17	2	3	5	7	8	10	12	14	15
.87	7413	7430	7447	7564	7482	7499	7516	7534	7551	7568	17	2	3	5	7	9	10	12	14	15
.88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	18	2	4	5	7	9	11	13	14	16
.89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	18	2	4	5	7	9	11	13	14	16
.90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	18	2	4	5	7	9	11	13	14	16
.91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	19	2	4	6	8	10	11	13	15	17
.92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	19	2	4	6	8	10	11	13	15	17
.93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	20	2	4	6	8	10	12	14	16	18
.94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	20	2	4	6	8	10	12	14	16	18
.95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	21	2	4	6	8	10	13	15	17	19
.96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	21	2	4	6	8	11	13	15	17	19
.97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	22	2	4	7	9	11	13	15	18	20
.98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	22	2	4	7	9	11	13	15	18	20
.99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	23	2	5	7	9	11	14	16	18	21

Permissible error :

$$K = \frac{msd}{\pi r^2 (\theta_1 - \theta_2)}\left[\frac{d\theta}{dt}\right]$$

Taking log, and differentiating, we have

$$\frac{\delta K}{K} = \frac{\delta m}{m} + \frac{\delta d}{d} + \frac{2\delta r}{r} + \frac{\delta(\theta_1 - \theta_2)}{(\theta_1 - \theta_2)} + \frac{\delta d\theta}{d\theta} + \frac{\delta dt}{dt} = \ldots$$

Maximum permissible error = ... %.

Viva-Voce

Q. 1. ***Why is the experimental material taken in the form of disc ?***

Ans. A thin disc is taken because its area of cross section is large, while thickness is small. It increases the quantity of heat conducted across its faces.

Q. 2. ***Why the two discs, between which the disc of bad conductor is pressed, are taken of metal ?***

Ans. It ensures the normal flow of heat from one face of experimental disc to another.

Q. 3. ***What is principle involved in this method ?***

Ans. In steady state, temperature of lower metal plate becomes constant and then the heat lost by it to the surroundings is just made up the heat gained by it through the experimental disc of bad conductor.

Q. 4. ***At what temperature, do you find rate of radiation ?***

Ans. At steady state temperature.

Q. 5. ***Can this method be used in case of good conductors ?***

Ans. No. because the two sides of the experimental disc will atonce acquire the same temperature.

Q. 6. ***Can this method be used in case of liquids ?***

Ans. With liquids, the difficulty is that the convection currents are easily set up and transfer more heat than the conduction actually does. To overcome this difficulty, liquid should be heated at the top and should be taken in the form of thin film.

□□□

EXPERIMENT No. 7

Object : To determine the thermal conductivity of rubber in the form of a tube.

Apparatus required. Calorimeter, balance with weight box, stop watch, thermometer, steam boiler, graduated cylinder, rubber tubing, wooden screen and vernier microscope.

Formula used :

The coefficient of thermal conductivity K of rubber in the form of a tube is given by the formula,

$$\boxed{K = \frac{(m + w)(\theta_4 - \theta_3) \times 2.3026 \times \log_{10} r_2/r_1}{2\pi l.t\left[\theta_{steam} - \left(\frac{\theta_4 + \theta_3}{2}\right)\right]}}$$

where m = mass of the water taken in the calorimeter,

w = water equivalent of calorimeter and its contents,

= mass of calorimeter with stirrer × specific heat of material of calorimeter (copper),

θ_4 = final temperature of water corrected for radiation,
θ_3 = initial temperature of water,
r_2 = external radius of the rubber tube,
r_1 = inner radius of the rubber tube,
t = time for which steam is passed in rubber tube,
l = length of rubber tube immersed in water.

Description of apparatus :

The apparatus is shown in fig. (1). A known length l of the rubber tube is immersed in weighed amount of water contained in a calorimeter. The steam from a boiler B is allowed to flow through the tube from one end which comes out from the other end. A wooden screen is placed between the boiler and calorimeter. The initial temperature as well as the final temperature of the water is recorded with the help of the thermometer T.

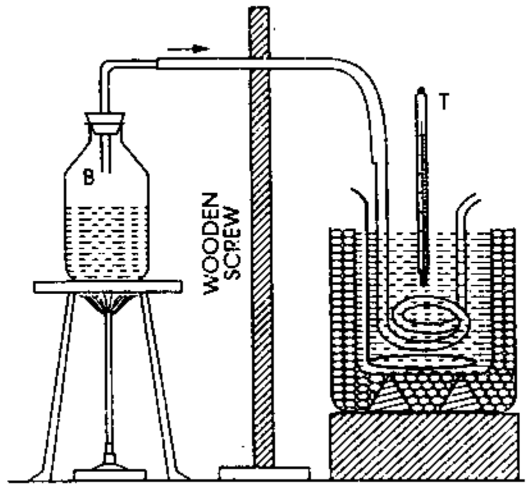

Fig. (1)

Procedure :

(i) Take a calorimeter of large capacity and weigh it in a balance. Fill about two thirds of it with water measured with a graduated cylinder. Note down its temperature, θ_3.

(ii) Coil a length of the rubber tubing and immerse it in the water contained in the calorimeter in such a way that both ends projected outside the calorimeter are at some distance. The two cotton cords are tied at the points where the tube enters and leaves the water so that the length of the tube inside the water may be measured.

(iii) Connect one end of the tubing to the steam generator and place a wooden screen between the two. The other end of the tube is dipped into another vessel to condense outgoing steam.

(iv) Allow the steam to pass in the tube and simultaneously start a stop watch. Stir the water continuously till there is a rise of nearly about 15-20°C. Note down the final temperature, θ_4 as well as time taken, t.

(v) Measure the length of the tube after opening the coil dipped in the water.

(vi) Measure the inner and outer diameters of the rubber tube by means of travelling microscope.

(vii) Calculate the value of K using the above mentioned formula.

Observation : Calorimeter observations :

(A) Mass of the calorimeter + stirrer = ... gm.

Specific heat of the material of calorimeter = ...

Water equivalent w = ... gm.

Mass of the water in calorimeter m = ...gm.

Initial temperature of water θ_3 = ... °C.

Final temperature of water θ_4 = ... °C.

Time for passing steam t = ... sec.

(B) Observation concerning tube :

Length of the tube dipped into water l = ... cm.

Mean outer temperature $(\theta_3 + \theta_4)/2$ = ...°C.

Inner temperature θ_{steam} = ... °C.

Table for Inner and Outer radii of the tube :

L.C. of microscope = ... cms.

S. No.	Reading at left end		Reading at right end		Input radius $r_1 = 1/2\,(b - c)$	Outer radius $r_2 = 1/2\,(a \sim d)$	Mean r_1 cm.	Mean r_2 cm.
	Outer surface (a) cm.	Inner surface (b) cm.	Inner surface (c) cm.	Outer surface (d) cm.				
1	...	...	...	...	...	...		
2	...	...	...	...	...	...	...	...
1	...	...	...	...	...	...		
2	...	...	...	...	...	...		

Calculations :

$$K = \frac{(m + w)\,(\theta_4 - \theta_3) \times 2.3026 \times \log_{10} r_2/r_1}{2\pi l.t\left[\theta_{\text{steam}} - \dfrac{(\theta_3 + \theta_4)}{2}\right]}$$

= ... cals./sec./sq. cm./unit temp. gradient.

Result. The coefficient of thermal conductivity of rubber

= ... cal./sec./sq. cm./unit temp. gradient

Standard result : = ...

Percentage Error : = ...%.

Sources of Error and Precautions :

(i) Tube should be of uniform bore.

(ii) Calorimeter should be of large thermal capacity.

(iii) To measure the length accurately, cord bands should be used.

(iv) Calorimeter should be protected from losing heat.

(v) The rise of temperature should not be more than 10°C.

(vi) r_1 and r_2 should be measured carefully.

Viva-Voce

Q. 1. ***Why do you take a long and thin rubber tube ?***

Ans. Rubber is a bad conductor of heat. By taking such a thin rubber tube, quantity of heat conducted across its walls becomes appreciable. As sufficient length of the tube is also immersed in water, heat conducted across walls of the tube becomes enough to cause measurable temperature difference.

Q. 2. ***Do you use a calorimeter of large thermal capacity ? Why ?***

Ans. Yes, to keep temperature difference $(\theta_4 - \theta_3)$ small even if the steam is passed for an appreciable time and thus to minimise radiation losses.

Q. 3. ***What is the main drawback of this method ?***

Ans. The outer surface of the tube does not remain at a constant temperature as assumed.

Q. 4. ***Why do you take rubber tubing of uniform wall thickness ?***

Ans. So that the ratio (r_2/r_1) may be constant throughout the length of the tube.

Q. 5. ***Do you know some other method for determining the conductivity of rubber?***

Ans. It can be determined by Lee's disc method.

❑❑❑

EXPERIMENT No. 8

Object : To determine the coefficient of thermal conductivity of glass in the form of a tube

Apparatus required. The given glass tube, a wider tube to serve as a steam Jacket, constant level water arrangement, two sensitive thermometers, boiler, graduated jar, stop watch and microscope.

Formula used.

The coefficient of thermal conductivity K of glass in the form of a tube is given by

$$\boxed{K = \frac{m(\theta_2 - \theta_1)\, 2.3026 \times \log_{10} r_2/r_1}{2\pi l \,.\, t\left[\theta_{\text{steam}} - \dfrac{(\theta_2 + \theta_1)}{2}\right]}}$$

where m = mass of the water collected in time t,

l = length of the tube within the steam jacket,

r_1, r_2 = internal and external radii of the tube,

θ_1, θ_2 = temperature of inflowing and out-flowing water,

θ_{steam} = temperature of the steam.

Description of the apparatus :

The thermal conductivity of glass in the form of a thick walled tube can be easily determined by accomplishing the radial heat flow with continuous flow calorimeter. The experimental arrangement is shown in figure (1).

AB is a long glass tube with thin walls and is held inside the wider jacket J through which steam can be allowed to pass. The glass tube at the ends is joined with two wider tubes CC which are provided with inlet I and outlet O for cold water. A spiral wire is placed inside AB in order that the water may be in good contact with the inner surface of the tube. Water is allowed to flow through the tube AB. Thermometers T_1 and T_2 are provided to measure the temperature of incoming and outflowing water respectively.

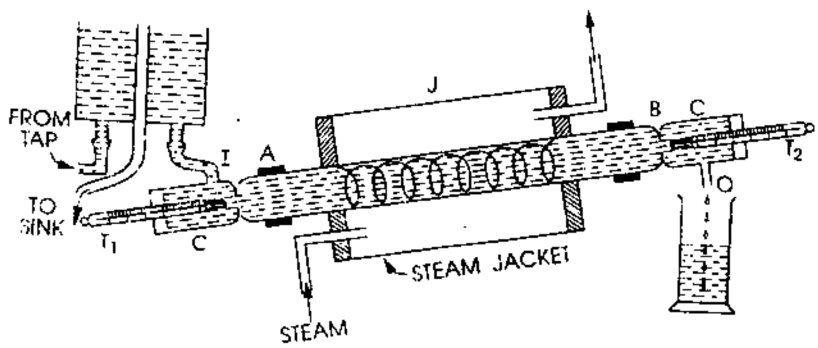

Fig. (1)

Procedure :

(i) Set up the arrangement as shown in fig. (1). Allow a steady stream of water to flow through the glass tube.

(ii) Allow the steam to flow through the steam jacket J and obtain a steady state, *i.e.* there should be no variation of the temperatures recorded by the two thermometers T_1 and T_2.

(2) Table for the measurement of rectangular aperture for just resolution:

S. No.	Side	Microscope reading when its cross wire is set at		Exposed width of the aperture for just resolution $(x \sim y)$	Mean aperture width $(x \sim y)$	No. of lines of grating in this width N_0	Order of spectrum n
		One end of the aperture x cm.	Other end of the aperture y cm.				
1	Left Side	...	...	...	...	...	1
2	Right Side	...	...	...			
3	Left Side	...	...	...	...	...	2
4	Right Side	...	...	...			

Calculations :

(1) The difference in wavelengths of the two yellow lines of Hg spectrum,

$$= 5790 - 5770$$
$$= 20 \text{ A.U.}$$

(2) Mean wavelength,

$$\lambda = \frac{\lambda_1 + \lambda_2}{2}$$
$$= \frac{5770 + 5790}{2}$$
$$= 5780 \text{ A.U.}$$

(3) Therefore theoretical resolving power,

$$\frac{\lambda}{d\lambda} = \frac{5780}{20}$$
$$= 289$$

(4) We have calculated already that the number of lines per cm. of grating = 2·54/N. Therefore :

Order of spectrum $= n$	No. of lines in mean width $x \sim y = N_0$	Product $N_0 n$	$\lambda/d\lambda$	Difference
1	$\frac{2 \cdot 54}{N} \times (x \sim y)$ $= \ldots$	...	...	...
2	$\frac{2 \cdot 54}{N} \times (x \sim y)$ $= \ldots$	...	...	...

Result : Comparison of theoretical and practical resolving power is shown in the table.

Sources of Error and Precautions :

Same as in experiment No. 18.

Viva-Voce

Q. 1. ***What do you mean by resolving power of grating ?***

Ans. The resolving power of grating is defined as the capacity to form separate diffraction maxima of two wavelengths which are very close to each other.

Q. 2. ***How the resolving power of a grating is measured ?***

Ans. This is measured by $\lambda/d\lambda$. The value is $N_0 n$, where n is order of spectrum and N_0 the number of lines on grating.

Q. 3. ***Upon what factors does the resolving power of a grating depend ?***

Ans. The resolving power depends upon the total number of rulings N in the grating and the order of spectrum.

Q. 4. ***Does the resolving power of a grating depends upon the spacing between the ruling ?***

Ans. No, when the number of lines in a given width increase the order of the spectrum in a given direction decrease such that the product $N_0 n$ remains constant.

Q. 5. ***How the resolving power can be increased ?***

Ans. This can be done by increasing the total number of ruling without decreasing the grating element.

Q. 6. ***If double the number of lines are ruled in the same space in a grating, what will happen to its resolving power ?***

Ans. The resolving power will not change because the grating element will be halved which will make the order of the spectrum half in a particular direction.

Q. 7. ***What is a normal spectrum ?***

Ans. A spectrum for which $d\theta \propto d\lambda$ (spectral lines differ in angle by amounts which are directly proportional to difference in wavelength) is known as normal spectrum.

Q. 8. ***How can you obtain a normal spectrum ?***

Ans. We can obtain a normal spectrum by using a concave grating in Rowland's mounting in which $\theta = 0$ *i.e.* $\cos\theta = 1$.

❑❑❑

EXPERIMENT No. 22

Object : To verify Fresnel's formulae for the reflection of light.

Apparatus used : Spectrometer, prism, sodium lamp, a pair of polaroids fitted inside circular stands provided with circular scales which may be clamped on the telescope and collimator tubes, reading lens, etc.

Theory of the experiment :

According to Fresnel's formulae

$$\boxed{\tan\theta = -\frac{\cos(i-r)}{\cos(i+r)},}$$

where $\theta =$ Angle between the direction of reflected light and the plane of incidence

$i =$ Angle of incidence of plane polarised light.

$r =$ corresponding angle of refraction.

A graph is plotted between $\tan\theta$ and $[-\cos(i-r)/\cos(i+r)]$. If the graph comes out to be a straight line inclined at 45° to the axes, then this may be taken as a verification of the Fresnel's formulae.

Procedure : The experiment is performed is the following three parts :

(1) Determination of refractive index μ of the material of the prism and then to calculate the polarising angle.

(2) Setting of the collimator polaroid to make the plane of vibration of plane polarised light (incident light) inclined at 45° to the plane of incidence.

(3) Determination of θ for various values of *i*.

(1) Determination of refractive index μ of the material of the prism and then to calculate the polarising angle :

(i) The slit of collimator is illuminated with sodium light.

(ii) Without polaroids, the spectrometer is adjusted for parallel rays using *Schuster's method.*

(iii) The angle of the prism (A) is determined as usual.

(iv) The angle of minimum deviation (δ_m) for sodium light is determined in usual way.

(v) The refractive index (μ) of the material of the prism is calculated by using the following formula :

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

(vi) The polarising angle (ϕ) is calculated from Brewster's law

$$\phi = \tan^{-1}\mu$$

(2) Setting of the collimator polaroid to make the plane of vibration of plane polarised light inclined at 45° to the plane of incidence.

(i) The prism is removed from the prism table and the telescope is adjusted for the direct image of the slit. The position of the telescope is noted.

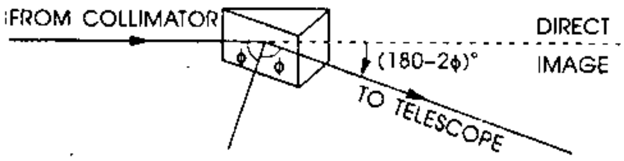

Fig. (1)

(ii) The telescope is turned through an angle $(180 - 2\phi)^\circ$ from the direct position as shown in fig. (1) and clamped.

(iii) The prism is placed on the prism table. The prism table is rotated slowly to receive the reflected image of the slit on the cross-wire of the telescope. In this position, the light incident on the prism face is at polarising angle ϕ. Now the light is plane polarised. The vibration of plane polarised light is perpendicular to the plane of incidence.

(iv) The polaroid (Analyser) is mounted on the objective of the telescope. Viewing through the telescope and rotating the polaroid slowly, the image of the slit is reduced to a minimum. The position of the pointer of the polaroid in its graduated scale is noted. Let it is β.

(v) The prism is removed from the prism table and the telescope is brought in the line of collimator to receive the direct image of slit on the cross wire. The second polaroid (Polariser) is mounted on the collimator lens. This is rotated till the direct image of the slit in the telescope reduces to minimum intensity. The reading of polariser is read on the circular scale attached with it. Further the polaroid is rotated through 45°. Now the polaroid is transmitting light whose plane of vibration is inclined at 45° to the plane of incidence.

(3) Determination of ϕ for various values of i :

(i) The telescope is rotated through a small angle α (say, about 10°) and clamped.

(ii) The prism is placed on the prism table and the prism table is rotated to receive the image of the slit on the cross wire of the telescope.

(iii) The analyser (Polaroid on telescope) is rotated from its initial setting β until the intensity of image of slit in telescope reduces to minimum. The angle of rotation will be θ *i.e.*, the angle which the reflected vibration makes with the plane of incidence. The angle of incidence (as shown in fig. (2)) for this setting will be

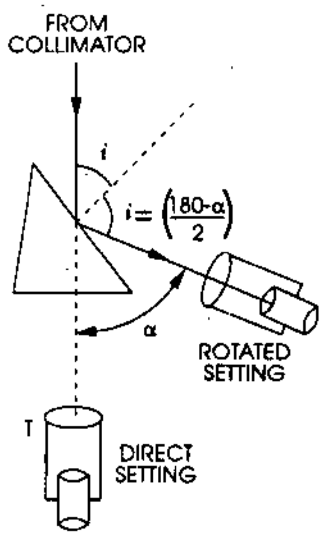

Fig. (2)

$$i = \frac{180 - \alpha}{2}$$

For $\alpha = 10°$, $i = \frac{180 - 10}{2} = 85°$

and $\quad \mu = \frac{\sin i}{\sin r} \quad$ or $\quad r = \sin^{-1}\left(\frac{\sin i}{\mu}\right)$

(iv) The angle of incidence is varied in steps of 10° by turning the telescope and angle θ is measured for all values of i.

Observations and Calculations :

(1) Table for the angle of prism (A)

S. No.	Position of telescope for the image of slit from one face		Position of telescope for the image of slit from other face		Difference 2A			Mean
	Vernier V_1	Vernier V_2	Vernier V_1	Vernier V_2	V_1	V_2	Mean	2A
1	...	...	...	...	...	...	...	
2	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	

(2) Table for the angle of minimum deviation (δ_m)

S. No.	Position of telescope for the minimum deviation		Position of telescope for direct image of the slit		Difference			Mean δ_m
	Vernier V_1 (a)	Vernier V_2 (b)	Vernier V_1 (c)	Vernier V_2 (d)	V_1 $(a - c)$	V_2 $(b - d)$	Mean	
1	...	...	...	...	...	...	...	
2	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	

Angle of the prism $A = \ldots$

$$\therefore \quad \mu = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin (A/2)} = \ldots \quad \text{and } \phi = \tan^{-1} \mu = \ldots$$

(3) Readings for setting the plane of vibration of incident light at 45° with the plane of incidence.

(i) Position of telescope on veriner V_1 for direct image of slit

$= \ldots$

(ii) The angle through which the telescope is rotated

$= (180 - 2\phi) = \ldots$

(iii) New position of telescope on vernier = ...

(iv) Reading of analyser for minimum intensity $\beta = \ldots$

(v) Reading of polariser for minimum intensity = ...

(vi) Reading of polariser after rotation of 45° = ...

(4) Table for finding θ for different values of i.

S. No.	Angle of rotation of telescope α	Reading of analyser for minimum intensity β'	Initial reading of analyser β	$\theta = (\beta' - \beta)$	tan θ
1	10°	...		...	...
2	20°	...		...	...
3	30°	...		...	...
4	40°	...		...	...
5	50°	...	...	...	...
6	60°	...		...	...
7	70°°	...		...	...
8	80°	...		...	...
9	90°	...		...	...

(5) Table for calculation of $[-\cos(i-r)/\cos(i+r)]$

S. No.	Angle of incidence $i = \left(\frac{180^\circ - \alpha}{2}\right)^\circ$	Angle of refraction $r = \sin^{-1}\left(\frac{\sin i}{\mu}\right)$	$(i-r)$	$(i+r)$	$-\frac{\cos(i-r)}{\cos(i+r)}$
1	...	...	...	...	...
2	...	...	...	...	...
3	...	...	...	...	...
4	...	...	...	...	...
5	...	...	...	...	...
6	...	...	...	...	...
7	...	...	...	...	...
8	...	...	...	...	...
9	...	...	...	...	...

A graph is plotted between $\tan\theta$ and corresponding values of $-\frac{\cos(i-r)}{\cos(i+r)}$. The graph comes out to be a straight line inclined at an angle 45° to the axes as shown in fig. (3).

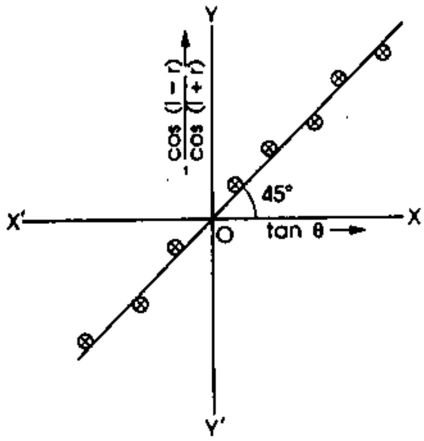

Fig. (3)

Result : The graph between $\tan\theta$ and $-[\cos(i-r)/\cos(i+r)]$ is a straight line passing through origin and inclined at an angle 45° with the axes. This shows the verification of Fresnel's formulae for reflection.

Sources of Error and Precautions :

(1) Spectrometer should be adjusted properly.
(2) The reflecting face of the prism should be clean.
(3) The angle θ should be measured for several values of i at interval of 10°.
(4) To find the value of θ, the analyser is set several times to minimise the intensity inside telescope and then mean value should be recorded.
(5) The setting of polariser should not be disturbed throughout the part third of the experiment.

❑❑❑

EXPERIMENT No. 23

Object : To determine the radii of curvature of the surfaces of a convergent lens and hence to calculate its refractive index.

Apparatus used : Convergent lens, pin, stand, clean mercury shallow dish, and screw gauge.

Formula used : The radius of curvature of the lens is given by

$$\boxed{R = \frac{uf}{f-u}}$$

where u = distance of the pin from the lens
f = focal length of the lens.

The refractive index of the material of the lens is calculated from the following formula

$$\boxed{\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)}$$

where R_1 = radius of curvature of first surface of lens

R_2 = radius of curvature of second surface of lens.

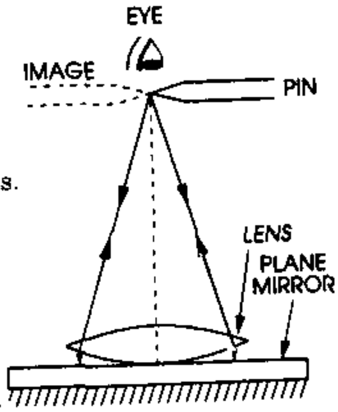

Fig. (1)

Procedure :

(i) The thickness t of the lens is measured with the help of screw gauge.

(ii) The focal length of the lens is determined by u-v method on the optical bench. The focal length may also be calculated with the arrangement shown in fig. (1). The lens is put on a plane mirror and a pin is mounted on a vertical stand. The pin is moved up or down and adjusted such that there is no parallax between the pin and its image formed by the lens. The distance of the pin from the plane mirror give the focal lenth of the lens.

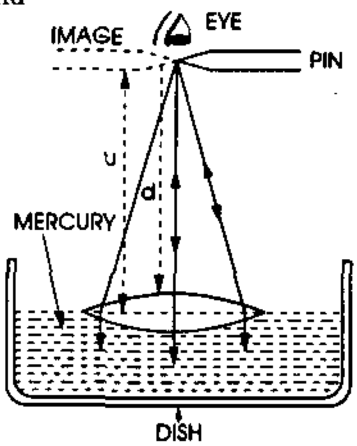

Fig. (2)

(iii) The lens is floated on the mercury contained in a dish. The pin is mounted on the vertical stand such that its tip is vertically above the centre of the lens as shown in fig. (2). The position of the pin is again adjusted till there is no parallax between the pin and its image. The distance d of the pin from the upper surface of the lens is measured. To obtain the value of u, half of the thickness of lens is added in d.

(iv) The lens is inverted and procedure (iii) is again repeated to know d for the second surface of the lens.

Observations :

(1) Thickness of the lens by screw gauge t = ... cm.

(2) Focal length of the convex lens of f = ... cm.

(3) Table for R_1 and R_2

Surface of the lens	distance d of pin from the top of the lens cm.	$u = d + \frac{t}{2}$	$R = \frac{uf}{f-u}$	Mean cm.
First surface	... ...	... ...	... ...	R_1 = ...
Second surface	... ...	... ...	... ...	R_2 = ...

Calculations : $R_1 = \frac{u_1 f}{f - u_1}$ = ... cm. ; $R_2 = \frac{u_2 f}{f - u_2}$ = ... cm.

Further, $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = (\mu - 1)\left(\frac{R_1 + R_2}{R_1 R_2}\right)$.

$$\mu = \left[\frac{f(R_1 R_2)}{(R_1 + R_2)}\right] = \ldots$$

Result : The refractive index of the material of the given lens = ...

Sources of Error and Precautions :

(i) Mercury taken should be pure.

(ii) Parallax should be removed very carefully.

(iii) Surfaces of the lens should be clean.

(iv) Half of the thickness of lens should be added in d to obtain the value of u.

(v) Focal length should be measured accurately.

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EXPERIMENT No. 24

Object : To determine the refractive index of the material of a concave lens.

Apparatus used : Optical bench, Pins, concave lens, metre scale, plane mirror, spherometer.

Formula used : The refractive index μ of the material of a concave lens is given by

$$\boxed{\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)}$$

where, f = focal length of the concave lens

R_1 = radius of curvature of first surface

R_2 = radius of curvature of second surface.

The radius of curvature R is given by

$$\boxed{R = \frac{l^2}{6h} + \frac{h}{2}}$$

where l = distance between the two legs of the spherometer

h = difference of readings of the spherometer when it is placed on the lens as well as when placed on plane surface.

Procedure.

(A) Determination of the focal length of concave lens.

(i) The given convex lens is mounted on one of the uprights of optical bench. A bright vertical pin O (mounted on the upright of optical bench) is placed at a certain distance from concave lens as shown in fig. (1).

(ii) The image of O is viewed through the lens from the other side. Another pin I is placed on the object side. The pin I is moved and adjusted such that there is no parallax between the image of O and pin I. Then I is the position of the image of O.

(iii) The positions of C, I and O are noted.

(iv) The experiment is repeated three or four times.

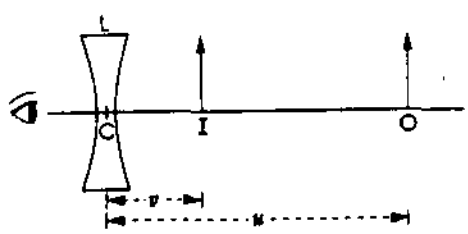

Fig. (1)

(B) Determination of radius of curvature.

(i) Determine the least count of the sphermometer.

(ii) The spherometer is placed on the plane surface and the screw is lowered until it just touches the surface. Note down the reading of spherometer.

(iii) Next, the spherometer is placed on one curved surface of the lens and the screw is lowered until it just touches the surface. The spherometer reading is noted.

(iv) Procedure (iii) is repeated for the second curved surface of the concave lens.

(v) Press the legs of the spherometer on a sheet of plane paper. Complete an equilateral traingle with the impressions of legs. Measure the sides of the triangle with meter scale. The average of the lengths of the three sides gives l.

Observations :

(A) Table for focal length f.

S. No.	Position of lens a cm	Position of object b cm.	Position of image pin c cm.	u = b – a cm.	v = c – a cm	$f = \frac{uv}{v-u}$	Mean f cm.
1	...	...	...	...	...	...	
2	...	...	...	...	...	...	
3	...	...	...	...	...	...	...
4	...	...	...	...	...	...	

(B) Table for h

Least count of screw gange $= \dfrac{\text{Pitch of the screw}}{\text{Number of divisions on circular scale}}$
$= \ldots$ cm.

S. No.	Spherometer reading on			h_1 $(b-a)$ cm	h_2 $(c-a)$ cm	Mean	
	Plane surface a cm	Ist surface of lens b cm.	2nd surface of lens c cm			h_1	h_2
1.	...	...	...	...	...		
2.	...	...	...	...	...	...	...
3.	...	...	...	...	...		
4.	...	...	...	...	...		

(c) Average length of legs of spherometer $l = \ldots$ cm.

Calculations :

Focal length of concave lens $f = \dfrac{uv}{v-u} = \ldots$ cm.

Radius of first surface $R_1 = \dfrac{l^2}{6h_1} + \dfrac{h_1^2}{2} = \ldots$ cm.

Radius of the second surface

$$R_2 = \frac{l^2}{6h_2} + \frac{h_2}{2} = \ldots \text{ cm.}$$

Further
$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$
$$= (\mu - 1)\left(\frac{R_1 + R_2}{R_1 R_2}\right)$$

or
$$\mu = \left[1 + \frac{R_1 R_2}{f(R_1 R_2)}\right] = \ldots$$

Result : The refractive index of concave lens = ...

Precautions and Sources of Error :

(i) Optical bench should be levelled.

(ii) Object pin and image pin heights should be upto the centre of concave lens.

(iii) Radius of curvature of both the surfaces should be determined.

(iv) Spherometer readings should be taken carefully.

(v) At least three or four readings should be taken for the determination of focal-length of the lens.

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EXPERIMENT No. 25

Object : To determine the refractive index of a liquid using Pulfrich refractometer.

Apparatus used : Pulfrich refractometer, glass cell, liquid, source of light, right angled prims.

Formula used : The refractive index of liquid is given by

$$\boxed{m = \sqrt{(\mu_0^2 - \sin^2 i)}}$$

where μ_0 = refractive index of the material of the prism.

i = minimum angle of emergence.

Description of apparatus :

Pulfrich refractometer is shown in fig. (1). It consists of a right angled prism A having it two faces perfectly plane. The liquid whose refractive index is to be determined is taken in a glass cell B and placed on prism A. Light is incident in a direction parallel to the horizontal surface so that light entering prism A is incident as the critical angle C with the normal. Finally it emerges from the prism at an angle i. The emergent lgiht is viewed with the help of telescope T which can be moved on a graduated circular scale.

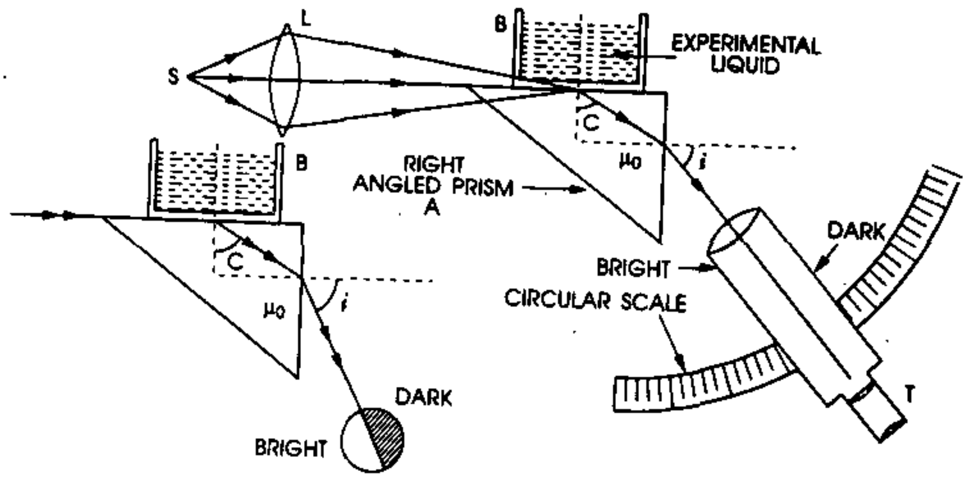

Fig. (1)

Procedrue :

(i) The glass cell is cleaned and experimental liquid is filled in it. This is properly placed at its place in the apparatus.

(ii) The source of light is switched on and the light is allowed to incident on the prism-cell system.

(iii) The emergent light from the prism is viewed by telescope T. The telescope is moved on the circular scale. One side of field of view appears dark while the other side appears bright.

The telescope is adjusted so that the cross wire lies on the dark edge of the field of view. This gives the position of the minimum angle of emergence i.

(iv) The experiment is repeated for three or four times to obtain the minimum angle of emergence. Then mean i is calculated.

Note. In modern instruments, the circular scale is calibrated in terms of the refractive index. So the readings can be read directly from the scale. In some cases, a table is provided with the instruments which gives the value of μ corresponding to i.

Observations :

(1) Refractive index of the material of the prism, $\mu_0 = \ldots$

(2) Table for the minimum angle i of emergence

S. No.	Minimum angle of emergence, *i* deg.	Mean, i deg.	Sin i
1	...	...	...
2	...		
3	...		
4	...		

Calculations : $\mu = \sqrt{\mu_0^2 - \sin^2 i} = \ldots$

Result : The refractive index of given liquid = ...

Precautions and sources of errror.

(1) There should be no air bubble in the liquid.

(2) The glass cell should be clean.

(3) The field of view should be judged correctly.

(4) The position of the cross-wire should be set on field of view carefully.

(5) A number of readings of the measurement of i should be taken.

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UNIVERSAL PHYSICAL CONSTANTS

(1) Elementary Charge = $e = 1.602 \times 10^{-19}$ C
(2) Electron rest mass : $m_e = 9.110 \times 10^{-3}$ kg.
(3) Proton rest mass : $m_p = 1.6735 \times 10^{-27}$ kg
(4) Neutron rest mass : $m_n = 1.675 \times 10^{-27}$ kg.
(5) Atomic mass unit : 1 amu = 1.661×10^{-27} kg.
(6) Planck constant : $h = 6.626 \times 10^{-34}$ J.s
: $h' = h/2\pi = 1.055 \times 10^{-34}$ J.s.
(7) Boltzmann constant : $k = 1.381 \times 10^{-23}$ J.K^{-1}
(8) Stefan-Boltzmann constant : $\sigma = 5.670 \times 10^{-8}$ W.m^{-2}.K^{-4}
(9) Wien's displacement law constant ; $b = 2.898 \times 10^{-3}$ m.K
(10) Speed of light in vacuum : $c = 2.998 \times 10^{23}$ m.s^{-1}
(11) Avogadro number : $N_A = 6.022 \times 10^{23}$ per mole.
(12) Bohr magneton : $\mu_B = 9.274 \times 10^{-24}$ A.m^2
(13) Nuclear magneton : $\mu_n = 5.051 \times 10^{-27}$ A.m^2
(14) First Bohr radius : $a_0 = 5.292 \times 10^{-11}$ m.
(15) Classical electron radius : $\gamma_e = 2.818 \times 10^{15}$ m.
(16) Standard volume of ideal gas : $V_0 = 22.414 \times 10^{-3}$ m^3/mole
(17) Gravitational constant : $G = 6.673 \times 10^{-11}$ N.m^2.kg^{-2}
(18) Standard acceleration of free fall : $g = 9.807$ m.s^{-2}
(19) Faraday constant : $F = 9.649 \times 10^4$ C.mole^{-1}
(20) Rydberg constant : $R'_\infty = 1.098 \times 10^7$ per m
(21) Fine structure constant : $\alpha = 7.297 \times 10^{-3}$
(22) First radiation constant : $C_1 = 4.993 \times 10^{-24}$ J.m
(23) Second radiation constant : $C_2 = 1.439 \times 10^{-2}$ m.K
(24) Electron rest energy : $m_e c^2 = 0.511$ MeV
(25) Proton rest energy : $m_p c^2 = 938.259$ MeV
(26) Neutron rest energy : $m_n c^2 = 939.553$ MeV
(27) Ratio : $h/2e = 2.068 \times 10^{-15}$ Wb (weber)
Ratio : $h/e = 4.136 \times 10^{-5}$ J-s/C
Ratio : $h/2m_e = 3.637 \times 10^{-4}$ J-s/kg
Ratio : $h/m_e = 7.274 \times 10^{-4}$ J-s/kg
(28) Normal atomspheric pressure : $P_0 = 1.013 \times 10^5$ N/m^2
(29) Charge to mass ratio of the electron :
$e/m_e = 1.759 \times 10^{11}$ C/kg.
(30) Compton wavelengths of the electron, proton, neutron respectively :
(a) $\lambda_e = 2.426 \times 10^{-12}$ m
(b) $\lambda_p = 1.321 \times 10^{-15}$ m
(c) $\lambda_n = 1.320 \times 10^{-5}$ m.
(31) Magnetic moments of electron and proton respectively :
(a) $\mu_e = 9.285 \times 10^{-24}$ A.m^2
(b) $\mu_p = 1.411 \times 10^{-26}$ A.m^2.
The respective ratios μ_e and μ_p with μ_B may be computed.

Densities

At ordinary temperature (17° – 23°)

Substance	Density $\times 10^3$ kg/m^3	Substance	Density $\times 10^3$ kg/m^3
Metals and alloys		Liquids	
Aluminium	2.7	Alcohol	0.80
Iron. Pure	7.88	Benzene	0.88
Wrought	7.85	Ether	0.74
Cast	7.6	Glycerine	1.26
Steel	7.7	Lubricating oil	0.91
Brass	8.4-8.7	Mercury	13.60
Chromium	6.92	Aniline	1.02
Copper	8.89	Ether	0.736
Gold	19.3	Turpentine	0.87
Antimony	6.62		
Bismuth	9.78		
Silver	10.5		
Mica	2.6-3.2		
Platinum	21.45		
Tungsten	19.3		
Tin	7.3		
Lead	11.34		
Magnesium	1.74		
Nickle	8.8		
Selenium	4.8	Gases :	
Germanium	5.3		
Bronze	8.8-8.9	Air	0.00129
Constantan	8.88	Carbon dioxide	0.00198
Manganin	8.50	Hydrogen	0.00609
Asbestos	2.0-2.8	Steam-(100°C)	0.00091
Cork	0.22-0.26	Helium	0.000179
Glass Crown	2.0		
Flint	4.0		
Zinc	7.1		

Acceleration due to Gravity :

Place	g	Place	g
Pole	9.8222	Allahabad	9.7895
Equator	9.7803	Gorakhpur	9.7905
Delhi	9.7915	Gwalior	9.7897
Meerut	9.7915	Indore	9.7860
DehraDun	9.7907	Jaipur	9.7852
Lucknow	9.7900	Ajmer	9.7890
Kanpur	9.7901	Bombay	9.7865
Varanasi	9.7899	Calcutta	9.7878
Agra	9.7606	Madras	9.7828
Aligarh	9.7808		

Elastic constants :

Substance	Young's Modulus Y Newton/$m^2 \times 10^{11}$	Modulus of rigidity η Newton/$m^2 \times 10^{11}$	Poisson's ratio σ
Aluminum	0.69—0.72	0.25—0.27	0.33—0.35
Brass	0.9—1.0	0.34—0.23	0.39—0.40
Copper	1.1—1.29	0.34—0.46	0.25—0.35
Iron Wrought	1.9—2.2	0.77—0.83	0.27—0.29
Cast	1.0—1.3	0.35—0.53	0.24—0.31
Steel Cast	1.9—2.1	0.74—0.76	—
Mild	2.1—2.3	0.80—0.89	0.25—0.31
Zinc	0.8—1.1	0.39—0.38	0.23—0.31
Glass Crown	0.6—0.78	0.26—0.32	0.25—0.27
Flint	0.5—0.6	0.2—0.25	0.21—0.26

Viscosity of water :

Temperature °C	Viscosity (Poise)	Temperature °C	Viscosity (Poise)
0	0.01793	60	0.00469
10	0.01311	70	0.00406
20	0.01000	80	0.00356
30	0.00800	90	0.00316
40	0.00657	100	0.00284
50	0.00550		

Surface tension of water :

Temperature °C	Surface tension Newton /m × 10^{-2}	Temperature °C	Surface tension Newton/m × 10^{-2}
0	7.5	60	6.56
10	7.35	70	6.38
20	7.21	80	6.20
30	7.06	90	6.02
40	6.89		
50	6.73	100	5.82

Velocity of sound (meter/sec) :

Substance	Velocity	Substance	Velocity
Solid		Liquid :	
Aluminium	5100	Alcohol	1275
Brass	3400	Mercury	1407
Copper	3560	Water	1447
Glass	5000	Gases :	
Iron	5130	Air	331 1
Steel	4990	Hydrogen	1262
		Nitrogen	338
		Oxygen	316

Refractive index of substances at 15°C for D-line of sodium relative to air :

Substance	μ	Substance	μ
Solids :		Liquids :	
Glass crown	1.50	Aniline	1.590
Glass flint	1.55	Benzene	1.504
Diamond	2.417	Chloroform	1.53
Mica	1,56—1.69	Glycerine	1.449
Sugar	1.56	Sulphuric acid	1.47
Quartz	1.544	Turpentine	1.43
		Water	1.333

Wavelength of spectral lines (A. U.)

Hydrogen :	Mercury :	Neon :
6562.784	4047 V	5765 y
4861.327	4078 V	5853 y
4340.466	4358 V	5882 o
4101.736	4916 bg	6507 r
Sodium :	4960 g	
5890 D_1	5461 g	Cadmium :
5896 D_2	5770 y	6438
Helium :	5791 y	5085
3889		4799
4026		4678
4471		4662
5876		