NATIONAL OPEN UNIVERSITY OF NIGERIA

SCHOOL OF SCIENCE AND TECHNOLOGY

COURSE CODE: PHY320

COURSE TITLE: LABORATORY PHYSICS

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(For Counsellor's use only)
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EXPERIMENT 1
A STUDY OF NETWORK THEOREMS
Structure

1.1   INTRODUCTION

Electric circuits form the backbone on which the study of most electrical phenomena is based. These circuits may contain resistors, capacitors, inductors which are passive elements, or some active devices such as vacuum tubes, transistors etc. In order to understand the nature of the circuits and their applications, one is required to perform the analysis for currents, voltages, power or frequency responses in the circuit. If the circuit is simple, one can do the analysis just using Ohm's Law. However, many circuits are complicated and analysis becomes difficult. Hence systematic methods should be developed to simplify the circuits and to make the analysis easy. In order to perform the analysis of a complicated circuit in a simplified manner, some theorems have been developed. These theorems are known as Network Theorems.

Objectives

After performing the experiments, you will be able to:
*   verify maximum power, superposition, reciprocity and Thevenin's theorems.
*   apply above theorems to different networks.

1.2   APPARATUS

Two transistorised power supplies (0 – 15V), resistors (100 – 1000 ohms) multimeters, connecting wires.

1.3   STUDY MATERIAL

Before   performing the experiments you may be interested   in knowing   more about a network and the theorems mentioned in the Objectives.

1.3.1   Network

An electrical network is any interconnection of electric circuit elements such as inductors, resistors, capacitors, generators, or branches where each branch may include *R*, *L*, *C*, or other types of linear elements. A linear element is one in which the current is proportional to the voltage. Such a linear network having two distinct pairs of terminals is called a four-terminal network 1,1 : 2,2. as shown in Fig. 1.1.a. However if one of the 1,1 terminals is common to the

2,2 pair, the circuit is known as 3-terminal network as shown in Fig. 1.1.b. If the 2,2 terminals are short circuited, it becomes a two-terminal network.

Networks may be of the following types:
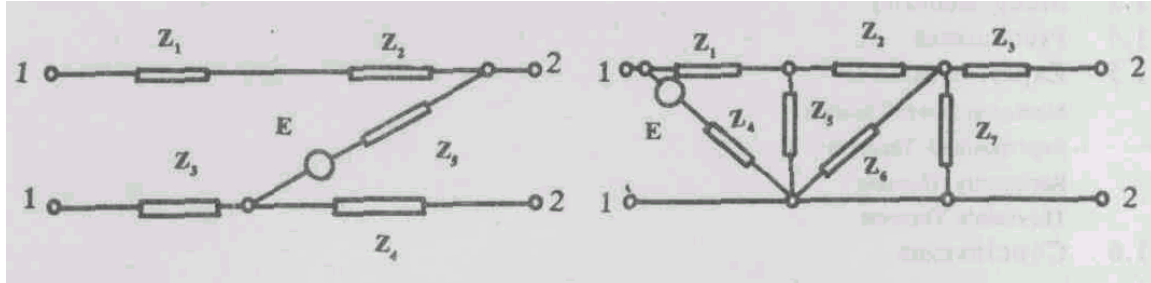
| **Fig. 1.1.a** | **Fig. 1.1.b** |
| **4-Terminal Network** | **3-Terminal Network** |

PASSIVE NETWORK:
A network containing circuit elements without any energy source such as a battery is known as **passive network.**

ACTIVENETWORK:
A network containing generators or energy sources along with other elements is known as an **active network.**

A specific path between two points in a network is called   a **branch.**

In a network a set of branches forming a closed path in such a way that if one branch is omitted the remaining branches do not form a closed path, is known as a **Mesh.**

A terminal of any branch of network, or a terminal common to two or more branches is known as a **Node or Junction.**

We can now summarise that a network may have active or passive elements, branches, nodes, meshes. Our aim is to analyse any such network for current in any loop, or the voltage across any element using appropriate network theorems. We will first try to understand some of the important network theorems and then proceed further for their applications using practical network circuits.

1.3.2 Superposition Theorem:
Let us consider the following circuits.
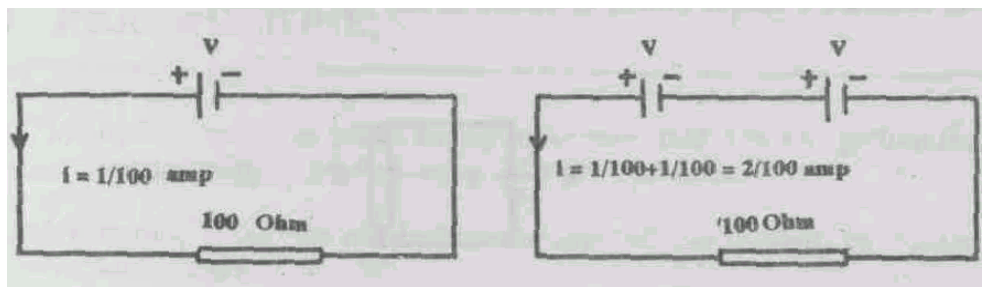
Fig. 1.2

A battery of 1 volt applied to a resistance of 100 ohms, causes a current of 1/100 ampere to flow . Two batteries in series, each of 1 volt connected to the same 100 ohm resistance, each cause 1/100 ampere to flow. Together they cause 2/100 ampere to flow. The total current is thus the sum of the currents produced by the individual batteries. This statement if generalised is known as the **Superposition Theorem.** This can be stated as follows.

Each emf in a linear network produces current in any given branch Independent of the action of other emf s, and that the resultant total current in any branch is the algebraic sum of the contribution of current due to each of the emfs.

You will be able to verify this theorem by performing the experiment.

SAQ
In the following circuit calculate the current caused to flow through the resistor due to the individual sources separately. Calculate the current when both sources are present.

**Verify your result experimentally,** later on.
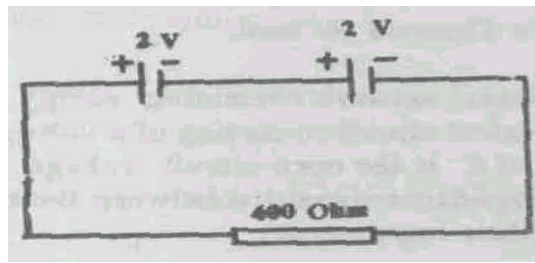
Fig. 1.3

Answer: With V_1 alone, the current expected is .... With V_2 alone the current is .... With both V_1 and V_2, the current expected is ....

1.3.3 Reciprocity Theorem:
The reciprocity theorem states that if an emf E is placed in one branch of an electrical circuit, giving rise to a current I in another branch, the same current I is obtained in the original branch when the emf E is transferred to the branch where the current I arose.

In order to understand clearly, let us consider the following circuit, as an example.
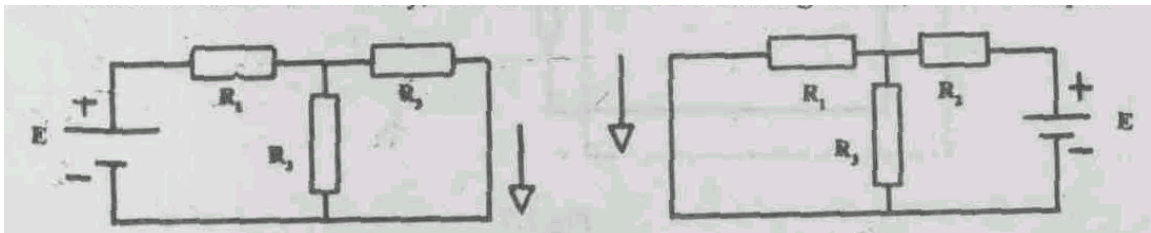
Fig. 1.4.a   **Fig. 1.4.b**

The Reciprocity Theorem assures that $I_1 = I_3$ since E is the same in each circuit.

1.3.4 Thevenin's Theorem:

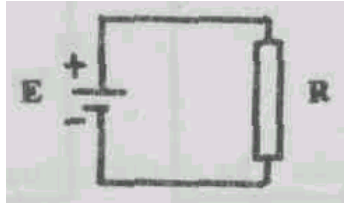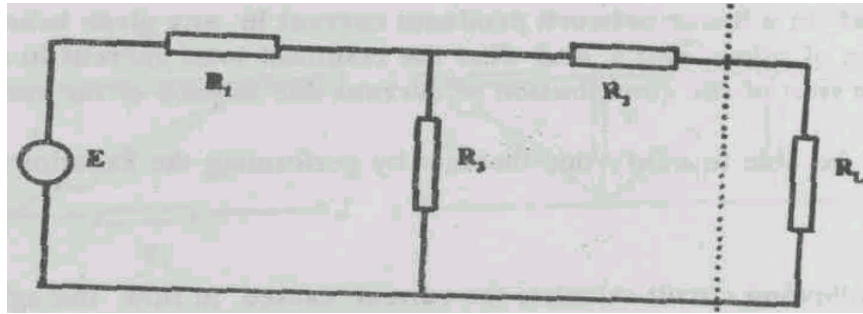Let us consider a simple circuit as shown in Fig. 1.5.

Fig.1.5

If you want to find out the current through the load R you can apply Ohm's Law and get $I = E / R$. However if the circuit (outlined in dashes) is complicated such as shown in Fig. 1.6, it is difficult to find the current or the voltage across the load R_L using Ohm's Law.

In order to analyse such circuits, Thevenin's Theorem is used.

This theorem states that any two terminal linear network containing energy sources and impedances can be replaced with an equivalent circuit consisting of a voltage source E' in series with an impedance R'. The value of E' is the open circuit voltage between the terminals of the network and R' is the impedance measured between the terminals with all energy sources eliminated (but not their impedances).

Thus the Thevenin's equivalent circuit of the above network is shown below.
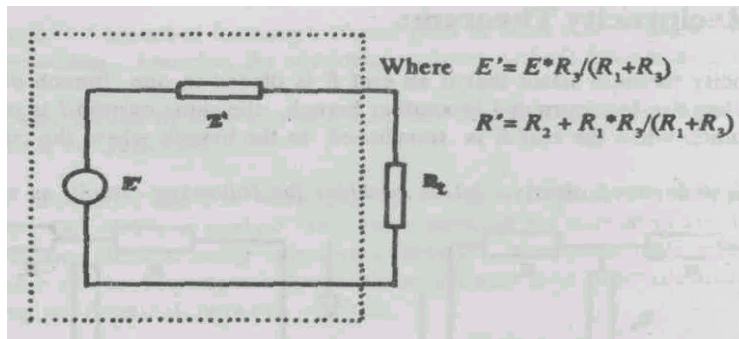

Where $E' = E * R_3 / (R_1 + R_3)$

$R' = R_2 + R_1 * R_3 / (R_1 + R_3)$

Fig. 1.7

We will study the application of Thevenin's Theorem in a network while performing the experiment.

1.4 PRECAUTIONS:

(a)   Before using the power supply make sure that you are getting the necessary voltage range, by measuring with the multimeter.

(b)   Before using the resistance make sure of their values, by measuring with a multimeter.

(c)   Before using the Ammeter and Voltmeter check for zero setting.

1.5 EXPERIMENTS
1.5.1 Verification of Maximum Power Transfer Theorem
APPARATUS:
Power supply (10 V dc), multimeter, resistors: 100 ohms, 200 ohms, 300 ohms, 400 ohms, 500 ohms, 600 ohms, 800 ohms, 1000 ohms (nominal values).

PROCEDURE:
Arrange the circuit as shown in Fig.1.8. Make $R = 500$ ohms, and R_L 100 ohms. Connect a voltmeter across the load to measure the voltage drop across the load (R_L). Keep the output of the power supply at 10V with the output-varying knob. Note the voltage across the load resistor in Observation Table I, Now replace the load resistor by another resistor of different value and measure the voltage across it. Make $V_1 = 10$ volts by adjustment, before you measure and note the value of voltage across R_L. Repeat the experiment with at least 8 different resistors. In each case record your measurements in the Observation Table I.
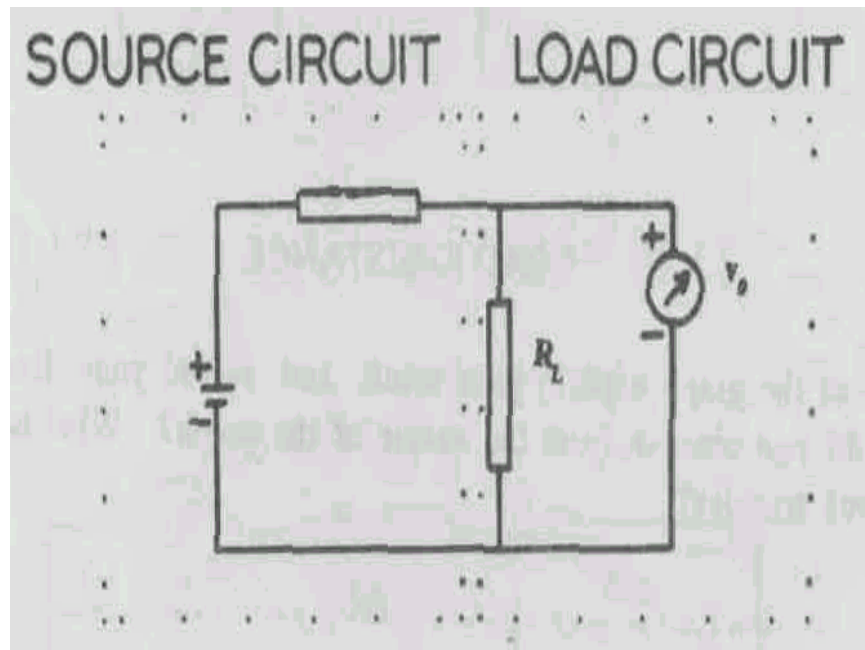
Fig. 1.8

OBSERVATION TABLE I

Value of source impedance *(R)*   =   500 ohms Source voltage   (V) =   10 volts.

S. No.	Load Resistance (R_L) ohms	Output voltage V_0 Volts	Power Transfer (calculate) $P = V_0^2 / R_L$ Watts
1. 2. 3. 4. 5. 6. 7. 8.			

Now plot a graph between load resistance R_L and the power transferred.

P
O
W
E
R

LOAD RESISTANCE

With the help of the graph explain your result and record your findings in the space below. What do you observe from the nature of the graph? What is the condition for maximum power transfer?

_____

_____

_____

_____

SAQ

When the maximum power is transferred from source to the load, then the output voltage V_0 compared to V_1? More? Less? Somewhat is the write your choice & your comments:

_____

_____

_____

1.5.2   Application of Superposition Theorem
APPARATUS
Two voltage sources, a multimeter, and three resistors 500 ohms each.

PROCEDURE
STEP 1: Connect the circuit as shown in Fig.l.9.a. Set V_1 about 10 volts, and V_2 about 5 volts. Before Turning on the power supplies, calculate the current expected. Write the value here............... Choose an appropriate multimeter range, and turn on the power supplies.

Record the supply voltage in each loop and the current in the first loop. Record the current as I_a, in Observation Table II. Repeat Step 1 three times.

Fig.1.9.a   **Fig.l.9.b**

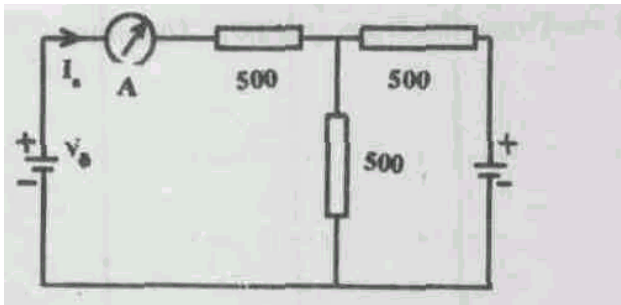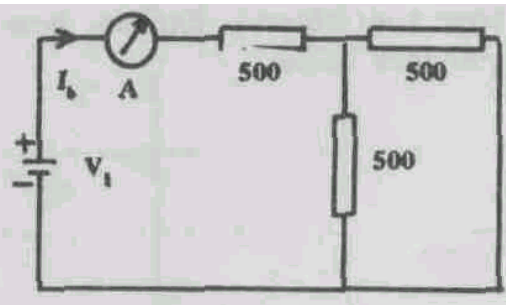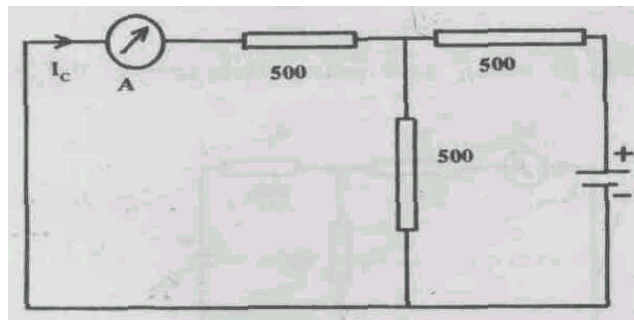**Fig. 1.9.c**

STEP 2:
Now change the circuit to that of Fig.l.9.b. With V_1 at the same value, note the current in the first loop as I_b. Repeat Step 2 three times.

STEP 3:
Now change the circuit to that of Fig.1.9.c. With V_2 the same as in STEP 1, note the current in the first loop as I_c. Repeat step 3 three times.

Repeat the three steps for $V_1 = 5$ volts and $V_2 = 5$ volts.

Repeat the three steps for $V_1 = 2$ volts and $V_2 = 6$ volts.

All readings should be recorded in Observation Table II.

OBSERVATION TABLE II

S. No.	V_1 (volts)	V_2 (volts)	I_a (amp)	I_b (amp)	I_c (amp)	$I_b + I_c$ (calculate) (amp)
			•			

With the help of the results compare the values I_a and $I_o + I_c$, taking into account the experimental error your observe. Explain how it confirms the Superposition Theorem, in the space provided below.
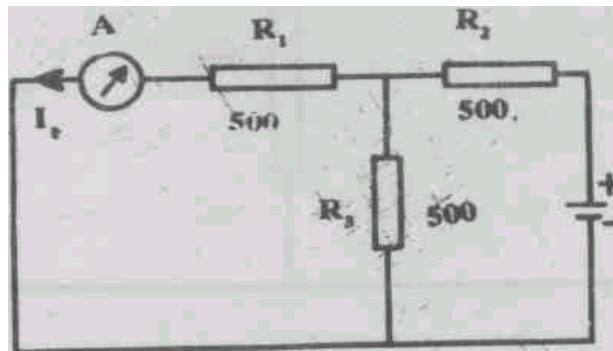
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1.5.3 Verification of the Reciprocity Theorem
APPARATUS
Two voltage sources (0 to 10 volts), multimeter, three resistors 500 ohms each, one 1000 ohms.

PROCEDURE

Fig. 1.10.a

STEP 1:

Arrange the circuit as shown in Fig. 1.10.a. Set V_2 at approximately 5 volts, and measure V_2 and I_1, noting them in Observation Table III. Repeat Step 1 three times.

STEP 2:

Now connect the circuit of Fig. 1.10.b. Set V_1 at approximately 3 volts and measure V_1 and I_2, noting them in Observation Table III. Repeat Step 2 three times.

STEP 3:

Calculate V_2 / I_1 and V_1 / I_2 and enter in the Observation Table III. Repeat Step 3 three times.

Repeat the steps above, using $R_1 = 1000$ ohms and $R_2 = R_3 = 500$ ohms.

Repeat the steps again, using the same set of resistors but with V_1 about 7 volts and V_2 about 10 volts.

OBSERVATION TABLE III

S. No.	V_1 (volts)	I_2 (amps)	V_2 (volts)	I_1 (amps)	V_2 / I_1 (ohms)	V_1 / I_2 (ohms)

How do the calculations agree with the predictions of the Reciprocity Theorem, taking into Account the experimental errors experienced?

SAQ:

In the above experiments, will the Theorem hold good if the two voltages V_1 and V_2 are present at the same time?

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_____

_____

1.5.4 Application of Thevenin's Theorem
APPARATUS:

Variable power supply (0 to 10 V), two resistors of 500 ohms each, a variable resistor and a multimeter.
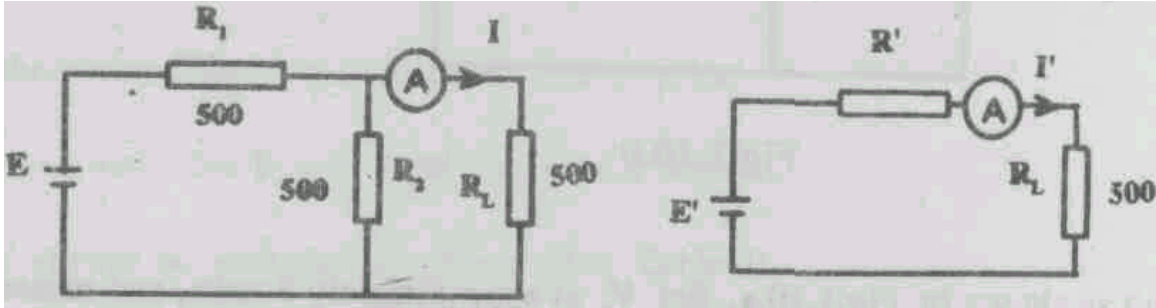
Fig. 1.11.a   Fig. 1.11.b

PROCEDURE:

Arrange the circuit as shown in Fig. 1.11a. Measure the current I through the load R_L. Now arrange the Thevenin's equivalent circuit Fig. 1.11.b by calculating the value of R' and E' as :

$$R' = \frac{R_1 \times R_2}{R_1 + R_2} \; ; \quad E' = \frac{E_1 \times R_2}{R_1 + R_2}$$

Measure the current I' through the load in the equivalent circuit. Repeat the experiment using two different pairs of resistors R_1 and R_2. Record the data in Observation Table IV. Repeat the Procedure three times.

OBSERVATION TABLE IV
$E = ...$ Volt $R_L = 500$ ohm

S. No.	R_1	R_2	I	E'	R'	I'

Compare the values I and I'.

Explain your result and record your findings in the space given below, taking into account the experiment errors experienced.

_____

_____

_____

In the above experiment, calculate the values of currents I and I' using Ohms's law and compare with your measured values.

1.6   CONCLUSIONS:
After the experiments, list your findings.

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_____

EXPERIMENT 2
CALIBRATION OF A THERMISTOR AND DETERMINATION OF ITS ENERGY GAP
Structure

2.1   INTRODUCTION
The electrical resistance of materials generally increases with increase of temperature. This increase is usually very small (< 1% degree C). The discovery of semiconducting materials and the techniques used in modifying their electrical properties have resulted in materials for which the variation in electrical resistance with temperature is large (as high as 3 to 10%). Such devices have very many applications in measurement and control of temperatures of objects. Thermistors are semiconductor devices, with a high (usually negative) temperature coefficient of resistance. Some thermistors have their room temperature resistance decrease 5% per degree rise in temperature. This high degree of sensitivity to temperature change, makes it possible to use the thermistor in temperature measurement and control etc. Thermistors are generally used in the temperature range of -100°C to 300° C. Thermistor have generally three important characteristics (Fig 2.1) which are extremely useful in measurement & control applications.

(i)   Resistance vs Temp, characteristics (Fig.2.1 (a))
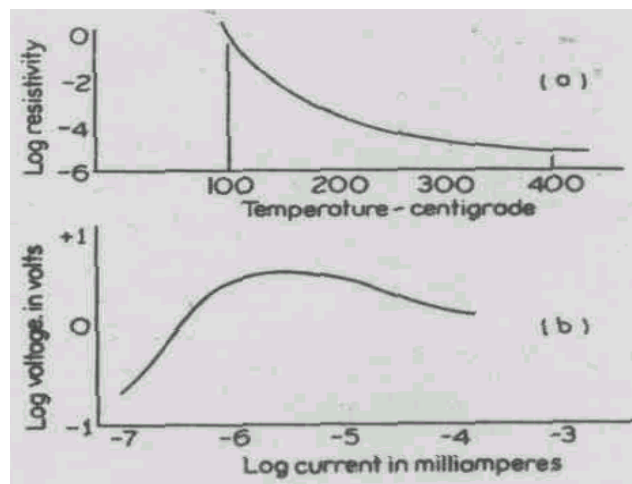(ii)   Voltage vs Current characteristics (Fig.2.1 (b))

Fig. 2.1

In this experiment you will find the resistance temperature characteristics of a thermistor, which has a high temperature coefficient of resistance. This property is used in making temperature transducers. Thermistors are used in other fields also. Some of the important applications of transducers are in remote measurement or control, temperature controller circuits, compensator circuits and in thermal conductivity measurements etc. For example the temperature inside a vacuum furnace, measurement of super heated steam inside a turbine of a thermal power station.

In the first part of the experiment you will calibrate the given thermistor using a thermocouple in the temperature range 30°C - 150°C. As you know that the thermistors are made of materials called semiconductors, we will calculate the band gap energy (See Fig.2.2) of the semiconducting material.

OBJECTIVES
The student will be able to:

- calibrate the given thermistor using a thermocouple.
- calculate the band gap energy, Eg of the thermistor material (semiconductor).

2.2 APPARATUS:
Thermo couple (copper - constantan)
Thermistor (7 K ohms at room temperature)
Water bath
Oil bath
Ice bath
Burner or stove or an electric hot plate
Wire gauze
Stands
Resistance Boxes (of different ranges 1K ohm to   3K ohm)
Low voltage D.C source (battery or power supply   0-4 Volts)
Galvanometer/ head phone
Millivoltmeter (0 to 10 mV)
Multimeter
Soldering iron, soldering rosin, and solder.
Connecting wires.

2.3 STUDY MATERIAL
The thermistor is a made of a semiconducting material. Its resistance generally decreases when the temperature is increased. The relation between resistance and temperature is given by:

$$R_T = R_0 \exp(E_g / 2kT)$$

Here R_T = resistance at temperature T in Kelvin degrees.

R_0 = resistance at 0 Kelvin.

E_g = the energy difference between the filled valence and the empty conduction

band of the particular semiconductor (Fig.2.2).

Electrons in a free atom have discrete energy levels. But when atoms are brought together to form molecules and solids the electronic energy levels became almost continuous over certain ranges. These ranges are separated by regions of energy values that electrons cannot possess. The energy

of the electrons in a semiconductor is represented on a one-dimensional energy diagram (see Fig. 2.2), showing ranges of energies the electrons are allowed to have and the ranges of energies in between the allowed bands where electrons are forbidden to exist.
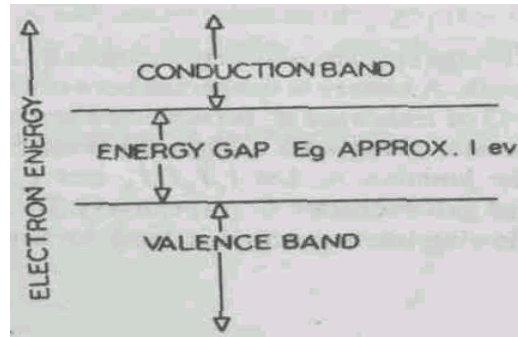
Fig. 2.2: Energy band diagram of a semiconductor

The highest occupied band corresponds to the ground state of the outmost or valence electrons in the atom. For this reason the upper occupied band is called the valence band. In a semiconductor, the valence band is full or nearly so. In addition the width of the forbidden energy gap (E_g , the band gap energy) between the top of the valence band and the bottom of the next allowed band, called the conduction band is of the order of 1 eV (e.g. for Ge = 0.7 eV, and for Si = 1.1 eV).

SAQ
What do you mean by the energy gap in a semiconductor?

_____

_____

_____

The resistance of a thermistor may be determined at various temperatures with the help of some type of bridge circuits. In these circuits we required the use of a galvanometer or head phone as a balancing indicator. All these bridges work on the principle of the Wheatstone's bridge. The circuit arrangement is shown in Fig.2.3.
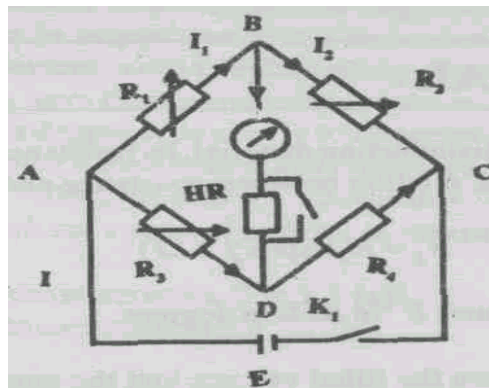
Fig. 2.3

Wheatstone's bridge consists of four resistances R_1, R_2, R_3 and R_4 connected as shown in Fig. 2.3 to form a network. A battery is connect between one pair of opposite junctions, A and C. A galvanometer G of resistance R_g is connected across the other pair of junctions B and D as a balancing indicator along with a high resistance *HR*. Let I be the current from the battery entering at the junction A. Let I_1, I_2, I_3, I_4 and I_g be the currents through the resistances R_1, R_2, R_3 and R_4 and galvanometer G respectively. By Kirchhoff's first law (The algebraic sum of the currents flowing into a junction is zero) we have the following relations.

For the junction A, $\qquad I - I_1 - I_3 \qquad = 0$ (1)

For the junction B, $\qquad I_1 - I_2 - I_g \qquad = 0$ (2)

For the junction D, $\qquad I_3 + I_g - I_4 \qquad = 0$ (3)

If the bridge is balanced, the voltage at point B and D is the same. So no current flows through the galvanometer, i.e., $I_g = 0$. It can be shown that the following equation is true.

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$ (4)

If three resistances (R_1, R_2, R_3) are known, the value of the fourth can be calculated.

The resistance of the thermistor (R_T) at various temperatures ($T°$ Kelvin) can be measured using the bridge circuit.

If we plot a graph between $1/T$ along the *x*-axis and $\ln(R_T)$ along the *y*-axis it will be a straight line since the following is true.

$$\ln(R_T) = \ln(R_0) + \frac{E_g}{2k} \times \frac{1}{T}$$ (5)

The slope of the line is ($E_g/2$k.).

If the graph is between $1/T$ and $\log_{10} R_T$, then the slope of the straight line is given by the following.

$$\frac{E_g}{2k \times 2.303}$$ (6)

The energy gap is calculated from the slope of the straight line.

$$E_g = 4.606 \times k \times (\text{Slope of the straight line})$$ (7)

Here E_g is expressed in electron volts.

SAQ

1.   List a few metals, semiconductors, and insulators that you are familiar with.

_____

_____

2.   Distinguish between metals, semiconductors and insulators in terms of energy gap.

_____

_____

_____

2.4 PRECAUTIONS

(a)   Care should be taken not to damage the balancing instrument. You can do this by using a high resistance in series with the galvanometer when the bridge is too for away from the balance. You can then remove this when the bridge is near the balance condition, by short-circuiting the high resistance.

(b)   Care should be taken to keep the thermocouple and thermistor in the same location during the calibration.

2.5 EXPERIMENT
2.5.1 Calibration of thermistor
APPARATUS:
As in Section 2.2.
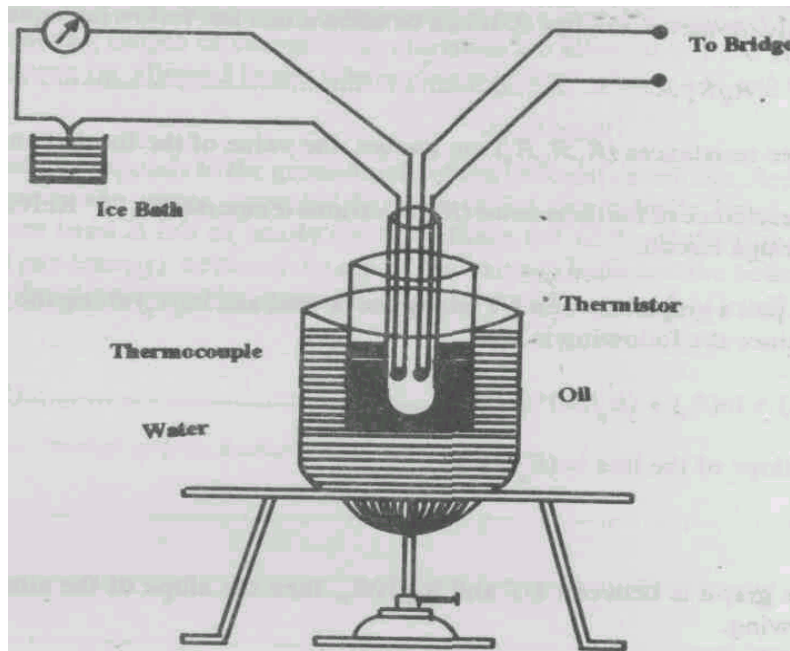
Fig.2.4

PROCEDURE:

Take the given thermistor, and measure its resistance with the help of a multimeter at room temperature. Solder its ends to long connecting wires. Connect this thermistor to one arm of the

bridge (between C & D of Fig.2.3) and place known resistance boxes in the other three arms. The voltage source (battery), with a plug key in series, is connected across one diagonal of the four-sided arrangement. A sensitive galvanometer or null detector or headphone and a high resistance (about 5000 ohms) is connected across the other diagonal as shown Fig.2.3. Now you can measure the resistance of the thermistor with the help of this bridge as follows:

Make R_1 and R_2, each equal to 1 K ohm and $R_3 = 0$, and close the key K_1 and then K_2, the key K_3, in the safety resistance being left open. The high resistance is then included in series with the balancing indicator and it cuts down the current to a low value. Note to which side the pointer moves on closing K_1. Repeat by having in R_3 the largest possible resistance or say 10000 ohm. Note the direction of the deflection. The galvanometer needle must deflect in the opposite direction for $R_3 = 0$ and $R_3 =$ infinity. If it is so, the network is connected correctly. Otherwise check the connection again.

Now take $R_1 = R_2 = 1$K ohm. Vary R_3 till this deflection is brought to zero. When the deflection is almost nil, short-circuit the high resistance. Now the measuring instrument becomes more sensitive and a large deflection is seen. Make final adjustment of R_3 needed for perfect balance (no movement of pointer). Then R_3 is equal to R_4 at room temperature. In this way you determine the value of the thermistor resistance at a given temperature. Now compare the resistance of this thermistor as measured by a digital ohm-meter and the value from the above bridge measurement. Is there any difference? Give reasons.

_____

_____

_____

Now you take the thermocouple, connect it to a millivoltmeter, or you can connect it with a digital multimeter in millivolt range. Mount the thermistor and thermocouple at the same location with the help of insulation tape. Insert them into a test tube. Dip this test tube in an oil bath and fix it on a stand. Now, immerse the oil bath (the test tube with the thermistor and thermocouple) into a large vessel of water and heat the water to boiling point, with the help of a burner. Now measure the voltage across the thermocouple in steps of 0.1 volt and measure the corresponding thermistor resistance using the bridge as described above.

In case the change in the resistance of the given thermistor is very small, then you can connect an OP AMP configuration as shown in Fig.2.5 (For detailed discussion see the experiment on Operational Amplifiers.)
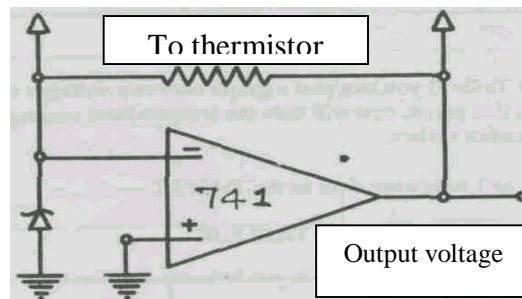
Fig.2.5

Record your data in Table I.

Table I

Resistance of the thermistor at room temperature = ...……

S.NO	Voltage across the Thermocouple		Resistance across the thermistor	
	WHEN HEATING	WHEN COOLING	WHEN HEATING	WHEN COOLING

The values of thermo-emf for different temperatures for a copper-constantan thermocouple is given in Table II.

TABLE II

Thermo-emf of Copper-Constantan thermocouple. Temp in °C. emf in millivolts.

TEMP	0	10	20	30	40	50	60	70	80	90	100
emf	0	0.39	0.79	1.19	1.61	2.03	2.47	2.91	3.36	3.81	4.28

With the help of the Table II you can plot a graph between voltages and temperatures of the thermocouple. From this graph, you will note the temperatures corresponding to the voltages which you have recorded earlier.

Record temperature and resistance data in the Table III.

TABLE III

S. No.	Temperature of the thermistor (T)	Resistance (R)

Plot a graph between temperature vs resistance on the following graph.

This is the calibration chart of the given thermistor.

2.5.2 Calculation of Band Gap Energy of a Thermistor
PROCEDURE
Take temperature vs resistance data of the given semiconductor. In this case we will use the data of the previous part of this experiment. Use the data from the observation Table III. Now, find the reciprocal of temperature and $\log_{10} R$. Record these values in observation Table IV.

Table IV

S. No.	$1/T$	$\log_{10} R$

Now plot a graph between $1/T$ on the *x*-axis and $\log_{10}R$ on the *y*-axis. Plot this graph in space given below:

You will find this to be straight line. Calculate the slope of this line. Put the value of this slope in Equation (7) and calculate the value of E_g.

RESULT
The band gap energy E_g of the given thermistor is ...…….. eV.

SAQ
What do you mean by the energy gap in a semiconductor? Can you calculate this gap in a metal or an insulator? If not, why not?

2.6 CONCLUSIONS
In this experiment you have studied bow a thermistor can be used as a temperature transducer and also some of the material properties of the thermistor materials, resists nee-temperature characteristics and the energy gap of toe semiconducting material. Is this energy band gap

temperature-dependent or not? Can you think of using this thermistor for temperature measurements in any real-life situation? Write some examples

_____

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_____

(For Counsellor's use only)
Grade.............................   Name ....………………..

Evaluated by…………………………….   Enrolment Number ………………

EXPERIMENT 3
CONSTRUCTION AND CHARATERISATION OF POWER SUPPLIES & FILTERS

Structure

3.1   INTRODUCTION

You have seen in daily life many electronic instruments including domestic electronics like radio, tape recorders, T.V, amplifiers, musical keyboards etc. Do you know whether these instruments work on D.C. (Direct Current) or A.C. (Alternating Current)?. In fact they all operate on D.C. So when we connect such equipment to the mains (A.C.), it is necessary to convert this A.C. into D.C. In all these electronic instruments there is a section inside the equipment, known as the power supply section which converts this A.C. into D.C. with the help of rectifiers etc. This rectified voltage is pulsating and has some (small) A.C. component. It is desirable to convert this pulsating D.C. into constant D.C. and reduce the A.C. component of the rectified voltage so that the output is a pure D.C. voltage. This is accomplished by means of filters, which are composed of suitably connected capacitors, inductors and their combinations in different ways.

The effectiveness of the filter is given by the RIPPLE FACTOR Y- It is defined as the ratio of rms* value of the A.C. component of the voltage to the D.C. voltage (or average value of the voltage). In this way we can identify the purity of the D.C. output in terms of ripple factor. It is desirable that the ripple factor is as small as possible. The capacitance filter has low ripple at heavy loads, while the inductor filter has low ripple at small loads. Depending on the requirements suitable filters can be selected.

* The rms of value of A.C current it one that will produce the same quantity of heat as that of a
  D.C current. The voltage measured using the A.C. range in multimeter gives the rms value of
  the A.C. voltage.

In the first part of the experiment we will construct half-wave and full-wave rectifiers and observe the waveforms on the cathode ray oscilloscope (C.R.O.). Then we will use capacitors and inductors as filters and observe the waveforms on the C.R.O. We will also measure the output voltages (both D.C. and A.C.) with the help of a multimeter and then calculate the ripple factor of these two filters. In laboratories not equipped with CRO, only multimeter readings nerd be used.

In the second part of this experiment we observe the effect of L and PI (π) filters on the output waveform of a full wave rectifier and then calculate the ripple factors in these two filters.

Objectives
After doing this experiment you will be able to:
- Design and construct half and full wave rectifier using step-down transformer and diodes.
- Show the output waveform of a full wave and ha If wave rectifier on a CRO screen.
- Show the effect of the filter (capacitor, inductor, Land PI filter) on the output voltage of a rectifier and compute ripple factor.
- Distinguish between output of L and PI filters.
- Trouble-shoot a power supply when it is defective.

3.2 APPARATUS
1. Centre-tapped transformer (9 V - 0 - 9 V)
2. Diodes - four numbers - (IN4007 or BY126 or BY127)
3. Electrolytic capacitors (1000/<F , 25 V)
4. Inductors - (150 rnH)
5. Resistors - (100 Ω - 2Ω)
6. Connecting wires, soldering iron, soldering flux (rosin), lead (solder)
7. CRO
8. Multimeter etc.,

3.3 STUDY MATERIAL
3.3.1 Half Wave Rectifier
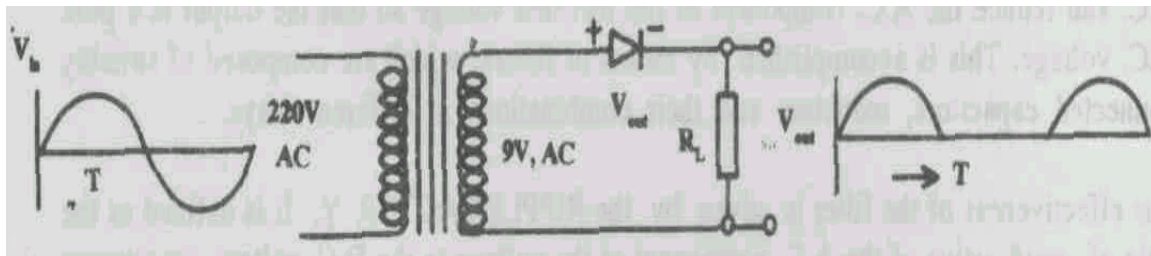
Fig.3.1

Consider the circuit given in Fig 3.1, where we have used a step-down transformer, a semiconductor diode and a load resistance. A sinusoidal 9 V from a step-down transformer is applied across the series-connected diode D_1 and the load resister R_L. The input voltage V_{in} is an A.C. voltage which changes its polarity every 1/100 sec. During the positive alternation the anode is positive (forward biased) with respect to the cathode and the current flows through the diode. During the negative alternation there is no current, because the anode is negative with respect to the cathode (reverse biased). The variation of current through the diode will result in the variation of voltage drop across R_L as shown in the Fig.3.1.

3.3.2 Full Wave Rectifier
Here we use a centre tapped step-down transformer and two diodes to achieve full wave rectification as shown in Fig.3.2.
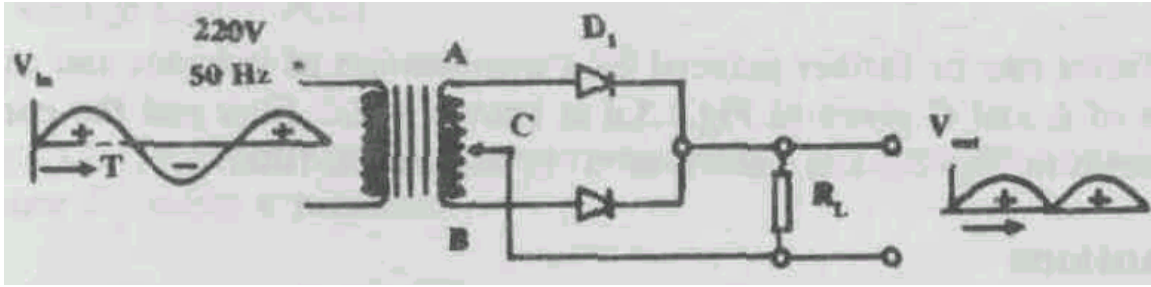
Fig. 3.2

At any moment during a cycle of V_{in} if point A is positive relative to C, point B is negative relative to C. The voltage applied to the anode of each diode is equal but opposite in polarity at any given instant.

When A is positive relative to C, The anode of D_1 is positive with respect to its cathode. Hence D_1 will conduct but D_2 will not. During the second alternation, B is positive relative to C. The anode of D_2 is therefore positive with respect to its cathode, and conducts while D_1 will not.

There is conduction by either D_1, or D_2 during the entire input - voltage cycle.

Since the two diodes have a common-cathode, load resistor R_L the output voltage across R_L will result from the alternate conduction of D_1 and D_2. The output waveform V across R_L is shown in Fig. 3.2.

The output of a full wave rectifier is also pulsating direct current as seen from the Fig. 3.2.

3.3.3 Capacitor Input Filter
Capacitor input filter is shown in Fig. 3.3.b.

Here the high value capacitor is connected across the output voltage. The working principle is as follows.
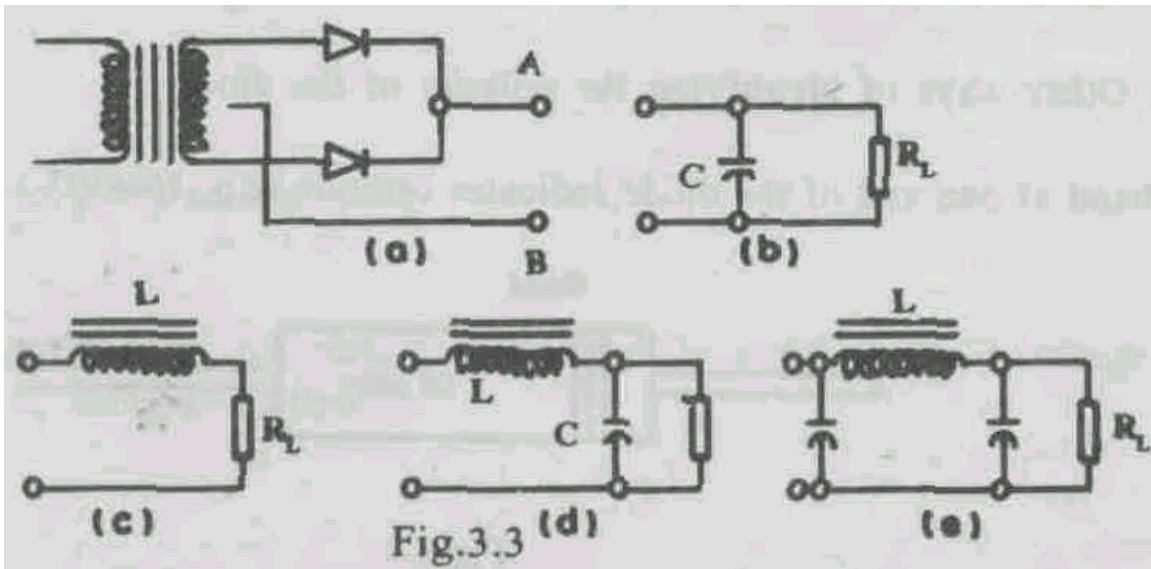
Fig.3.3

The output of the rectifier contains both A.C and D.C. When the capacitor is connected across the output terminal, A and B in Fig. 3.3.a, A.C. components arc by-passed while the D.C. component is blocked and they develop a voltage across the capacitor. Now the capacitor is discharged through the load resistance R_L which is of high value. So it delivers continuous D.C. across the load resistor.

3.3.4 Inductor Filters
Connect between A and B in Fig. 3.3.a inductor L and the load resistor R_L given in Fig. 3.3.c.

The impedance of an inductor is equal to $2\pi fL$, where f = frequency and L = inductance. If both A.C. and D.C. are flowing through an inductor, it has a high impedance for A.C. but not for D.C. So we will find a constant D.C. voltage across the load. In this way it will remove ripples (i.e. A.C. components) and convert pulsating D.C. into constant D.C.

The ripple factor can be further reduced by a combination of inductor and capacitor. The combination of L and C given in Fig.3.3.d is known as LC filter and the combination of L and C shown in Fig. 3.3.e is known as a π section LC filter.

3.4 Precautions
(a)   While measuring voltages using multimeters,   select the correct/appropriate ranges and keep the selector knobs   in the   correct position.
(b)   Check the polarity of the diode using the multimeters and make sure that you have connected them correctly. How to check?
(c)   Make sure that you are connecting the electrolytic capacitor with correct polarity.
(d)   Soldering should be done perfectly.

3.5 THE EXPERIMENT
3.5.1 Half Wave Rectifier
To construct a half wave rectifier and observe the output waveform using a CRO and measure the output voltage.

APPARATUS
Step-down transformer, diode, resistors, soldering iron, solder and rosin.

Step (1)
Check the continuity of the primary and secondary winding of the step-down transformer.

Step (2)
Find the polarity of the diode using the multimeter. (By applying either forward bias or reverse bias one can identify the polarity of the diode.)

Note: Other ways of identifying the polarity of the diode.
(a) A band at one end of the diode indicates cathode (e.g., IN4007) as shown in Fig.3.4.
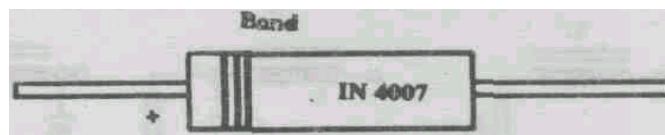
Fig. 3.4

(b)   A Flat portion in a diode like BY126 or BY127 is anode and the curved end or an arrow shaped portion is cathode as shown in Fig.3.5.

Fig. 3.5

Step (3)
Connect the circuit as shown in Fig 3.1.

Step 3(c)
Give input voltage (220V A.C)

Step 4
Measure the A.C. input voltage, A.C. output voltage and the rectified voltage across the load resistance R_L using a multimeter.

Step 5
The output voltage across R_L is given to the Y-Y input of the CRO. Adjust the appropriate   knobs to get the wave pattern of the output .

Trace the output on a tracing paper, and paste it in this report, below. Compare the figure with the expected figure.

3.5.2 Full Wave Rectifier
To construct a full wave rectifier and observe the output waveform using a CRO and measure the output voltage.

PROCEDURE
Take a centre-tapped step-down transformer (9V - 0 - 9V)

Step 1
Follow step 1 and 2 of the experiment in Section 3.5.1 (Here two diodes have to be checked)

Step 2
Connect the circuit as given in Fig. (3.2).

Step 3
Measure the A.C. input voltage, A.C. output voltage and the rectified (D.C) voltage across the load resistance R_L using a multimeter.

Step 4
Voltages across R_L, Diode 1, and Diode 2 are measured using a CRO as in the experiment in section 3.5.1.

Trace the output waveform on a tracing paper, and paste it in this report in the space below.

3.5.3 Capacitor Input Filters
To study the capacitor filter and calculate the ripple factor and record the output wave form with and without filters.

Step 1
Connect a high value (1000 μ F, *25* V) capacitor (electrolytic capacitor) across R_L as shown in Fig. 3.3.b and connect it between A and B as shown in Fig 3.3.a.

The circuit has only a simple capacitor filter.

Step 2
Measure the D.C. and A.C. voltage across R_L. Repeat the experiment for different R_L values and calculate the ripple factor for each load and tabulate the values.

Table I

S. No.	Load	Output (d.c) Voltage	Output (a.c) Voltage	ripple factor $\gamma = \dfrac{E_{rms}}{E_{dc}}$

Step 3

Record the waveform of the output voltage with and without capacitor (trace it from the CRO screen and paste it below).
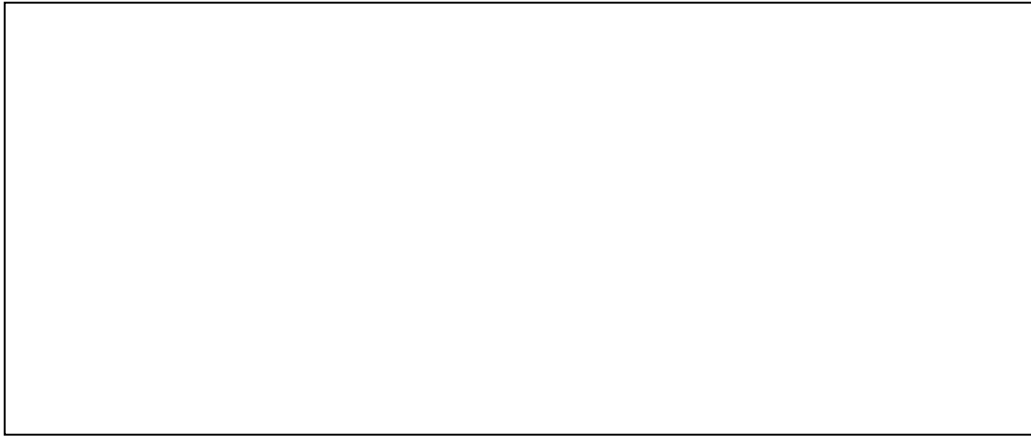
SAQ

Note down your observations when you compare the waveform of the output with and without the capacitor.
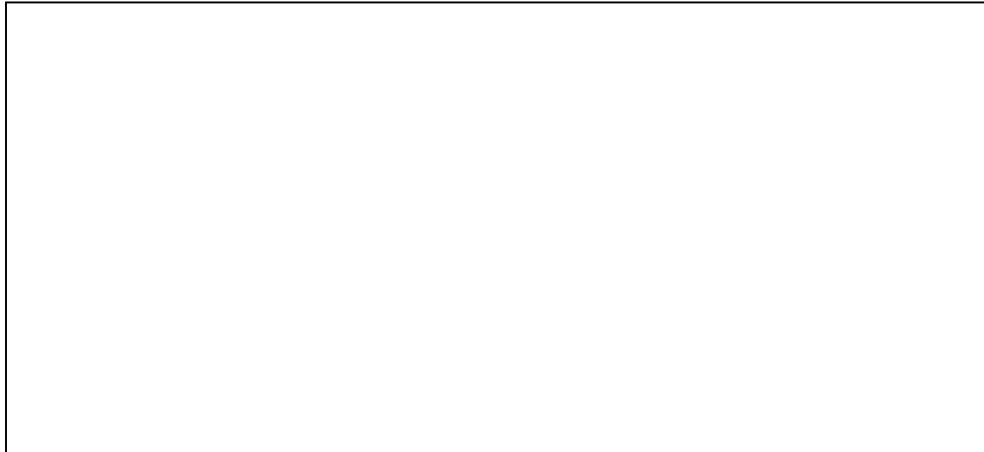
3.5.4 Inductor Filters

To study the inductor filter and calculate the ripple factor.

Step 1

Follow step 1 and 2 of the experiment in Section 3.5.1.

Step 2

With the circuit given in Fig. 3.3.a, between A and B connect the circuit given in Fig. 3.3.c. Here the inductor is connected in series. The circuit is called inductor filter.

Step 3

Connect the primary of the transformer to the mains and measure the output voltage across R_L (both A.C. and D.C). Repeat the experiment for different load values and tabulate your data:

Table II

S. No.	Load	Output (d.c) Voltage	Output (a.c) Voltage	ripple factor $\gamma = \dfrac{E_{rms}}{E_{dc}}$

3.5.5 *LC* and π Filters
To study *LC* and π filters and compare the ripple factor in these two filters.

Procedure:
In the previous part of the experiment you have used an inductor as a filter. Now, connect a capacitor in parallel to the load resistance as shown in Fig. 3.3.d. This combination of inductor and capacitor is known as an *LC* filter. Now measure D.C. and A.C. voltages across the load as measured in the previous part of this experiment. Repeat the experiment for different load resistances and record your data in Table III. Calculate the ripple factor for each load.

TABLE III

| S. No.	Load	Output (d.c) Voltage	Output (a.c) Voltage	ripple factor $\gamma = \dfrac{E_{rms}}{E_{dc}}$

Now connect the output of load resistance R_L to the Y plate of the oscilloscope. You will find the output waveform. Now, you trace these waveforms on a tracing paper and paste in the space given below:
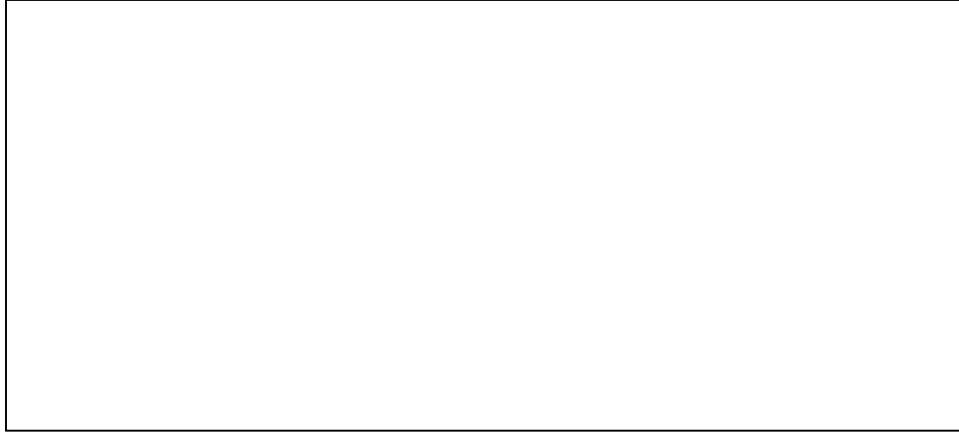
SAQ
Compare the waveform of *C, L* and *LC* filter.

Write your conclusion in the space below:

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SAQ
What is the difference in the ripple factor in I, C, and *1C* filter?

_____

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_____

Now connect one more capacitor before the inductor, in parallel to the previous capacitor. It is shown in Fig.3.3.e.

Such a combination is known as a π filter. Now measure D.C. and A.C. voltages across load resistance R_L as measured in the above part of this experiment. Repeat the experiment for different load and record your data in Table IV. Calculate the ripple factor for different loads.

Table IV

S. No.	Load	Output (d.c) Voltage	Output (a.c) Voltage	ripple factor $\gamma = \dfrac{E_{rms}}{E_{dc}}$

Write your conclusion in the space given below:

_____

_____

_____

Now connect the output of the load resistance R_L to the Y-Y input of the oscilloscope. You will find the output waveform. Now, you trace this waveform on a tracing paper and paste in the space given below:

SAQ
From your data find the difference between the waveforms of the *LC* and π filters. Write your conclusion in the space given below:

_____

_____

_____

Note: Due to technological advancement, the present day power supplies are made more compact by using integrated chips (like 7905) for power regulation instead of all kinds of filters.

3.6 CONCLUSIONS
You have constructed half and full wave rectifiers and smoothed the output using different types of filters. Now answer the questions below in a brief manner.

(a) What will happen if you give an unfiltered voltage to a radio set?
(b) At heavy loads which kind of filter is preferable?
(c) How will you check the polarity of a semiconductor diode?
(d) How does an inductor filter work?

EXPERIMENT 4
STUDY OF OPAMP AS SUMMING AND INVERTING AMPLIFIER

4.1   INTRODUCTION

Given below is a list of some systems and equipment that I hope you have seen and/or used in your everyday life.
(a) A radio set
(b) A doctor's stethoscope
(c) An electrocardiography (ECG) machine
(d) A microscope
(e) A public address system.

I am sure you will be surprised if I ask you what is common in all the above equipment? The answer is "Some sort of an amplifier". In a radio set, we have an amplifier which amplifies very small electrical signals (of the order of a few millivolts). These signals are received from distant radio stations. Not only that, you can even change the amplification by turning the volume control. In a doctor's stethoscope, sound of heartbeat is amplified. In an ECG, we have amplification of small electrical signals (a few microvolt) given out by the heart. A microscope is an optical instrument to see amplified (magnified) images of very small, microscopic objects. In a public address system, speech is given to the microphone by the person speaking. Speech is converted into electrical signals, amplified and fed to the loudspeaker. Thus, in all above examples, we have some type of amplifier.

Today you shall study a special type of amplifier, to amplify electrical signals, called an Operational Amplifier (Opamp).

Opamps may be treated as multipurpose devices which may be used as amplifiers, oscillators, differentiators, integrators, and can also perform other mathematical operations like addition, subtraction, multiplication etc.(and hence the name Opamp).They are very extensively used in present day electronics ranging from entertainment electronics to medical instrumentation and computers.

In this laboratory, we will carry out some simple experiments on an Opamp illustrating some-of its elementary characteristics.

Objectives
After performing this experiment you will be able to use an Opamp as:
- Inverting amplifier
- Summing amplifier

4.2. APPARATUS
2 nos.   - Variable power supplies of +15 V and -15 V.
2 nos.   - Drycells of 1.5 V each.
1 no.   - Digital multimeter for both a.c and d.c   measurements.
2 nos.   - Rheostats, or Potentiometer, Resistance, 10 K ohms each.
1 no.   - Half-watt resistance of different values like 4.7 K ohm, 10 K ohm etc.
2 nos.   - Switches.
1 no.   - Oscilloscope.
1 no.   - Opamp 1C 741, with socket.

4.3 STUDY MATERIAL
4.3.1 Stages of OPAMP
The opamp is a high gain direct coupled amplifier, has high input impedance and low output impedance. Multiple applications of the opamp are made possible by the external control of the variable feedback employed in it. Feedback means that some or all of the output is connected to one of the inputs. The connection may be simple or it may be through a complicated circuit. Fig.4.1.shows the symbol for an opamp. It has two inputs marked.
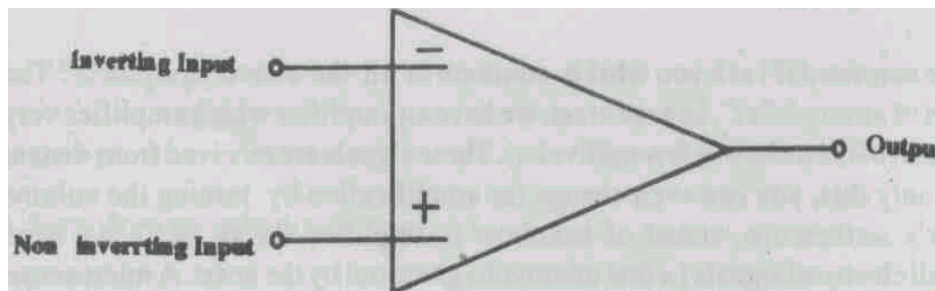
Fig. 4.1

The (-) input is called the "inverting input" The (+) input is called the " non-inverting input". A signal applied to the (•) input will be shifted in phase by 180° at the output. It means that if a -ve pulse is given at inverting input it will appear as a +ve pulse at the output. On the other hand, a signal applied to the non-inverting (+) input will appear in the same phase at the output. This is shown in Figs.4.2 and 4.3, for inverting and non-inverting cases, respectively.
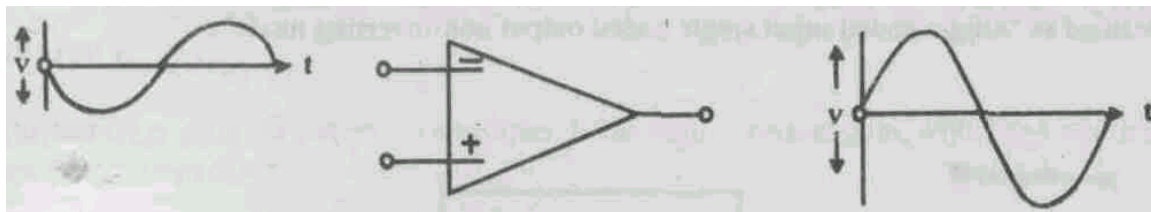
Fig.4.2
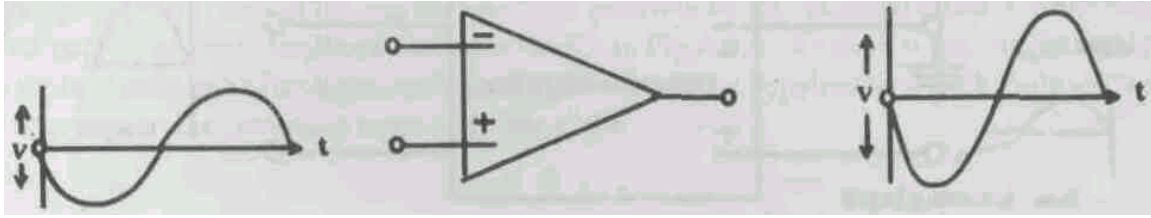
Fig.4.3

Though from the point of using the opamp it is not necessary to go into the details of the inside circuits of the opamp, but from the point of view of learning one may understand its working with reference to the block diagram shown in Fig.4.4.
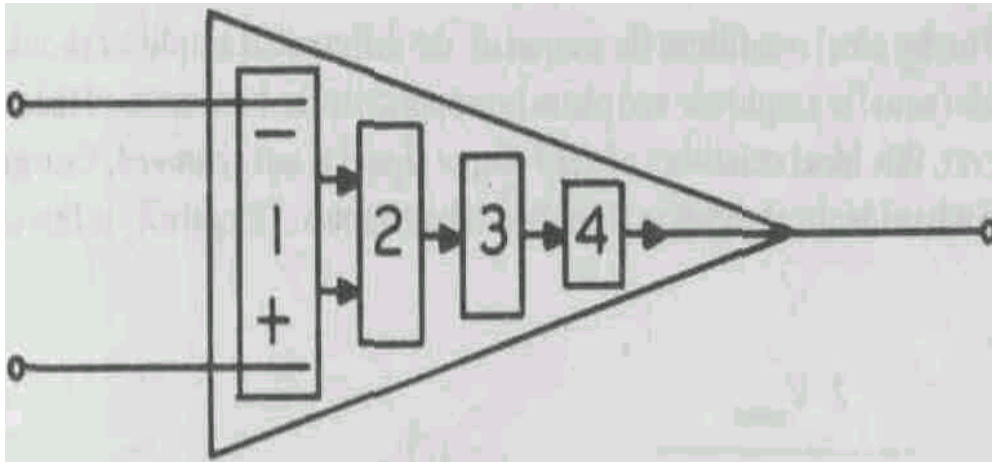
Fig.4.4

STAGE 1
The first stage of an opamp is a difference amplifier.

For most of the parameters like open loop gain, input impedance etc., we refer to the data sheet provided at the end of this experiment.

The difference amplifier amplifies the difference between the two input signals. It is an amplifier that could amplify a small difference in voltage between the inputs, even if the inputs themselves may be at a few volts above ground. For example, if the terminal marked -ve is at +2.01 volt DC and the other at +2.00 volts DC, the difference 0.01 volt DC alone will be amplified. A well designed difference amplifier is not sensitive to environmental changes. The output signal from a difference amplifier is proportional to the difference between the two input signals. The mode of operation in which two different signals are applied at the inputs to get an output signal proportional to the difference of the two input signals is called "differential input differential output mode". The difference amplifier may also be used in a single ended output mode if one of the two inputs is grounded. When the +ve input (non-inverting) is grounded, a +ve input signal at the inverting input will appear as a-ve signal at the output (see Fig.4.5). This is referred to as "single ended input single ended output inverting mode". Similarly, if the inverting input is grounded and a signal is applied at the noninverting input it will appear at the output without any phase change. The operation will be termed as "single ended input single ended output non-inverting mode".
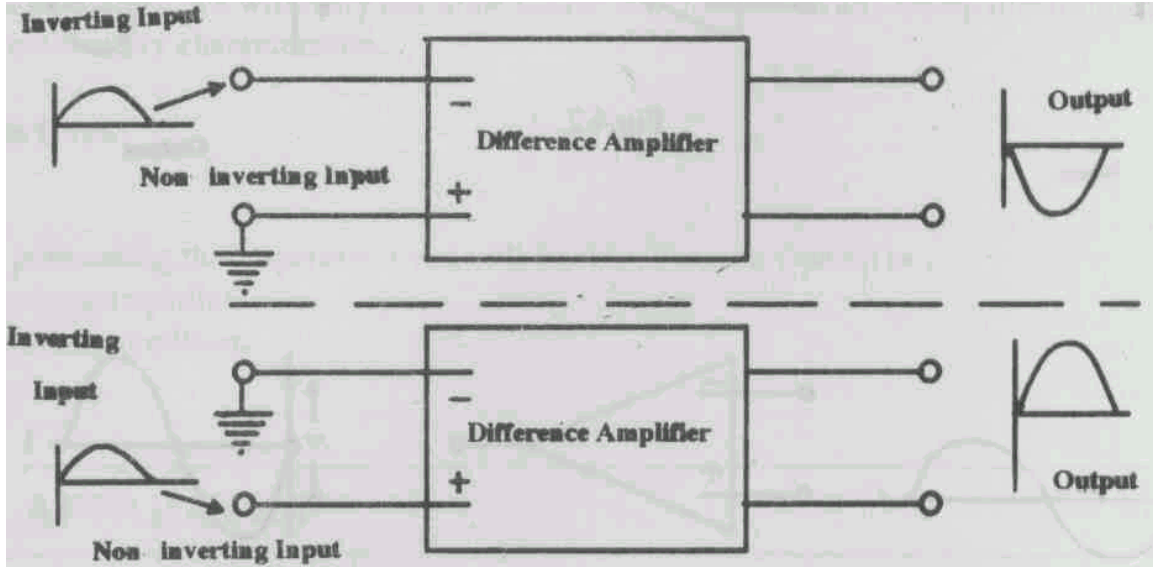
Fig.4.5

If in differential mode operation inputs V_1 and V_2 are applied respectively at the inverting and non-inverting inputs such that $V = -V_1 = V_2$ the differential gain A_d is given by

$$A_d = \frac{V_{output}}{V_{input}} = \frac{V_{output}}{V_1 - (+V_2)} \tag{1}$$

On the other hand under ideal conditions the output of the differential amplifier should be zero if identical signals (equal in amplitude and phase) are applied to the two inputs of the amplifier. In practice, however, this ideal condition of zero output signal is not achieved. One gets some output signal even when identical signals are applied at both inputs. The gain A_c in this condition is given by

$$A_c = \frac{2V_{output}}{(V_1 + V_2)} \tag{2}$$

The ratio A_d/A_c is called the common mode rejection ratio (CMRR). It is an index of the ability of the amplifier to reject signals common to both the inputs. In other words CMRR may be looked on as the quality factor of the amplifier to select proper signals out of a mass of noise common to both the inputs. The range of the common mode voltage over which the difference amplifier works properly is called the common mode voltage range.

STAGE 2
Stage 2 is the second amplifier and may be another difference amplifier with single ended input mode. It provides further gain.

STAGE 3
The third stage in the opamp is the "level shifter". Since each stage in the opamp is directly coupled to the next stage, the dc level increases from one stage to the next and ultimately

approaches the power supply voltage. The level shifter stage provides compensation for this rise in the dc level.

STAGE 4
The last stage is the output power amplifier. It has high current gain, wide band width and low output impedance.

4.3.2 Use of negative feedback
The output of the opamp is always inverted with respect to the inverting input. If a small amount of output is fed back (added) along with the inverting input, it will result in a feedback called negative feedback.

Multiple applications of the opamp a re made possible by the external control of the negative feed back. The basic feedback circuit is shown in Fig.4.6.a. As shown, the output is fed back to the inverting input through a resistance R_f. This provides negative feedback. Suppose a signal is applied at the inverting input as in Fig.4.6.a.
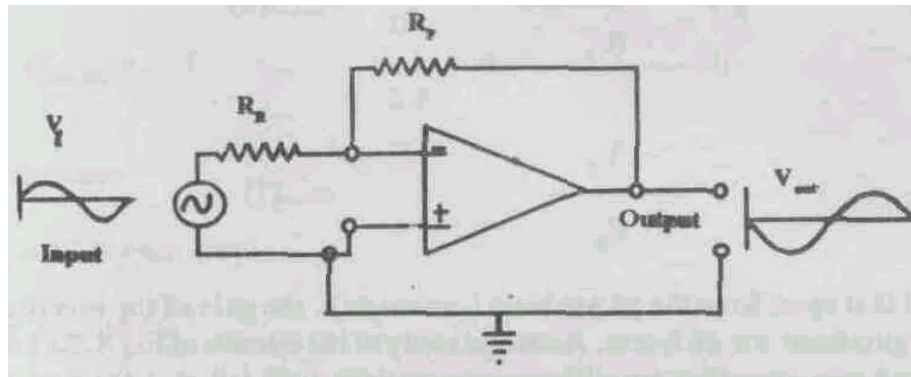

Fig. 4.6.a

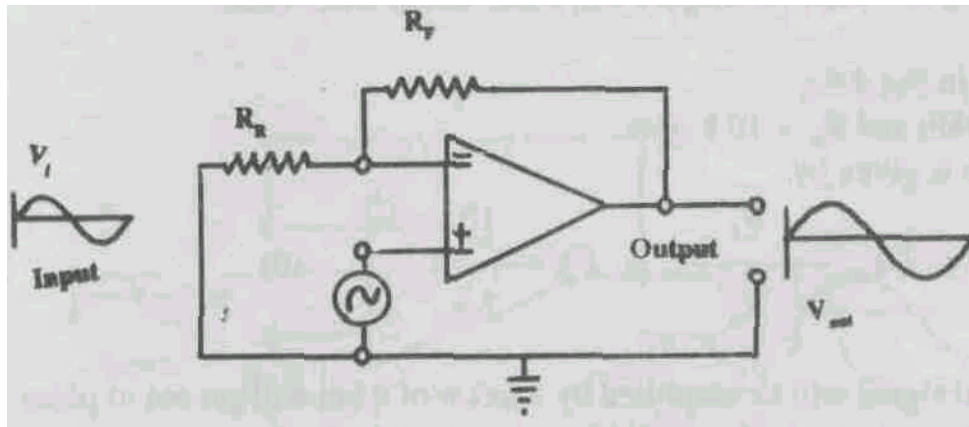**Fig. 4.6.b**

The output will be an amplified and inverted signal. A part of this output signal which is 180° out of phase with the input is fed back at the inverting input through resistance R_F and hence negative feed back lakes place. It is also possible to use the opamp as a non-inverting amplifier by

applying signal to the (+) input (non-inverting), as shown in Fig.4.6.b. It may, however, be noted that the feed back network (resistance R_F) is still connected to the inverting input. From the detailed analysis which is beyond the scope of the present discussion it can be shown that for the arrangement of Fig.4.6,a, (inverting amplifier) the output voltage V_{output} is given by

$$V_{output} = (-)\frac{R_F}{R_R} \times V_{input} \qquad (4)$$

here V_{input} is the input voltage and the -ve sign represents the phase change of 180°.

For the non-inverting amplifier circuit of Fig. 4.6.b the total output voltage V_{output} is given by

$$V_{output} = \left(1 + \frac{R_F}{R_R}\right) \times V_{input} \qquad (5)$$

the +ve sign in the above equation indicates no phase change. As such the gains for the inverting and the non-inverting amplifier circuits are respectively G_{inv} and $G_{non-inv}$ is given by

$$G_{inv} = (-)\frac{R_F}{R_R} \qquad (6)$$

$$G_{non-inv} = 1 + \frac{R_F}{R_R} \qquad (7)$$

It may be noted that apart from the phase term (-ve or +ve) the gain of the inverting and non-inverting configurations are different. A careful study of the circuits of Fig.4.6.a and Fig.4.6.b for inverting and non-inverting amplifier configurations will tell that the two circuits are identical except for the interchange of input terminals and the ground connections. The expressions for the gain differ because in inverting configuration resistances R_F and R_R form a voltage division network for both the input signal V and the signal fed back from output to the input through R_F. In the non-inverting configuration Fig. 4.6.b the voltage division takes place only for the feedback signal and not for the input signal.

The following numerical examples will make things more clear.

(a)   Suppose in Fig.4.6.a
        R_R = 2.5 k ohm and R_F = 10 k ohm,
        then the gain is given by

$$G_{inv} = (-)\frac{R_F}{R_R} = (-)\frac{10}{2.5} \qquad (8)$$

        i.e., the output signal will be amplified by a factor of 4 but will get out of phase by 180° w.r.t the input. One may use both a.c. and d.c. signals at the input.

(b)   If $R_R = R_F$ the gain will be unity, and the signal in the output will be of the same magnitude but in opposite phase.

(c)   If $R_R > R_F$, G_{inv} will be <1.

Do you know why? Write a possible reason.

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In all above three cases one can see that by controlling the ratio of R_F and R_R, an output signal of increased amplitude, same amplitude or of diminished amplitude may be obtained, but the phase change is always 180°.

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In a similar way for the non-inverting amplifier configuration if
(a) $R_F = 10$Kohm, $R_R = 2.5$ K ohm

$$G_{non-inv} = 1 + \frac{10}{25} = 5 \tag{9}$$

(b)   For the case

$R_F = R_R = 10$ K ohm (say)

$G_{non-inv} = 2$, and for

(c) $R_R > R_F$. $G_{non-inv}$ will always be greater than unity.

(d)   In the extreme case when in non-inverting configuration

$R_F = 0$ and $R_R = \infty$ (see Fig.4.7)

$$G_{non-inv} = 1 + 0 = 1 \tag{10}$$

So in this configuration the output voltage is equal in amplitude and in phase with the input. This is called the **voltage follower circuit**.

Mathematical operation of summing may   also be performed by the opamp, using the connection shown in Fig.4.8.
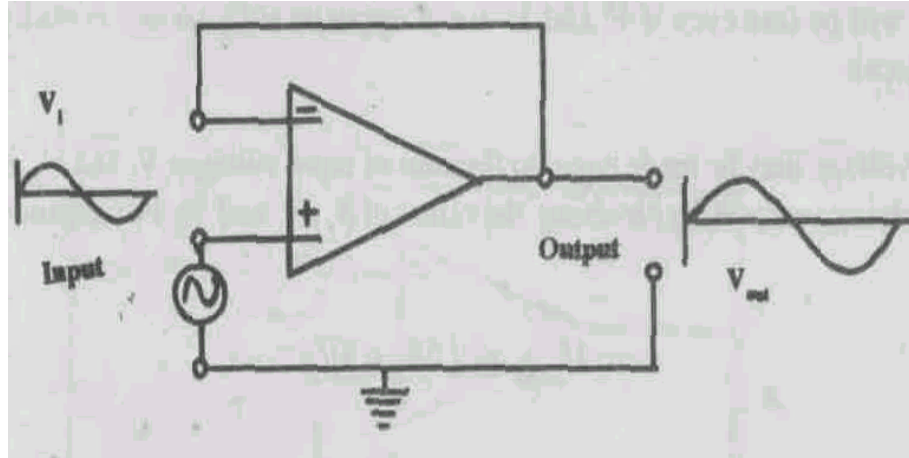
Fig. 4.7
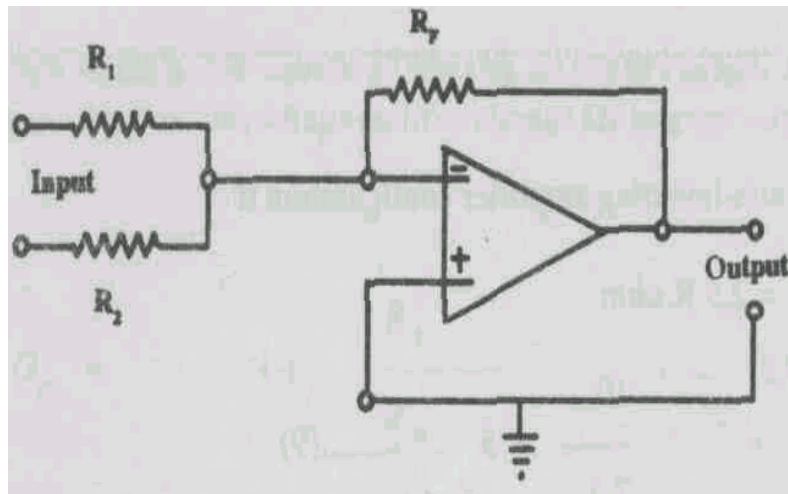
Fig. 4.8

The gain of the above circuit is given by

$$G = \frac{-\left(\dfrac{R_F}{R_1}V_1 + \dfrac{R_F}{R_2}V_2\right)}{(V_1 + V_2)} \tag{11}$$

If $R_F = R_1 = R_2$, then the gain $G = -1$, and therefore $V_{output} = -(V_1 + V_2)$ which is the sum of input voltage signal. This will be true even if V_1 and V_2 are of opposite sign, so this is really an algebraic summing circuit.

The output voltage may be made equal to the sum of input voltages V_1 and V_2, each scaled by some multiplying constant, by choosing the values of R_F, R_1 and R_2. For instance, $R_F = 2R_1 = 3R_2$.

4.3.3. OPAMP as a Half-Wave rectifier and as an Electronic Ammeter
Opamp half-wave rectifier circuit is shown in Fig.4.9.

This is a modified version of Fig.4.7, with diode inserted in the output. When the output is positive, the diode conducts and the circuital acts exactly as Fig.4.7. The gain is 1, and the positive part of the signal is faithfully given to the output.

When the output is negative the diode does not conduct. The output is effectively disconnected from the opamp, and only connected to ground through the resistor.

Thus the circuit acts as an amplifier for only positive signals. It acts as a half-wave rectifier. So does a diode by itself! But in the opamp circuit the signal source always faces a high-impedance amplifier input. With a simple diode the source is short-circuited on positive inputs.
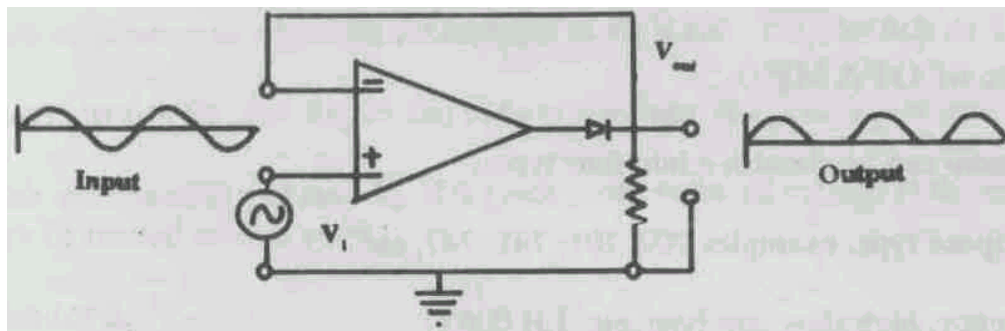
Fig.4.9

In the following circuit diagram (Fig.4.10) an opamp works as an electronic ammeter.

The input voltage V_i applied to the left end of R causes a current A_i to flow in the input circuit. It is this current which is to be measured. The output voltage of the opamp is V_O.

Thus the output voltage is proportional to the current A_i and does not depend on R_R. This is the action for which the circuit is called an "electronic ammeter".
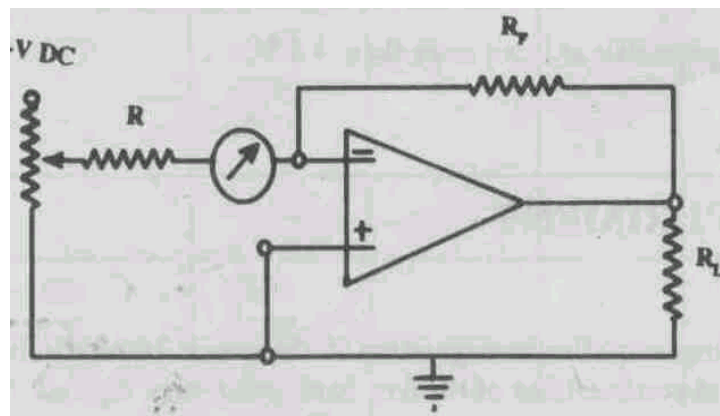
Fig.4.10

4.3.4 OPAMP   Specification
The manufacturer provides a circuit diagram, a base diagram and specifications for each opamp type including performance graphs. These specifications are also available in opamp manuals.

Opamp specifications can be divided into two types.

Data Sheet Specifications give **maximum ratings** or limits which if exceeded may **permanently damage** the device. They are,

(Please refer the data sheet attached)

(a)   Supply Voltage: In most of the opamp two power supplies such as +15 V and -15 V are required. However some opamps require only a single supply.

(b)   Power Dissipation: The maximum power that the opamp IC can dissipate without being damaged is always specified. A typical value is 0.5 watt.

(c)   Bandwidth: Roughly, this indicates the maximum frequency at which a signal will experience the other characteristic values.

(d)   Input and output impedances: The input and output impedances in normal operation are specified.

4.3.5 Types of OPAMP
In general opamps can be classified into four types,

a.   General purpose type, e.g., 709,101, 741, 747, etc.

b.   High frequency, high slew rate type, e.g., LH 0063

c.   High voltage, high power type, e.g., LH 0004, LH 0021

d.   programmable type or micropower opamp, e.g., 4250.

Most of the opamps are manufactured in three types of the base packages having different number of pins in their bases namely (i) Metal can Package (ii) flat packages and (iii) Dual -in-line package.

4.4 PRECAUTIONS
1.   Never exceed V+,V-potentials +9V. These are the maximum values to avoid electrical damage.
2.   Never apply potentials at input more than + 5 V.

4.5. THE EXPERIMENT
To study the inverting amplifier configuration of the opamp 741 and to find the gain of the amplifier for different combinations of the feed back resistances R_F and R_R.

Procedure- 1. Make the connections as shown in Fig.4.11 and follow the steps given below.
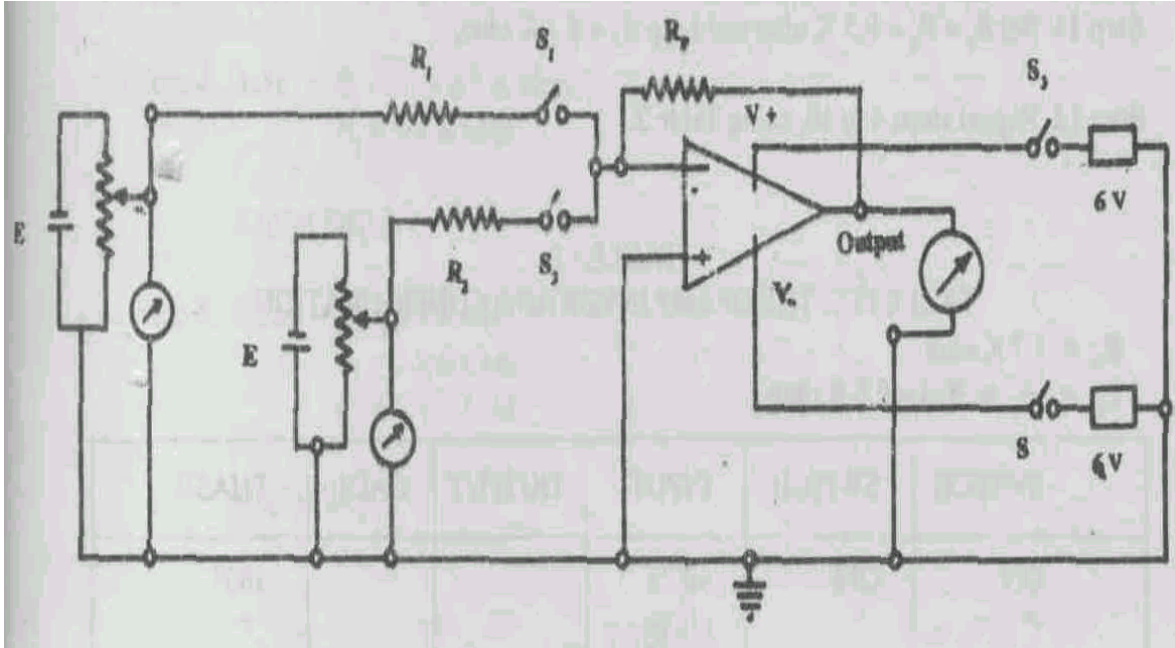
Fig.4.11

Step 1. Keep $R_1 = R_2 = R_F = 4.7$ K ohm

Step 2. Open switch S_1, S_2, S_3, S_4.

Step 3. Switch on power and adjust power supplies to +6 V and - 6 V. Switch on S_3 and S_4.

Step 4. Adjust rheostats Rh₁, and Rh₂, so that voltage readings of V_1 and V_2 are zero.

Step 5. Switch on S_1 and S_2 and read V_3. If it gives some value of voltage at the output (V_3) note it. It may be treated as zero error.

Step 6. Switch off S_2.

Step 7. By varying rheostat Rh₁ change V_1. This will also change the output voltage V_3. Take readings of V_1 and V_3 for different settings of V_1.

Step 8. Switch off S_1 and switch on S_2 vary rheostat Rh₃ to change V_2. Take readings of V_3, for different settings of V_2.

Step 9. Tabulate your data in Table 1.

TABLE-1
TABLE FOR THE OPAMP INVERTING CONFIGURATION

$R_F \quad = 4.7 \text{ K ohm}$

$R_R = (R_1 = R_2) = 4.7 \text{ K ohm}$

SWITCH	SWITCH	INPUT	OUTPUT	GAIN	PHASE
ON	OFF	+0.25			180°
,,	,,	+0.50			,,
,,	,,	+0.75			,,
,,	,,	+1.00			,,
,,	,,	+1.25			,,
,,	,,	+ 1.50			,,
OFF	ON	-0.25			,,
,,	,,	-0.50			,,
,,	,,	-0.75			,,
,,	,,	-1.00			,,
,,	,,	-1.25			,,
,,	,,	-1.50			,,

MEAN GAIN =

Step 10. Switch off S_1 & S_2.

Step 11. Set $R_1 = R_2 = 9.5$ K ohm and keep $R_F = 4.7$ K ohm.

Step 12. Repeat steps 4 to 10, using Table 2.

Table 2
TABLE FOR THE OPAMP INVERTING CONFIGURATION

$R_F = 4.7 \text{ K ohm}$

$R_R = (R_1 = R_2) = 9.5 \text{ K ohm}$

SWITCH	SWITCH	INPUT	OUTPUT	GAIN	PHASE
ON	OFF	+0.25			180°
,,	,,	+0.50			,,
,,	,,	+0.75			,,
,,	,,	+1.00			,,
,,	,,	+1.25			,,
,,	,,	+ 1.50			,,
OFF	ON	-0.25			,,
,,	,,	-0.50			,,
,,	,,	-0.75			,,
,,	,,	-1.00			,,
,,	,,	-1.25			,,
,,	,,	-1.50			,,

MEAN GAIN =

Step 13. Set $R_1 = R_2 = 2.5$ K ohm
Step 14. Repeat steps 4 to 10, using Table 3.

Table 3
TABLE FOR THE OPAMP INVERTING CONFIGURATION
$R_F = 4.7$ K ohm
$R_R = (R_1 = R_2) = 2.5$ K ohm

SWITCH	SWITCH	INPUT	OUTPUT	GAIN	PHASE
ON	OFF	+0.25			180°
,,	,,	+0.50			,,
,,	,,	+0.75			,,
,,	,,	+1.00			,,
,,	,,	+1.25			,,
,,	,,	+ 1.50			,,
OFF	ON	-0.25			,,
,,	,,	-0.50			,,
,,	,,	-0.75			,,
,,	,,	-1.00			,,
,,	,,	-1.25			,,
,,	,,	-1.50			,,

MEAN GAIN =

Procedure-2
Using the same circuit connections you can investigate the summing operation of an opamp.

Step 1. Adjust the power supplies to +6 V and -6 V and turn ON S_3 and S_4.

Step 2. Make $R_F = R_1 = R_2 = 4.7$ K ohm

Step 3. Make $V_1 = V_2 = 1$ Volt, and note the measured values of V_1, V_2 and V_3 in Table 4.

Step 4. Make $\quad R_F = R_1 = 4.7$ K ohm
$\qquad\qquad R_2 = 9.4$ K ohm

Repeat Step 3.

Step 5. Make $\quad R_F = 4.7$ K ohm
$\qquad\qquad R_1 = 2.3$ K ohm
$\qquad\qquad R_2 = 9.4$ K ohm

Repeat Step 3.

Table 4

R_1	R_2	R_F	V_1	V_2	V_3	Expected V_3

Calculations: For each set of R_F and R_R calculate gain using Equation (6), Equation (7) or Equation (11).

Compare the mean gain obtained by doing the experiment with the one calculated.

Result & Discussion: Discuss the variation of gain with R_F and R_R, Also estimate the likely error in your measurements discuss possible reasons for these.

4.6 CONCLUSIONS
You have found out how to amplify signal voltages and perform the summing operations upon two voltage signals.

(a)   Write down 3 situations where you can use this type of amplifier.

_____

_____

_____

(b)   What output will you get if you give zero volt to both inputs?

_____

_____

_____

(c)   Do you find any change in gain when you change supply voltages?

_____

_____

_____
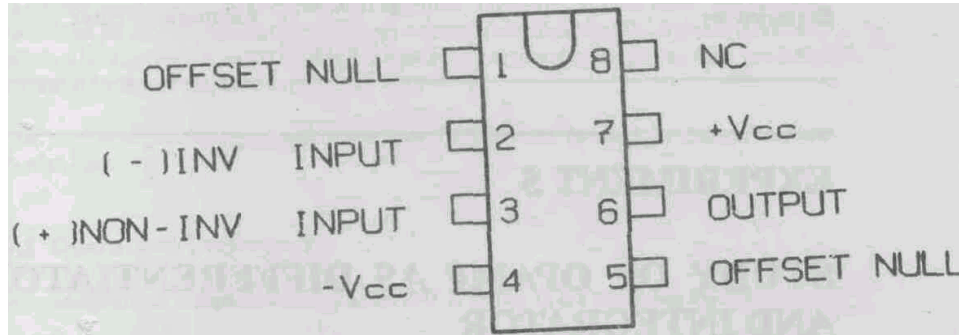
OPERATIONAL AMPLIFIER μ A 741

Top View

SUPPLY VOLTAGE   + 15 V
POWER DISSIPATION   500 raw
OPEN LOOP GAIN   106
BANDWIDTH   1 KHz
INPUT BIAS CURRENT   1 microampere
INPUT IMPEDANCE   1 megohm
OUTPUT IMPEDANCE   100 Ohm

INPUT OFFSET VOLTAGE
INPUT BIAS CURRENT
LARGE SIGNAL GAIN
CMMR
SLEW RATE & SETTLING TIME

(For Counsellor's use only)
Grade.............................   Name ....………………..

Evaluated by…………………………….   Enrolment Number ………………

EXPERIMENT 5
STUDY OF OPAMP AS DIFFERENTIATOR AND INTEGRATOR
Structure
5.1   Introduction
         Objective
5.2   Apparatus
5.3   Study Material
5.4   Precautions
5.5   The Experiment
         Integrator Circuit using Opamp 741
         Differentiator Circuit using OPAMP 741
5.6   Conclusions

5.1 INTRODUCTION
You might have used electronic calculators, or computers at some stage. How does a computer perform mathematical operations? In fact some electronic circuits are designed to perform the various mathematical calculations. Examples of such circuits are integrators and differentiators. In these circuits, if you apply any electrical signal in the input, you will get its integrated or differentiated form at the output. These circuits are extremely useful in computing, signal processing and signal generating applications. Operational amplifiers can be used for such applications.

Objectives
After performing the experiment you will be able to:
- Integrate a sine wave or a square wave using OPAMP
- Differentiate a sine or a square wave using OPAMP
- Compare the expected and observed integrated and differentiated signals

5.2 APPARATUS
OPAMP (741)
2 power supplies (+15V and -I5V)
oscillator giving sine and square waves of various   frequencies
oscilloscope (CRO)
connecting wires

5.3 STUDY MATERIAL
You already have a write-up on operational amplifier. OPAMPs, as their name suggests, are devices used for carrying out mathematical operations on electrical signals. If you have already performed the experiment on the OP AMP as a summing or inverting amplifier, then you know that OPAMP can add and subtract.

In the present experiment you will know how OPAMP can be used for integration and differentiation.

5.3.1 Operations Performed
The basic circuit for integration using an OPAMP is shown in the following Fig.5.1.
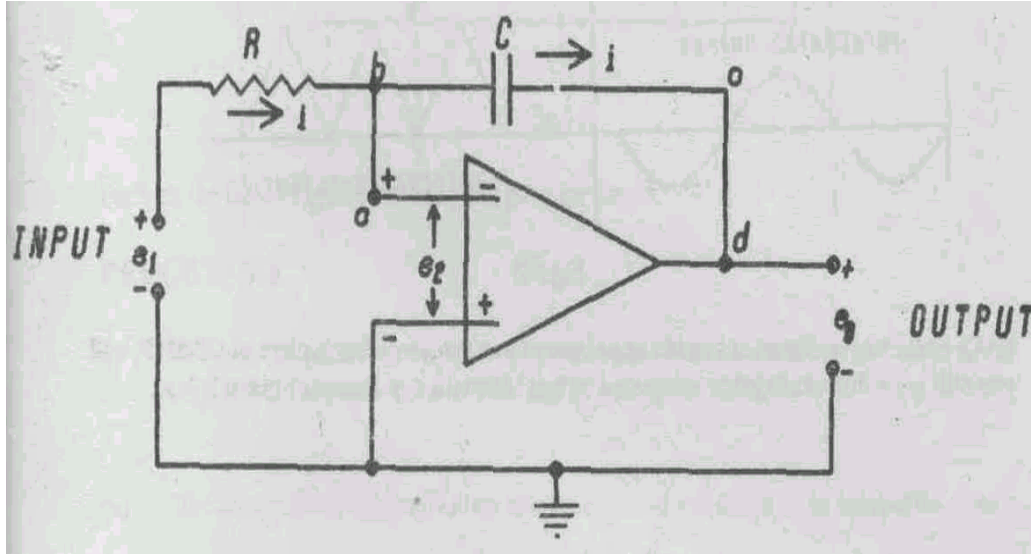
Fig.5.1

This is a circuit using the inverting configuration. The equations of the operation can be derived by using an ideal operational amplifier of open loop gain A.

In Fig. 5.1 the current flowing through resistance R is given by

$$\frac{e_1 - e_2}{R} = i$$

$$e_2 - e_0 = \frac{1}{C}\int_0^t i\,dt = \frac{1}{RC}\int_0^t (e_1 - e_2)\,dt$$

$$e_2 = -\frac{e_0}{A}$$

If $A \to \infty$, then $e_2 \to 0$, also, $e_0 = \frac{1}{RC}\int_0^t e_1\,dt$

Thus you can see that you have an integrated output of the input signal.

5.3.2 Differentiation
In the circuit of Fig. 5.1, if the position of the resistor and capacitor are interchanged, you can similarly derive and see that the output will be

$$e_0 = -RC\frac{de_1}{dt}$$

Hence you can get the differential output of the input. The differentiated and integrated outputs for sine and square waves are shown in Fig.5.2.
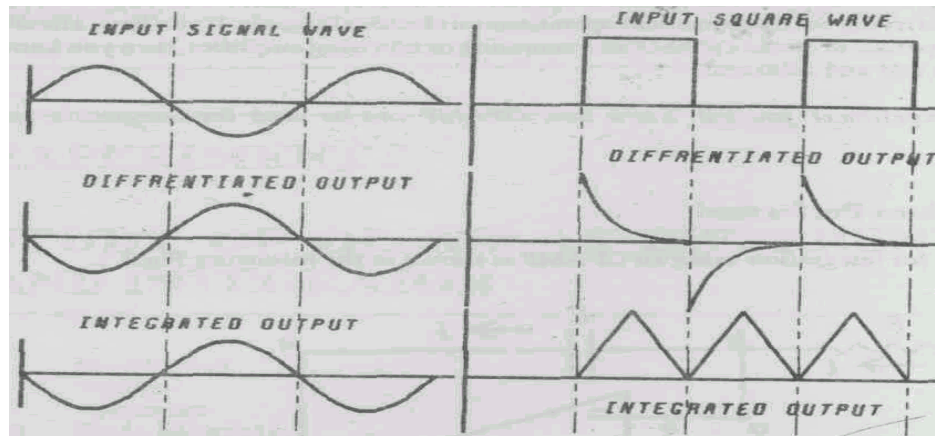
Fig.5.2

SAQ:
In the above circuit, if you see an ordinary transistor amplifier in place of OPAMP, will you still get a differentiated or integrated output? Explain it in the space given below.

_____

_____

_____

_____

5.4   PRECAUTIONS
1.   The potential + V should not exceed a volts.
2.   Choose a good operational amplifier with low bias current, to perform the operations
          below correctly.

5.5   THE EXPERIMENT
5.5.1 Integrator Circuit using OPAMP 741
Make the circuit as shown in Fig.5.3 using OPAMP 741.
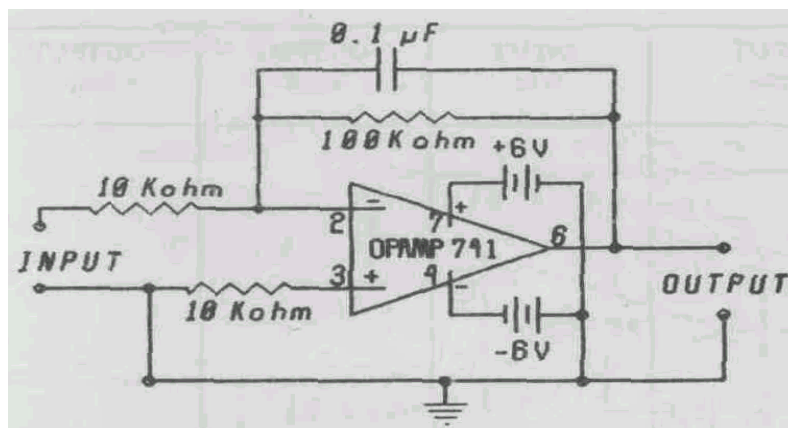
Fig. 5.3

Perform the following steps to carry out the experiment.

PROCEDURE

(i)   Connect the oscillator output to y-y terminals of the oscilloscope and adjust the amplitude of the sine wave to 0.5V and frequency to IK Hz.

(ii)   Disconnect the oscillator from the oscilloscope and connect it to the input of the circuit.

(iii)   Connect the oscilloscope to the output of the circuit.

(iv)   Synchronise the output signal on the screen of the   oscilloscope.

(v)   Measure the output signal amplitude and frequency.

(vi)   Change the frequency and amplitude of the input signal and again measure the output voltage and frequency repeating steps (i) - (vi).

(vii)   Repeat the experiment using square wave input from the oscillator.

(viii)   Record your observations in the following table.

OBSERVATION TABLE I

For sine-wave input

Serial	INPUT volts	INPUT freq.	OUTPUT volts	OUTPUT freq.
1				
2				
3				
4				
5				

OBSERVATION TABLE II

For square-wave input

Serial	INPUT volts	INPUT freq.	OUTPUT volts	OUTPUT freq.
1				
2				
3				
4				
5				

SAQ:
What do you observe in the output of the circuits as displayed on the screen of the oscilloscope, compare it with the input and record your findings in the space given below.

_____

_____

_____

_____

5.5.2 Differentiator Circuit using OPAMP 741

PROCEDURE
Make the circuit as shown in Fig.5.4.
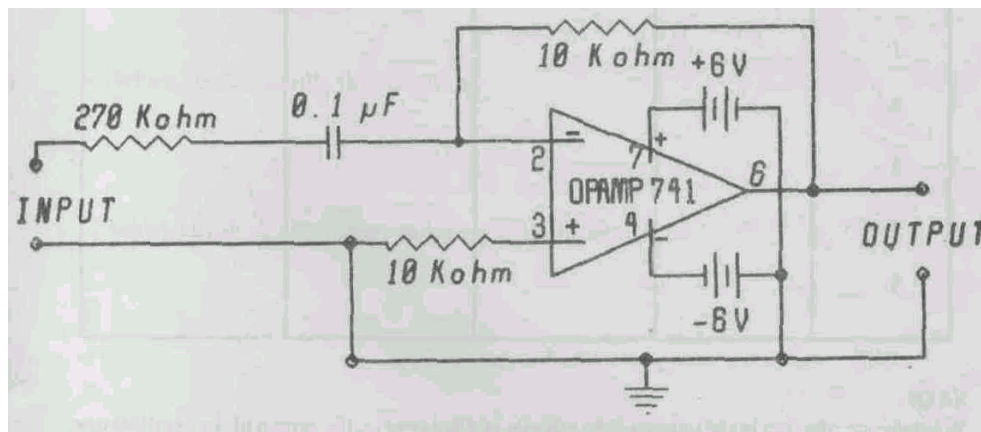
Fig. 5.4

Follow the same procedure as mentioned in the previous opamp experiment and record your observations in a similar table both sine and square inputs. Compare the outputs with corresponding inputs and record your findings in the space given below.

OBSERVATION TABLE III
For sine-wave input

Serial	INPUT volts	INPUT freq.	OUTPUT volts	OUTPUT freq.
1				
2				
3				
4				
5				

OBSERVATION TABLE IV
For square-wave input

Serial	INPUT volts	INPUT freq.	OUTPUT volts	OUTPUT freq.
1				
2				
3				
4				
5				

SAQ:
What do you observe in the output of the circuits as displayed on the screen of the oscilloscope, compare it with the input and record your findings in the space given below.

_____

_____

_____

_____

SAQ:
In the above experiment of integrator circuit with a square wave input, connect its output to the differentiating circuit. What do you observe in the output on the screen. Explain your findings in the space given below.

_____

_____

_____

_____

5.6 CONCLUSIONS
You have found out how to integrate and differentiate sinusoidal and square wave forms,
(a)   What happens to the fast-rising portions of the waveform after integration?

(b)   Find that if the input oscillates equally in positive and negative voltages the output of the integrator is zero. Explain this in simple terms.

(c)   What happened to the constant of integration in this case?

(d)   What response do you get when you apply a d.c. voltage to the input of the differentiator?
(e)   Which circuit smooths the waveform?
(f)   Which circuit picks up sharp variations in the input?

EXPERIMENT 6
DETECTION AND MEASUREMENT OF CHARGE USING AN OPAMP
Structure

6.1 INTRODUCTION

A transducer converts a physical variable into a suitable output. For example, a piezo-electric transducer converts mechanical pressure into an electrical signal, which can further be used to drive another circuit. On the other hand an optoelectrical transducer such as a pbotodiode gives an electrical signal when visible light shines on its cathode.

Varied examples of such transducers can be found in our day to-day life, right from a door buzzer to a gas lighter. Transducers are used to measure a physical parameter or to control it. Signals obtained from the transducers usually need amplification before measurement.

In this experiment, you will see how an electrical charge can be measured. Such a charge is generated by an electromechanical transducer.

You have already studied about a nope rational amplifier (OP AMP) and the various mathematical operations it can perform. You have also seen earlier the various opamp configurations.

Objective

- In the following experiment, we will use a circuit for an electronic system composed of three opamps to detect and measure the electrical charge such as that on a charged capacitor, or a charge generated by an electromechanical transducer.

6.2 APPARATUS
1 no.   strong magnet
1 no.   search coil of 300 turns, dia. 3mm.

3 no.   OPAMP 741
1 no.   circuit board with resistors, capacitors and switches
1 no.   transistor power supply, plus and minus 12 volts

6.3 STUDY MATERIAL
6.3.1 Coil of Wire as a Transducer

The basic principle of an electromechanical transducer is that of electromagnetic induction, namely generation of an induced emf in a conductor (coil) caused by a change of magnetic flux linking the coil.
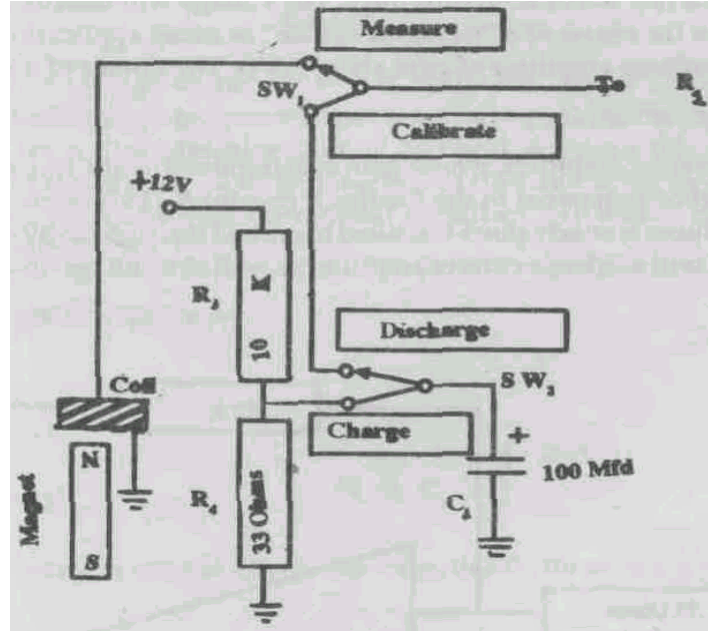
Fig.6.1

The magnet shown in Fig.6.1 is a magnet which can lift an iron nail from a distance of about 5 mm, and hold it vertically. When the magnet is moved very fast near the search coil an emf is induced in the coil. The emf in the coil, has an equivalent of charge Q, as explained below. Faraday's Law of Induction gives this emf as the following.

$$e_i = -N \frac{d\phi}{dt}$$

where de/dt is the rate of change of flux linked with the coil. N is the number of turns in the search coil. The negative sign indicates that the direction of the emf from this coil is such as to oppose the motion of the coil in the field. The charge amplifier measures the transferred charge Q in terms of the output voltage e_O.

6.3.2 Principle of the charge-measuring system

The output from the transducer is in the form of voltage in some cases, and in the form of current in other cases. The output varies with time, and the total charge transferred during the process is the quantity of interest. The charge transferred (as indicated by the transducer) is easily found by integrating using an integrating circuit, which you have built and tested in a previous experiment.

If the transducer output is a voltage, it is simply amplified with a voltage amplifier and then sent to the input of a voltage integrator. If the transducer output is a current then it is first sent to a current-to-voltage circuit, whose output in turn is sent to the integrator.

Because of some inherent defects in the 741 opamps you will use, it is not possible to integrate over a very long time (more than a few seconds). So a separate sampling circuit is used to take the output from the integrator and keep it in storage for an extended time so that you can note the value conveniently,

6.3.3 Current amplifier, and current-to-voltage conversion

The voltage signal that may come out of a typical charge-output transducer like a search coil will be of the order of a few ten of millivolts only. The voltage will usually last for only a few milliseconds, and is in the shape of a "triangular pulse" in many applications. This pulse has to be amplified by a voltage amplifier of gain about 1000. The circuit of a useful amplifier is shown in Fig.6.2.

Note that this is an inverting amplifier, whose gain is determined by the resistors R_1 and R_2. The value of R_1 is small when compared to the feedback resistor R_2.This combination is selected so that the input transducer is nearly short-circuited to ground through the 39-ohm resistor. This ensures that the circuit wilt work as a current amplifier as well as a voltage-to-current converter.
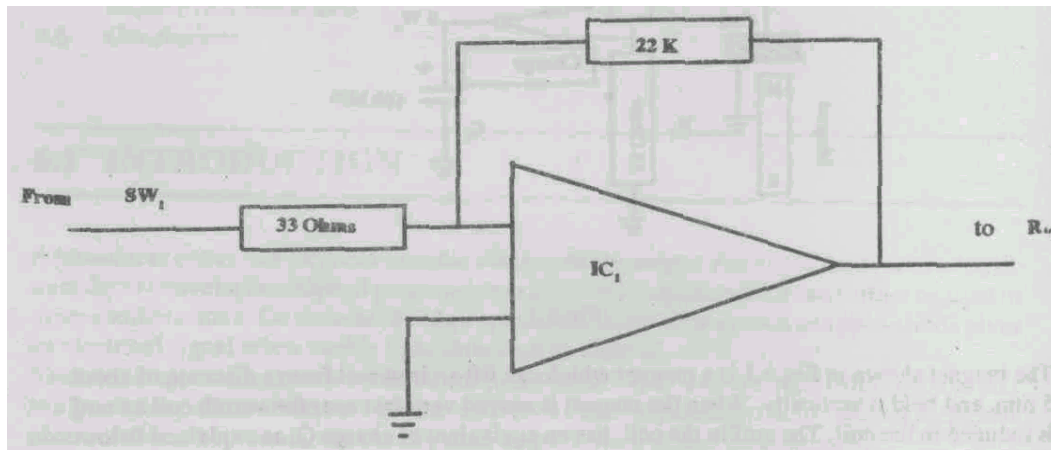
Fig.6.2

6.3.4 Voltage Integrator

The voltage integrator is designed using741 (IC2) Operational amplifier. The circuit is shown in Fig.6.3.

The amplifier has offset voltage of the order few millivolts. When used for a long time integration the offset is also integrated, sometimes completely masking the input. High quality Amplifiers like FET input Operational amplifier 740 will not pose this problem but are expensive. By doing the integration for a short interval of time and using an offset null circuit the following circuit is designed with operational amplifier 741 which is suitable for the experiments in this section-
The output of the integrator is given by

$$V_0 = \frac{R_2}{R_1 R_L C_2} \int V_i dt$$
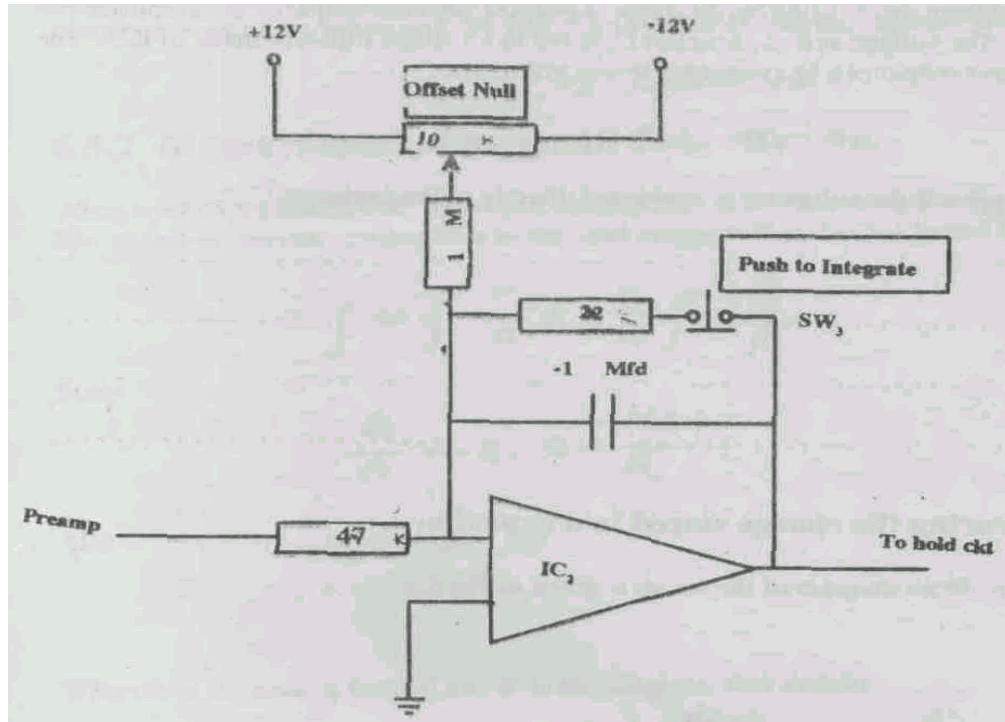
Fig. 6.3

6.3.5. Holding circuit

The output of the integrator is used to charge the capacitor C_3 through a diode. The circuit is shown in Fig.6.4.
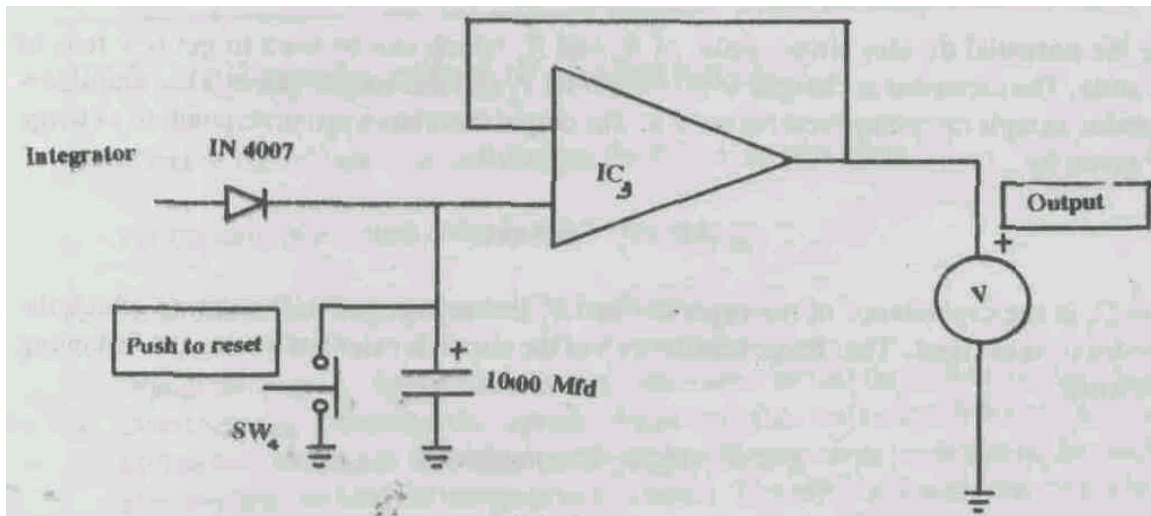
Fig.6.4

Thus the output of the integrator is copied on the capacitor. The integrator is then switched to the scalar mode as soon as the integration is over by releasing the switch SW The capacitor C_3 is prevented from discharging by the diode connected between output of the amplifier and capacitor

C_3. The voltage across capacitor C_3 is fed to a voltage follower made of IC3. The voltage follower output can be connected to any voltmeter.

SAQ:
What will happen if the voltmeter is connected directly to the capacitor C_3?

6.3.6 Measuring the charge stored in a capacitor
The complete circuit diagram of the set up is given in Fig.6.5.
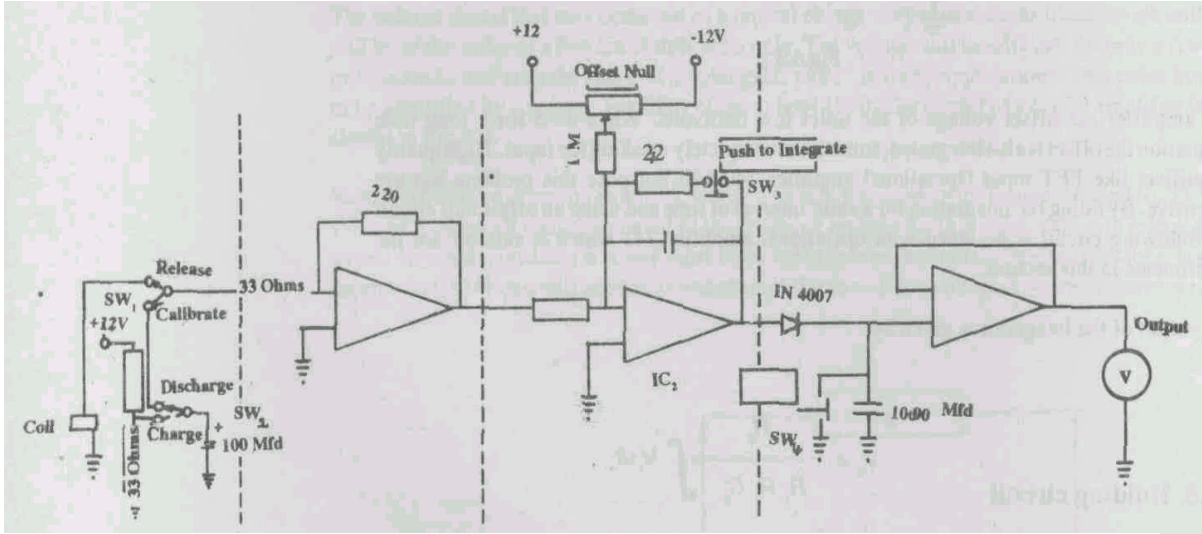
Fig.6.5

Note the potential divider circuit made of R_3 and R_4, which can be used to get few tens of millivolts. The capacitor is charged to 50 millivolts V_1 and discharged through the amplifier-integrator-sample circuit by pressing switch. The output that shows up corresponds to a charge of Q given by

$$Q = C_1 V_1 \text{ coulombs}$$

where C_1 is the capacitance of the capacitor and V_1, the voltage (50 millivolts) to which the capacitor C_1 is charged. The charge sensitivity S of the circuit is calculated using the following expression.

$$S = (C_1 V_1)/V_O \text{ Coulomb/volt}$$

To find the total amount of unknown charge transferred, the output due to the charge V_x is measured. Q_x the unknown charge is given by the following expression.

$$Q_x = V_x S \text{ Coulomb}$$

The capacitance of an unknown capacitor is determined by charging the capacitor C_x to a voltage V_1, and discharging through the same circuit. If the output voltage in this case is V_x then the capacitance of the unknown capacitance is calculated using the expression which follows.

$$C_x = S(V_x / V_1) \quad \text{Coulombs/volt}$$

6.3.7 Measurement of magnetic field strength

When used with a **search** coil, the output corresponds to the time integral of induced voltage. The output in this case corresponds to the total magnetic flux that has linked the search coil.

$$Q = \int idt = \int \frac{E}{R_1} dt = \frac{N}{R_1} - \frac{d\phi}{dt} dt$$

Since

$$N - \frac{d\phi}{dt} = -E \; ; \; Q = -\frac{N\Delta\phi}{R_1}$$

Also, $\quad Q = V_x S \; ; \; \Delta\phi = AB$

Where A is the area of the coil and B is the magnetic flux density.

Comparing the expressions for Q we write the following.

$$V_x S = \frac{NAB}{R_1}$$

B the magnetic flux density is calculated from

$$B = V_x S \frac{R_1}{NA} \, B = V \, S$$

in Tesla.

6.4. PRECAUTIONS

It is very important to choose an Operational Amplifier with very small bias current. Take care to discharge the capacitor before beginning the measurement.

6.5 PROCEDURE
6.5.1 Nulling the offset of the integrator

The offset of the integrator is nullified by the following procedure,

a.   Put the calibrate switch SW1 in **CAL** position

b.   Hold down the integrate push switch SW3.

c.   Watch the output. Adjust the offset potentiometer so that the output shows a steady but slow increase. Discharge the capacitor by pressing the rest switch SW4. Adjust the offset so that the variation at the output is still slower. Repeat steps b and c until the output stays at zero when you hold the integrate switch down. This offset adjustment need not be carried out every time you use the circuit, because the settings will stay fixed for a long time.

6.5.2 Calibration of the circuit

The amplifier is calibrated by discharging a known quantity of charge. By this means the charge sensitivity is measured.

a. Discharge the capacitor by pressing SW2 while holding the integrate key down. Then release the integrate switch. Note down the out put and enter in the Table 1.

Table 1

Capacitance in microfarads	Input V_1 in volts	Output V_O in volts	Charge Sensit. In Coul./volt

Repeat the measurement with an unknown capacitor of capacitance C_x by replacing the capacitor C_1 with C_x. The capacitor C_x is charged and then discharged. The output V_x is noted down and entered in the Table 2 given below.

Table 2

Input V_1 in volts	Output V_x in volts	Capacitance C_x in microfarads

Repeat the measurements with series and parallel combinations of capacitors and verify the law Charge Using an OPAMP of capacitor combinations, Enter your findings in Table 3.

Table 3

Input V_1 in volts	Output V_x in volts	Capacitance C_x in microfarads

6.5.3 Magnetic Flux Density Measurement
a. Put the CAL switch in **MEASURE** position.

b. Move a magnet into the search coil while holding the integrate switch down.

c. Note down the output in volts and enter the value in the TAELE 4.

Table 4

Coil and Magnet movement	Output V_x in volts	Flux density B in Tesla (calc.)

SAQ:
When you move the magnet very very slowly you do not get any output even though the same amount of flux has been linked. Explain how the circuit is not able to follow very very slow change in the magnetic fields.

_____

_____

_____

6.6 CONCLUSIONS

VQU have noticed the properties of integrating a charge pulse signal in this experiment. The integral of the pulse is proportional to the total amount of charge that has flowed through the coil. Hence you can measure the charge flowed through a circuit. You have also measured the magnetic field density that existed near the search coil.

SAQ:

(1)   Compare Fig.6.3 with the integration circuit provided in the experiment on OPAMP INTEGRATION and note down the similarities and differences.

_____

_____

_____

(2)   Replace the 741 Opamp with FET(740) Opamp and note down the performance, compared to the 741.

_____

_____

_____

(3)   Leave the circuit for a long time, say about 10 minutes, and watch the output. Give a reason for the behaviour you observe.

_____

_____

_____

(4)   If you feed 50m V AC through the input, what do you expect at the output? Could you estimate the AC voltage?

_____

_____

_____

EXPERIMENT 7
STUDY OF SOME PROPERTIES OF LENSES
Structure

7.1 INTRODUCTION

Most of you have handled a camera at one time or other. A most important part of a camera is its lens. It forms the image of the scene at the plane where a film is kept. The telescope, the microscope and reading lens are some optical instruments used in the laboratories. All of them use at least one lens. Therefore it is important that we learn the properties of lenses. A lens system is a combination of two or more lenses. We will learn about some of these combinations also.

Objectives:

After doing this experiment, you should be able to determine the focal length of a given convex lens by the following method:

- Distant object method
- Image coincidence method
- *U-V* method
- Graphical method

(2)   After doing this experiment you should be able to explain the relationship between • lens focal length, lens diameter and brightness of an image.

(3)   After doing this experiment you would   be able to determine the focal length bf a concave lens using another convex lens of known focal length.

    (i)   By contact method with a convex lens of known focal length,
    (ii)   By the method of "separation by a distance", using a convex lens.

7.2 APPARATUS
Two convex lenses of focal length about 15 cm
Two concave lenses of focal length 10 cm
Meter - scale
60 watts frosted incandescent bulb, holder and wires
Wire mesh
Lens holders
Plane-mirror
Screen
Stop
Note: Lens holders, if not available can be made conveniently and cheaply by cutting circular holes on 15 cm squares of "thermocole" material. The circular holes have a diameter slightly less than the diameter of the lens. A lens is kept sandwiched between two thermocole pieces and rubber bands can be used to press the two thermocoles together. To keep the lens mount sturdy, an aluminium T frame can be inserted at the bottom in between the two thermocoles, as shown in Fig.7.1.
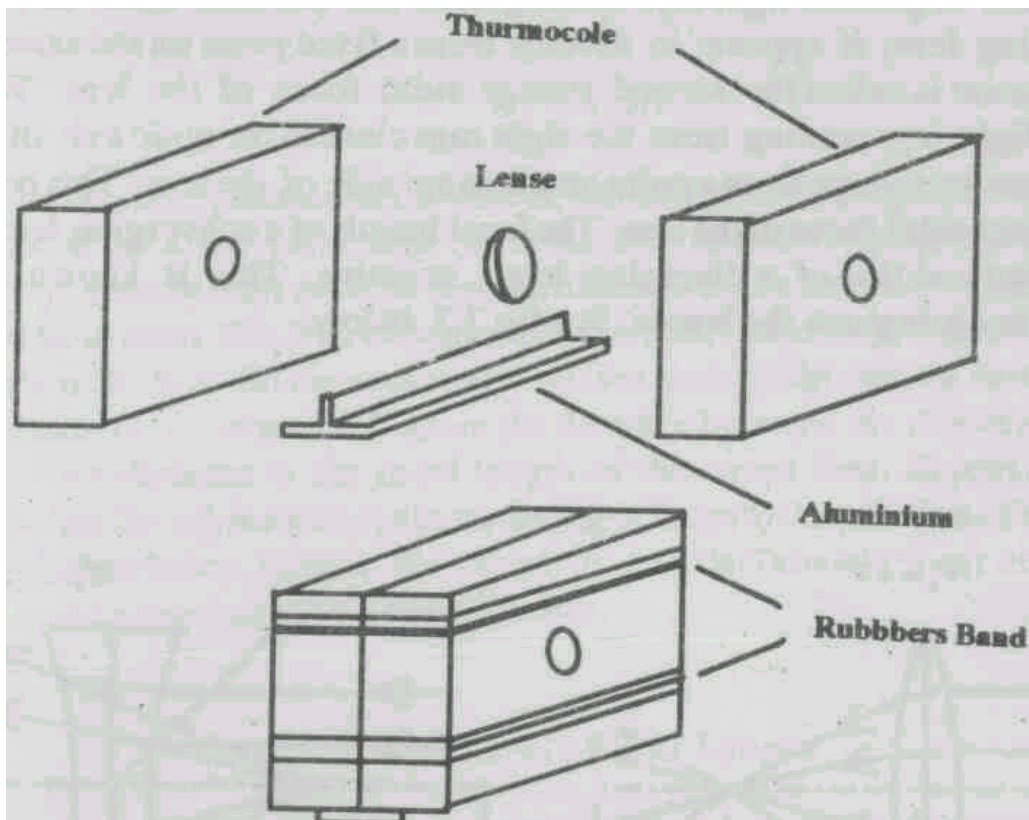

Fig 7.1

7.3 STUDY MATERIAL
7.3.1 Classification of Lenses
There are two classification of lenses:
(1) converging lens or positive lens and (2) diverging lens or negative lens.
A converging lens forms a real image on a plane in space. If a screen is placed at that plane, the image can be seen. For this reason the converging lens is also called a positive lens.

A diverging lens cannot forma real image. It produces a virtual image, which cannot be caught on a screen. So diverging lens is also called a as negative lens.

7.3.2 Distinction between the Lenses
How to distinguish between converging lens and a diverging lens?

A converging lens is thick at the centre and is thin at the edge. A diverging lens is thin at the centre and thick at the edge. We can also distinguish them by their optical properties. When a lens is kept close to an object and viewed through the lens, if the object appears enlarged, it is a converging lens. If the object appears smaller, it is a diverging lens. If the thickness of the lens is neglected, a lens can be regarded as a thin lens. For a system of lenses, consisting of two or more lenses separated by a distance this approximation is not valid.

A lens has two spherical surfaces. The straight line joining the centres of curvature of these surfaces is called the "optic axis" of the Jens. The "optic centre" of the lens is the point of intersection of the straight line connecting the diametrically opposite points on the edge of the lens and the optic axis of the lens. For a thin lens, the optic centre is situated at the centre of the lens, as shown in Fig.7.2.

Focus and focal length; When a beam of parallel light rays, coming from the left, runs close to the optic axis of a converging lens, it converges to a fixed point on the other side of the lens. This point is called the "principal focus" or simply the "focus" of the lens. The focal length is positive for a converging lens. This focus is called the second (image side) focus. When a beam of parallel light rays coming from the right runs close to the principal axis of a converging lens, it converges to a fixed point on the other side of the lens. This focus is called the first (object side) focus of the lens.
When a beam of parallel light rays coming from the left runs close to the optic axis of a diverging lens, it appears to diverge from a fixed point on the same side of the lens. This point is called the second (image side) focus of the lens. When a beam of parallel light rays coming from the right runs close to the optic axis of a diverging lens, it appears to diverge from a point on the same side of the lens. This point is called the first (object side) focus of the lens. The focal length of a converging lens is assigned a positive sign and that of a diverging lens, negative. This is known as the sign convention to distinguish the lenses. See fig.7.2. below.
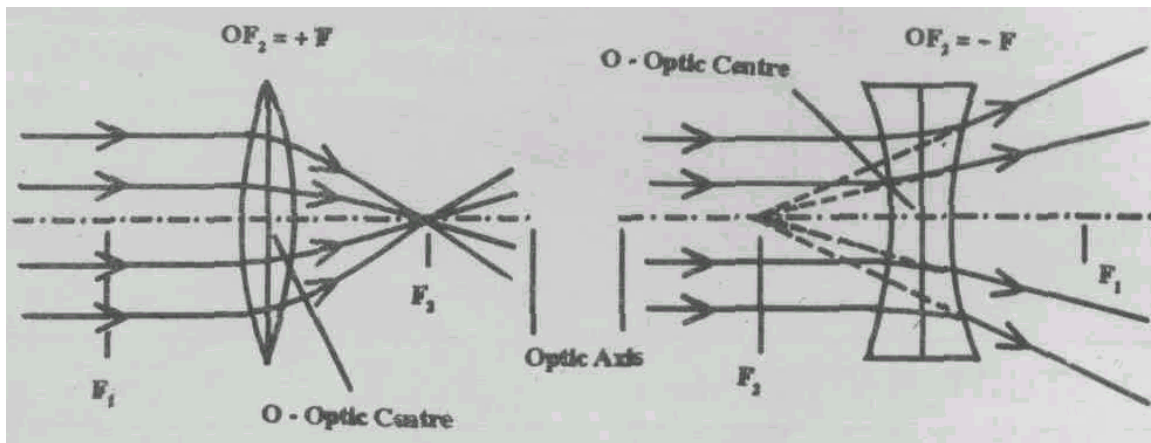

Fig.7.2

7.4 PRECAUTIONS

Lenses should not be kept on rough surfaces like the table. A lens should be handled by the edge of the lens with fingers only. When lenses are not used, they should be put in their enclosures so that dust does not gather on the surface of the lens. Lenses should be mounted vertically and at a proper height from the sources.

7.5 EXPERIMENTS

7.5.1 Image Coincidence Method

Illuminate the wire mesh with the frosted bulb. Cover the bulb with a card board to stop the unwanted light. Use this illuminated wire mesh as the object 'O' in the experiments to follow. Place this object in front of the convex lens and a plane mirror at the back of the lens as shown below:
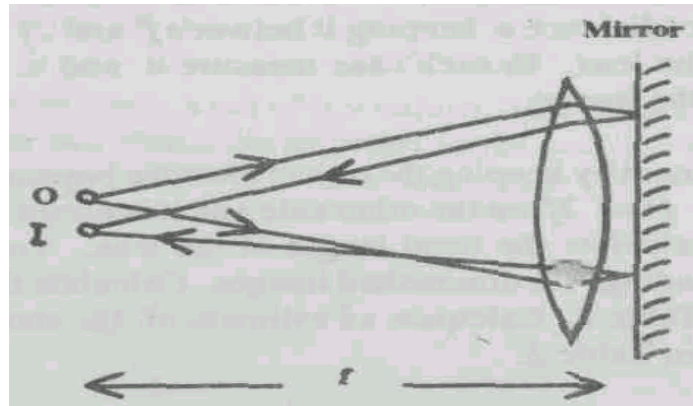
Fig 7.3

If you adjust the position of the object, the image T the object is seen by the side of the object on the same plane. The light incident normally on the mirror is reflected back and rays retrace their path. When the object is at the front focal plane, the light after refraction from the lens becomes parallel and, incident normally on the plane mirror which reflects it. So the rays nearly retrace their paths and an image is formed on the same side of the object. Measure the distance between the object and the centre of the lens. This distance is the focal length of the convex lens. Repeat the experiment by removing the mirror and again replacing it. Locate the position of a clear image by the side of the object. Repeat for a total of 5 trials. Tabulate your observations in Table 1. Do the experiment with another lens.

Table 1: Focal Length

	trial 1	trial 2	trial 3	trial 4	trial 5	average	error estimate
lens 1							
lens 2							

Calculate the average of each set of measurements. For each set of measurements estimate the measurement error, by methods you know already. Enter values in the Table 1.

7.5.2 *U-V* Method

The first method gives an estimate of the focal length of the converging lens. In the *u-v* method you measure the object and image distances from the lens many times and using a formula, you calculate the focal length. There is a control over the distances of the object and image from the lens you measure. Besides, you can see magnified and diminished images of the object.

Mount the "15cm focal length" lens. Keep the object at a distance from the lens greater than the focal length but less then twice the focal length of lens. The screen is placed on the other side. Adjust the screen position until a well defined clear image of the object is obtained. Measure the distance between the object and the centre of the lens. Enter this as in Table 2. Measure the distance of the image and the centre of the lens. Enter it as *v* in Table 2. Then use the formula to calculate the focal length of the lens, and enter in Table 2. Note the characteristics of the image and enter in the last two columns of Table 2. Repeat the experiment by changing the object distance *u* keeping it between f and $2f$ of the lens, where f is the focal length of the lens. In each case measure *u* and *v*. Calculate f and note the characteristics of the image.

Repeat the experiment by keeping the object distance beyond *2f*. In this case, the image is formed between *f* and *2f* on the other side and it is diminished and inverted. Use the same formula to calculate the focal length of the lens. You can take 5 readings for magnified and 5 readings for diminished images. Calculate the mean focal length of the lens, and enter in Table 2. Calculate an estimate of the statistical error by your usual method and enter in Table 2.

TABLE 2: Focal length of a convex lens: *u-v* method

u	*v*	$f = \dfrac{uv}{u+v}$		Image inverted? Not?	Image enlarged? Reduced?

$$f_{mean} =$$
$$\text{Error estimate} =$$

The linear magnification of the image is given by $M = v/u$. Calculate and enter in the fourth column in Table 2. This corresponds to the ratio of the size of the image and the size of the object.

7.5.3 Graphical Method

Graphical method makes it easy to visualise the relative magnitude of *u* and *v*. Draw each of the following graphs.

(i)   *u-v* **graph**

The object distance '*u*' is plotted along the *x*-axis and the image distance *v*, along the *y*-axis. Take a suitable 'scale' to cover the maximum distance in the observations. Take the same 'scale' on both axes. For each trial in Table 2, plot the *u* and *v* values as a point. When all are plotted, sketch a smooth curve connecting the points as near as possible.

Draw a straight line through the origin, and at an angle of 45 degrees to the *x* - axis. It intersects the curve at a point. Find the co-ordinates of this point. They are equal. Each co-ordinate gives $2f$. Enter the value of f here.

SAQ:

Each point on the curve gives a set of *u*, *v* values. The point of intersection of the straight line with the *u*, *v* curve corresponds to the position of the object at a distance $2f$ from the lens. What is the distance of the image from the lens?

$u - v$ graph

(ii)   **1/*u* vs 1/*v* Graph**

In this method, plot $1/u$ along the *x*-axis and $1/v$ along the *y*-axis, by choosing proper scales. Calculate   the appropriate values using the *u-v* pairs from the Table 2 and enter in Table 3.

Table 3

$1/u$	$1/v$

Choose a proper scale for the *x*-axis (l/*u*) and the y-axis (l/*v*) so that all points can be plotted. Plot the points, and draw a smooth curve connecting the points as near as possible. This graph is a nearly a straight line. You extrapolate the straight line to intersect the axes at points P and Q, respectively. Calculate $f =1/OP$ and $f =1/OQ$. Enter here, and calculate the mean value.

1/OP   = …………..

1/OQ   = …………..

Average f = …………..

The formula of 7.5.2 is written here again.

$$f = \frac{uv}{u+v}$$

It can be rewritten as $1/u + 1/v = 1/f$. Along an axis, $1/u = 1/f$ or $1/v = 1/f$. $1/f$ is called the "power" of the lens.

$1/u - 1/v$ graph

7.5.4 Distant Object Method
Keep a 15 cm focal length convex lens in the mount and place it on a laboratory bench in front of an open window. Place a sheet of thin white paper in one of the thermocole holders, in place of a lens. This will act as a screen. If you are not using thermocole holders, gum a white paper to a 5cm x 10 cm stiff cardboard and mount vertically in a clamp, as a screen. Place the screen on the other side of the lens. Adjust the distance between the lens and the screen so that the distant object is clearly imaged on the screen. Measure the distance between the centre of the lens and the plane of the screen with the meter scale, and enter in Table 4. Remove the screen, again replace it and locate the position of the sharp image. Measure the lens-to screen distance and enter in Table 4. Repeat for a total of 5 trials. Repeat for a lens of different focal length. Calculate the average value for the trials of each lens, and calculate the estimated error by your usual method. Enter in the Table 4.

Table 4: Focal Length

	trial 1	trial 2	trial 3	trial 4	trial 5	average	error estimate
lens 1							
lens 2							

7.5.5. Focal Length and Brightness
Mount two or three converging lenses of the same diameter and of different focal lengths. Place them side by side to face a distant object such a tree. Place a screen on the opposite side of the

lenses and adjust the distance between each of the lenses and the fixed wider screen such that the images formed on the screen are clear. You will now see these images side by side. Now compare the brightness of the images formed by the lenses, and their sizes. Enter your visual observation in the Table 5.

Table 5

	Focal length	relative brightness	size of the image
lens 1			
lens 2			

Write in the space below any relationship you find in Table 5 between relative brightness, size of the image and the focal length of each lens.

Take a cardboard with a round hole, called the 'aperture', in it. Such a cardboard is called a 'stop'. The diameter of the aperture should be about 70 % of the diameter of lens. Take one of the lenses and keep the stop just in front of the lens. The stop reduces the amount of light falling on the lens. Measure the focal length of this lens with the stop by the distant object method of Sec 7.5.4. Enter the data in Table 6.

Table 6: Focal Length

stop	trial 1	trial 2	trial 3	trial 4	trial 5	average	error estimate
lens 1							
lens 2							

Are you able to locale the position of the focus precisely? Why? Repeat the experiment with the stops of smaller apertures: 50 %and 30 % of the diameter of the lens. Enter the data in Tables 7 and 8 respectively.

Table 7: Focal Length

— % stop	trial 1	trial 2	trial 3	trial 4	trial 5	average	error estimate
lens 1							
lens 2							

Table 8: Focal Length

---% stop	trial 1	trial 2	trial 3	trial 4	trial *5*	average	error estimate
lens 1							
lens 2							

As you use stops of lesser diameter in conjunction with a lens, the 'error' of your measurement may change. The 'error' represents the range of distance of acceptable focus. However the amount of light passing through the lens decreases when you use a stop of smaller diameter. The compensation you get is that there is a greater range of object distance of acceptable focus on the image plane.

SAQ'S
In your **high-school, you** have studied about 'pin-hole' camera. What is the focal length of a pin-hole camera?

_____

_____

You know that some cameras are expensive and these cameras have lenses of large diameter. There is a provision to adjust the distance of the lens from the film plane. With a range finder you first measure the distance of the scene you want lo photograph and adjust the lens accordingly.

The 'Aim and shoot' cameras are not very expensive and the lenses of these cameras have a small aperture. There is no provision for the adjustments of the lens. Why? Correlate these cameras with the results of the experiment you have done with stops and lenses.

7.5.6 Focal Length of a Concave Lens
Since a concave lens cannot form a real image on a screen, we have to combine it with a convex lens of suitable known focal length. This lens-combination is called a lens-system. There are two methods by which you can find the focal length of a concave lens:

(1)   Contact method.

(2)   "Separated by a distance" method.

(1)   Contact method: Keep the given concave leas and a single convex lens together in-contact. This combination is treated as though it were a single lens. Adopt the *u-v* method to find the effective focal length F. If f_1 and f_2 are the focal lengths of the convex lens and concave lens respectively, then

$$\frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{F}$$

You will find that $F > f_1$ and therefore the focal length of the concave lens is negative as expected. The experimental procedure is identical to the one you did earlier, namely the determination of focal length of a convex lens, U and V are the distances of the object and image distances from the centre of the lens system.

Enter the readings in the Table 9 shown below:

Table 9: Focal length of a concave lens - Contact method

Focal length of convex lens = f_1 = _____

U	V	$F = \dfrac{UV}{U+V}$

$$f_{mean} = \text{\underline{\hspace{3cm}}}$$

$$\text{estimated error} = \text{\underline{\hspace{3cm}}}$$

$$f_2 = -\frac{Ff_1}{F - f_1} = \text{\underline{\hspace{3cm}}}$$

(2) "Separated by a distance" method:
With the convex lens, an image I' of the screen source is formed on the screen. Note the position of the screen. The concave lens is introduced in between the convex lens and the screen at a distance U from the image I'. You observe that the image I' after the introduction of the concave lens becomes blurred. Move the screen away from the concave lens to a new position where the new image I formed on it is clear. The distance of this new image I from the concave lens is measured as V. Enter the distances U and V in the Table 10. Calculate f_2. For the concave lens, the <u>virtual</u> object I' produces a <u>real</u> image I'. See Fig.7.4.
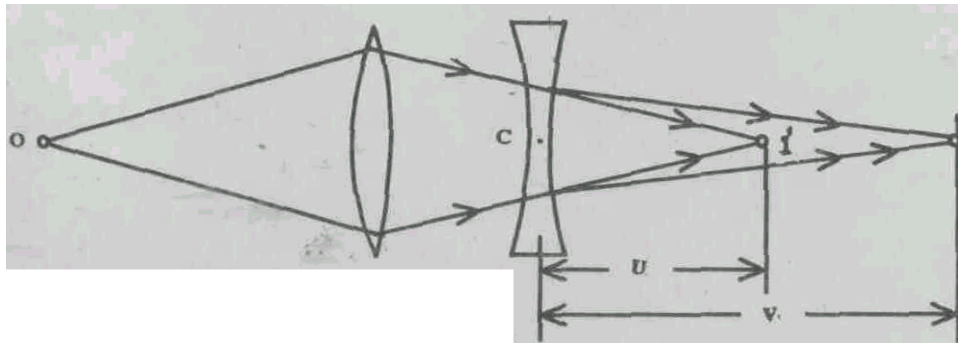
Fig. 7.4

We have $\dfrac{1}{f_2} = \dfrac{1}{U} + \dfrac{1}{V}$

$f_2 = -\dfrac{UV}{V-U}$ as $V > U$

Repeat the experiment by changing the distance between the concave lens and the convex lens. Make measurements for two such lenses.

TABLE 10: Focal length of a concave lens - "Separated by a distance" method

Focal length of convex lens = f_1 = _____

U	V	$F = \dfrac{UV}{U+V}$

CONCLUSION

You have determined the focal length of a convex lens by a number of methods. The focal length of a concave lens was determined using another convex lens of known focal length. You have observed the way in which focal length and diameter affect the brightness and size of an image formed by a lens.

You now know quite a lot about lenses and how they behave!

(For Counsellor's use only)

Grade.............................   Name ....………………..

Evaluated by…………………………….   Enrolment Number ………………

EXPERIMENT 8
SPECTRAL ANALYSIS USING A PRISM SPECTROMETER
Structure

8.1   INTRODUCTION

You have already learned about the phenomena of dispersion, interference and diffraction in your school. These phenomena are beautiful to observe and give a lot of scientific information. Most of the information gathered regarding heavenly bodies a re due to the study of these phenomena. In the experiments you are going to perform, you observe these phenomena and determine values of some physical quantities such as refractive index of the material of the prism for different wavelengths of lines of various colours in the visible spectrum of some sources of light. You should be aware that the observation of the solar spectrum gives information regarding the constituents of the atmosphere of the sun.

Of course before you are able to determine the quantities you will learn to use the apparatus required. They are the spectrometer, prisms, and sources of light. The knowledge and skills you acquire in this experiment will form the basis of your future experiments in spectroscopy. The Experiment will be a sequential experiment with this experiment.

Objectives
After performing this experiment you should he able to:

- Identify the various parts of spectrometer and make initial adjustments in order to obtain a clear and resolved spectrum.
- Determine the refractive indices of the material of the prism for different wavelengths.
- Observe and interpret the solar spectrum.

8.2   APPARATUS
Student spectrometer
Dense flint glass equilateral prism Mercury vapour lamp
Spirit level
Reading lens.

8.3   STUDY MATERIAL
8.3.1   Refractive Index
When a composite visible light is dispersed in a medium, the light of different colours are separated and propagated in different directions. The light of different colours travel with different speeds in a transparent medium. This phenomenon is called dispersion. The speed of light in vacuum is a constant equal to 3×10^8 m/s. The speed of blue light is less than that of the red light in the dispersive medium. The ratio of the speed of light in vacuum to the speed of light of a particular colour in the medium called refractive index.

$$n = \text{ refractive index} = \frac{\text{speed of light in vacuum}}{\text{speed of light of a particular colour in the medium}} \qquad (1)$$

These different colours of light also have different wavelengths: the wavelength of blue light is less than the wavelength of red light. There is a relation between the wavelength and refractive index.

$$n = A + (B / \lambda^2)$$

where λ = wavelength, and *A* and *B* are called the Cauchy's constants.

To determine the wavelength and the refractive index, we use a spectrometer. With a spectrometer and a prism we can determine the refractive indices of various colours of lights. With a spectrometer and a grating, we can determine the wavelengths of lights of different colours.

8.3.2 Light Sources
The source of light can be a white light source such as incandescent light, sunlight or mercury vapour light.

In the laboratory, we use two types of light, monochromatic light source; polychromatic light source. Sodium vapour lamp emits light of one wavelength (actually a doublet) at yellow region of spectrum. Its wavelength is 589.3nm. The low-pressure mercury lamp emits lights of different colours. They are two closely spaced lines (doublet) in yellow region, a few lines in bluish green region, a bright line in green region and a bright line in blue region.

Identification of elements by the spectrum of emitted light is a part of the study of spectroscopy.

8.4   PRECAUTIONS
(1)   Sometimes, it may happen *that you are able to see the reflected light from one side of the prism and not from the other side The slit might not have received light properly.*

(2)   *Fix the prism table and the telescope firmly while taking readings.*

(3)   *When the prism is fixed on the prism table, the refracting edge of the prism should be at the centre* of the prism table while measuring the angle of the prism. This enables to get the reflected light from the slit, on both the sides of the prism.

SAQ's

(1)   The refractive indices of blue and red colour are denoted as n_b and n_r. What does $(n_b - n_r)$ denote? What is its value in your observations?

(2)   The mean refractive index of the material of the prism is Calculate its value.

$$n = \frac{n_b + n_r}{2}$$

(3)   The dispersive power of the material of the prism between the blue and yellow colours is

$$dw = \frac{n_b - n_r}{n - 1}$$

Calculate its value.

(4)   How will you identify the refracting angle of the prism? From the geometry of the prism, what is its value?

8.5   THE EXPERIMENT
PARTS OF A SPECTROMETER
1.   Telescope
2.   Collimator
3.   Prism-table

8.5.1 Adjustments of a Spectrometer
ADJUSTMENT OF THE EYE-PIECE: Looking through the eyepiece of the telescope, you can see the cross wire. The cross wire can be clearly seen on a white back-ground when the eyepiece is moved in or away in the slot, for a particular position, the cross wire is clearly seen. After setting this, do-not disturb the eye-piece. This adjustment has to be done by every person who uses a spectrometer as the eye-lens also plays a role in focusing the cross wire.

Turn the telescope towards the distant object like a building or a tree more than 20 metres away. Focus the telescope, so that the details of the distant objects are clearly seen; for example the leaves of the distant tree shall be clearly seen. You know that light rays coming from a distant object is parallel and the telescope is able to receive parallel beam of light and brings it into its focal plane. After doing this adjustment, do not disturb the telescope adjustment throughout the experiment.

8.5.2 Adjustment of the Collimator
After the adjustment of the telescope, we turn towards the collimator and adjust the collimator. The collimator has a slit at one end of it. Keep the slit width minimum keeping good visibility. Look through the telescope, and focus it so that the slit is seen clearly. A parallel beam of light then emerges from the collimator. The telescope which is already set to receive parallel beam of light, is able to converge the light at its back focal plane, where the image of the slit is formed.

Throughout the experiment the telescope that is adjusted to receive parallel rays and the collimator that is adjusted to produce pa railed rays should not be altered.

8.5.3 Adjustment of the Prism Table

Using the spirit level, adjust the prism table to be horizontal. There are three screws on the prism table rests. Keep the spirit level on the line joining two screws and turn the screws suitably to bring the bubble to the centre. Then keep the spirit level perpendicular to the original position and turn the third screw to keep the bubble at the centre. Repeat this alternatively till the bubble of the spirit level is always at the centre. Now if you keep the spirit level in any position on the prism table, the bubble is always at the centre. Then the prism table is horizontal.

Keep the prism on the prism table and clamp it. The base of the prism is against the clamp.

There is a facility to rotate the prism-table along with the vernier scale by releasing a main screw at the base of the instrument. By tightening the screw, the vernier scale can be fixed and the prism-table alone can be rotated.

The telescope can be rotated and fixed at any desired positions by fixing a mainscrew, which is also at the base of the instrument.

Any fine movements of the telescope or the vernier scale are possible by working the screws called vernier screw. Vernier screw can work only when the main screws are fixed.

The circular scale is graduated in degrees. The value of main scale divisions, is usually 1/2° or 30'.

The number of divisions in the vernier scale is usually 30(VSD), which is equal to 29 main scale divisions. The least count of the vernier is usually 1'.

8.5.4 Measurement of Angle of the Prism

In this case we measure the refractive indices of the various lines of the mercury vapour lamp by using an equilateral prism and a spectrometer.

APPARATUS REQUIRED:
Prism (dense flint glass),
Spirit level,
Reading Lens,
Mirrors,
Mercury lamp,
Spectrometer.

After making the adjustments of the spectrometer, the prism is mounted on the prism-table. The reflection edges are kept symmetrically on the prism table with respect to the collimator. Rotate the telescope to receive the reflected light from one side of the prism. Fix the main screw of the telescope and then turn the fine screw of the telescope so that the cross wire is coinciding with the image of the slit, as shown below in Fig. 8.1.
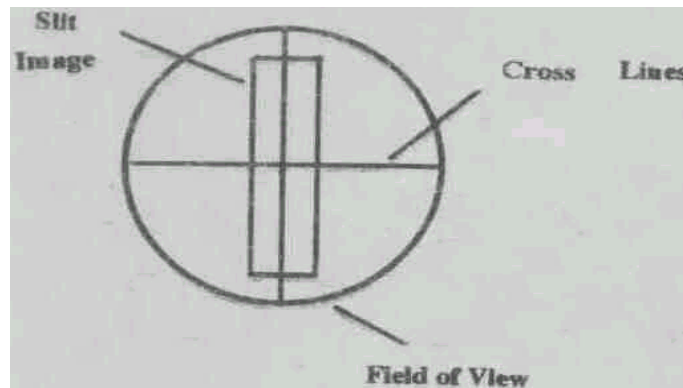
Fig 8.1

Refer to Fig. 8.2. Note the main scale readings and vernier scale coincidence on both scales, A and B. Release the telescope and rotate it to receive the reflected light from the second face and do exactly as before to take the readings on both scales. The difference in the two readings of scales A and B is equal to the angle through which the telescope is rotated and this is equal to twice the angle of the prism (2A). Hence we can determine A. Tabulate the readings. Repeat the experiment by keeping the vernier scale at other positions and fixing it. The mean value of a number of trials gives a better estimate of A, Write your measurements in Table I.

Table I

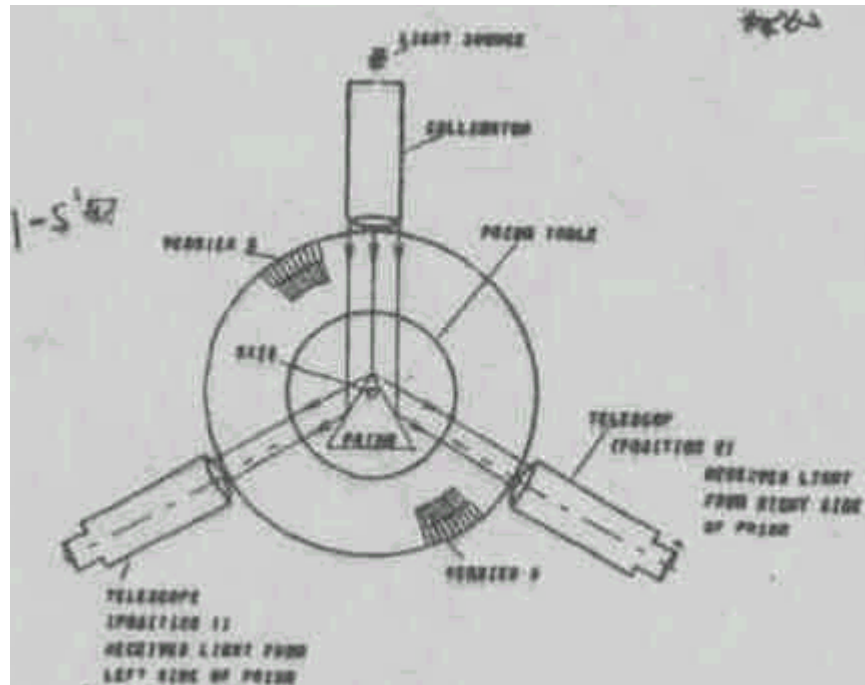| SIDE I VERI VERII	SIDEII VERI VERII	2A VERI VERII DIFF. DIFF.	A MEAN
MEAN PRISM ANGLE = _____			

Fig. 8.2

8.5.5 Measurement of Angles of Minimum Deviation for various Colours of Light
After measuring the angle of the prism, let us turn the prism table so that the side of the prism is inclined to the collimator as shown in Fig. 8.3.
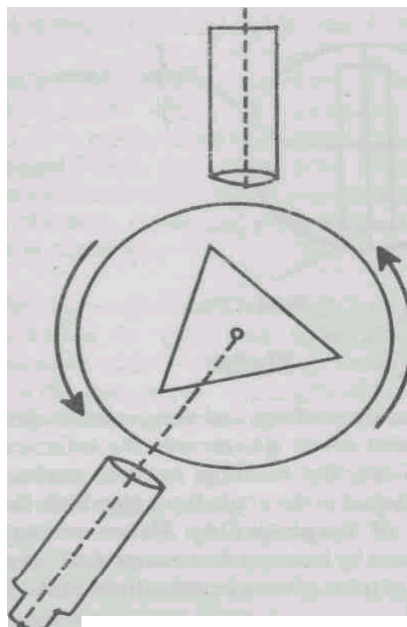

Fig 8.3

After refraction through the prism in which direction the emergent ray will come out?

The emergent ray will be deviated towards the base of the prism. Now rotate the telescope so that the emergent rays pass through the telescope. You can see the beautiful spectrum of the incident light. Refer to Fig.8.4.
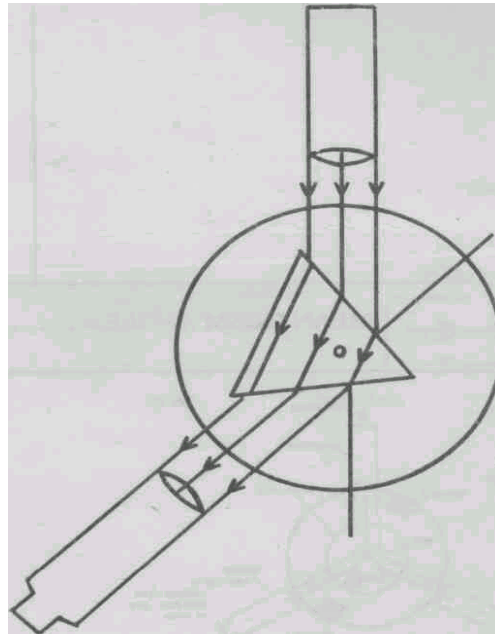
Fig 8.4

When the prism table is rotated, the angle of incidence changes and the angle of emergence also changes. Consequently the angle of deviation also changes, as shown in Fig. 8.5
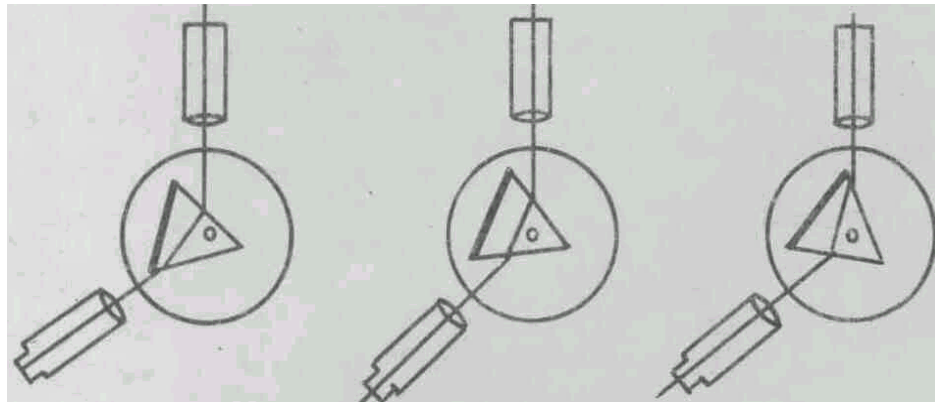
Fig 8.5

Our aim is to fix the prism-table at the minimum deviation position. For this, you observe the spectrum through the telescope and simultaneously rotate the prism-table and follow the spectrum. If you rotate the prism table in one direction the spectrum will move towards one end. As you rotated prism more in the same direction you will see the spectrum halt its motion and then move in the opposite direction. Fix the prism table at the "halt" position. This is the position of minimum deviation.

Table II
DIRECT RAY READING   - VERNIER I
                         - VERNIER II

COLOURS	MIN.DEV.POS.		ANGLE OF MIN.DEV.			n
	VERI	VERII	VERI DIFF.	VERII DIFF.	MEAN D	

SAQ:
Do you need to adjust the prism table for each line of the spectrum? Does the adjustment of the prism table for one line in minimum deviation position automatically guarantee minimum deviations for all the other lines? Do the experiment and the answer in Table II.

After taking the readings of the minimum deviation position for all the lines, remove the prism. Release the telescope and turn it in line with the axis of the collimator and take the direct ray reading on both verniers.

Calculate the difference in the readings on the same vernier for the two positions of the telescope, that is, the positions to receive the deviated and the direct rays. Take the mean of the two difference readings. It gives *D*, the angle of minimum deviation.

Using the formula $n = \sin((A+D)/2)/\sin(A/2)$ and substituting the values for *A* and *D*, the refractive index can be calculated.

8.5.6 Observations

1 msd	=	$1/2^O$	
30 vsd	=	29 msd	
1 vsd	=	29/30 msd	
Least count	=	1 msd - 1 vsd	= (1-29/30) msd = 1/30 msd
	=	$1/30 \times 1/2$ = 1/60	= 1'

Least Count = 1'   Angle of the prism = *A* =

Set the prism and prism table at minimum deviation position for the green line in the mercury spectrum. Now adjust the telescope so that the cross-wire falls on the prominent lines, one by one. Record the scales for each line in Table III, which you should draw in the space below.

8.5.7 Solar Spectrum

In observing solar spectrum in the visible region, instead of the laboratory sources, we use the sun light. Keep the prism position the same as for 8.4.6. Adjust a small mirror to reflect sunlight straight into the Spectrometer through the slit. Adjust the slit to the narrowest possible, while letting through appreciable light.

The procedure of taking readings is the same as before. Here one observes dark lines on a continuous background spectrum. These dark lines correspond to absorption lines of elements which are in vapour state on the Sun. So these absorption lines appear as dark lines. The H-alpha and H-beta lines are prominently seen as dark lines.

Measure the angles at which very prominent (dark) absorption lines are seen. Enter your scale readings in Table IV, which you should draw in the space below.

8.6 CALCULATIONS

Make a graph in which you plot the calculated indexes of refraction for various colours (Table II). The wavelength (nm) of the colours (see the chart below).

Colour	Red	Yellow	Green	Blue l	Blue 2	Violet	
wavelength (nm)	690.72	546.07'	491.61		435.83	404.66	

8.7 CONCLUSIONS

The angle of the prism is determined. The refractive indices of the material of the prism are determined for various colours of the spectrum of light emitted from a source. The spectrometer is calibrated for the mercury lines using green-light minimum deviators. The prominent solar absorptions lines are observed and their wavelength calculated.

Make a graph in which you plot the wavelengths of prominent mercury lines or telescope angle readings (Table III).

From the telescope angle readings of prominent solar absorptions lines (Table IV) and by use of the above graph, find the wavelength of the solar lines. Enter in Table V.

EXPERIMENT 9
INTERFERENCE OF LIGHT - YOUNG'S EXPERIMENT
Structure

9.1 INTRODUCTION

Knowing about the nature of light will be helpful to us in many ways. In fact the knowledge of its behaviour helped us to use it in technology, medicine, industry, communication, cinematography, photography and in quite a number of useful areas.

Interestingly, people thought in the early days that light travels in straight lines only. Newton proposed the corpuscular theory of light, which was found to be inadequate later.

It was Young, who performed a very simple experiment but very significant one, that suggests that light is propagated by means of waves. Anyone, including you, can perform what Young did.

Since you are a science student you might have observed the fact that soap bubbles and also thin films of oil spread over water surface appear to be coloured. Later you would know that the reason for the above is due to interference of light which is the subject of this experiment, You will realise how simple is the Young's experiment from the following description. It is shown in Fig.9.1
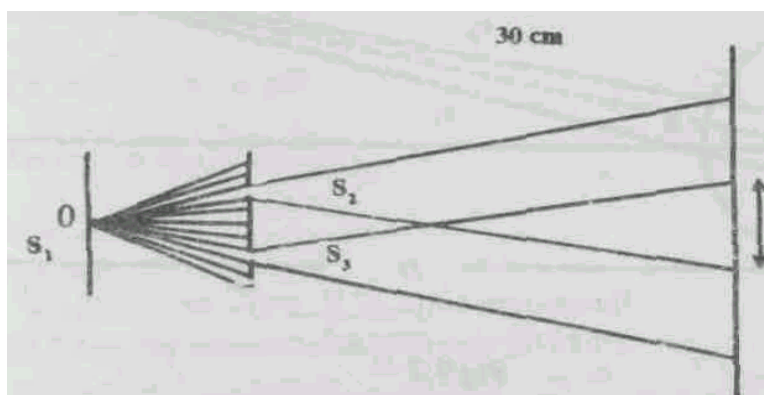
Fig 9.1

S is a source of light having single colour (called monochromatic source). S_1, S_2 and S_3 are narrow rectangular parallel slits of width order of magnitude .03mm to .02mm. Light from each of the slits spreads out, and light from sources S_2 and S_3 overlap in the region X on the screen. In this interfering region one finds alternate bright and dark parallel bands of equal width, the bands being perpendicular to the plane of the figure and parallel to the slit opening. It is shown in Fig 9.7. This observation formed the basis for the wave theory of light.

Objectives
After performing the experiment you will be able to:

- Explain the phenomenon of interfere rice.
- Measure the wave length of any given monochromatic source, using a Young's two-slit interference experiment.

9.2 APPARATUS
A monochromatic source like sodium vapour lamp
Glass plates 1mm or 2mm thick
Kerosene lamp or any other lamp that could be used to smoke the glass surfaces
Sharp edge like the tip of *a* shaving blade
Meter scale

9.3 BACKGROUND MATERIAL
YOUNG'S EXPERIMENT
Assume two waves of equal frequency travelling in approximately in the same direction, having nearly equal intensities and having a phase difference that remains constant with time. Such waves combine so that their energy is not distributed uniformly in space but is a maximum at certain points and minimum at other points. Young was able to measure the wavelength of tight from such an experiment.
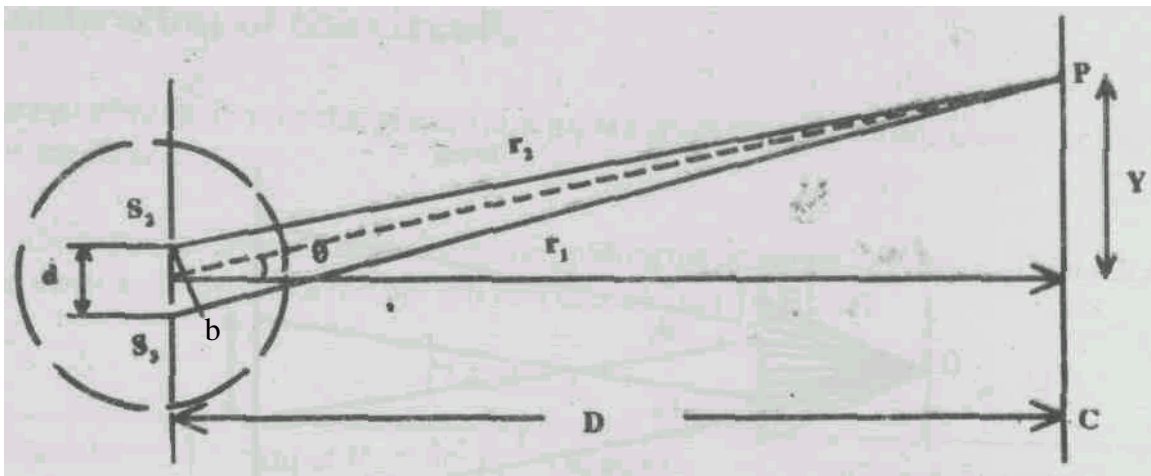
Fig. 9.2

In Fig 9.2, S_3 and S_3 represent the narrow parallel slits separated from each other by a distance *d*. *P* is any point on the screen *C*. *P* is at distances r_1 and r_2 from the narrow slits S_3 and S_2 respectively. Draw a line from S_2 to b in such a way that the lines PS_2 and Pb are equal. If the distance between the slits S_3 and S_2 is much smaller than the distance D, then S_2b is almost

perpendicular to both r_1 and r_2. This means that angle S_3S_2b is almost equal to angle Pao, in the Fig 9.2.

The two rays arriving at P from S_3 and S_2 are coherent since both are derived from the same sources, S_1. Because the rays have different optical path lengths, they arrive at P with a constant phase difference. The number of wavelengths contained in S_3b, which is the path difference, determines the nature of the interference at P, i.e., whether it is a maximum intensity or minimum intensity at *P*.
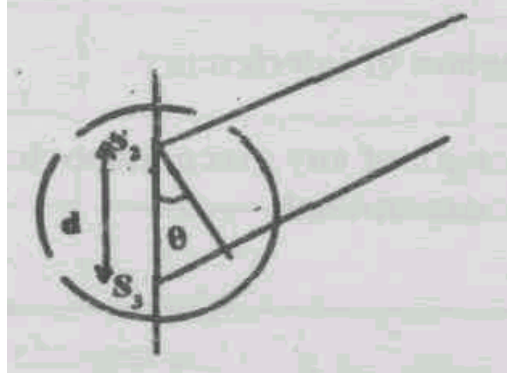
Fig.9.3

To have maximum at P: (See Fig. 9.3)

$S_3b = d \sin \theta$ - must contain an integral number of wave lengths (mL)

$S_3b = mL$ $\qquad m = 0, 1, 2, 3, ...$

Which can be written as

$$d \sin \theta = mL \qquad m = 0, 1, 2, 3, ... \tag{1}$$

Note that each maximum above O in the Fig. 7.2 has a symmetrically located maximum below O.

The central maximum occurs at O for $m = 0$. For minimum intensity to occur at *P:*

$S_3b\, d \sin \theta$ - must contain a half integral number of wave lengths, i.e.

$$d \sin \theta = (m + 1/2)L \qquad m = 0, 1, 2, 3, \tag{2}$$

From Fig. 9.2 if θ is small enough we can use the following approximation.

$\sin \theta \approx \tan \theta \approx \theta$

We see that $\tan \theta = \theta = y / D$
Substituting this equation in Eqn.(1) we get

$d\theta = mL$

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$$dy / D = mL$$

$$y = mLD / d \qquad m = 0, 1, 2, 3, ... \text{ (for maximum)}$$

This positions of any two adjacent maxima are given by

$$Y_m = mLD / d \tag{3}$$

$$Y_{m+1} = (m + 1)LD / d = (m + 1)LD / d \tag{4}$$

Their separation W that is the width of a single fringe or band is obtained by subtracting equation (3) from eqn (4).

$$W = Y_{m+1} - y_m = LD / d \tag{5}$$

$$L = dW / D$$

From the above equation, L is given by

$$L = dW/D \tag{6}$$

9.4 PRECAUTIONS

Care should be taken to keep the centre slits S_1, S_2 and S_3 and the eye piece in the travelling microscope almost in a straight line. The slits S_1, S_2 and S_3 must all be parallel. Care should be taken to locate the eye piece in the region where light from S_2 and S_3 overlap. To do this, take out the eyepiece also, and look through the microscope tube. Move it until both slits show light. Replace the eyepiece-fringes appear!

9.5 EXPERIMENT

AIM: To set up Young's Double slit Experiment and to measure the wave length of the monochromatic source (Sodium light).

9.5.1 Procedure
MAKING THE SLITS

First you should make rectangular slits of your own. Take two ordinary transparent glass plates (approximately) 3cm* 5cm of 0.2cm thick or any convenient dimensions. Using a kerosene lamp, smoke the two glass plates (one side only) to a convenient area so that the glass plate becomes completely opaque as shown in the Fig 9.4.a.
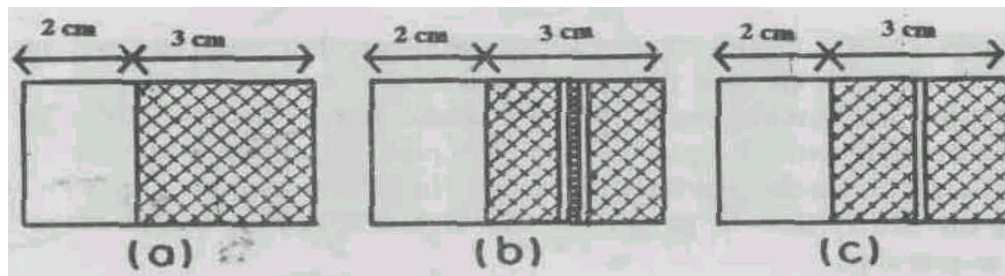
Fig 9.4

Take any two wooden strips of 5mm or 6mm thick. Place them apart on a plane table sufficiently apart in order to place the smoked glass plate in in-between them. Place the scale over the two wooden blocks, then with a pointed tip (which could be the tip of a ball point pen or a blunt needle or blunt edge of a shaving blade) scratch-the smoked surface by drawing a straight line with the help of the scale. This arrangement is shown in Fig. 9.5. The transparent scratch mark acts as a rectangular slit, you draw two close-by lines. This acts as a double slit. As shown in Fig 9.4.b and 9.4.c, make a single slit and a double slit.
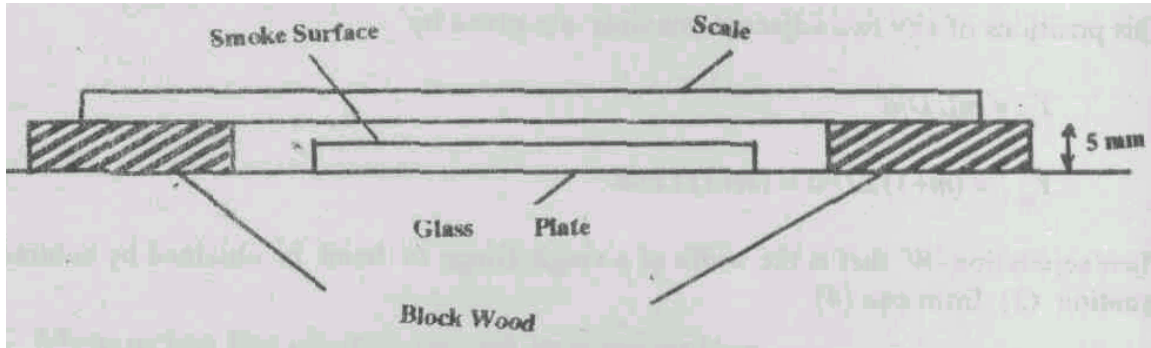
Fig 9.5

For performing Young's Experiment, we need a single slit a double slit and an eye piece. The widths of the slits should be as narrow as possible, say of the order of 0.02mm. The length of the slit shall be about 2 cm. The distance between the centres of the closely spaced double slits shall be of the order of 0.05 mm. You can use the eye piece attached to any travelling microscope by removing the objective lens.

ADJUSTMENT TO GET INTERFERENCE FRINGES

Place the single slit in a clamp close to the sodium light (about 10 to 20 cm). Then place the double slit, you made, about 20-25 cm away from the single slit. The experimental set up is shown in the Fig 9.6.
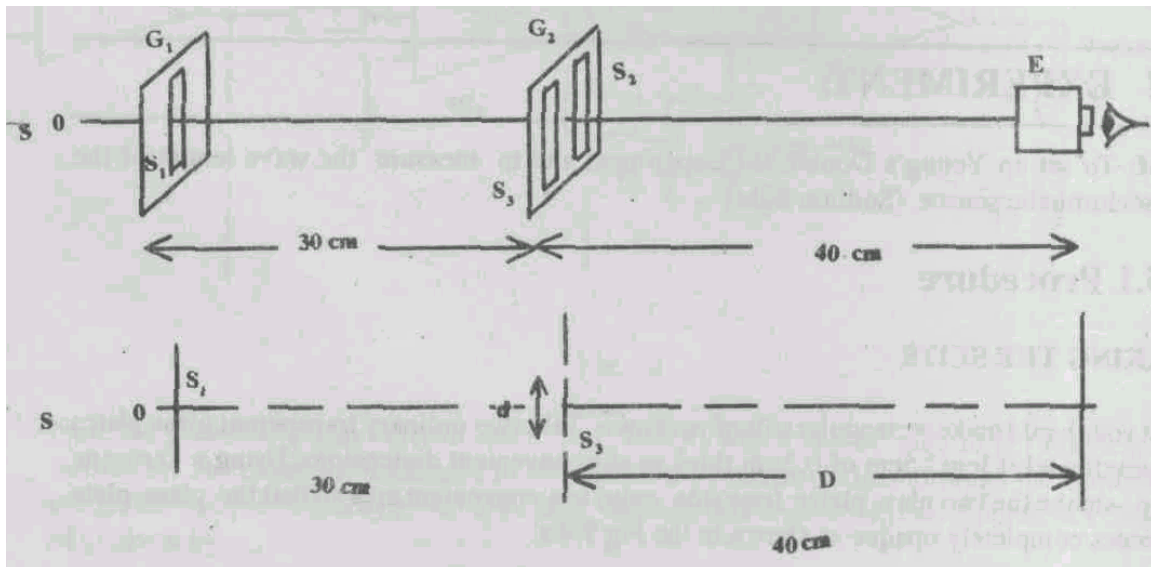
Fig. 9.6

Place the eye piece of a travelling microscope (you can just remove the objective lens temporarily). So that S_1, the mid point of S_2 and S_3 are in a line. You probably see the interference pattern of alternate bright and dark bands. If not rotate slightly either G_1 or G_2 about an axis perpendicular to the plane of the glass plates G_1 and G_2 while looking through the eye piece, until you get the interference pattern. In order to get sharp interference bands it is necessary that slit S_1 must be parallel to slits S_2 and S_3 and the widths of the slits shall be as narrow as possible.

9.5.2 Measurements and Tabulations
The wavelength of light of the given source (monochromatic) is given by the equation

$$L = dW/D \tag{6}$$

Where: d is the distance between the centres of the double slits S_2 and S_3.

D is the distance between the glass plate G_2 (which is the plane which carries the double slit S_2 and S_3) and the position of the crosswire of the eye piece E.
W is the width of the band (either dark or bright).

MEASUREMENT OF 'd' THE DISTANCE BETWEKN THE CENTRES OF THE TWO SLITS S_2 AND S_3
The travelling microscope with the objective lens (replaced back) could be used for measuring d. The glass plate G_1 is held with the help of a stand and clamp such that the plane of the glass plate, G_2 is vertical which contains the slits S_2 and S_3. The axis of the microscope is kept in the horizontal position. The microscope is focussed on the slit S_2. Its position on the horizontal scale is noted. Again the microscope is focussed on the slit S_3, Its position on the horizontal scale is noted. The difference between the two positions give the distance between the two slits S_2 and S_3 and that is d. Tabulate the observations as in the Table I.

Table I
MEASUREMENT OF THE DISTANCE d BETWEEN THE TWO SOURCES S_2 AND S_3

Position of the Microscope when the vertical cross wire coincides with the centre of the		The distance between centres of the two slits S_2 and S_3
Slit S_2 cm	Slit S_3 cm	d cm

The mean value of d =   cm

MEASUREMENT OF *W* AND *L*
Again remove the objective lens from the microscope, and observe the interference "fringes".

Make the vertical cross-wire of the eye-piece to coincide with the centre of any of the dark or bright fringe. Consider it as the *m*th order fringe (band). See Fig 9.7
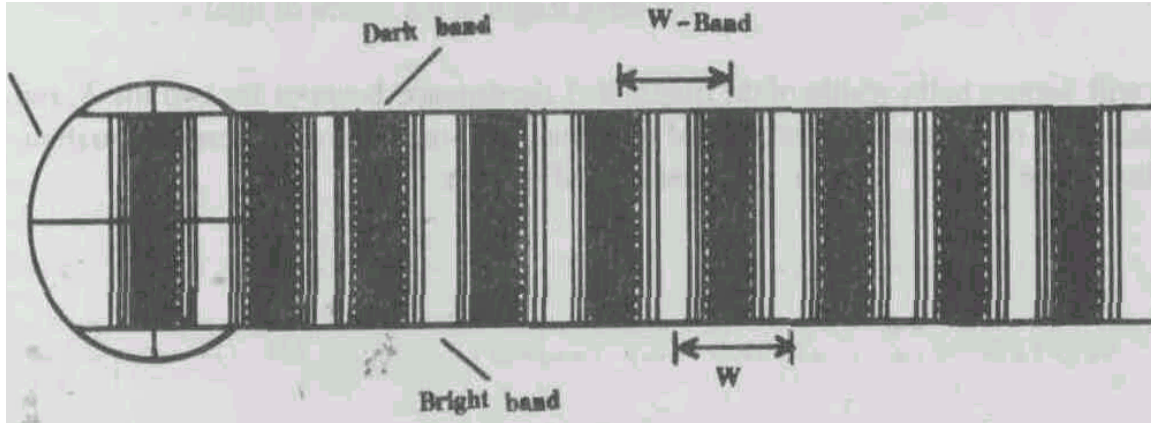
Fig. 7

Note the initial position of the eye piece reading of the microscope. Then move the eye piece lateral to the direction of light rays from the slits such that the alternate bright and dark bands cross the field of view. Count them by watching the number of fringes shifted. Then make the cross wire to coincide with the $(m + n)$th fringe, *n* could be 10 or 11. Note the reading on the travelling microscope which gives the final positions of the eye piece corresponding to the $(m + n)$th fringe. The difference between the initial and final positions of the eye piece will give the width of *n* fringes. Hence calculate the width of one fringe *W*. Tabulate the readings. The tabular form is shown in Table II.

D -   The distance between$<7_2$ (containing sources S_2 and S_3) and the position of the crosswire in the eye piece.

P_i -   The position of the eye-piece in the horizontal scale of the travelling microscope when the vertical crosswire coincides with the *m*th order bright fringe.

P_2 -   The position of the eyepiece in the horizontal scale of the travelling microscope when the vertical crosswire coincides with the $(m + n)$th order of the bright fringe.

n -   The number of fringes that has shifted in the field of view when the position of the eye piece is shifted from P_1 to P_2.

W_n -   Width of the fringes

W -   Width of one fringe

L -   The wave length of the source light ($L = (d/D) \times W$)

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Table II
MEASUREMENT OF THE WIDTH OF THE FRINGE *W* AND THE WAVE LENGTH *L*

D cm	P_1 cm	P_2 cm	n	W_n cm	W cm	L nm

Mean value of L　　　＝　　*nm*

The standard deviation　　＝　　*nm*

The wave length of the source of light　＝

What will happen to the widths of the fringes if *d* the distance between the two slits S_2 and S_3 is increased or decreased? Find slits of other students which have a different separation, and observe the figures. Answer the question, and explain.

SAQ's
1.　　Why do the fringes in Young's experiment have equal width?
_____

_____

_____

2.　　Suggest any other method to produce interference of light waves.
_____

_____

_____

3.　　Can interference be observed for (a) sound waves? (b) radio waves? Give reason.
_____

_____

_____

_____

4.   If the sodium light is replaced by a filament bulb what will you observe on the screen? Try, and verify your idea. Record here what you find.

_____

_____

_____

9.6 CONCLUSIONS

The alternate bright and dark bands obtained due to two closely spaced slits suggest that the light propagates by means of waves. This method helps to determine the wavelength of a given monochromatic source.

EXPERIMENT 10
SPECTRAL ANALYSIS USING A GRATING SPECTROMETER
Structure

10.1 INTRODUCTION
You have used a spectrometer to determine the index of refraction of the material of the prism for various colours of light. In that process you have learned to adjust the prism and the telescope. You have also learned to make measurement of angles. This experiment, using a grating can be considered as a sequence to that experiment, where you have used a prism.

Objective
After performing this experiment, you will be able to:

* standardise a grating, and
* determine the wavelength of the various colours of light.

10.2 APPARATUS
Student spectrometer
Transmission grating
Mercury vapour lamp
Sodium vapour lamp
Spirit level
Reading lens

10.3 STUDY MATERIAL
10.3.1 Standardisation of Grating
The determination of number of lines per meter of the grating is called standardisation of the grating. Usually, this information is written on the grating. This information is sometimes given as certain number of lines per inch or centimetre, or metre.

What does this number denote? For this you must know how a grating is made and how it acts on the light falling on it. On a plane transparent glass, parallel lines are drawn with a very small separation between adjacent ones using diamond point. Through the transparent portion between

the two adjacent lines, light passes and the opaque portions stop the incident light. The gap between the opaque lines is so small that light is diffracted by it. Diffracted light from all such transparent slits interfere to form various inference orders.

The width of the transparent slit is *a*. The width of the opaque portion is *b,* then grating element is *e = a + b.* (See Fig. 10.1) The reciprocal of *e* (*N* = l/*e*) is called "number of lines" or equivalently number of slits per unit length. Measurement of *N* is known as standardisation of grating.
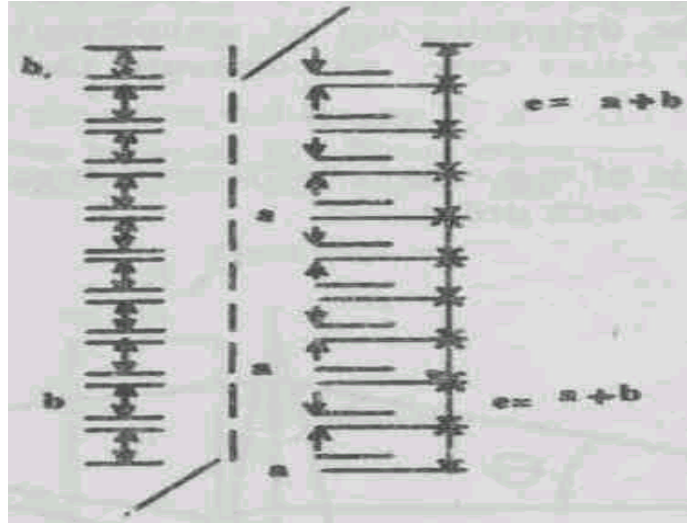
Fig.10.1

When you look at a source of light through a grating, you see that light is pulled to the sides into a patch of coloured light. This patch is due to the interference of diffracted light from the many tiny slits.

10.3.2 Interference Orders

The light coming from adjacent slits has a path difference $e\sin\theta$ as shown in Fig. 10.2. If $e\sin\theta = m \times$ (wavelength of light), where θ is the angle of diffraction and *m* is the order of interference, then all the diffracted light from the many slits interferes to form an image of the slit in the direction of θ. If *m* = 1, it is called first order, and if *m* = 2, it is called second order. The above equation can be written as:

$$\sin\theta = N \times m \times \text{(wavelength)}$$
where $N = 1/e =$ number of lines per meter.

If we are able to determine θ of a known wavelength of light, then *N* can be determined, by setting *m* =1 or 2 for the order of the spectrum.
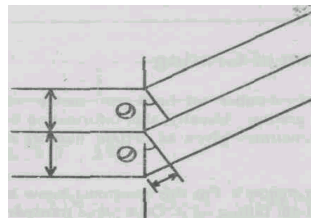
Fig. 10.2

For the determination of *N*, the angle of diffraction θ is determined for a monochromatic line of a spectrum. In the laboratory, sodium vapour light is used as a source of spectrum. With two lines at wavelengths 589.0 nm and 589.6nm, sodium vapour lamp is usually used to determine *N*. With mercury vapour lamp, we determine the angle θ for the green light which has a standard wavelength 546.1 nm, and thus we can determine *N*. In your laboratory if both sodium light and mercury light are available, you can choose any one source to determine *N*.

It is interesting to note that determination of *N* and the determination of wavelength involves the same formula. For the determination of *N*, We assume wavelength while in the determination of wavelength we assume *N*, which was already determined. In either case, we measure the angle of diffraction θ from the experiment.

Fig. 10.3 shows how light of one colour is diffracted at each of the slits. Some light from ecede slit reaches each order.
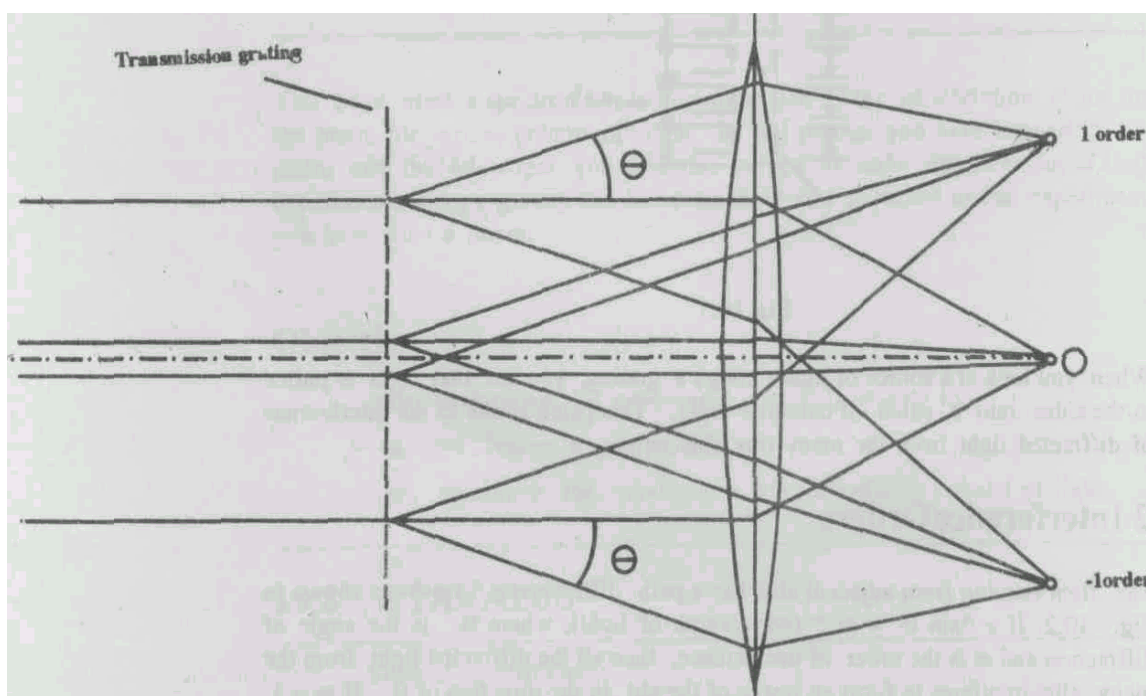
Fig.10.3

10.4 PRECAUTIONS
Spectral Analysis lining a Grating Spectrometer
(1)   Fix the grating on the central round table called the "prism table", in a vertical position in between the clips.

(2)   Perform all adjustments as in the prism experiment before taking readings.

(3)   Fix the telescope firmly while taking readings.

(4)   Carefully note the readings on vernier 1 and vernier II in their respective places in tabular column.

10.5 THE EXPERIMENT
10.5.1 Normal Incidence
TO SET THE PLANE TRANSMISSION GRATING FOR NORMAL INCIDENCE OF LIGHT
The light incident on the grating from the collimator is a plane wave and there is no phase difference between waves from adjacent slits. If you have not already performed the Experiment 8 "Spectral Analysis using a Prism Spectrometer", read it now. Then carry out the spectrometer adjustments described. After having done all the adjustments of the spectrometer, keep the telescope so as to receive the light from collimator directly. Note the readings on the verniers.

The telescope is then released and turned exactly through 90° and held fixed. Thus the axis of the telescope and the collimator axis are perpendicular to each other.

Now rotate the prism-table such that the reflected image of the slit from the plane surface of toe grating is received at the cross wire of the fixed telescope. You **move only the prism table** for achieving this coincidence and **not the telescope**. The situation is described in Fig.10.4 below:
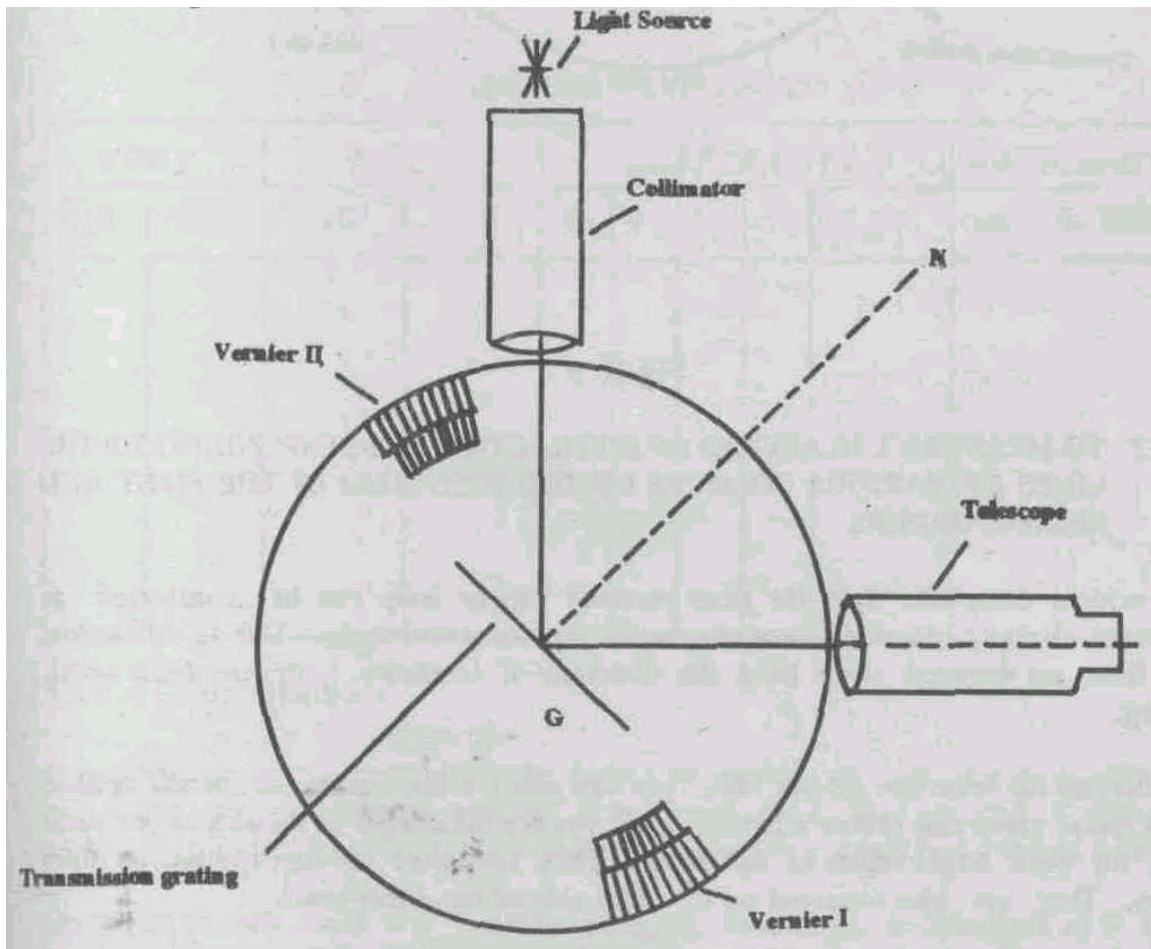
Fig.10.4

The angle between the collimator and normal GN to the grating is 45o. If the grating is turned exactly through 45° towards the collimator, then the parallel light from the collimator will be incident normally on the grating surface. How to rotate the grating exactly through 45°? Since the mere rotation of the prism table cannot determine the angle of rotation precisely, the prism-table

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has to be rotated along with the vernier scale through 45°. Thus the grating is set at normal incidence, as shown in Fig. 10.5.
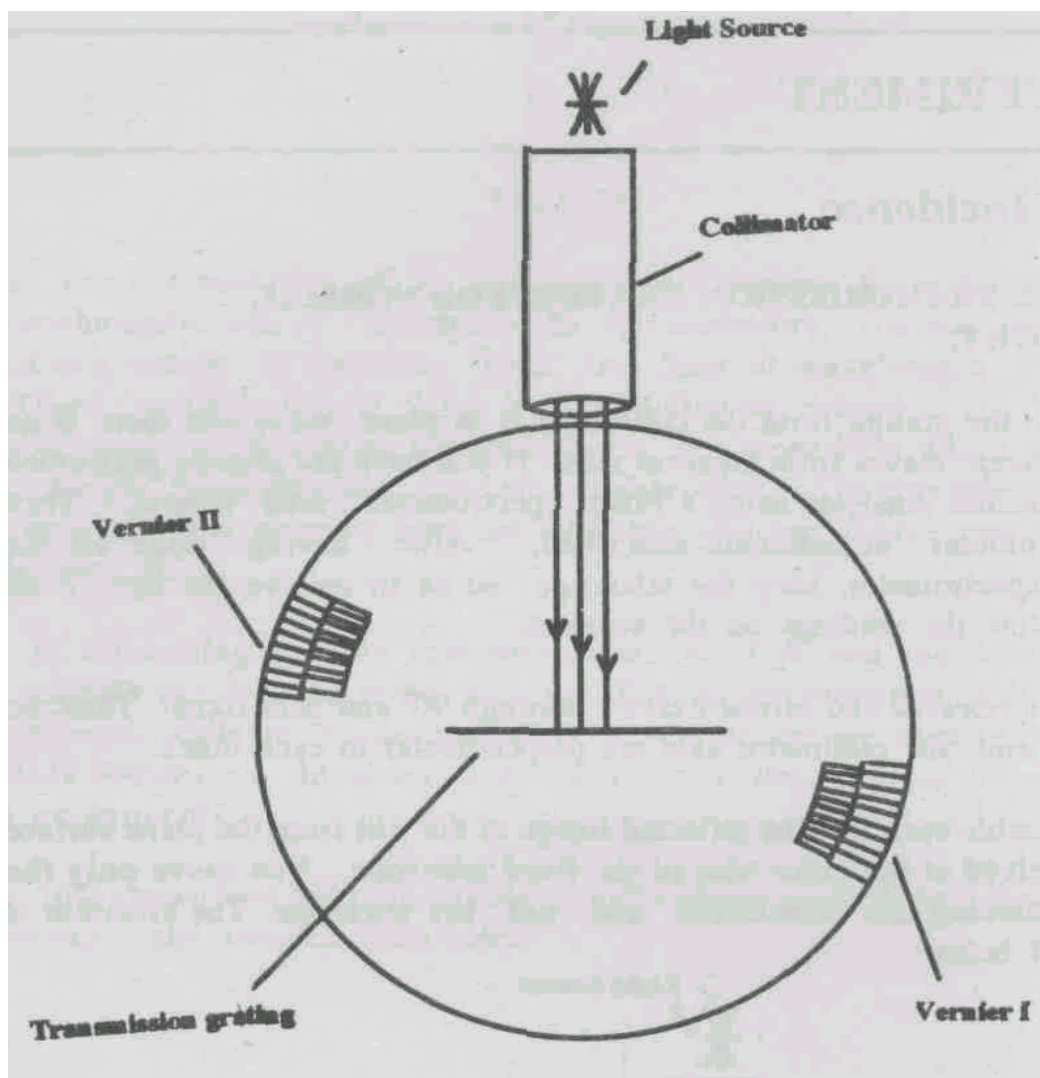
Fig.10.5

10.5.2 TO MEASURE THE ANGLES OF DIFFRACTION CORRESPONDING TO THE LINES OF VARIOUS COLOURS OF THE SPECTRUM IN THE FIRST AND SECOND ORDERS

The incident composite light the from mercury vapour lamp can be considered as composed of many discrete monochromatic lines or wavelengths. Due to diffraction, these lines are deviated away from the direction of incidence, after incidence on the grating.

By rotating the telescope on one side, you can observe the images of the slit in blue, bluish green, green and yellow regions. Again you see the images of the slits in the same series for even larger angles of diffraction. They are called the first and second order spectra. They are also observed on the other side of the direct beam.

The direct beam suffers no diffraction. All the wavelengths present in the source of light reinforce together and so the direct light has the same resultant colour as the source itself.

The cross wire of the telescope is made to coincidence with of the image of the slit and the readings of vernier I and vernier II are noted. In the same way, the readings for, all the prominent lines in the blue, bluish green, green and yellow are noted. Enter your readings in the table.

After all the readings are taken on one side, the readings of the direct ray is noted down. You have already noted the direct ray reading before you turned the telescope to 90°. Then why is it necessary to take this readings for a second time? Yes, you have turned the prism table along with the vernier through 45° and this has changed the direct ray reading. So you have to once again determine the direct ray reading. The difference between the direct ray and the various deviated rays gives the angles of diffraction.

TABLE FOR STANDARDISATION

SIDE1		SIDE 2		ANGLE OF DIFFR.					WAVELENGTH (*nm*) Dir. Beam
VNI	VNII	VNI	VNII	θ_1	θ_2	θ_3	θ_4	θ_{mean}	

NUMBER OF LINES PER METER = _____

TABLE FOR WAVELENGTH

SIDE1		SIDE 2		ANGLE OF DIFFR.					WAVELENGTH (*nm*) Dir. Beam
VNI	VNII	VNI	VNII	θ_1	θ_2	θ_3	θ_4	θ_{mean}	

10.5.3 Calculations
In general the grating produces many orders of visible spectrum. Usually there are two orders of spectrum corresponding to $m = 1$ and $m = 2$. They are seen on either side of the direct image. The angles of diffraction for $m = 2$ can should be taken and tabulated.

Using the formula $\sin\theta = N \times m \times$ (wavelength), wavelength is calculated as θ and N are known. Put $m = 1$ for first order and $m = 2$ for second order. The results are tabulated, and compared with "standard" values.

Answer the following questions

1. In the grating experiments you are using a standard grating with 7000 lines /cm. Supposing I have only a grating with 700 lines /cm, how would the spectrum appear.

    _____

    _____

    _____

2. If I break the grating by mistake & only one cm width of the piece of it available
    (a)   Can one still see the diffraction pattern?
    (b)   If so how does it differ from that of a grating of larger size?

    _____

    _____

    _____

3. Draw the diagram of a spectrometer and identify its parts.

    _____

    _____

    _____

4. Using a spectrometer, one observes coloured lines both by using a prism and a grating. You have observed the angles of deviation for each coloured line with respect to the direct light. What are the differences between these two spectra observed? List as many differences as you can.

    _____

    _____

    _____

5. While you are doing an experiment with the grating, a mischievous student slightly pushes the grating in its plane. Will this affect your reading? Explain.

    _____

    _____

    _____

10.6 CONCLUSIONS

You have determined the wavelengths of various colours of light using a transmission grating and a spectrometer. You have observed the first and the second order spectra on either side of the direct light, and compared your results with standard values.

(For Counsellor's use only)

Grade.............................   Name ....………………..

Evaluated by………………………….   Enrolment Number ………………

EXPERIMENT 11
PRODUCTION, DETECTION AND REFLECTION OF POLARISED LIGHT
Structure

11.1   Introduction
         Objective
11.2   Apparatus
11.3   Study Material
         A Model of Perpendicular or Transverse waves
         A special case
         How to produce polarised light
         How to observe polarised light
         How to find the Polaroid transmitting plane
         Polariser and analyser
         Another way to make polarised light
         Yet another way to make polarised light
         Dielectric reflection in detail
11.4   Precautions
11.5   The Experiments Polaroid
         Polarisation by reflection
         Polarisation by scattering
         The rule of reflection polarisation
         Calculations
         Another Experiment, using a calcite crystal
11.6   Conclusions

11.1 INTRODUCTION

Experience in optics, especially in interference experiments, reveals that light is a wave phenomenon.

Question: Have you done any experiments in your school which are explained by interference of light? Write down what you remember.

       _____

       _____

       _____

Question: Do you remember any natural observations which are explained by interference of light? Write down what you remember. (Hint: Oil films on a wet pavement?)

       _____

       _____

       _____

The theory of electromagnetic waves requires that the quantity which changes in an electromagnetic wave must be only in the plane of the wave front and hence must have a vector character. This means it must be transverse, or perpendicular to the direction of propagation of the wave. Light, of course, is one example of an electromagnetic wave!

It is this transverse character of light which gives rise to experimental effects called **polarisation.** This experiment will help you to find out yourself if this is the case. You will find out if experiments come to the same conclusion as the theory about how light behaves - as a polarised wave or otherwise. Some of the experiments will be done in the lab, and some of those will measure quantities numerically. In addition to those "quantitative" experiments, you can do quite a few non-measuring experiments just in the world around you. In fact there are many polarisation effects in nature which can be seen without apparatus or with really simple apparatus. You can look at the sky or at light reflected from various surfaces to find these effects.

How many can you think of now?

Probably not a lot, but ask yourself this question again after the experiment is over!

OBJECTIVES
After performing this experiment you should be able to:
- Verify by knowing some examples, that the electromagnetic wave theory predicts polarisation effects correctly.
- Produce, by several methods, both linearly polarised and partially polarised light.
- Demonstrate the methods of detecting the polarisations mentioned in the previous sentence.
- Find the rules by which polarised light is reflected from glass, as a function of the angle of incidence.
- Correlate this experimental rule with the predictions of electromagnetic theory.

11.2 APPARATUS
2 - polariser/analyser eyepieces with angle scales. 1 - student spectrometer.
1 - prism for the spectrometer.
2 -calcite plates.
1 - 60-watt filament frosted bulb and holder.
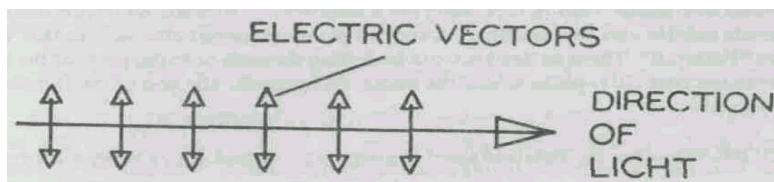1 - coloured filter.

11.3 STUDY MATERIAL
113.1 A model of perpendicular, or transverse waves
Let us think of a light wave as going in a particular direction in a straight line, say left-to-right.

The oscillating quantities are perpendicular to this direction, so we can think of them as lying on this page, as shown by the short arrows shown in Fig. 11.1.

Fig. 11.1

But we can as easily think of the arrows as being also perpendicular to the page, in which case the heads of the arrows would just be visible as dots, as shown in Fig. 11.2.
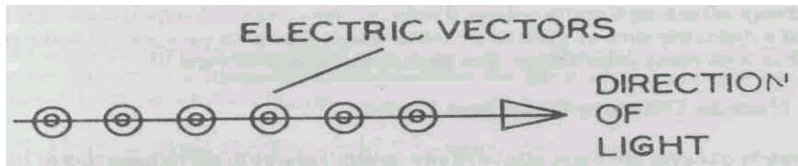

Fig. 11.2

Or we could also think of them as being a combination of oscillations **both** lying in the page, perpendicular to the page, or in fact in any direction at all. But remember that the arrows are perpendicular to the direction of the light! The Figure 11.3 shows these possibilities, looking from the direction in which the light is going, that is, as though the light is approaching your eye.
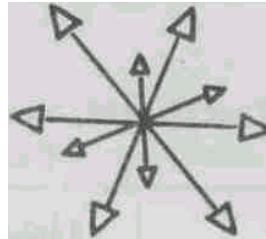
Fig. 11.3

Further, these arrows need not be in phase. This means that at a time when one direction is at a maximum, the other need not be also at a maximum. What a lot of possibilities there are!

11.3.2   A SPECIAL CASE
In this experiment we will think only of light in which the oscillating quantities lie in one plane only. This is a plane which also contains the direction of the wave. You could think of this as the example in Figure 11.1 above, or the example in Figure 11.2 above. Such a light wave is called a "**LINEARLY POLARISED WAVE**". (Some books may refer to this as plane-polarized wave). In electromagnetic wave theory you learn that the quantities which oscillate are the electric and the magnetic field vectors. Light which does not have this special property, but in which the oscillating quantities lie in randomly-placed planes containing the direction of the wave, is called "**UNPOLARISED LIGHT**".

11.3.3   Some Ways to Produce Linearly Polarised Light
The simplest way is to have a special material that simply filters out all of the light except the part for which the electric vectors lie in one plane (the "PLANE OF POLARISATION"). This might sound like magic - but in fact there are a number of materials which do that! Some are the minerals **calcite and tourmaline.** A special plastic material also acts in this way and is known as "Polaroid". These materials work by letting through only the parts of the oscillation which lie in the particular plane which the materials transmit. The rest of the light is absorbed in the material.

Question: Why does the Polaroid sheet in your eyepiece look grey? Write your answer here.

_____

_____

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A second way of making linearly polarised light involves reflecting unpolarised light from the surface of a dielectric such as glass or polished wood. This is an easy way to make polarised light, but as with many other things, you have to know how to view it!

11.3.4 How to Observe Polarised Light

Unfortunately our eyes are not sensitive in any significant way to the polarisation of light. That means that we need some help to overcome the problem of detecting polarisation. The answer to this problem is really simple. You observe polarised light by the same means you produced it! The easiest way is to view light through a Polaroid sheet.

Question: What is the polarising property of such a sheet?

_____

_____

If indeed the sheet lets through light of one plane of oscillation, then the following table could be true.

Light incident the Polaroid	Light coming through on the Polaroid
Oscillation of electric field is parallel to the direction which the Polaroid transmits	All of the light comes through.
Same, but the oscillation is perpendicular to the Polaroid direction.	None of the light comes through.

Question: Make a suitable sketch illustrating the above conditions.

_____

_____

_____

Question: What happens for in-between cases? Write your present idea, if you have one.

_____

_____

_____

We can guess that the **component** of linearly polarised light parallel to the transmitting direction will be transmitted, while the component perpendicular will be not transmitted. Remember "components"? You used them in mechanical problems to "resolve" velocities in various directions. In just the same way you resolved velocity vectors, you can resolve the electric vectors of a light wave. The usual resolution is along the Polaroid transmitting direction, and the perpendicular direction. And the **same rule** is used: the component of a linearly-polarised wave transmitted through a Polaroid is proportional to the COSINE of the angle θ between the oscillation plane and the Polaroid transmitting plane!

Amplitude transmitted = Incident Amplitude $\times \cos \theta$

So - that's how you find the plane of oscillation of a linearly polarised wave. You turn a Polaroid until none of the wave is transmitted. Then the wave has an oscillation plane just perpendicular (90°) to the Polaroid transmitting plane.

11.3.5 How to Find the Polaroid Transmitting Plane
You may have noticed a problem in the previous section. How are you to find out the transmitting direction of the Polaroid?

The answer to this is to observe a wave whose polarisation you know from some fundamental physics reasoning. We usually use light reflected from a dielectric surface at a fairly glancing angle, say about 60 degrees. The rule which theory gives us is that at such an angle, most if not all of the light is polarised with the oscillations parallel to the dielectric surface.

You will try this out in the experiment. It is a lot easier to do than it is to explain!

11.3.6 Polariser and Analyser
From the above, you will understand that sometimes a Polaroid acts to produce polarised light. Then we call it a "polariser".

Sometimes the same Polaroid acts to find out the presence of polarised light. Then we call it an "analyser".

We can say the following, in terms of these two new words.

When a polariser and analyser are **parallel,** then maximum light is transmitted through the pair.

When a polariser and analyser are crossed (perpendicular) then no light is transmitted.

When the angle between the polariser direction and the analyser direction is theta, the transmitted light has an amplitude proportional to $\cos\theta$. This is known as "the law of Malus".

Question: To transmit half the light amplitude incident, what angle should there be between polariser and analyser?

CALCULATION:

ANSWER: _____

Please note that our eye (and almost every other detector of light) responds not to the amplitude of the light, but to the light, which is the amplitude.

Thus the law of Malus is:

Transmitted intensity = (incident intensity) $\times \cos^2\theta$

Question: To transmit half the light intensity incident, what angle should there be between polariser and analyser?

CALCULATION:

ANSWER: _____

11.3.7 Another way to Make Polarised Light

Some crystals and other materials have a property known as **optical activity.** They don't treat light of two perpendicular polarisations in different ways. Calcite (calcium carbonate) is one of those materials. (It is found very commonly in many countries, including India.) Calcite is often found in crystalline form, when it is clear and colourless. Such crystals often have flat and clear developed crystal faces or plane surfaces.

If you place such a crystal on a paper you will find that two images of the writing on the paper will appear. You'll do this in the experiment. What distinguishes the two images? Try it later and see, but we can reveal now that the difference has to do with polarisation!

11.3.8 Yet Another Example of Polarised Light

Polarised light this way, but you can of light which is scattered from molecules. Try looking at the blue sky through a Polaroid analyser. (We'll try this later in the experiment, or you can take your analyser and have an advance look!).

You'll see several interesting and important effects which are due to polarisation of the blue-sky light. Be patient, and we'll see these later.

Hint: The effects are most prominent if you look at right angles to the direction of the direct sunlight, in early morning or late afternoon.

11.3.9 Dielectric Reflection in Detail

You have read several times above about the polarising effect of reflection from a dielectric surface.

Question: How do you characterise a "dielectric"? Remember your electricity studies to answer this question!

_____

_____

_____

Now we will look at the quantitative rules that govern this kind of reflection. We won't deal with derivations, but we can use the electromagnetic theory. In the experiment you will try to find bow closely nature agrees with the theory!

First a little setting-up of the scene.

A wave-front incident on a plane surface defines. This is determined by the incident ray (direction-vector of the wave-front) and the component of this vector onto the surface. We'll take the special case where the wavefront is linearly polarised.

This polarisation has two components (there is that concept again - and not for the last time!). One is perpendicular to the plane of incidence ("senkrecht" in German) and quantities relating to this component get the subscript s . The other component is parallel to the plane, and quantities relating to this get the subscript p.

Traditionally, quantities relating to the incident, reflected and refracted wavefront are denoted as follows:

E: Refers to incident quantities.

R: Refers to reflected quantities.

E': Refers to refracted quantities.

The rules for reflection from dielectrics provide us a way to calculate the *R* and *E'* values for an E-wave incident under quite a complete range of conditions. The reflection rules are as follows.

$$R_s / E_s = (-)\sin(i - r)/\sin(i + r)$$

$$R_p / E_p = \tan(i - r)/\tan(i + r)$$

$$E_s' / E_s = 2\sin(r)\cos(i)/\sin(i + r)$$

$$E_p' / E_p = 2\sin i \cos i / \sin(i + r)\cos(i - r)$$

where *i* = angle of incidence *r* = angle of refraction.

Question: If you know the angle of incidence how will you will find the angle of refraction?

_____

_____

A special case is one in which the plane of incident polarisation is at 45 degrees to the plane of incidence. This means the E_s component is the same as the E_p component.

Then

$$(R_p / E_p)/(R_s / E_s) = R_p / R_s = \tan\theta$$

So,

$$R_p / R_s = \tan\theta = \cos(i + r)/\cos(i - r),$$

(where modulus values are taken)

where θ is the angle of the plane of the reflected polarisation compared to the plane of the P-polarisation. In the experiment you will try to create this special situation. You will see how the result compares with the relation above. Thus you will see that the polarisation rules are really followed in practice.

REFERENCES:

Jenkins & White **Fundamentals of Optics** McGraw-Hill (any edition)

Longhurst, R. S. **Geometrical and Physical Optics** Longmans (any edition)

Ghatak, A. J. **An Introduction to Modern Optics** Tata Mc-Graw Hill (1971) Chapter 3.

11.4   PRECAUTIONS

A.   Generally, with any optics experiment, you must keep all the surfaces clean! You can use a clean soft cloth, and plain water.

Before you start the experiment, look at each surface:

>   Polaroid analyser/polarisers
>   Prisms
>   Telescope lens
>   Collimator lens

Often you will see finger marks made by earlier users.

Make the clean cloth damp, and gently rub each surface until the marks are less. Just the way you clean eye-glasses.

Keep the surfaces clean!

B.   Please follow the adjustment steps for section 11.5.4. very carefully. If results seem unexpected, go back to the Step 1, and repeat the whole series.

C.   Optics experiments can be a lot of fun, but see, not always for what "the book" says you should see!

You will learn a lot.

11.5 THE EXPERIMENTS
11.5.1 Polaroid

Take one tube with a Polaroid mounted on it and just look through it at a light (say a tube light). Note the brightness with & without the Polaroid. Rotate the Polaroid and note variations of the light seen through the Polaroid.

Source: Tube Light

With Polaroid   -   _____

Without Polaroid   -   _____

Rotating Polaroid   -   _____

Fill in the table with your observations **most bright, less bright, more bright, changing brightness,** etc.

Put the two Polaroids in **series** (one after another) and again look at the tube light. Rotate the second Polaroid (the analyser). Record your observations.

Source: Tube Light   _____

Second Polaroid rotated :   _____

Try to notice any special directions **(most bright, least bright)**.

Set the analyser for most brightness. Remove the analyser (look just through the polariser). Describe the relative brightness.

_____

_____

Write your explanation of this.

_____

_____

Set the analyser for least brightness. Remove the analyser. Describe the relative brightness.

_____

_____

Write your explanation of this.

_____

_____

11.5.2 Polarisation by Reflection
Look at the tube-light, or any other light reflected on a desk-top or from a glass window. See the actual light, in the reflecting surface.

Look now at this reflected light through an analyser (Polaroid) and describe the brightness as you rotate the analyser.

ROTARY POSITION OF ANALYSER POLAROID	BRIGHTNESS
Perpendicular to surface	_____
Parallel to surface	_____
Intermediate Position	_____

11.5.3 Polarisation by Scattering
Look it the blue sky through a Polaroid. Do this in the morning or evening. Keep the sun on your right side or left side, observe the sky in front of you and above you. Rotate the analyser and describe your observations of brightness, for several positions of the Polaroid rotation.

11.5.4 The Rule of Reflection Polarisation
You will find the rule by which polarised light is reflected from a dielectric surface, at least for the special case of 11.3.9.

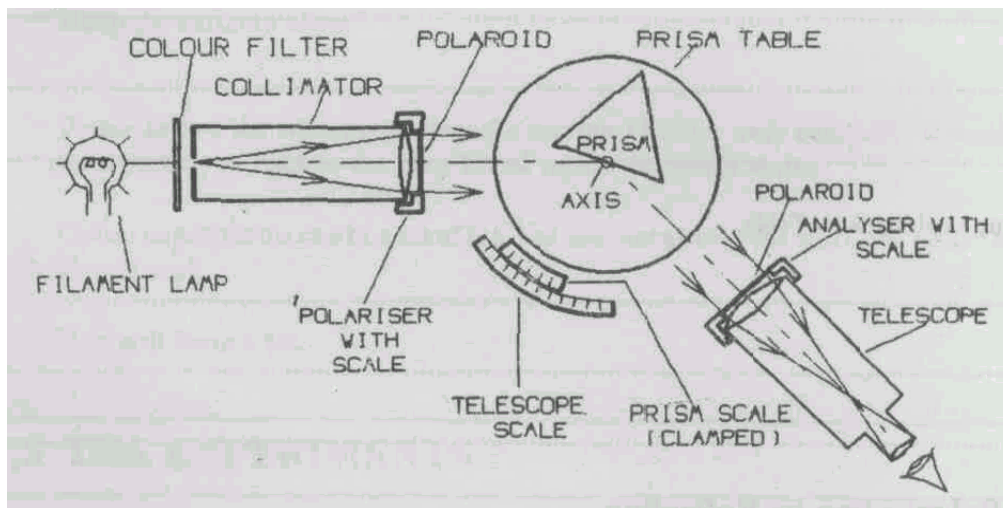Set up a prism on a spectrograph. As shown, in Figure 11.4

Fig. 11.4

The following adjustments must be made:
1.   Make sure the eyepiece is focussed clearly on the cross-wire. Push or pull the eyepiece to adjust this. Focus the telescope at a very distant object. (Do not change these adjustments, ever!)

2.   Look through the telescope at the collimator and adjust the collimator (slit-width and then collimator focus) until you see a slit image which is somewhat wide, with edges in sharp focus. Then don't change this adjustment.

3.   Adjust the prism table until one polished prism face is perpendicular to the telescope. (This means using the levelling screws, while looking at the slit reflected in the face of the prism).

4.   Remove prism, look through telescope at the slit, line up the vertical cross-wire with the edge of the slit, then fix the prism-table with table scale to read 180 degrees and clamp it Don't unclamp later on!

5.   Put the Polaroid analyser on the telescope lens, put the prism on the table with table axis in the prism face, set the telescope at about 115 degrees.

6.   Rotate the prism table (But not its scale. Loosen the little screw on the table rod to do this) until you see the slit reflected in the prism. (This is near the angle of most polarisation.)

7.   Rotate the analyser Polaroid until brightness is minimum. Hold the Polaroid and set it scale to "zero", or note the reading. Enter in the Table as "Zero Analyser Reading". This is the "perpendicular" polarisation direction.

8.   Take off the prism. Look straight at the slit again. (180 degrees scale). Rotate analyser to 45 degrees. Put polariser on the collimator lens. Rotate polariser to minimum brightness. Now incident light must be at 45° degrees, which is the required case!

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9.   Replace prism. Set telescope to about 50 degrees (angle of incidence-abut 25 degrees). Rotate the prism table (as in 6. above) to reflect the slit into the telescope.

10.   Rotate the analyser for minimum brightness. Note the analyser scale reading in the next Table. Repeat the adjustment for minimum brightness two more times, and enter the readings.

11.   Repeat from Step 9, for angles of incidence between 25 degrees and 80 degrees in steps of 5 degrees, noting the analyser angle each time.

Table 1

Zero analyser reading: ....

ANGLE OF INCIDENCE	ANALYSER READING			OF 1,2,3	AVG. ANALYSER ANGLE"	AVG R_p / R_s	$\tan\theta$
	TRIAL 1	TRIAL 2	TRIAL 3				
25							
30							
35							
40							
45							
50							
55							
60							
65							
70							
75							
80							

** AVERAGE ANALYSER ANGLE = AVERAGE ANALYSER READING ZERO READING (STEP 7.)

Estimate the percent error of the average.

11.5.5 CALCULATIONS

For each of the angles of incidences above, calculate R_p / R_s. Add one column to the Table above, for this.

Now calculate the TAN (average analyser angle) and add a column to the table also. Compare these last two columns. You can make graphs of each vs incident angle, or from the ratio of the two columns, or other means of comparison. Use the graph area below, if want. Use another graph sheet and attach it, if you need more space.
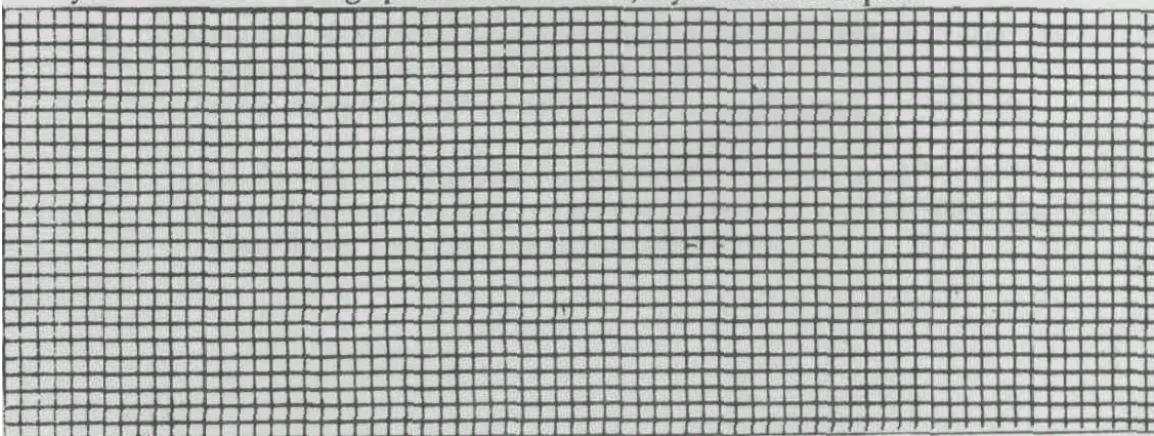
Comment on your comparisons. Comment on whether you feel your theoretical calculations agreed with the experiment.

_____

_____

_____

11.5.6 ANOTHER EXPERIMENT USING A CALCITE CRYSTAL
Take the crystal, lay it on your paper and trace the edges. By extending these edge lines, measure the two angles which characterise the crystal shape.

Obtuse angle = _____

Acute angle =   _____

Place the crystal over a very black dot, on a white paper. Mark the dots you see, on the sketch below.
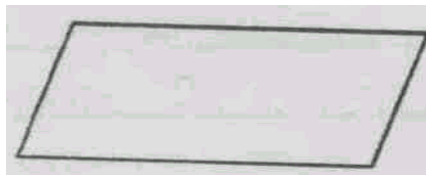
Using a Polaroid analyser, mark on the diagram below the direction of polarisation of each dot.
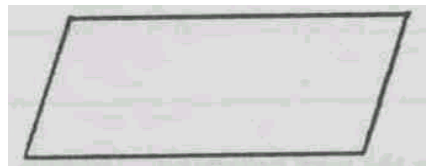
Rotate the crystal about an axis perpendicular to the table. Mark on the diagram here how the dots move, as the crystal has rotated.

Place another crystal just over the first, in the same orientation. What happens to the dots as the pair of crystals are rotated together? Mark their apparent motion on the diagrams below. Rotate the second one by 180 degrees so the crystals are in opposite orientation with each other. What do you see?

Test and record the polarisation in all cases, using your Polaroid as analyser. Write your explanation of these observations.

_____

_____

_____

11.6   CONCLUSIONS
Here you can find out if you have met the Objectives listed in Section 11.1. Answer the questions below in a brief manner

a.   Do any of the experiments reveal an agreement with the results of the theory of polarised light? Which experiments?

_____

_____

_____

b.   Write down one method at least for producing linearly   polarised light, and one for partially polarised light.

_____

_____

_____

c.   Describe one rule you have found for the way polarised light is reflected from glass, at various angles. Refer to   any useful results above in section 1 1.5.

d.   In your opinion, how well does this rule agree with the stated results of electromagnetic theory?

EXPERIMENT 12
STUDY OF INTERFERENCE OF POLARISED LIGHT
Structure

12.1 INTRODUCTION
When you studied polarised light you first made many interesting observations using **linearly polarised light** only. You found such light could be represented as a time- varying vector. This vector pointed in the direction of polarisation, and was perpendicular to the direction in which the light travelled.

Now we ask the question, "How can two such beams be combined?" What are the rules? What are the limitations? The answers come from the subject of **interference** of polarised light.

One limitation is very plain - the two beams must be synchronised in **time.** In optics this is called time - coherence. If the beams are coherent then there is no changing of phases between the two vibrations - except the changes **we** introduce.

One common way to introduce such shifts is with a "doubly - refracting" material. So your experiment will use such materials.

OBJECTIVES
After performing this experiment, you will be able to:
- Demonstrate at least one way in which monochromatic polarised light interferes.
- Demonstrate the properties of doubly - refracting plates, in regard to polarised light velocities.

- Demonstrate some white - light effects of interference of polarised light, and correctly explain them according to interference principles.
- Demonstrate quarter-wave-plate and ha If-wave-plate interference, using birefringent plates, polarisers and a spectrograph.

12.2   APPARATUS

2 nos.- Polaroid eye-pieces
2 nos - holder, with graduated angle scale.
1 nos - slotted connector tube
4 nos - sample holders, to fit into connector tube
1 no - student spectrograph with prism.
1 no - red-plastic filter.
1 roll- 'CELLOTAPE'
1 no - white-light source, tube light or 60 w bulb.
1 no - +10 cm focal-length lens, and lens-holder

12.3   STUDY MATERIAL
GENERAL FEATURES OF DOUBLE REFRACTION

The optical effects known as "interference of polarised light" are the result of a special property of some materials. This property is called "birefringence" or "double refraction". This is just a technical word which means that light in such materials travels at different velocities, depending on the following.

1.   The direction of travel and
2.   The direction of polarisation of the light.

What is the relation between the velocity of light and the index of refraction? The actual velocity v is given by c/n, where c = velocity in free space, n is index of refraction.

Since there are two directions of polarisation, and each has a separate velocity (or refractive index), the property is called birefringence, and **depends on the direction of travel**.

Lots of materials have this property. Some are crystals. Calcite and tourmaline are two examples. But several transparent plastics have the property also, specially when they are stretched or squeezed. Plastics are easy to get, so we will use them in the experiments to be done later.

There are a lot of complicated observations possible with these effects, and their explanation is often confusing. We will use one particularly simple situation. It will be very direct to analyse and explain. It also has some very important technical applications.

A fact about birefringence.

In almost all doubly-refracting materials there is just one direction along which light waves having either direction of polarisation travel at the same velocity (have the same index of refraction).
This **direction** is called the **optic axis**. Please note this "axis" is not a single line, but a direction in the material. A linearly polarised beam of light travelling in the material can be considered as two beams, in phase.

We are going to make an important simplifying assumption, which will agree with the conditions we will encounter in the experiment.

Assume that the optic axis of the doubly-refracting material lies in the plane of the surface of the material.

Then the two beams consist of one whose direction of polarisation is **perpendicular to the optic axis**, and called the **O-ray,** and another whose plane of polarisation is **parallel to the optic axis,** and called the **E-ray,** These two letters come from the words "Ordinary" and "Extraordinary," which are the traditional names of the two beams or rays.

Together they combine to form the original beam.

Sometimes this idea is described by saying the following, for the special case assumed.

A beam of linearly polarised light is **resolved** into two components, one polarised parallel to the optic axis (E-component), and one polarised perpendicular to the optic axis (O-component).

The two ways of looking at this idea give the same result. How do the two waves travel in a doubly-refracting material?

Well, one component, with a plane of polarisation perpendicular to the optics axis, is found to travel at the same speed in all directions (O-component). This is shown in the Fig. 12.1 by "Huygens construction".
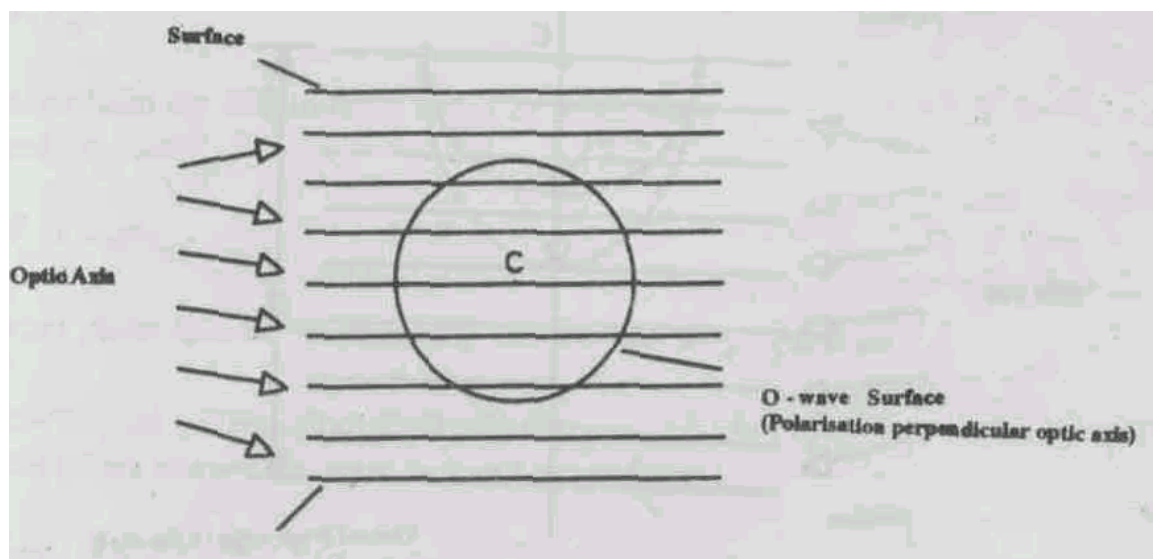
Fig. 12.1

The other component, with a plane of polarisation different from the O-component travels in different velocities, in different directions. The same, along the optic axis, and **greater** for other directions (this is called 'negative birefringence', because the E-component index of retraction is **less** than the O-component). The Huygens construction is shown in the Fig.12.2.
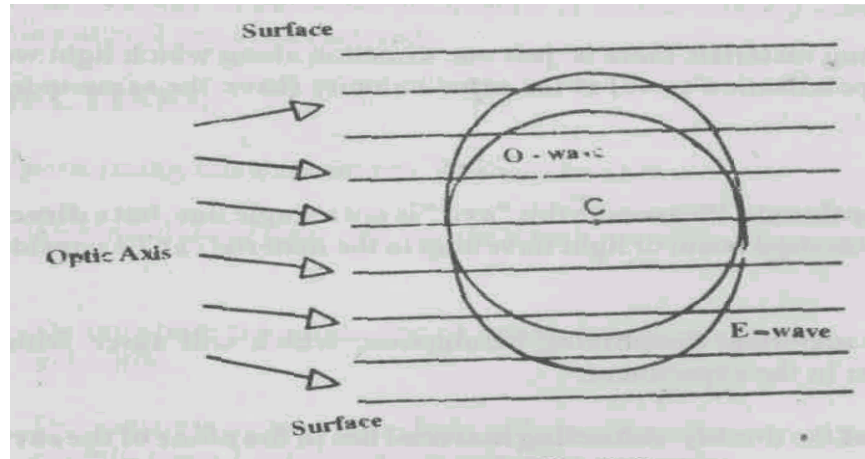
Fig. 12.2

The construction gives a Fig. 12.2 as shown, and the new wave is called the extraordinary wave, or **E-wave**.

OUR SPECIAL CASE
There are lots of geometric situations possible, some of which lead to very complex ideas. Luckily there is one very simple setup which explains a lot. It is also very important practically. We will stick almost entirely to this situation. Here it is.

The doubly-refracting material is a sheet (layer) of thickness d.

The optic axis is parallel to the layer surface.

The beam of linearly polarised light is incident perpendicular to the surface.

With these restrictions in mind we can draw a Fig. 12.3 showing rays of light inside a negative birefringent material.
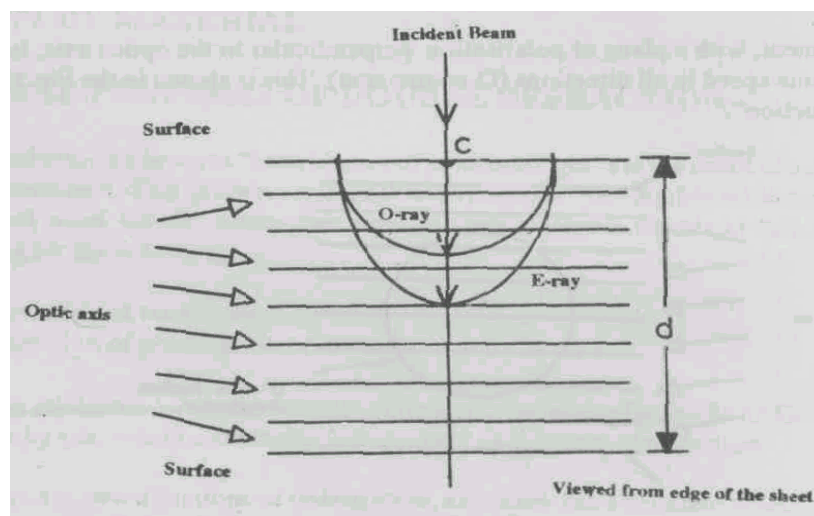
Fig.12.3

Notice a few simple aspects of the Figure 12.3.

1.   The incident beam is not deflected by refraction. That means all the light goes straight through the sheet.

2.   Some of the light (O-ray) travels at a relatively slow velocity $V_o = c/n_o$, where n_o is called the **ordinary index of refraction.** This ray goes straight through the crystal, and is called the **slow ray, or O - ray**.

3.   Some of the light (E-ray) travels at a relatively fast velocity $V_E = c/n_E$. Where n_E is called the extraordinary **index of refraction.** This ray goes straight through the crystal also, and is called the E - ray, or fast ray.

The O - ray and E - ray were in phase when they were incident, hut one **emerges** before the other in time. Hence a phase difference has been created.

QUANTITATIVE PHASE SHIFTS
How much? Here is one way to calculate. Please follow the argument, as well as the algebra!
1.   How much time corresponds to one full oscillation of the light?
Well, $\lambda v = V$, where λ = wavelength of the light
v - frequency of the light vibration.
V = velocity of the light. This has the special symbol c for light travelling in free space.

So, time for one oscillation is inverse of the frequency, hence:
P = time for one oscillation = $1/v = \lambda/V$

2.   How much phase is this? (Remember your wave-studies)
Ans: The phase for 1 oscillation is 2π radians.
3.   What is the time difference between O and E rays?
dT = time-difference = (time for O-ray to go through the layer of thickness d)
MINUS
(time for the E-ray to go the same distance).
= d/(O-velocity) -d/(E-velocity)
So the result is that the time-difference is:

$$T = d/V_O - d/V_E$$

Now remember from the definition of index of refraction:
$n_O = c/v_O$ and $n_E = c/v_E$

Hence: $T = d(n_O - n_E)/c$

4.   To find what phase this corresponds to, use the rule of proportions.

Time for 1 oscillation / Time between O and E rays = $2\dfrac{\pi}{\gamma}$, where γ is the phase change

we want to know, in radians.

So, by algebra: $\gamma = 2\pi d(n_O - n_E)/\lambda$

What is the meaning of the equation just derived?

The O and E rays travel through a birefringent material perpendicular to **the optic** axis for a distance d and get a phase difference of $2\pi d(n_O - n_E)/\lambda$.

INTERFERENCE

But this is by no means the end of the possibilities, when linearly-polarised light is incident on the material as above, one part acts as an O-ray and one part acts as an E-ray. The Fig.12.4 shows the situation.
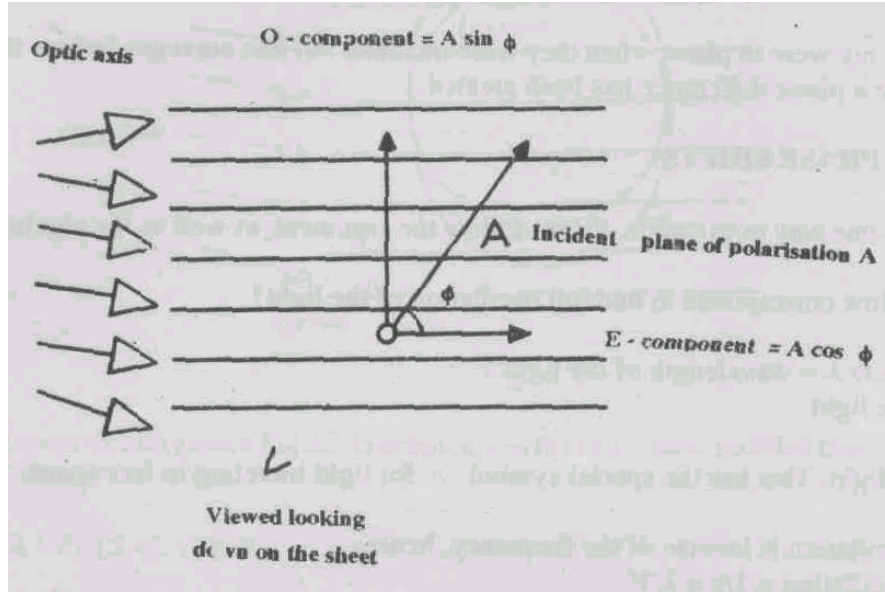
Fig.12.4

A linearly-polarised wave of amplitude A is incident perpendicularly to a material with optic axis in the plane of the surface, and with the plane of the polarisation at the angle ϕ to the optic axis. This divides into two parts as follows.

1. A component $E = A\cos\phi$ with plane of polarisation parallel to optic axis and moving with velocity V_E.

2. A component $O = A\sin\phi$ with plane of polarisation perpendicular to the optic axis and moving with velocity V_O.

These two components move through the material and can be observed as they leave the crystal. When the two components leave, they recombine. This is interference! If the phase-difference is 2π or 4π, etc., then the emerging wave is unchanged. Or, if it is π or 3π, then the emerging wave is plane-polarised also, but in another direction!

As an example, suppose the original plane of polarisation is at angle 0 to the optic axis, and the phase-difference y is π or 3π, etc., what is the angle of the emerging plane?

The diagrams below show both the incident and the emerging situation.

119
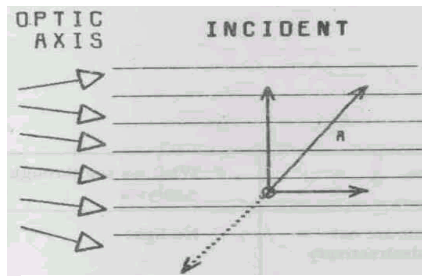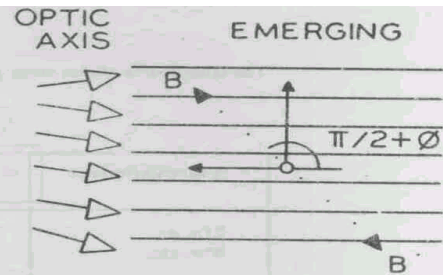
Fig. 12.5   **Fig. 12.6**

Here the vector describing the emergent light has a head which moves on a line B-B'.

Well, as an aside, how does the head of the vector move if the phase-change is **not** one of the special cases above?

The answer is: the head moves on an **elliptical path**, and the light is called "**elliptically polarised**".

Of course you know that a special case of an ellipse is a circle. If two conditions are satisfied:

$$\phi = \pi / 4 \text{, so that } \sin \phi = \cos \phi$$

and

phase-difference $= \gamma = \pi / 2$ or $3\pi / 2$, etc.

then the ellipse will be a circle, and the light emerging will be "**circularly polarised**".

Your experiment is going to investigate the effects above, by putting a birefringent plate between an analyser, crossed with a polariser. So let us find out what we can expect to see. The are many possible predictions, depending on circumstances!

Case 1: Monochromatic light
         Polaroids crossed
         Birefringent sheet of thickness d
         Indexes of refraction n_O and n_E
         Optic axis at an angle ϕ to polariser axis

Fig. 12.7

120
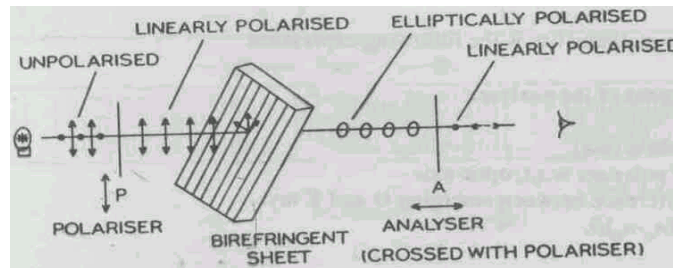
Question: What are the Amplitudes of the two components in the analyser direction? (refer to the previous Figure 12.6)

Ans: Each has the valued $A \sin \phi \cos \phi$.

You will see the two components have the same amplitude. These are the components that will come out of the analyser, but they will have a phase difference which determines what we see through the analyser of Fig. 12.7.

The table below shows some possibilities.

Phase Difference	Situation	What we see through, Analyser
2π, or 4π, etc.	The components are out of phase, and destructively interfere.	No light
π, or 3π, etc.	The components are in-phase so add for biggest value.	Maximum intensity
Other phase differences	The components are partly in phase, so add for lesser value.	Intensity between zero and brightest.

We will test this prediction in the experiment.
Case 2: White Light
        Polaroids crossed
        Other conditions same as Case 1

Now to predict the result for this case we have to calculate the quantitative effect of phase-difference on the transmitted intensity.

This just means starting in the right place, doing a lot of trigonometry, and getting a compact and useful answer.

To start, you have to begin with two vectors each of size $E = A \sin \phi \cos \phi$, but with a phase difference of $(\gamma + \pi)$, since when ϕ is zero the two are oppositely directed, from the Fig.12.6. So, the transmitted intensity is the square of the sum of the two vectors.

This is the start mentioned above.

The final result of the mathematics is the following expression.

$$A_2 = \text{intensity coming out of the analyser}$$
$$= 4E^2 \sin^2 \phi \cos^2 \phi \sin^2 \phi(\gamma / 2)$$

Where ϕ = angle of polariser w.r.t. the optic axis.
        γ = phase difference between emerging O and E rays.

$$= (2\pi d) \times (n_O - n_E)/\lambda$$

This is a very useful expression to use in predicting the result of several experiments.

CASE 3: Like Case 2, but λ is allowed to vary. This means the white light is spread out by a spectrometer.

Probably, if d is more than a few wavelengths, there will be some value of λ for which $\gamma = 0$, or $\pi/2$, or π, etc. For these values, no light emerges from the analyser. That means the light from the birefringent plate is linearly polarised, with plane perpendicular to the analyser plane.
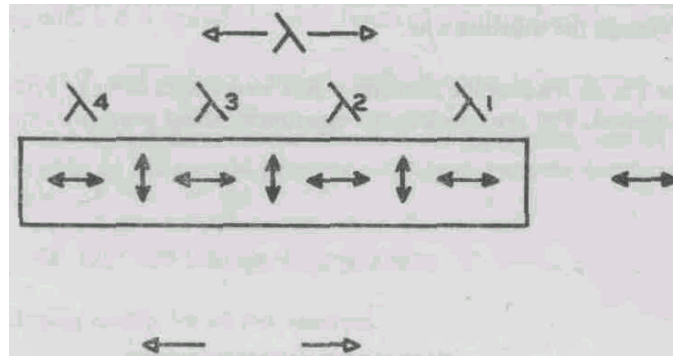
Fig.12.8

Similarly there will be values of λ for which $\gamma = \pi/2$, or $3\pi/2$, etc. For these values maximum light emerges from the analyser. The light from the birefringent layer is linearly polarised, with plane parallel to the analyser plane.

In-between the light will be elliptically polarised as it emerges from the birefringent layer. The result is as suggested in Fig. 12.9.
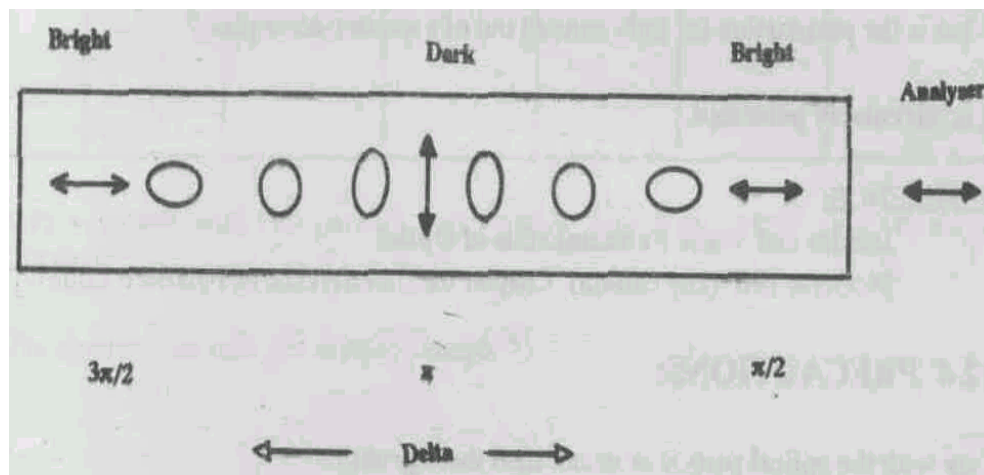
Fig.12.9

This in turn should give rise to an intensity as shown in Fig. 12.10.
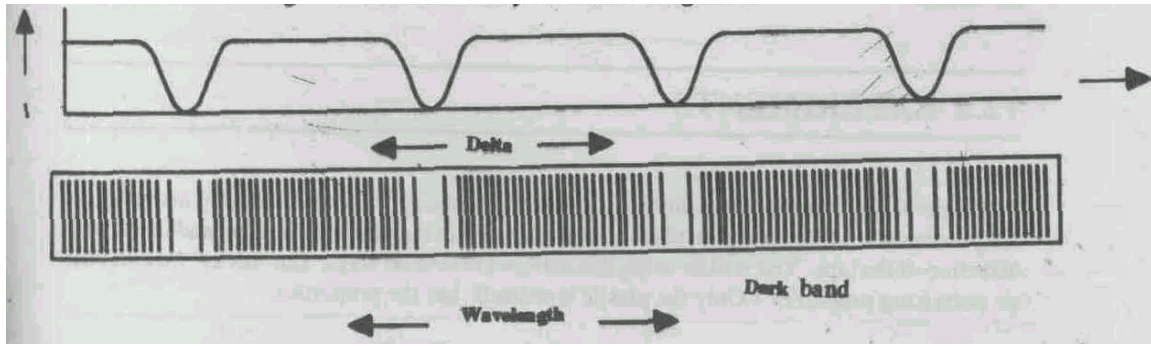
Fig. 12.10

CASE 4: White-light
            Thin birefringent film
            (Only one dark band)

Then, through the analyser all colours will come **except** the blocked colour! The light will appear coloured, by the **absence** of a certain colour. These effects are very beautiful. In the experiment you will see several examples of this idea.

Suppose the analyser plane is now turned 90°, to be **parallel to** the plane of the polariser. This will change the situation a lot.

Try yourself to sketch here the intensity versus wavelength curve to expect, and what colour may be expected. You can check in the experiment, about your own expectations.

PUT YOUR SKETCH **HERE**

ONE LAST REMARK

For the case of monochromatic light, with polarised light incident 45° on a birefringent plate with optic axis in the surface, there is a thickness for which the emergent light is just rotated by 90°. You have seen this described above, for positions where $\gamma = \pi$. Such plates retard the O beam by a half-wave-length, and are called **half-wave-length** plates. There are also plates called quarter-wave plates.

What is the polarisation for light coming out of a quarter-wave plate? It **is circularly polarised**.

REFERENCE:
Jenkins and White **Fundamentals of Optics**
McGraw-Hill (any edition) Chapter on "Interference of Polarised Light".

12.4   PRECAUTIONS
Care with the optical parts is as usual: treat them gently, and keep them clean!

In setting up the spectrograph, make sure the light is travelling straight through the apparatus. The easiest way to assure this is to place your eye at each place possible, looking back toward the source.

12.5   EXPERIMENTS
Throughout, the birefringent material to be used is ordinary 'cellotape'. During manufacture the process gives a birefringent plastic with optic axis in the plane of the tape, and in the long direction of the tape. You will be using this material in several ways. The 'sticky' material has no polarising properties ! Only the plastic tape itself has the properties.

12.5.1 Case 1
Assemble a 'polarimeter' from the parts. Two Polaroids and scales should be fixed, one on each end of the tube for holding the samples and the filter.

Make sure the red filter is in place.

Prepare 4 glass slides, with 1, 2, 3, 4 parallel-placed layers of cellotape stuck on, respectively.

Start with polariser set at 0°, and analyser "crossed" with it, so no light emerges.

Place the sample with one layer in the connector tube, look at a light source, and record what you see, in terms of brightness. Then set the polariser at 45°, cross analyser, insert sample and again record brightness.

Proceed this way for 90°, 135°, 180° settings of the polariser. Fill in the Table with your results, for all four samples.

Table

Polariser	Angle	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
0						
45						
90						
135						
180						

Now make a sample with two parallel layers and a third layer   stuck on cross-ways (perpendicular).

Repeat the observations with this sample (Sample 5).

Does it behave like any of the other samples?

_____

_____

_____

Can you give any explanation?

_____

_____

_____

_____

_____

12.5.2 Case 2

Use the **same** arrangement and samples as Experiment 1 **except** remove the red filter. Now, crossed Polariser + Analyser may not give complete dark, but some dim colour. Record this.

Now, repeat the observations of 12.5.1 but record for each sample and angle some estimate of the colours seen. Note any colour-similarities or colour-complements especially.

Table 1

(Crossed Polaroids)

Polariser	Angle	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
0						
45						
90						
135						
180						

Again, compare Sample 5 results with other samples.

Rotate the Analyser until it is parallel to the Polariser and again note colours observed.

Table 2

(**Parallel Polaroids**)

Polariser	Angle	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
0						
45						
90						
135						
180						

Please note any ways in which the "crossed" table and the "parallel" table have similarities.

12.5.3 Case 3

In this experiment you just set up a prism spectrograph instead of your eye. The arrangement is as shown.
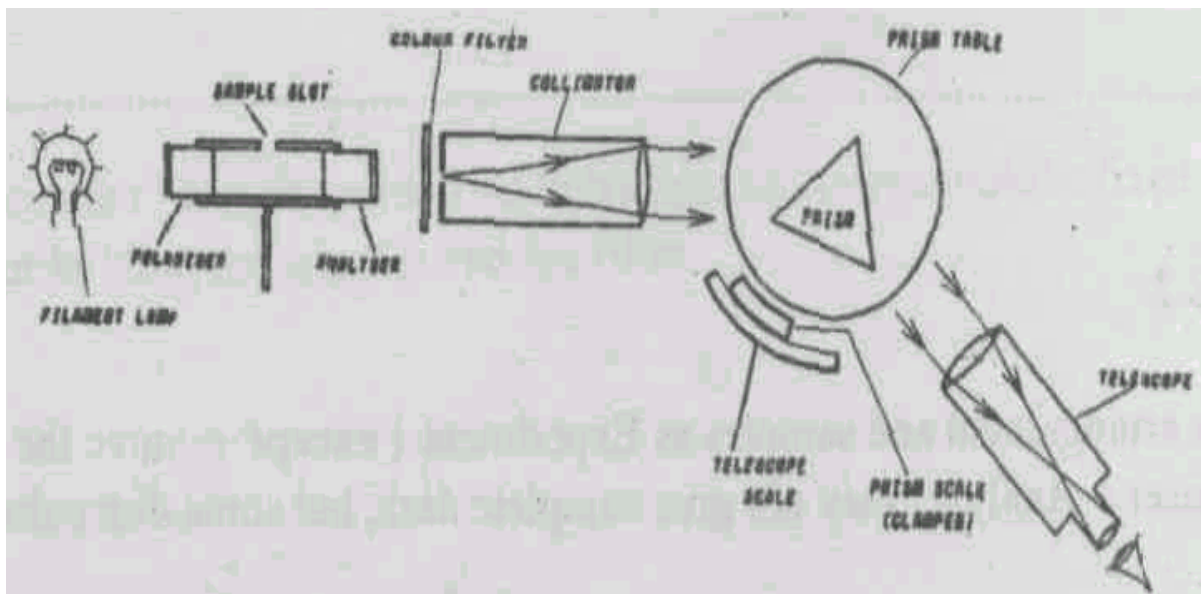
Fig.12.11

Again insert the 5 samples one-by one and sketch the spectrum observed, for the two   Study of Interference of polarisations suggested, especially to note black regions, for crossed polariser and analyser.

Sample 1, polariser set at 0°

VIOLET   BLUE GREEN   YELLOW   RED

Sample 2, polariser set at 0°

VIOLET   BLUE GREEN   YELLOW   RED

Sample 3, polariser set at 0"

VIOLET   BLUE GREEN   YELLOW   RED

Sample 4, polariser set at 0°

VIOLET   BLUE GREEN   YELLOW   RED

Sample 5, polariser set at 0"

```

```

VIOLET   BLUE GREEN   YELLOW   RED

Sample 1, polariser set at 45°

```

```

VIOLET   BLUE GREEN   YELLOW   RED

Sample 2, polariser set at 45°

```

```

VIOLET   BLUE GREEN   YELLOW   RED

Sample 3, polariser set at 45°

```

```

VIOLET   BLUE GREEN   YELLOW   RED

Sample 4, polariser set at 45°

```

```

VIOLET   BLUE GREEN   YELLOW   RED

Sample 5, polariser set at 45°

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VIOLET   BLUE GREEN   YELLOW   RED

After you have completed this, please try to point out at least a few examples where the thickness-variations or/and the wavelength variation agree with what is expected in the Study Material.

_____

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_____

_____

_____

_____

Any cases you find which **contradict** the expectations of the study material?

_____

_____

_____

12.6   CONCLUSIONS
Write in your own words what you have found in this experiment, especially if your observations agree with the expectations of the Study Material.

(For Counsellor's use only)
Grade.............................   Name ....………………..

Evaluated by…………………………….   Enrolment Number ………………

EXPERIMENT 13
MEASUREMENT OF C_p/C_v BY AN ACOUSTIC METHOD

13.1 INTRODUCTION

The properties of matter depend ultimately on the details way in which atoms and molecules are arranged with respect to each other. It is all the more remarkable then that the properties of gases should largely depend on the simple perfect-gas law, for very many gases of a wide range of composition.

While the Law itself is obeyed in large part, the constants which appear in the Law do themselves depend on the particular gas atoms or molecules involved. In this way the properties of the particular gas molecules are made evident.

This experiment is designed to let you see how the gas molecules control to some extent one gas property, namely the speed with which sound moves through a gas. As we will see, this in turn depends on the way the atoms of the gas molecule are arranged. Fortunately some very simple molecules are available to use in the investigation.

OBJECTIVES

At the end of this experiment a student will be able to do the following:

*   Set up and use apparatus of a resonant-tube sort, to measure the speed of sound in several simple gases.
*   Calculate the statistical errors involved in the measurements.
*   Be able to correlate the speed of sound with the molecular structure of the gases, through thermodynamic quantities calculated.

13.2   APPARATUS
One audio-frequency oscillator of low power and variable frequency.
One power amplifier, of the sort used for public- address systems.
One born driver, from a public-address system, with the horn unscrewed.
One glass tubing about 1.5 cm to 3 cm diameter.
One cap for tube, with gas-admitting arrangement
One meter-scale
One thermometer for measuring room temperature.
One generator for carUv dioxide (acid - marble chip).
cotton for ear-plugs.

13.3   STUDY MATERIAL
133.1   An Ideal Gas
Thermodynamics takes its importance from the combination of two aspects of physics. One is the rules by which materials and their properties are related. The other is the rules by which processes proceed, that means the way in which quantities change under various conditions.

You have studied in school the way an ideal gas behaves. The quantities which describe the behaviour of an ideal gas are: the temperature, the pressure and the volume of the gas. You have learned that these are related by the following formula.

$$PV = nR\Theta$$

Where the symbols have the following meaning.
P = Pressure, in units of pascals (a pascal is one newton per square meter)
V = Volume, in cubic meters.
n = number of moles in the volume of gas.
R = universal gas constant, with the value 831 Joules/mol K-degrees
Θ = Meal-gas temperature, which for our purposes can be considered to be identical to the Kelvin temperature.

It is one of the properties of an ideal gas that the internal energy U is a function only of the temperature Θ . This will turn out to be a useful fact.

13.3.2   First Law of Thermodynamics
If you have studied your course in Heat and Thermodynamics you will be familiar with the following statement. If you have not yet studied that course you should accept for the time being the truth of what follows.

All material has been found to follow a very important and simple rule, when the thermodynamic quantities for the material are changed little-by-little, and fairly slowly. In those circumstances the following rule applies.

When such a material undergoes a process in which energy is transferred by non-mechanical means, the difference in the internal energy change for the system, and the work done is called HEAT.

This sounds like a strange rule, but when it is properly applied it can help us understand a lot.

13.3.3   Application to a Hydrodynamic System
For the case where pressure and volume are the quantities which are determining the system, this rule can be written in a neat mathematical form as follows.

$$dQ = dU + PdV$$

Where the new symbols have the following meaning.

$Q =$ energy in the form of heat.

$U =$ internal energy of a system (in this case a gas). This will be composed of the kinetic and potential energies of the atoms and molecules which compose the gas.

Just take this equation as true, if you have not yet progressed to where you can derive it.

Now we need a definition - the definition of the heat capacity of such a system at constant volume. This is given by the following expression, for the case of the restricted dependence mentioned above.

$$C_v = \left(\frac{dU}{d\Theta} \right)_v$$

Now, the First Law of Thermodynamics above may be used at constant volume ($dV = 0$), when $dQ = dU$. Hence the following equation.

$$C_v = \left(\frac{dU}{d\Theta} \right)_v$$

$$dU = C_v d\Theta$$

This expression is substituted in the expression above, for the change in heat of the system when a change occurs. This results in the following important relation.

$$gQ = C_v d\Theta + PdV$$

13.3.4   Application to an Ideal Gas

This expression is good for all kinds of materials. If now we look at the equation for an ideal gas (above) and substitute it; in the general expression for dQ then we get the following, considering a process involving very small changes.

$$dQ = (C_v + nR)d\Theta$$

SAQ: Please use the space here lo actually fill in the derivation referred to, by substitution. It will take only a few lines!

_____

_____

_____

If the process takes place at constant pressure then this expression, when divided by dQ results in the value of C_p, the heat capacity at constant pressure. This results in the following very useful relation.

$$C_p = C_v + nR$$

SAQ: Please fill in here the few lines needed to actually carry out the derivation of the previous equation.

_____

_____

_____

This shows that the heat capacity of a gas is always greater at constant pressure than it is at constant temperature, and the difference is constant and equal to *nR*. This is indeed a remarkable fact!

Now using the ideal gas law in the expression for *dQ*, you can get the following other expression for *dQ*.

$$dQ = C_p d\,\Theta - VdP$$

SAQ: Please actually place here the few lines needed to get this expression.

_____

_____

_____

Now these two expressions for *dQ* can be combined for the case of adiabatic processes (those for which *dQ* = 0) to get the following important expression.

$$\frac{dP}{P} = -\gamma \frac{dV}{V}$$

where $\gamma = C_p / C_v = c_p / c_v$, and c_p and c_v are molar heat capacities.

SAQ: Please use the space below fordoing this combination and arriving at the above expression.

13.3.5 Heat Capacities of Various Gases
The subject of statistical mechanics is closely linked with heat and thermodynamics. One important result of that subject is that the molar heat capacities of gases are closely linked with the **number** of motions which a gas atom *can* undertake. In fact the rule is as follows.

For every motion a gas atom can have, there is an amount of molar heat capacity at constant volume equal to (1/2)*R*.

So, for a monatomic gas like helium, which can move independently in any of three directions (*x, y* or *z*) the following is true.

$$c_v = (3/2)R$$

$c_p = (3/2)R + R = (5/2)R$ (see an equation above)

$\gamma = 5/3 = 1.67$

A diatomic gas like oxygen or nitrogen (mostly what composes the atmospheric air) has molecules which, in addition to x-y-z motions can rotate about an axis (not the axis which joins the atoms, though!)

In addition, the atoms can vibrate along an axis which joins the atoms. Hence the following.

$c_v = (5/2)R$

$c_p = (5/2)R + R = (7/2)R$ (see an equation above)

$\gamma = 7/5 = 1.4$

A gas like carbon dioxide (CO_2) which has three atoms strung out in almost a straight line, can in addition bend in two Independent ways. Hence the following.

$c_v = (7/2)R$

$c_p = (7/2)R + R = (9/2)R$ (see an equation above)

$\gamma = 9/7 = 1.29$

So, by a measurement of γ we can find out something about the atomic and molecular structure of UK elements composing a gas! This is exactly what you will do in the experiment.

13.3.6 Velocity of Sound In a Gas
We have assumed an adiabatic process above. For such a process,

$$w = \left(\frac{1}{\rho} \times \frac{1}{\dfrac{dV}{dP} \times V} \right)^{1/2}$$

$$= \left(\frac{\gamma P}{\rho} \right)^{1/2}$$

Where
w = velocity of sound in m/s

ρ = gas density in kg/m^3

SAQ: Please verify using the equations 13.3.4 that the second equality above follows from the first.

_____

_____

_____

So, you can find out γ by finding out w and this is the experimental objective you have now.

13.3.6 Acoustic Resonance in a Tube

The method you are going to use to measure the speed of sound in a gas is often called "Kundt's Tube Method", after a German physicist. It simply depends on the fact that longitudinal sound waves travelling in a tube closed at one end have a resonant phenomenon.
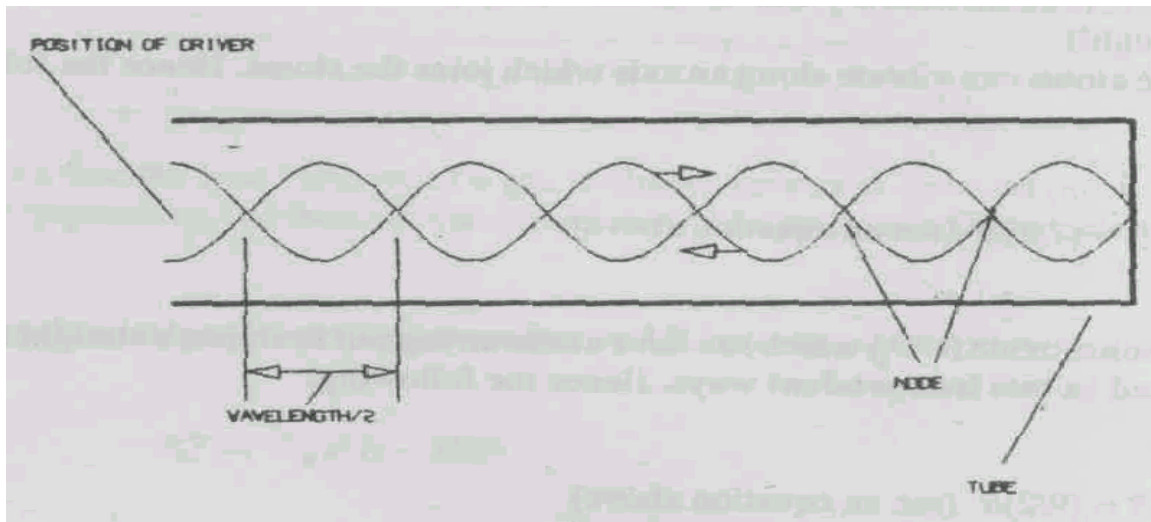
Fig. 13.1

The wave which progresses to the right in Fig. 13.1, and the reflected wave which proceeds to the left are coherent since they have the same source. These two pressure waves add up and produce a standing-wave pattern of alternating minima and maxima. The distance between these is $\lambda/2$, where λ is the wavelength of the acoustic wave.

Usually the driver for the sound wave is at the open end of the tube, where the amplitude of the wave is a maximum. If the length of the tube is equal to an odd-integral number of wavelengths then the interference will be resonant and the pressure maxima and minima will be very pronounced.

In your experiment you win put a small amount of very light power along the bottom inside of a glass tube closed at one end, and introduce sound at the open end. When the frequency is adjusted so that resonance is observed, you will see that the strong sound waves displace the powder, which accumulates at the resonant nodes. These are the places where there is very little net motion of the gas in the tube.

With this observation you can easily measure the distance! between nodes separated by N half-wavelengths. This will then allow the calculation of the wavelength λ. If the frequency ν is known then the speed of sound w can be calculated from the following expression.

$$w = \lambda \nu$$

This in turn will allow the verification of the ratio if heat capacities, $_Y$, which is one object of this experiment.

13.4   PRECAUTIONS

The chief precautions in this experiment concern the high levels of sound power you will be using. It is really best to plug your ears with cotton bits before you start the experiment. This will go a long way lo avoiding any painful experience, or even the possibility of ear damage.

Next, make sure that you start each section of the experiment with the volume control on the power amplifier set to "zero". You can then turn up the oscillator level to say mid-range value, and slowly and carefully increase the power amplifier volume until you have enough power to move the powder in the tube.

Remember that when you tune the oscillator to a resonance a lot of sound energy will escape from the tube, so be prepared to turn the power volume down.

Once you have established a resonance with modest power output, you can just quickly increase the power and immediately decrease it. This will boost the powder to the regions of the nodes. Then you can measure the node spacing with the oscillator **and power amplifier turned completely down!** This will avoid your becoming unpopular with your fellow-students, from having the sound blasting ALL the time.

13.5   THE EXPERIMENT

13.5.1 Setting up the Apparatus
Please arrange and clamp your glass tube. The tube should have a small amount (one or two "pinches") of a light powder inside and distributed along the whole bottom length. You can do this by rotating the tube and tapping it to move the powder.

The usual powder is 'lycopodium powder.' You could also use the pollen from pine tree blossoms, or from reed-flower blossoms. Both are excellent but require to be gathered at the right time of year! If no preparation has been made for this, you can even use the chalk dust from the chalkboard rail in your classroom!

Close the end of the tube with a piece of aluminium foil held in place by several layers of black electrical insulation tape. This will give a satisfactory sound reflection, and permit you to introduce other gases besides air just by poking a hole!

The driver from the loudspeaker horn is heavy. Clamp it solidly to a stand. You may be able to force on the threaded portion a short tube which will help you to hold the driver.
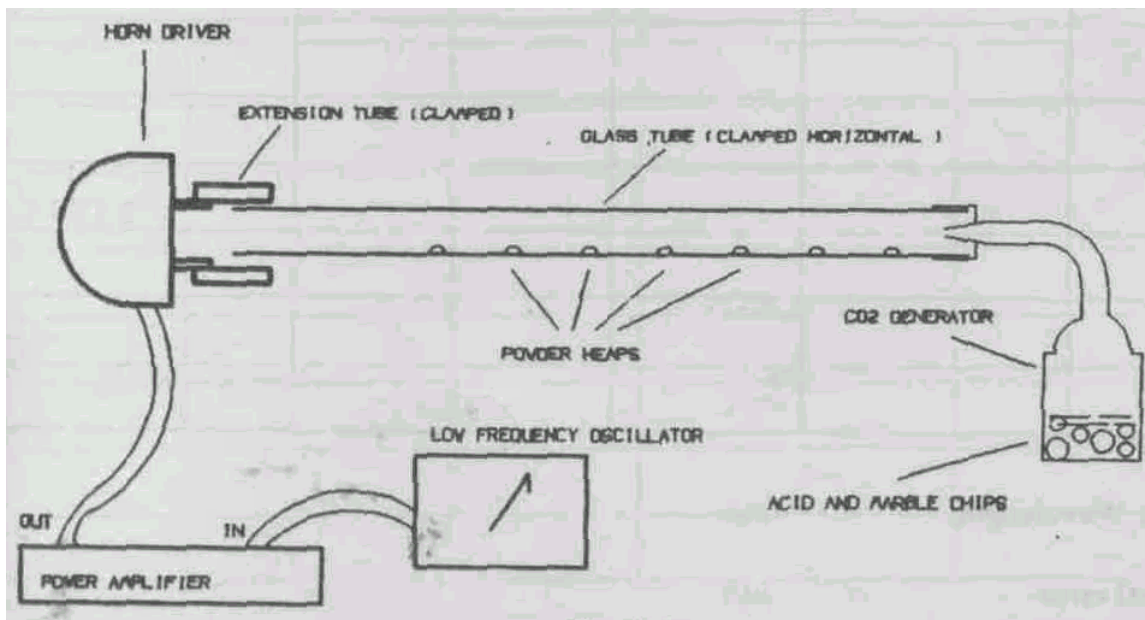
Fig.13.2

Clamp the entire apparatus as shown in Fig.13.2. It is important that the tube be horizontal - otherwise the powder will slowly drift out of the tube as it is agitated by the sound!

Once the apparatus is mechanically clamped, connect the driver to the output terminal of the power amplifier, and the output of the oscillator to the input terminals of the power amplifier. Of course both of these should be OFF when the connections are being made!

13.5.2 Measurement of Wavelength in Air
Set the oscillator frequency to about 1000 Hz. Set the output to about midway to the maximum.

Set the power amplifier volume to ZERO. Switch on the oscillator and the power amplifier and wait a little while for them to function. After a minute or so, slowly increase the volume of the power amplifier until some sound is heard. If nothing is heard at all, TURN DOWN THE VOLUME, and go back to check your connections.

When some sound is heard, slowly increase the frequency of the oscillator. You will notice t hut at certain frequencies the sound is suddenly louder. These are the resonant frequencies.

STEP 1:Increase the power (the sound level) near such a resonance until you see the powder in the tube begin to "dance" a little. Then tune the oscillator very slowly to maximise the "dancing". Note the frequency of the oscillator and record in Table 1.

STEP 2: Now just quickly turn up the volume and immediately turn it down again. This short blast of sound power will move the powder towards the nodes of the resonance. Do this a few times until the powder is in small and clearly-defined heaps. Then turn down the power to zero.

STEP 3: Measure the distance between the most widely-separated clear heaps, as well as the number of gaps between these heaps. Enter these values in Table 1.

Table1

	FREQUENCY	No. OF	DISTANCE TO	WAVELENGTH
PART 1				
PART 2				

Average Wavelength   = _____ m/s

Statistical error   = _____ m/s

Now turn up the power oscillator a bit and increase the frequency of the oscillator until another resonance is observed.

Repeat Steps 1 - 3, and do this for at least three more frequencies.

The result of these measurements will be a series of values for the speed of sound over the frequency range you covered.

Please now repeat the entire measurement sequence, starting again at about 1000 Hz frequency. Enter all the readings in the second part of Table 13.1. = _____ m/s.

13.5.3 Measurement of Wavelength in Carbon-Dioxide

First you must set up a generator of carbon-dioxide gas. This is easily done with a little chemistry. Take the generator-jar and place a small handful of marble chips in the bottom. Add hydrochloric acid to cover the chips, and close the apparatus. Carbon-dioxide should be generated for at least 1/2 hour in the small quantities you need.

Connect a rubber tubing to the generator, and a glass nozzle to the other end. Push the sharp glass nozzle through the black-tape-and-aluminium-foil end of the resonant tube. Gas will slowly flow into the tube and fill it after a few minutes. The gas is heavier than air so it will not easily just run out.

Now, repeat all the measurements suggested for 13.5.2, and enter the results in Table 2.

When you have finished, remove the gas generator, flush it with water to remove all traces of acid, and return the marble chip residue to its stock. Clean and dry the generator apparatus for the next student.

Table 2

	FREQUENCY	NO.OF SPACES	DISTANCE TO COVER THESE SPACES	WAVELENGTH (CALC)
PART 1				
PART 2				

13.5.4 Calculations and Estimation of Errors

For each resonant frequency, calculate the speed of the sound wave, as suggested in 13.3.6. Form the average value for air including all the readings in Part 1 and Part 2 of Table 1. Using all the values and your usual method, find the statistical error of the readings."

If you find a value greater than 2% for the error, then you should look at your readings for possible actual mistakes (wrong number of spaces counted, oscillator calibration no good, etc.). This is an experiment in which you can expect pretty good accuracy - at least 1% or less.

Now repeat the calculations for the readings in carbon-dioxide, and enter in the suitable part of Table 2.

Now using the equation suggested in 13.3.6 you can calculate the values for γ and see if they agree with the values predicted in 13.3.5. You can take the pressure from the daily weather map in your local newspaper, and the value for density you should find from a handbook in your library. Please look these up in advance!

13.6   CONCLUSIONS

You should be in a position now to say whether your experimental experience agrees with the predictions of the study material or not. You will probably find some deviations - the world is often not ideal! Please write here what you feel about the results you have obtained.

_____

_____

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(For Counsellor's use only)
Grade.............................   Name ....………………..

Evaluated by………………………….   Enrolment Number ………………

EXPERIMENT 14
PHASE CHANGE

14.1 INTRODUCTION
It is well known that matter around us exists in solid, liquid and gaseous (vapour) forms. It is also well known that under suitable conditions the same substance (such as water) can exist as ice (solid), water (liquid) and steam (vapour/gas). In scientific language these are referred to as solid phase, liquid phase and gaseous phase, respectively, A change from one phase to another is usually accompanied by a change in volume and some absorption or liberation of heat.

SAQ: When you go to a doctor for an "injection", before injecting the needle (be doctor wipes an area of your skin with a ball-of cotton soaked in spirit. Write down how you had felt in that region soon after wiping.

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OBJECTIVES
After performing the experiment you should be able to:

- Infer that there is a transfer of heat without any change in temperature, during a phase change.
- Estimate the amount of heat given out when a liquid freezes into a solid.
- Understand and interpret cooling curves.
- Verify that there is a change in volume during phase changes.
- Correlate the experiment with other phase changes that you come across every day.

14.2   APPARATUS
Glass test tube
Bunsen burner or a spirit lamp
Water bath
Stand and clamp
Thermistor
Resistance (ohm) meter, or LCR bridge.
Clock or stop watch
Spring balance or rough balance

14.3   STUDY MATERIAL
14.3.1 Kinetic Theory and Phase Change
The kinetic theory of matter tells us that matter exists as molecules, and molecules are in constant motion. In the case of solids the molecules are almost fixed around certain locations and the motion in such cases is one of vibration only. When the solid is heated (more energy is supplied) the vibrations become more and more energetic and the molecules are no longer tied to fixed locations. They move randomly within the body of the material and we get the liquid phase which is defined by a surface. When the liquid is heated the molecules gain more and more energy and are able to overcome the pull of the other molecules near the surface and evaporation sets in. The molecules get into the vapour phase. Likewise when a liquid is to be frozen the kinetic energy of the molecules is to be reduced. This is done by removing some energy from the liquid. The same is true for condensations of vapour.

The energy needed for the phase change at a given temperature is known as the latent heat. Since the mean distance between the molecules changes, the volume also changes during a phase change.

14.3.2 Evaporation Causes Cooling
The average kinetic energy of the molecules is a measure of the temperature of the material. When there is evaporation it is the energetic molecules that are able to overcome the pull of the other molecules at the surface of the liquid. Thus evaporation reduces the average kinetic energy of the molecules left behind in the liquid and the result is "evaporation causes cooling".

14.3.3 First Order Phase Change
The phase change of the type described above with changes in volume, and absorption or liberation of heat (change in entropy) is known as a **first order phase change.**

14.3.4 Transition Temperature
The melting of a solid (fusion) or the boiling of a liquid takes place at certain temperatures known as the melting point (m.p) or "boiling point" (b.p). These temperatures are also known as the transition temperatures for the respective phase changes.

14.4.   PRECAUTIONS
You will be using naphthalene as the solid for this experiment. Make sure you don't inhale the vapour of naphthalene directly. It is unpleasant and may be harmful.

While melting naphthalene to avoid overheating. It is suggested that you heat the test tube containing naphthalene by keeping it in hot water in a water bath. Do not heat the test tube directly as the liquid naphthalene may catch fire and sometimes the test tube may crack.

14.5   THE EXPERIMENT
14.5.1 Melting

Find the weight of the empty test-tube and record it here.

Weight of empty test-tube = m_1 = _____ Kg

Now take about 15 or 20 grams of naphthalene bits, and find their weight. Record the weight here.

Weight of naphthalene = m_2 = _____ Kg

Pour the naphthalene bits into the test-tube. Melt it by keeping the test tube immersed in hot water in a water bath. Naphthalene will melt into a clear liquid. You would notice that the naphthalene melts even before the water boils! When you see entirely clear liquid within the test-tube, remove the test tube from the bath and wipe the outside of the tube dry using a piece of cloth. Clamp the test-tube near the top (above the level of the liquid naphthalene) so that air can circulate freely around the tube for cooling.

14.5.2 Measurement of Temperature

Lower the given thermistor half-way down inside the molten liquid (without touching the wall of the test-tube)and measure its resistance using an LCR bridge or ohm-meter. You would have performed an experiment for Calibrating a thermistor. If not, you may get from your instructor a calibration graph connecting the temperature and resistance of the given thermistor.

14.5.3 Cooling Curve

Measure the resistance of the thermistor at regular intervals of time (say every 30 seconds) until the liquid gets frozen into a solid and the solid also gets cooled to about room temperature. Enter your values into Table 1.

Table 1

Time (minutes)	Resistance (ohms)	Temperature from calib.

Draw a graph connecting the time (*x*-axis) and temperature (*y*-axis). This graph is known as the cooling curve.
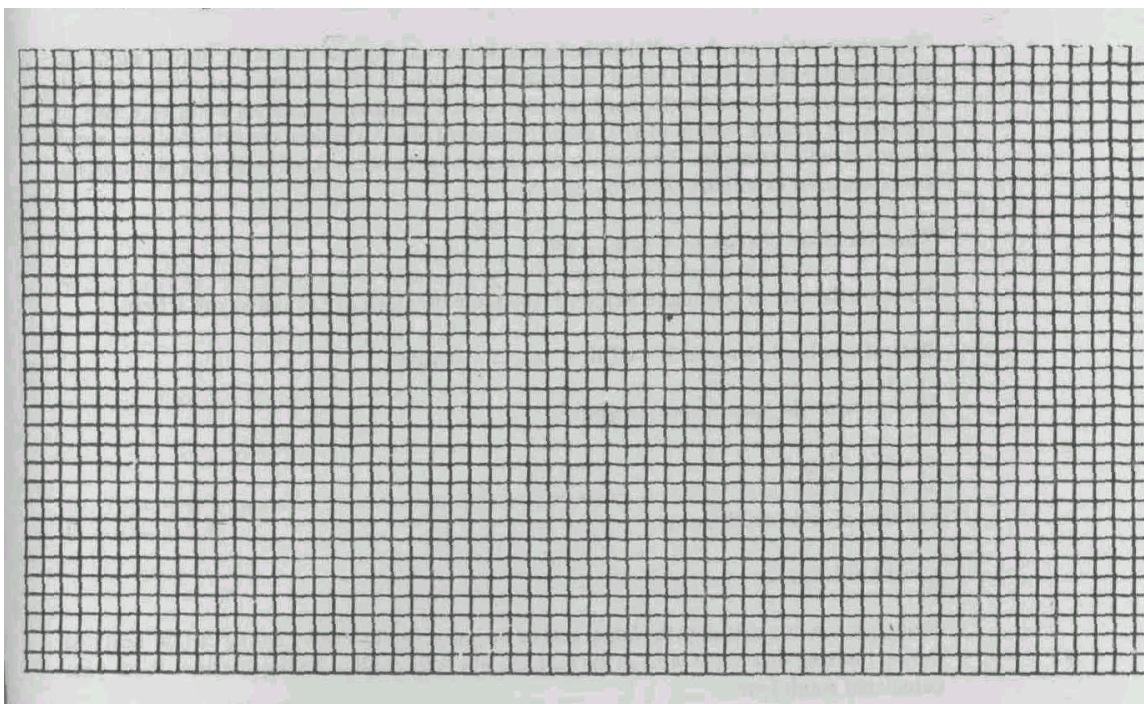
14.5.4 Calculation
The graph will look something like the example in Fig. 14.1

It has three distinct regions. (1) The cooling region for liquid. (2) The region during which the change of phase takes place. (3) The cooling region for the solid.

The region of the graph parallel to the time axis (*x*-axis) represent the time during which the phase change takes place. During this time the test-tube is giving away heat without any fall of temperature. Extend the Region 2 on either side of your graph, as shown in Fig.14.1. Extend the smooth cooling regions of your graph (Regions 1 and 3) to meet the extended line, again as shown in the example. The duration represented by the interval AB is the time taken for the entire material to solidify. Record this here.

Time for phase change = $t =$ _____ sec.

Measure the rate of cooling in Region 3 (measure the slope dT / dt) and record it here.

Rate of cooling in Region 3 = $dT / dt =$ _____ deg/sec.
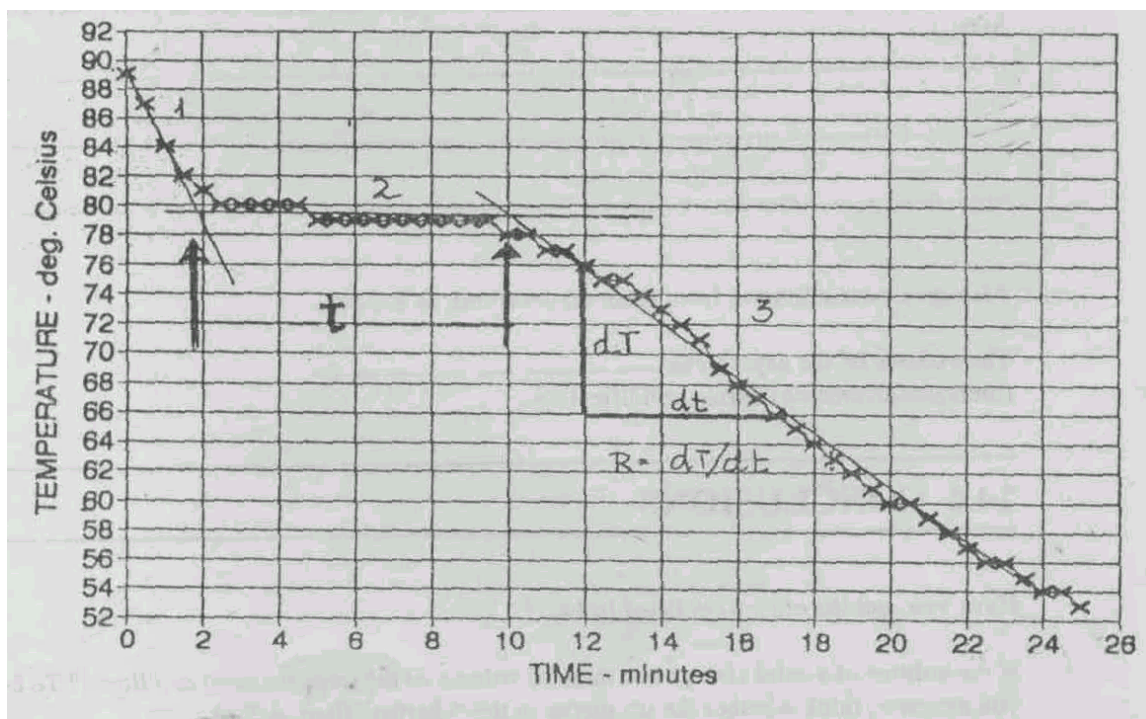
Now assume the specific heat of glass is

Fig. 14.1

$$c_1 = 670\text{J/Kg}$$

and that of solid naphthalene

$$c_2 = 1170\text{J/Kg}$$

From this you can calculate the latent heal of fusion of naphthalene by noting that the heat loss during freezing time is the same as the heat loss of a solid cooling during that time. Write your calculated result here.

$$m_2 L = m_2 c_2 R t + m_2 c_1 R t$$

Hence $L = c_2 R t + (m_1 / m_2) c_1 R t = \underline{\hspace{2cm}}$ J/Kg

14.5.5 Observation
Note the surface of the liquid inside the test tube during solidification, record your observation as here.

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Also give your inference from these observations, as follows.

The volume of the naphthalene _____
(increases/decreases) during solidification.

14.6 CONCLUSIONS

Have you met the objectives listed in 14.1?

Is the volume of a solid always less than the volume of the same material as a liquid?

Will the slope of the time-vs-temperature curve depend on the quantity of solid taken in the test tube? Give reasons.

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Suggest a suitable experiment for determining the latent heat of fusion of ice?

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For preparing ice cream ice is not sufficient to cool the cream. A mixture of ice and salt is used. How does it help?

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