BSCPH-204

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Practical Physics II

DEPARTMENT OF PHYSICS
SCHOOL OF SCIENCES
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Practical Physics II

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Course 8: Practical Physics II

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EXPERIMENT 1: STUDY OF MALUS LAW

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1.1 OBJECTIVES

To verify the Law of Malus for plane polarized light with the help of photovoltaic cell.

1.2 INTRODUCTION

According to Malus, when completely plane polarized light is incident on the analyzer, the intensity I of the light transmitted by the analyzer is directly proportional to the square of the cosine of angle between the transmission axes of the analyzer and the polarizer.

1.3 APPARATUS

Optical bench, halogen lamp, double convex lens, polarizer, analyzer, photo voltaic cell and micro-ammeter (0-50mA).

1.4 THEORY AND FORMULA USED

According to Malus Law, when a beam of completely plane polarized light is incident on the analyzer, then the intensity I of the emergent light is given by

$$I= I_o \cos^2 \phi$$

Where I_o = Intensity of plane polarized light incident on the analyzer.

Φ= angles between planes of transmission of polarizer and the analyzer

Figure 1: Experimental Setup for studying Malus Law

To verify this law, light from the analyzer is made to enter in a photovoltaic cell. The current output of photovoltaic cell is connected to microammeter.

1.5 PROCEDURE

1. The experimental setup is arranged as shown in Figure 1. In this arrangement, the source S, convex lens, Polarizer P, Analyzer A and the window of Photovoltaic cell should be at the same height.
2. Now switch on the incandescent bulb. Light from the source S rendered parallel with the help of convex lens L is allowed to fall on polarizer P.
3. For any orientation of the polarizer P, the polarized light passes through analyzer A. The analyzer A is rotated till there is maximum deflection in the micro-ammeter. The position of analyzer is noted on the circular scale. The corresponding micro-ammeter deflection is also recorded. The position of analyzer corresponds to ϕ=0 (here ϕ is the angle between Planes of transmission of polarizer and analyzer.)
4. The analyzer A is rotated through a small angle, say 10^o and then the steady micro-ammeter deflection is noted.
5. The experiment is repeated by rotating the analyzer through 10^o degree each time and noting down the corresponding micro-ammeter deflection till it become practically zero.

1.6 OBSERVATION

S. No.	Angles through which analyzer is rotated ϕ	Micro-ammeter reading		$\cos\phi$	$\cos^2\phi$	$\theta/\cos^2\phi$
		μA	θ			
1.	10^o					
2.	20^o					
3.	30^o					
4.	40^o					
5.	50^o					
6.	60^o					
7.	70^o					
8.	80^o					

1.7 CALCULATION

Find the value of $\theta/\cos^2\phi$ from each observation and plot the graph for $\cos^2\phi$ on X-Axis and θ on Y-Axis.

1.8 RESULT

The graph for $\cos^2\phi$ on X-Axis and θ on Y-Axis is a straight line and hence, Malus law is verified.

1.9 PRECAUTIONS AND SOURCES OF ERROR

1. The position of the polarizer should not be disturbed throughout the experiment.
2. The source of light, lens, polarizer, analyzer, and the solar cell should be adjusted to the same height.
3. The voltage applied to the light source should be constant throughout the experiment.
4. The experiment should be performed in the dark room to avoid any external light inside the photovoltaic cell.
5. Care should be taken while performing the experiment as the bulb becomes very hot.

1.10 SUMMARY

Malus law is the law stating that the intensity of a beam of plane-polarized light after passing through a rotatable polarizer varies as the square of the cosine of the angle through which the polarizer is rotated from the position that gives maximum intensity.

This law is named after E. L. Malus (1775-1812), a French physicist.

1.11 GLOSSARY

Convex Lens – Convex lenses are thicker at the middle. Rays of light that pass through the lens are brought closer together (they converge). A convex lens is a converging lens.

A double convex lens is symmetrical across both its horizontal and vertical axis.

Halogen Lamp – A halogen lamp, also known as a tungsten halogen, quartz-halogen or quartz iodine lamp, is an incandescent lamp consisting of a tungsten filament sealed into a compact transparent envelope that is filled with a mixture of an inert gas and a small amount of a halogen such as iodine or bromine.

Intensity – In physics, intensity is the power transferred per unit area, where the area is measured on the plane perpendicular to the direction of propagation of the energy. In the SI system, it has units watts per square metre.

Microammeter – an instrument for measuring extremely small electric currents, calibrated in microamperes.

Photovoltaic Cell – A solar cell, or photovoltaic cell, is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon.

Polarizer – A polarizer or polarizer is an optical filter that lets light waves of a specific polarization pass through while blocking light waves of other polarizations. It can convert a beam of light of undefined or mixed polarization into a beam of well-defined polarization, i.e. polarized light.

1.12 REFERENCES

1. Introduction to Physics, Cutnell, Johnson, Young, Stadler – Wiley India, 2017

2. University Practical Physics, D. C. Tayal – Himalaya Publishing House, 2000

1.13 VIVA-VOCE QUESTIONS AND ANSWERS

1. Can we interchange polarizer and analyzer in this experiment?

Ans: Yes.

2. When the polarizer and analyzer are crossed, will any light reach the photocell?

Ans: No light will reach the photocell.

3. What is the meaning of polarization?

Ans: Polarization is a property applying to transverse waves that specifies the geometrical orientation of the oscillations.

EXPERIMENT 2: CHARACTERISTICS OF A PHOTOELECTRIC CELL

CONTENTS

2.1 OBJECTIVES

To verify inverse square law of radiations using a Photo-electric cell.

2.2 INTRODUCTION

A device used to convert light energy into electrical energy is called Photo Electric Cell. Photocell is based on the phenomenon of Photoelectric effect. Photo cell are of three types:

1. Photo-Emissive Cell.
2. Photo-Voltaic Cell.
3. Photo-Conductive Cell.

Photo-Emissive Cell: There are two types of photo-emissive cells; Vacuum type or gas filled type cells. Generally, it consists of two electrodes i.e. cathode (K) and anode (A). The cathode is in the form of semi-cylindrical plate coated with photo-sensitive material like sodium potassium or cesium i.e. alkali metals. To have large current, it is usually coated with antimony cesium alloy or combination of bismuth, silver, oxygen and cesium. The anode (A) is in the form of a straight wire made of nickel or platinum. The anode (A) faces the cathode (K). These electrodes are sealed in an evacuated glass or quartz bulb according to weather it is to be used with visible or ultra-violet light. As the current due to vacuum is small, so to increase the current, the bulb of the cells is filled with an inert gas like helium, neon, argon etc. at pressure of 1mm of mercury.

When photo-electrons flow from cathode to anode, they ionize the gas filled and hence the current gets modified. The main drawback of this type of cell (i.e., gas filled cell) is that the photo-electric current does not vary linearly with the intensity of the light.

Since there is no time lag between the incident light and the flow of electrons and hence current, therefore such a cell is used in television, photometry, fire alarm etc.

Photo-Voltaic Cell:
Photo-Voltaic Cell is based on the principle of inner photo electric cell. This is called true cell because it generates e.m.f. without the application of any external potential difference but by only the light incident on it. It consists of a semi conductor layer formed on the surface of the metal plate by either heat treatment or cathode sputting. A film of semi-transparent metal is coated over the semi-conductor. This film maintains the electrical contact with the semi-conductor and simultaneously allows the incident light to fall on the semi-conductor.

When light is incident on the semi-conductor, electrons are emitted which flow in a direction opposite to the light rays. If the circuit is completed between the surface transparent film and metal base through a low resistance galvanometer (G), the current can be measured. If the resistance of the circuit is very small, the current is proportional to the intensity of incident light. The main advantage of this cell is that it requires no external voltage for its operation. This type of cell is widely used in photographic exposure meters, photometers and illumination meters etc.

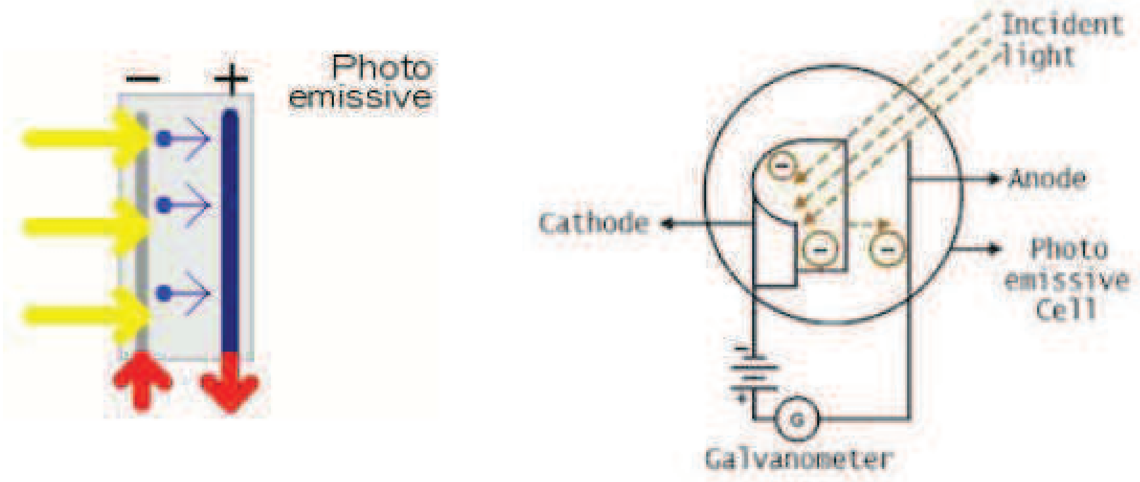


Figure 2: Schematic and working of photo emissive cell

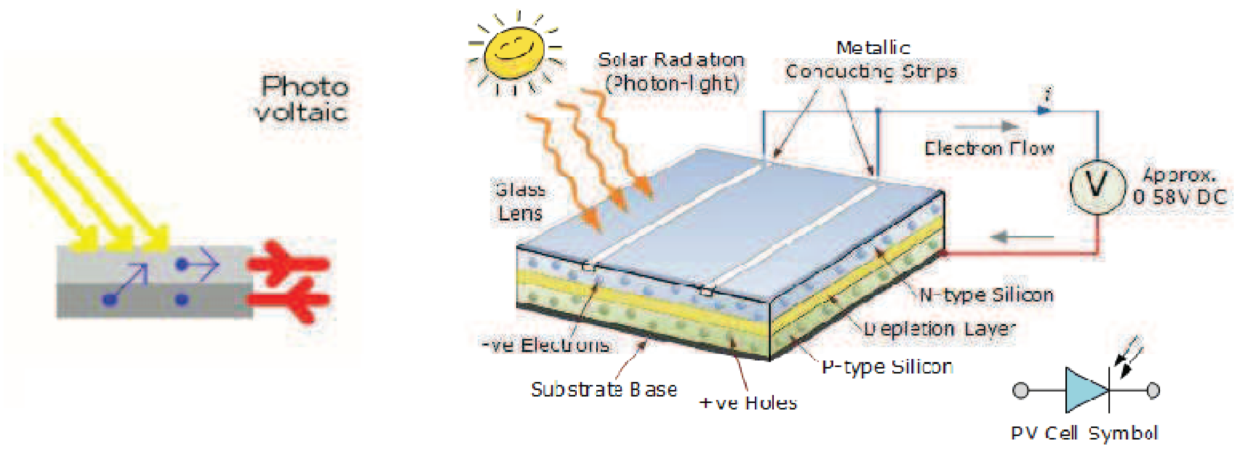


Figure 2: Schematic and working of photovoltaic cell (Solar cell)

Photo-Conductive Cell:

Photo-Conductive Cell is also based on the principle of inner photoelectric effect. It consists of a thin film of semi-conductor like Selenium or Thallium sulphide placed below a thin film of semi-transparent metal. The combination is placed over the block of iron. The iron base and the transparent metal film is connected through battery and resistance. When light falls on the cell, its resistance decreases and hence the current starts flowing in the external circuit.

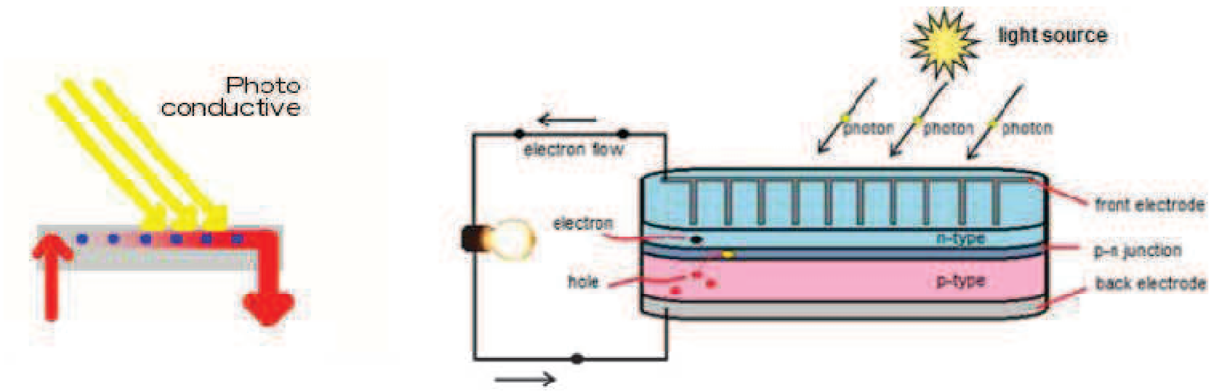


Figure 3: Schematic and working of Photo conductive cell.

2.3 APPARATUS

Photo cell (Selenium) mounted in the metal box with connections brought out at terminals, Lamp holder with 60W bulb, Two moving coil analog meters (1000μA & 500mV) mounted on the front panel and connections brought out at terminals, Two single point and two multi points patch cords.

2.4 THEORY AND FORMULA USED

Let 'I' be the luminous intensity of an electric lamp and 'E' be the illuminance at a point distance'd' from it. According to the inverse square law;

$$E = \frac{I}{d^2}$$

If light from the lamp be incident on the photovoltaic cell placed at a distance'd' from it, then the photo-current given out is proportional to E and if θ be the corresponding deflection shown by the microammeter then,

$$\theta \propto E$$

$$\theta \propto \frac{I}{d^2}$$

$$\theta \times d^2 = \text{constant}$$

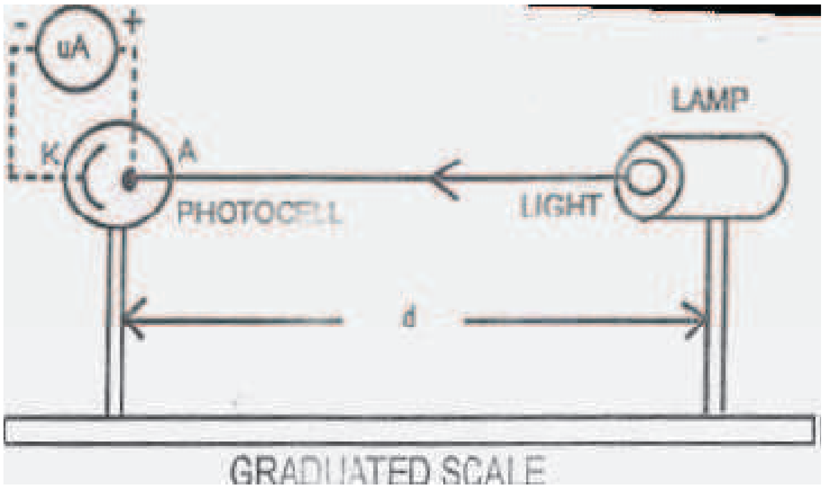


Figure 4: Experimental Board

2.5 PROCEDURE

1. The experiment can be performed in the laboratory but it is always good to perform it in a dark room where stray light falling on the photocell can be avoided. In the dark room mount the various parts of the apparatus on the wooden plank provided with a ½ meter scale. Make the other connections as shown in the Fig. 4.

2. Switch on the lamp and adjust it at a suitable distance from the photocell so that the micro ammeter and mill-voltmeter indicate a reasonable deflection.

3. Change the distance of lamp from the voltaic cell and take a series of observations for the corresponding values of distance (d) and deflection (θ).

2.6 OBSERVATION

S. No.	Position of the lamp	Deflection (θ)	Distance from the photocell (d)	$E = I/d^2$
1.				
2.				
3.				
4.				

2.7 CALCULATION

Plot a graph between $1/d^2$ and θ, taking $1/d^2$ along X-axis and θ along Y-axis.

2.8 RESULT

The graph should be a straight line.

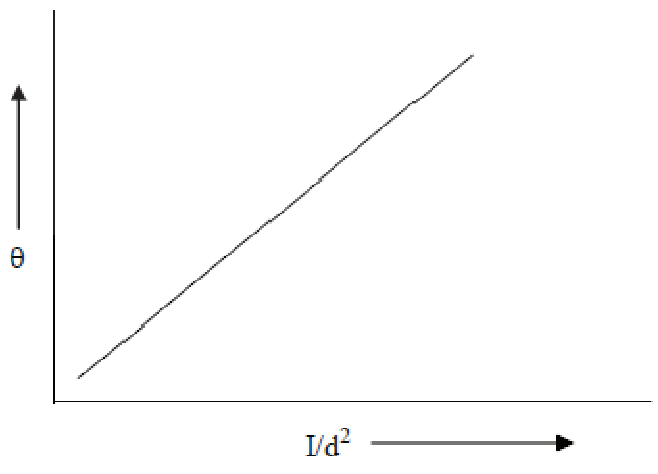


Figure 5:

2.9 PRECAUTIONS AND SOURCES OF ERROR

1. Stray light should be avoided.

2. The effect of the reflected light from the bench surface should be minimized.

3. Very sensitive micro ammeter should be used.

2.10 SUMMARY

Photo-electricity is about light energy being converted into electrical energy and it happens in three different (though, on the face of it, quite similar) ways. They're known as the photoconductive, photoemissive, and photovoltaic effects.

2.11 GLOSSARY

Illuminance – In photometry, illuminance is the total luminous flux incident on a surface, per unit area. It is a measure of how much the incident light illuminates the surface, wavelength-weighted by the luminosity function to correlate with human brightness perception.

Intensity – In physics, intensity is the power transferred per unit area, where the area is measured on the plane perpendicular to the direction of propagation of the energy. In the SI system, it has units watts per square metre.

Photoconductive Cell – Photoconductive cells are light-sensitive resistors in which resistance decreases with an increase in light intensity when illuminated. These devices consist of a thin single-crystal or polycrystalline film of compound semiconductor substances.

Photoemissive Cell – A photoemissive cell, commonly known as a phototube, makes use of the photoelectric effect, the phenomenon whereby light-sensitive surfaces give off electrons when struck by light.

Photovoltaic Cell – A solar cell, or photovoltaic cell, is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon.

2.12 REFERENCES

1. Introduction to Physics, Cutnell, Johnson, Young, Stadler – Wiley India, 2017

2. Practical Physics, Gupta and Kumar – Pragati Prakashan, Meerut, 1985

2.13 VIVA-VOCE QUESTIONS AND ANSWERS

1. What is photoelectric effect?

Ans: The photoelectric effect is a phenomenon in physics. The effect is based on the idea that electromagnetic radiation is made of a series of particles called photons. When a photon hits an electron on a metal surface, the electron can be emitted. The emitted electrons are called photoelectrons.

2. What is the photo cell?

Ans: A device in which the photoelectric or photovoltaic effect or photoconductivity is used to produce a current or voltage when exposed to light or other electromagnetic radiation. They are used in exposure meters, burglar alarms, etc.

3. Define the illuminating power and intensity of illumination.

Ans: The illuminating power of a lamp or source of light may vary in different directions, as in the case of a gas burner or incandescent lamp. The average illuminating power determined by photometric test or by calculation in all directions from the source of light is called the spherical illuminating power, or if stated in candles is called the spherical candle power.

In photometry, luminous intensity is a measure of the wavelength-weighted power emitted by a light source in a particular direction per unit solid angle, based on the luminosity function, a standardized model of the sensitivity of the human eye. The SI unit of luminous intensity is the candela (cd), an SI base unit.

4. Why should we use solar cells?

Ans: • Low maintenance, long lasting sources of energy

• Provides cost-effective power supplies for people remote from the main electricity grid

• Non-polluting and silent sources of electricity

• Convenient and flexible source of small amounts of power

• Renewable and sustainable power, as a means to reduce global warming

4. Give some of the applications of solar cells.

Ans: • Toys, watches, calculators

• Electric fences

• Remote lighting systems

• Water pumping

• Water treatment

• Emergency power

• Portable power supplies

• Satellites

EXPERIMENT 3: PLANCK'S CONSTANT BY PHOTOCELL

CONTENTS

3.1 OBJECTIVES

To study the photoelectric effect and determine the value of Planck's constant 'h' by a photocell.

3.2 INTRODUCTION

If light is incident on certain metals, the electrons are emitted. These electrons are known as photo-electrons and the metal is known as photo-metal. The emission of electrons by the action of light (Photo) is called photo-electric effect.

It was found that negative particles were emitted by illuminated metallic surfaces. After Anton von Lenard measured the particles to have same charge to mass ratio as electrons then the term photo electron was coined.

3.3 APPARATUS

D.C. Power supply, Nanometer, Photocell with housing and mount, Optical bench, Mercury vapor lamp fitted in wooden box, Choke of mercury lamp, A set of optical filters (4900Å, 5400Å, 5800Å)

3.4 THEORY AND FORMULA USED

Light striking a metal surface stimulates electrons causing them to be emitted from the surface. We know that the energy from the light is $h\upsilon$. This energy, when absorbed by an electron will cause the electron to move from metal surface, will free the electron from metal's electrostatic pull (the work function ϕ) and imparts kinetic energy to the electron.

Thus, Maximum Kinetic energy = $h\upsilon - \phi$

Or $$h\upsilon = \phi + \frac{1}{2}mv^2 \qquad (1)$$

Where h is Planck's constant, υ is frequency of incident radiation, ϕ is work function and is constant for a material, m is mass of electron and v is velocity of electron.

Above equation (1) is known as Einstein Photo-Electric equation. It gives us the following information:

1. There should be a minimum frequency υ_0 called the threshold frequency at which photo energy becomes equal to work function and the photo electric effect ceases below this frequency.

2. The number of electron emitted by the photo metal is directly proportional to the received intensity.

3. Kinetic energy of the Photoelectrons is directly proportional to the frequency of incident radiation.

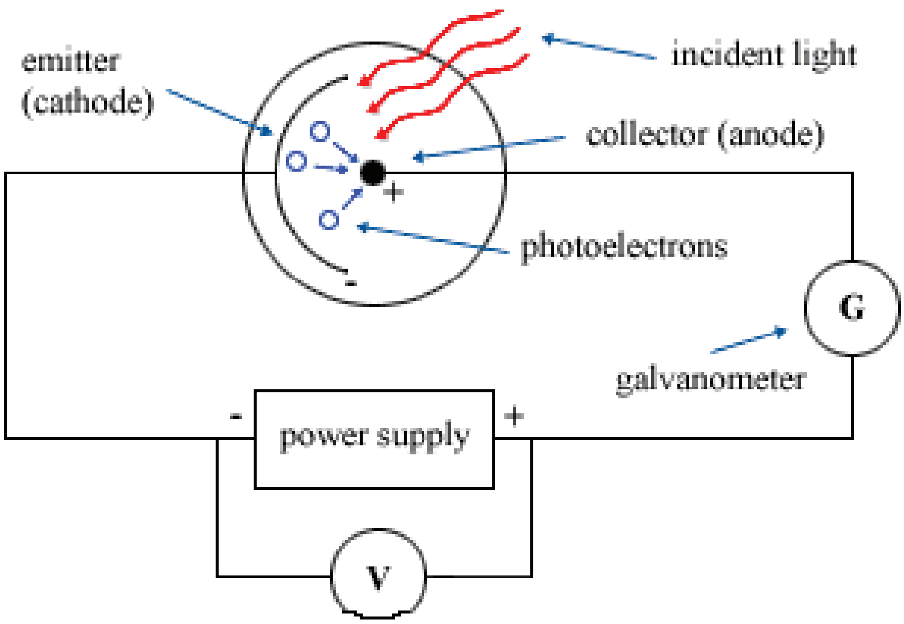


Figure 1: Circuit shows Photoelectric effect.

In the experiment, Light strikes an electron emitter (cathode) in the tube and the emitting electrons move to anode creating a current. Filters are placed in front of photoelectric tube which will allow a particular frequency of light to reach the emitter. A negative voltage is applied to anode creating a repulsive force against the incoming electrons (Anode is normally at a higher potential than the cathode, attracting the electrons. By making Anode more negative, the electrons begin to be repelled.)When the repulsive force is strong enough to block the electrons then the current will stop. This potential is known as the stopping potential (eV).

Thus equation (1) becomes $h\upsilon = \phi + eV$

If $\lambda_1 and \lambda_2$ be the wavelengths of light used to illuminate the cathode and $V_1 \& V_2$ be their respective stopping potentials then,

$$h\upsilon_1 = \phi + eV_1$$
$$h\upsilon_2 = \phi + eV_2$$
$$h(\upsilon_2 - \upsilon_1) = e(V_2 - V_1) \qquad (2)$$

We know that $\upsilon = \frac{c}{\lambda}$

Therefore above equation (2) becomes,

$$hc\frac{(\lambda_1 - \lambda_2)}{\lambda_1 \lambda_2} = e(V_2 - V_1)$$

$$\Rightarrow h = \frac{e(V_2 - V_1)\lambda_1 \lambda_2}{c(\lambda_1 - \lambda_2)}$$

Therefore, for any two wavelengths (i.e. for a pair of filter) λ_i and λ_j we can write:

$$\therefore h_{ij} = \frac{e(V_j - V_i)\left(\lambda_i \lambda_j\right)}{c(\lambda_i - \lambda_j)} \text{ Joule sec} \qquad (3)$$

We shall use this formula to find value of Planck's constant.

3.5 PROCEDURE

1. Put the Photo cell and source of light on the optical bench and align them.
2. Make proper connections of Planck's constant set up with the Photo-cell through the cable provided with the set up.
3. Switch 'ON' the Planck's constant set up and adjust the zero in the nanometer (Photo current meter) keeping the anode potential zero. Put a filter between the Photo cell and source of light.
4. Switch "ON" the Mercury bulb and adjust the slit to get some deflection in the photocurrent meter at zero anode potential.
5. Note this Photo current for zero anode potential and make table as shown below.
6. Apply a small negative potential on the anode say 50 mV with the help of knob, provided in the supply and measure the corresponding Photo current. Note this Photo current in the observation table.
7. Increase the negative anode potential (may be in step of 50 mV) and note the corresponding Photo current for same filter till it becomes zero.
8. Repeat the experiment for different light filters.
9. Plot a graph between negative anode potential on x axis and the corresponding Photo current on y-axis for different filters of wavelength of light.
10. Find the stopping potential for each wavelength from the graph.
11. Calculate the value of Planck's constant for each wavelength and find its mean.

3.6 OBSERVATION

S.No.	Negative Anode Potential (Volt.)	Corresponding Photo-current (nA)		
		Blue Filter 4900 Å	Green filter 5400 Å	Red filter 5800Å
1	0.0			
2	0.050			
3	0.100			
4	0.150			
5	0.200			
6	0.250			
7	0.300			
8	0.350			
9	0.400			
10	0.450			
11	0.500			
12	0.550			
13	0.600			
14	0.650			
15	0.700			
16	0.750			
17	0.800			
18	0.850			
19	0.900			
20	0.950			

3.7 CALCULATION

Graph:

Plot a graph between Negative Anode Potential (on X-axis) and the corresponding Photocurrent (on Y-axis) for different wavelengths of light and obtain the values of stopping potential for each wavelength.

Stopping potential for red filter V_1 = ... ….V.

Stopping potential for green filter V_2 = …………….V.

Stopping potential for blue filter V_3 = ……………….V.

Electronic charge $= 1.6x10^{-19}$ Coulomb

Velocity of light(c) = $3x10^8$ m/sec

Using equation (3) we can find different values of Planck's constant

$$h_{12} = \frac{e(V_2 - V_1)(\lambda_1\lambda_2)}{c(\lambda_1 - \lambda_2)} J \sec = ...J \sec$$

$$h_{23} = \frac{e(V_3 - V_2)(\lambda_1\lambda_3)}{c(\lambda_2 - \lambda_3)} J \sec = ...J \sec$$

$$h_{13} = \frac{e(V_3 - V_1)(\lambda_1\lambda_3)}{c(\lambda_1 - \lambda_3)} J \sec = ...J \sec$$

3.8 RESULT

Mean 'h'= $\frac{h_{12} + h_{23} + h_{13}}{3}$

= ....$J \sec$

Maximum Percentage Error:

Percentage error = (Observed value ~ Standard value) x 100 / Standard value

(Standard Value of Planck's constant (h) = 6.6262 x 10^{-34} Joule sec)

3.9 PRECAUTIONS AND SOURCES OF ERROR

1. The entire cathode surface should be uniformly illuminated since the same emitting surface may possess different emitting sensitivities at different portions of the surface.

2. Observation should be taken by altering anode potential in small steps(0.05volt)
3. Corresponding to zero anode potential the deflection of light spot on scale should be adjusted to its maximum value.
4. The experiment should be performed with at least three filters.
5. The stopping potential should be measured by the graph to avoid error that exists due to nonlinearity of the matter.
6. The slit of the photocell should be kept close after completing the experiment.
7. The photocell, source of light and filter should be aligned perfectly.
8. The slit of the photocell should not be kept very small.

3.10 SUMMARY

Photoelectric effect, phenomenon in which electrically charged particles are released from or within a material when it absorbs electromagnetic radiation. The effect is often defined as the ejection of electrons from a metal plate when light falls on it. In a broader definition, the radiant energy may be infrared, visible, or ultraviolet light, X rays, or gamma rays; the material may be a solid, liquid, or gas; and the released particles may be ions (electrically charged atoms or molecules) as well as electrons. The phenomenon was fundamentally significant in the development of modern physics because of the puzzling questions it raised about the nature of light—particle versus wavelike behavior—that were finally resolved by Albert Einstein in 1905. The effect remains important for research in areas from materials science to astrophysics, as well as forming the basis for a variety of useful devices.

Research showed that the photoelectric effect represents an interaction between light and matter that cannot be explained by classical physics, which describes light as an electromagnetic wave. One inexplicable observation was that the maximum kinetic energy of the released electrons did not vary with the intensity of the light, as expected according to the wave theory, but was proportional instead to the frequency of the light. What the light intensity did determine was the number of electrons released from the metal (measured as an electric current). Another puzzling observation was that there was virtually no time lag between the arrival of radiation and the emission of electrons.

Consideration of these unexpected behaviours led Albert Einstein to formulate in 1905 a new corpuscular theory of light in which each particle of light, or photon, contains a fixed amount of energy, or quantum, that depends on the light's frequency.

3.11 GLOSSARY

Illuminance – In photometry, illuminance is the total luminous flux incident on a surface, per unit area. It is a measure of how much the incident light illuminates the surface, wavelength-weighted by the luminosity function to correlate with human brightness perception.

Intensity – In physics, intensity is the power transferred per unit area, where the area is measured on the plane perpendicular to the direction of propagation of the energy. In the SI system, it has units watts per square metre.

Mercury vapor lamp –It is a gaseous lamp that consists of two bulbs, one within the other. The inner bulb is called the arc tube, which is made of quartz and the outer bulb serves to protect the arc tube. The arc tube contains argon gas and a small amount of pure mercury. Mercury lamps need a certain voltage to start up the arcs, which have an electrode on each end. Once there is a full voltage running from the starting electrode to the main electrode, the argon gas begins to become ionized by the electrons and an arc is formed between two electrodes, like a bridge. The heat produced from the arc vaporizes the mercury droplets, which become ionized as well. The mercury vapor now carries current within the arc. The current continues to increase to its full potential, which can be found in a mercury vapor lamp and hence serves as a resistor. So as the current is increasing, the ballast reduces the supply voltage simultaneously to keep the mercury-vapor lamp running under stable operation. As a result of the decreased voltage, a glow between the two electrodes is emitted within the arc tube. A mercury vapor lamp lasts longer than electric lights of similar wattages. But, mercury vapor lamps require five to seven minutes for it to reach its full brightness.

Photocell- The photo-metal as cathode and another electrode as anode enclosed in a glass bulb is known as a photocell. The experimental electrons are emitted by the Photo-metal by the action of light and attract by the anode and thus a photo current flows in the circuit.

Stopping Potential – A minimum negative anode potential at a particular frequency to stop the faster emitted electrons is known as Stopping Potential. Thus stopping potential is directly proportional to the frequency of incident radiation.

3.12 REFERENCES

1. Introduction to Physics, Cutnell, Johnson, Young, Stadler – Wiley India, 2017

2. Practical Physics, Gupta and Kumar – Pragati Prakashan, Meerut, 1985

3.13 VIVA-VOCE QUESTIONS AND ANSWERS

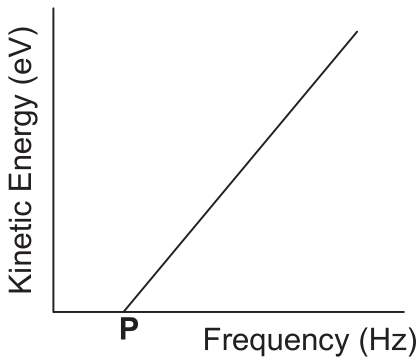
1. What is photoelectric effect?

Ans: The photoelectric effect is a phenomenon in physics. The effect is based on the idea that electromagnetic radiation is made of a series of particles called photons. When a photon hits an electron on a metal surface, the electron can be emitted. The emitted electrons are called photoelectrons.

2. What is the photo cell?

Ans: A device in which the photoelectric or photovoltaic effect or photoconductivity is used to produce a current or voltage when exposed to light or other electromagnetic radiation. They are used in exposure meters, burglar alarms, etc.

3. The graph below shows the relationship between the frequency of radiation incident on a photosensitive surface and the maximum kinetic energy of the emitted photoelectrons.



4. What does point P represent?

Ans: Threshold Frequency

5. The threshold frequency has a value of X. If the frequency of the incident light increases from 2X to 4X, then the resulting current of photoelectrons

A. is doubled
B. is increased by a factor or 3
C. reduced by half
D. remains the same

Ans: D.

Because current is proportional to the intensity of the incident light and not the threshold frequency.

EXPERIMENT 4: FOCAL LENGTH BY NODAL SLIDE

CONTENTS

4.1 OBJECTIVES

To determine the focal length of the combination of two lenses separated by a distance with the help of a nodal slide and then to verify the formula

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

where F is the focal length of the combination of two convex lenses of focal lengths f_1 and f_2, when they are separated by a distance d.

4.2 INTRODUCTION

The focal length of the combination of two lenses separated by a distance d is given by the formula

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

The focal point for the combined combination of lenses is a distance f from the secondary principal point of the second lens. If you are approximating the lenses as thin then the answer you're looking for is the distance from the second lens to the final focal point.

4.3 APPARATUS

Nodal slide assembly consisting of an optical bench comprising of four uprights – a bulb in a metallic container, cross-slits screen, nodal slide and plane mirror, and two convex lenses of nearly the same short focal lengths.

The function of the nodal slide is based on one property of nodal points of an optical system. According to this property, if an incident ray passes through first nodal point N_1 of an optical system, then after refraction through the system, the refracted ray necessarily emerges through its second nodal point N_2 in a direction parallel to the original direction.

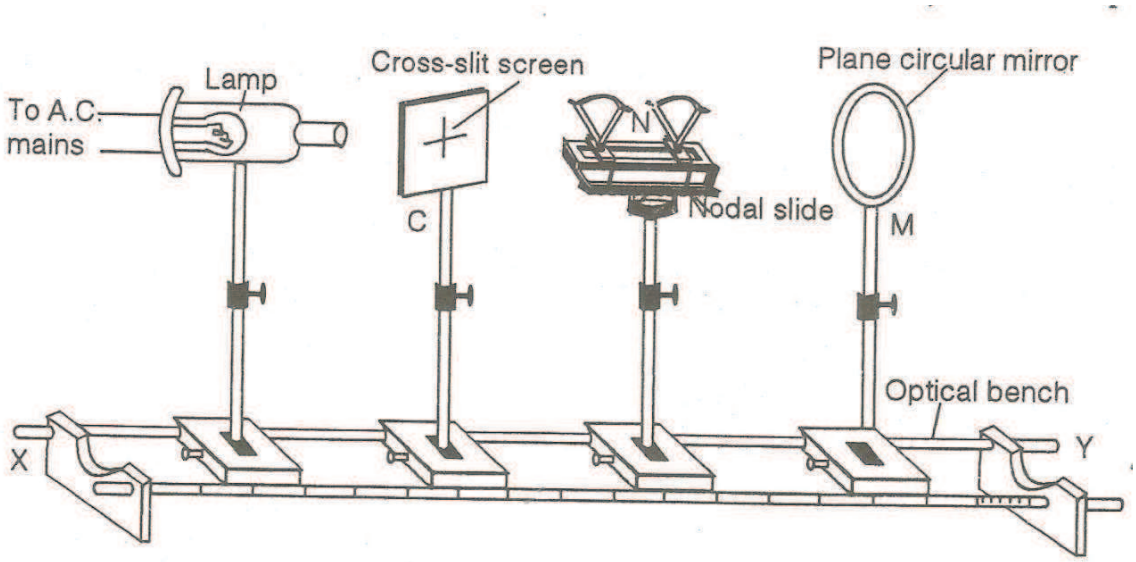


Figure 3: Experimental Setup

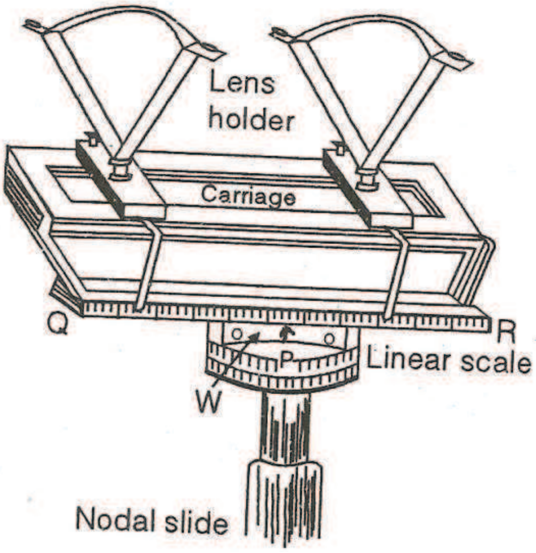


Figure 2: Nodal Slide

4.4 THEORY AND FORMULA USED

If f_1 and f_2 are the focal lengths of the two given convex lenses, separated by a distance 'd', then the focal length of the combined system is given by the relation

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

Thus, the determination of the focal length of the combination of the two lenses involves the separate measurements of focal lengths of the two lenses f_1 and f_2. Moreover, the verification of the focal length formula for the combination of two converging lenses system involves the measurement of F.

4.5 PROCEDURE

1. Mount a plane mirror, the nodal slide, the cross□slit screen holder and the lamp on the optical bench in such a way that their axis lies along the same horizontal line as illustrated in Figure 3.
2. Clamp one convex lens on the lens carriage at the centre of the nodal slide assembly. Adjust the position of the nodal slide until the distance between the lens and screen is approximately the focal length of the lens. Orient the mirror until the light from the object O on the screen, rendered parallel by the lens, is reflected back normally and forms an image I of the object O on the same screen. Move the nodal slide along the bench until the image I is sharply focused.
3. The lens carriage is now rotated through a small angle and it will be found that the image shifts sideward's to the right or the left. The lens carriage and the nodal slide upright are then adjusted such that the image remains stationary for a slight rotation of the lens carriage.
4. The distance between the screen and the axis of the rotation of nodal slide for no shift in the image measures the focal length of one face of the lens. The focal length of other face can be determined by the turning the nodal slide through 180° and repeating the experiment. The mean of focal length of both the faces is the focal length f_1 of one lens.
5. Repeat the above procedure with the other lens and determine the focal length f_2.
6. Now clamp both the lenses on the lens carriage at a known separation (d) in such a way that both the lenses are at equidistance from the centre of the nodal slide assembly, shown in Figure 4. Repeat the procedure with the combination of two lenses and determine the focal length F.
7. The procedure is repeated at least three times with changing the distance between the lenses.

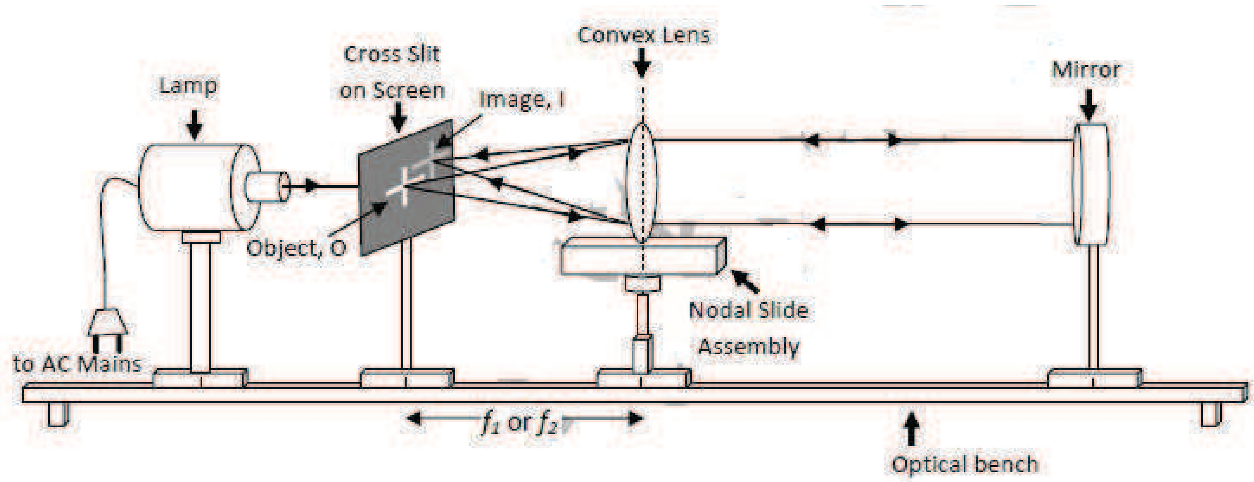


Figure 3: Experimental arrangement to observe focal length f_1 or f_2 of any one convex lens.

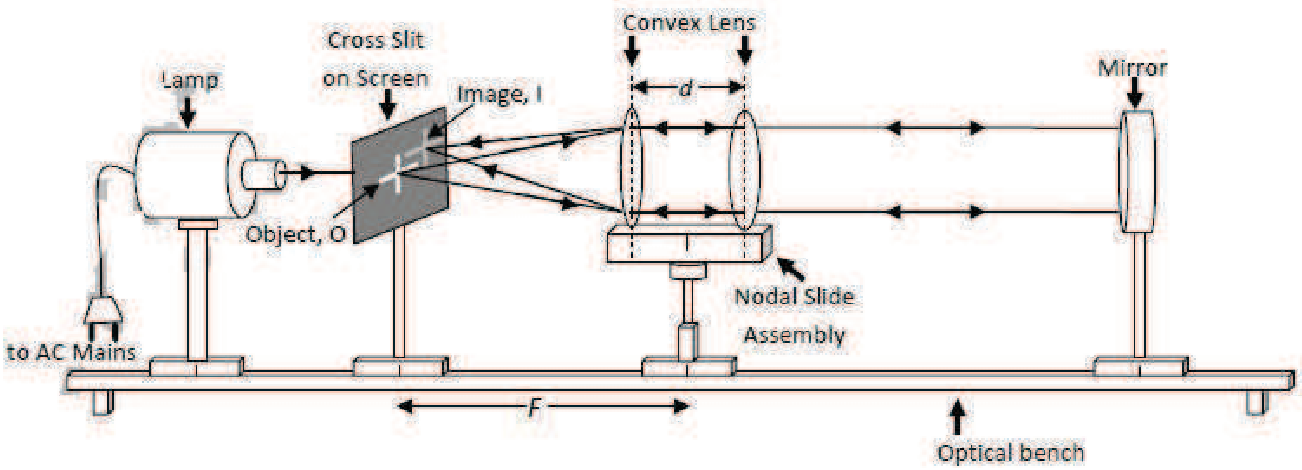


Figure 4: Experimental arrangement to observe focal length F of combination of two lenses.

4.6 OBSERVATION

(i) Table for determination of focal length f_1 and f_2 of two convex lenses:

Position of Lamp = …….. cm

Lens	Light incident on	Position of upright of (in cm)		Focal length of the lens = $(a - b)$	Mean focal length in cm
		Cross-slit (a)	Nodal Slide (b)		
First	One face				f_1 =
	Other face				
Second	One face				f_2 =
	Other face				

(ii) Table for determination of focal length *F* of combination of two convex lenses:

Position of Lamp = ……… cm

Sr. No.	Distance between two lenses d, in cm	Light incident on	Position of upright of (in cm)		Focal length of the combined lenses = $(a - b)$	Mean focal length F, in cm
			Cross-slit (a)	Nodal Slide (b)		
1	d_1 =	One face				F_1 =
		Other face				
2	d_2 =	One face				F_2 =
		Other face				
3	d_3 =	One face				F_3 =
		Other face				

4.7 CALCULATION

Theoretically, the focal length of a combination of two convex lenses is given by,

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

where F is the focal length of the combination of two convex lenses of focal lengths f_1 and f_2, when they are separated by a distance d. Hence, calculate the value of focal length for different distances using above formula.

Distance, d	Observed focal length (from Table ii)	Calculated focal length (from calculation)
d_1 =	F_1 =	F_1' =
d_2 =	F_2 =	F_2' =
d_3 =	F_3 =	F_3' =

4.8 RESULT

The values of calculated and observed focal lengths of combination of two lenses for each separation are matching nearly. Hence the expression for the focal length of a combination of two convex lenses is verified.

4.9 PRECAUTIONS AND SOURCES OF ERROR

1. The parallax should be removed very carefully and the stationary point is obtained.
2. All the uprights should be exactly at same height and at same horizontal axis.
3. The cross□slit must be properly illuminated by the intense light coming from the lamp.
4. The rotation of the nodal slide carriage about the vertical axis while testing stationary point of the image should not exceed by 5° or so.

5. Lenses should be of small aperture to get well defined and sharp image on the screen.
6. The mirror employed must be truly plane mirror.

4.10 SUMMARY

In many optical instruments there may be compound lenses, that is, two or more lenses in contact.

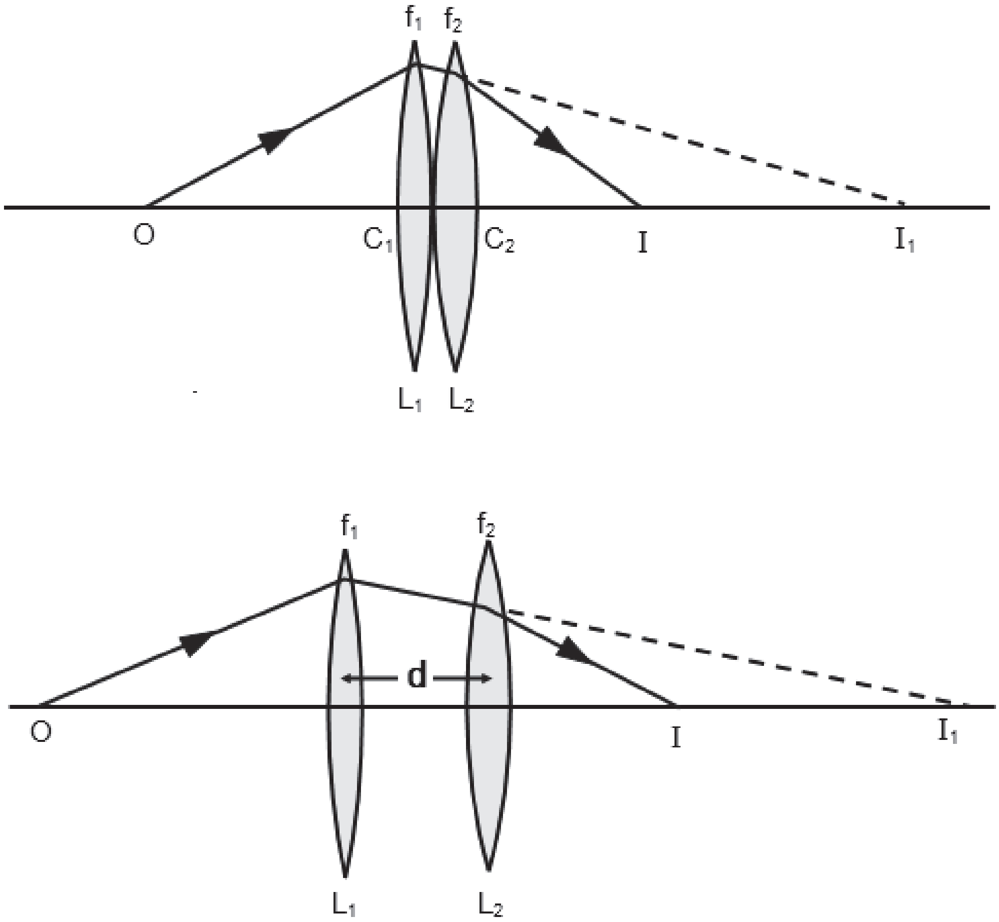


Figure 5

In the first case, when the two lenses are in contact, the combined focal length F is given by the formula

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

When the two lenses are separated by a distance d, the combined focal length of the combination of lenses is given by the following formula

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

4.11 GLOSSARY

Concave Lens – Concave lenses are thinner at the middle. Rays of light that pass through the lens are spread out (they diverge). A concave lens is a diverging lens. When parallel rays of light pass through a concave lens the refracted rays diverge so that they appear to come from one point called the principal focus.

A bi-concave lens is symmetrical across both its horizontal and vertical axis.

Convex Lens – Convex lenses are thicker at the middle. Rays of light that pass through the lens are brought closer together (they converge). A convex lens is a converging lens.

A bi-convex lens is symmetrical across both its horizontal and vertical axis.

Focal Length – The focal length of an optical system is a measure of how strongly the system converges or diverges light. For an optical system in air, it is the distance over which initially collimated (parallel) rays are brought to a focus. A system with a shorter focal length has greater optical power than one with a long focal length; that is, it bends the rays more sharply, bringing them to a focus in a shorter distance.

Nodal Slide – The nodal slide is an instrument used for locating and measuring the cardinal points of a lens or a system of lenses.

Principal Axis – a line passing through the centre of curvature of a lens or spherical mirror and parallel to the axis of symmetry.

Reflection – Reflection is the change in direction of a wavefront at an interface between two different media so that the wavefront returns into the medium from which it originated. Common examples include the reflection of light, sound and water waves.

Refraction – Refraction is the change in direction of wave propagation due to a change in its transmission medium. The phenomenon is explained by the conservation of energy and the conservation of momentum.

Refractive Index – In optics, the refractive index or index of refraction of a material is a dimensionless number that describes how light propagates through that medium.

4.12 REFERENCES

1. Introduction to Physics, Cutnell, Johnson, Young, Stadler – Wiley India, 2017

2. Engineering Physics Practical, S. K. Gupta – Krishna Prakashan Media, Meerut, 2010

4.13 sVIVA-VOCE QUESTIONS AND ANSWERS

1. A bi-convex lens of focal length 10 cm is fixed to a plano-concave lens of focal length 20 cm made of glass of the same refractive index. What is the focal length of the combination?

Ans: F = 10x(-20)/[10-20] = +20 cm

The focal length of the combination is positive and so it acts as a convex lens.

2. Why do you call it nodal slide?

Ans: It is so called because it is used to locate the nodal points of a lens system.

3. What do you mean by coaxial lens system?

Ans: A system of two or more lenses having common principal axis is called a coaxial lens system.

EXPERIMENT 5: LOCATION OF CARDINAL POINTS BY NODAL SLIDE METHOD

CONTENTS

5.1 OBJECT IVES

To locate the positions of cardinal points of a coaxial optical system of two thin convergent lenses separated by a distance, with the help of nodal slide and then to verify the formulae

$$L_1H_1 = +\frac{xF}{f_2} \quad and \quad L_2H_2 = -\frac{xF}{f_1}$$

where F is the focal length of the coaxial optical system of two thin convex lenses of focal lengths f_1 and f_2, when they are separated by a distance x.

5.2 INTRODUCTION

The cardinal points lie on the optical axis of the optical system. Each point is defined by the effect the optical system has on rays that pass through that point, in the paraxial approximation. The paraxial approximation assumes that rays travel at shallow angles with respect to the optical axis, so that $\sin\theta \approx \theta$and $\cos\theta \approx 1$.

Principal planes and points

The two principal planes have the property that a ray emerging from the lens appears to have crossed the rear principal plane at the same distance from the axis that the ray appeared to cross the front principal plane, as viewed from the front of the lens. This means that the lens can be treated as if all of the refraction happened at the principal planes. The principal planes are crucial in defining the optical properties of the system, since it is the distance of the object and image from the front and rear principal planes that determine the magnification of the system. The principal points are the points where the principal planes cross the optical axis.

If the medium surrounding the optical system has a refractive index of 1 (e.g., air or vacuum), then the distance from the principal planes to their corresponding focal points is just the focal length of the system. In the more general case, the distance to the foci is the focal length multiplied by the index of refraction of the medium.

For a thin lens in air, the principal planes both lie at the location of the lens. The point where they cross the optical axis is sometimes misleadingly called the optical centre of the lens. Note, however, that for a real lens the principal planes do not necessarily pass through the centre of the lens, and in general may not lie inside the lens at all.

Nodal points

The front and rear nodal points have the property that a ray aimed at one of them will be refracted by the lens such that it appears to have come from the other, and with the same angle with respect to the optical axis. The nodal points therefore do for angles what the principal planes do for transverse distance. If the medium on both sides of the optical system is the same (e.g., air), then the front and rear nodal points coincide with the front and rear principal points, respectively.

5.3 APPARATUS

Nodal slide assembly consisting of an optical bench comprising of four uprights – a bulb in a metallic container, cross-slits screen, nodal slide and plane mirror, and two convex lenses of nearly the same short focal lengths.

The function of the nodal slide is based on one property of nodal points of an optical system. According to this property, if an incident ray passes through first nodal point N_1 of an optical system, then after refraction through the system, the refracted ray necessarily emerges through its second nodal point N_2 in a direction parallel to the original direction.

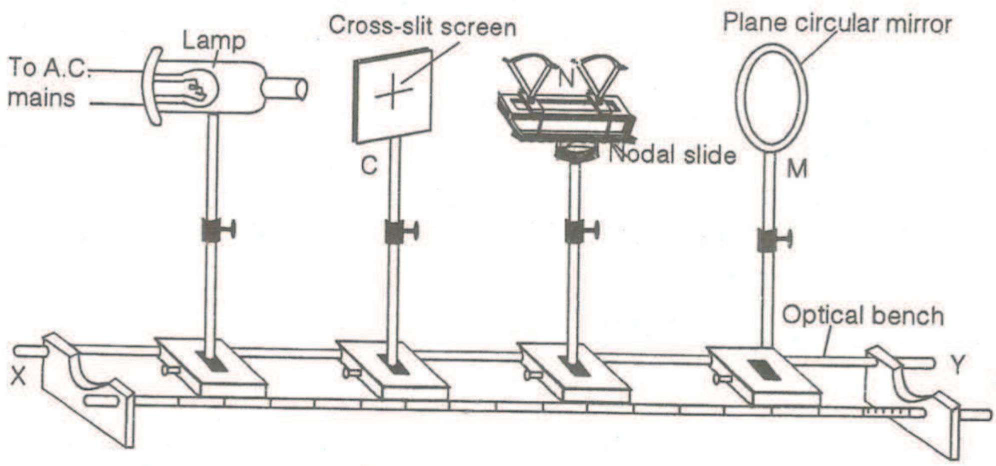


Figure 4: Experimental Setup

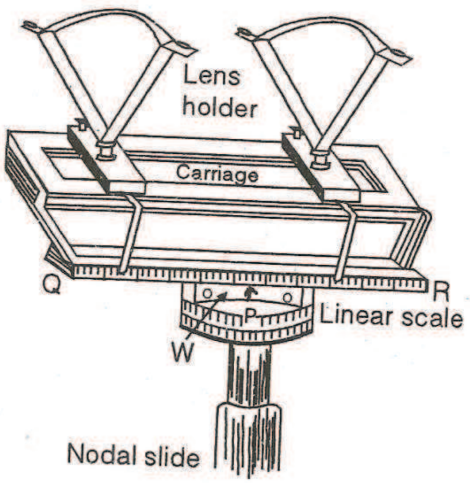


Figure 2: Nodal Slide

5.4 THEORY AND FORMULA USED

In a coaxial optical system of two thin convergent lenses, the medium on either side of the lenses and also between them is air; therefore, the nodal points coincide with the principal points. Hence, such an optical system has 4 cardinal points.

— Two principal points (H_1, H_2) or nodal points (N_1, N_2), and
— Two focal points (F_1, F_2)

1. The distance of the first principal point H_1 from the first lens L_1 is given by

$$L_1H_1 = +\frac{xF}{f_2}$$

2. The distance of the first principal point H_2 from the first lens L_2 is given by

5.5 PROCEDURE

1. Make all the adjustments in the apparatus and measure the focal lengths f_1 and f_2 of the two convergent lenses separately in a similar way as described in experiment 4.
2. Mount the convex lenses on the lens holders of the nodal slide such that the lens L_1 is towards the plane mirror and lens L_2 faces the cross-slits as shown in Figure 3.
3. Proceed as described in the previous experiment to measure the focal length of the combination of lenses. When the position of the nodal slide carriage and nodal slide upright are adjusted for no lateral shift, the cross-slit screen lies in the second focal plane and the nodal slide upright represents the second nodal plane of the lens system. Since the

nodal points coincide with the principal points, the distance between the lens L_2 and the principal point H_2 or axis of rotation $H_2 L_2$. Note this distance between lens L_2 and axis of rotation of nodal slide or nodal slide upright. The distance $H_2 F_2$ between the nodal slide upright (or axis of rotation of nodal slide) and cross-slit upright are recorded from their index marks on the optical bench. This is equal to the focal length F of the combination. By convention L_2H_2 is negative as it lies left to the lens L_2.

4. Now rotate the nodal slide carriage through 180^0 so that the positions of lenses L_1 and L_2 interchange. In this stage, L_1 faces the cross-slit and L_2 is towards the plane mirror. Again, obtain the position of no lateral shift of the image. Note the distance of the first principal point H_1 from the first lens L_1 by recording readings of their respective uprights. Also note the distance H_1F_1, that is the focal length of combination of two lenses when separated by distance x.
5. **Calculate the bench correction.** The distance measured between index marks of the cross-slits and nodal slide uprights may not be the same as the actual distance between pole of the lens or lens system and the center of the cross-slit. Thus, there is an error in the measurement of the focal length. To find the correct focal length, index correction or bench error is to be applied. To find the bench error, a glass rod of about 1 m is kept parallel to the bench such that its one end touches the center of the slit and the other to the center of the lens of optical system. Note the position index marks of the uprights on the optical bench. Let their difference be y, then

   Bench error = Actual distance or actual length of the rod – observed distance
   = (y – x) [+ve or –ve]

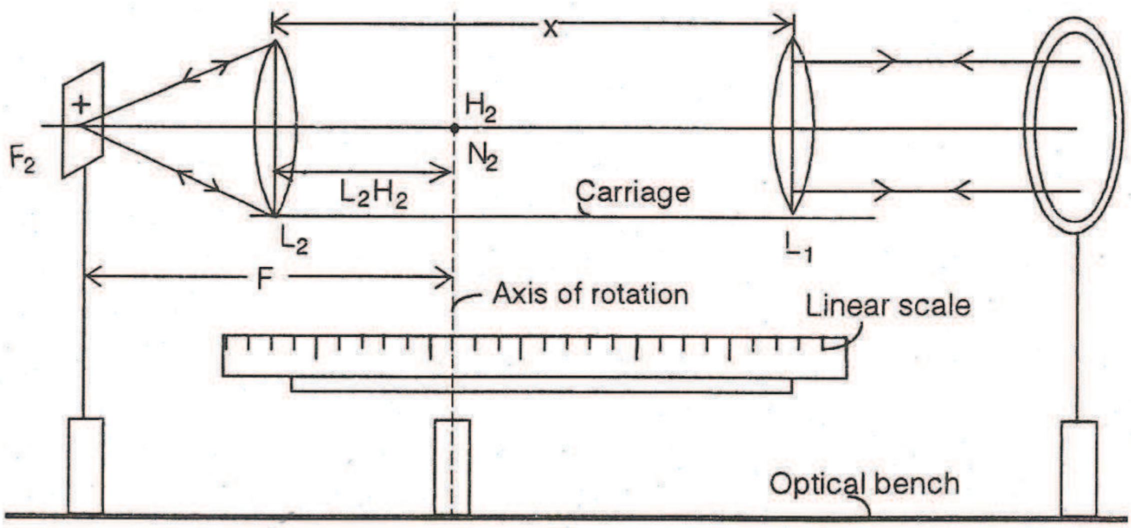


Figure 3: Experimental setup

5.6 OBSERVATION

(i) Table for the measurement of focal lengths of the two lenses

Length of glass rod, y = …….. cm

Observed distance between the cross-slits and nodal slide upright, x = ………. cm

Bench correction, y – x = ………….. cm

S.No.	Light incident on	For Lens L_1					For Lens L_2				
		Position of cross-slit upright (a) (cm)	Position of Lens upright (b) (cm)	Observed focal length f_1 (a – b) (cm)	Corrected focal length f_1 (cm)	Mean focal length f_1 (cm)	Position of cross-slit upright (a′) (cm)	Position of Lens upright (b′) (cm)	Observed focal length f_2 (a′ – b′) (cm)	Corrected focal length f_2 (cm)	Mean focal length f_2 (cm)
1.	One face of the lens	...	...	...	...		...	...	...	...	
	Other face of the lens	...	...	...	...		...	...	...	...	
2.	One face of the lens	...	...	...	...	...	...	...	...	...	...
	Other face of the lens	...	...	...	...		...	...	...	...	
3.	One face of the lens	...	...	...	...		...	...	...	...	
	Other face of the lens	...	...	...	...		...	...	...	...	

(ii) Table for determination of focal length *F* of the combination and distance L_1H_1 and L_2H_2:

Separation between the two lenses, x = …….. cm

Lens towards cross-slits	S.No.	Position of cross-slit (a) (cm)	Position of axis of rotation of nodal slide (b) (cm)	Focal length of combination F(a – b) (cm)	Mean F (cm)	Position of Lens (L) on Linear Scale attached to the carriage (cm)	Position of the axis of rotation of nodal slide or Principal point on the linear scale attached to the carriage H (cm)	Distance between Lens towards cross-slit and axis of rotation of nodal slide (cm)	Mean distance (cm) Practical value
L_1	1. 2. 3.	... ...	... ...	... ...	H_2F_2 = ... cm	... ...	... ...	... ...	L_2H_2 = ... cm
L_2	1. 2. 3.	... ...	... ...	... ...	H_1F_1 = ... cm	... ...	... ...	... ...	L_1H_1 = ... cm

5.7 CALCULATION

1. The mean focal length of the combination of two coaxial thin convex lenses F = ……cm
2. The theoretical value of L_1H_1 as obtained by the relation

$$L_1H_1 = +\frac{xF}{f_2} = +\_\_\_ cm$$

3. The theoretical value of L_2H_2 as obtained by the relation

$$L_2H_2 = -\frac{xF}{f_1} = +\_\_\_ cm$$

5.8 RESULT

The calculated and experimentally determined values of L_1H_1 and L_2H_2 are approximately the same and hence the formulae

$$L_1H_1 = +\frac{xF}{f_2} \quad and \quad L_2H_2 = -\frac{xF}{f_1}$$

are verified.

Location of Cardinal Points

To locate the cardinal points, sketch the two thin converging lenses at a known distance x as shown in Figure 4. Mark the positions of first and second nodal points H_1 and H_2 at a distance L_1H_1 from lens L_1 and L_2H_2 from lens L_2 on the common principal axis of the two lenses with proper sign. As the medium on both sides of the lenses are air, the principal points coincide with the nodal points, therefore, mark N_1 and N_2 on H_1 and H_2, respectively. Measure the distance H_1F_1 from H_1 and H_2F_2 from H_2 and locate focal points F_1 and F_2 with proper sign.

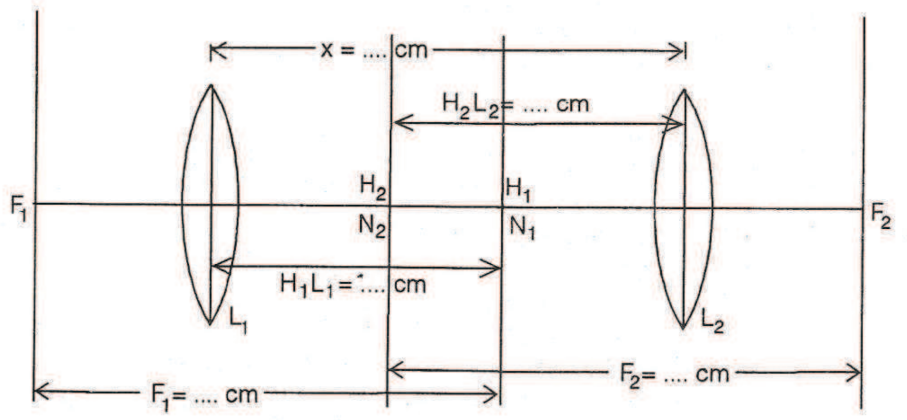


Figure 4

5.9 PRECAUTIONS AND SOURCES OF ERROR

1. All uprights arranged on the optical bench should be adjusted to the same height.
2. The cross-slits must be properly and intensely illuminated.
3. For obtaining well defined and sharp image of the cross-slit on the cross-slit screen, the aperture of the lens or lenses should be taken small.
4. For searching nodal points on the principal axis of the lens system or lens, the rotation of the nodal slide about the vertical axis should not exceed 5^0 or so.
5. The mirror used in the experiment should be truly plane.
6. The position of no shift should be precisely determined.
7. Bench error should be properly accounted for.
8. To avoid false images, the plane mirror is slightly turned, which turns the genuine image while the false image will remain stationary.

5.10 SUMMARY

The points on the optical axis *OO'* (see Figure 4) of a centered optical system that can be used to construct the image of an arbitrary point in space for objects in the paraxial region, which is the region around the axis of symmetry of the system where a point is represented by a point, a straight line by a straight line, and a plane by a plane.

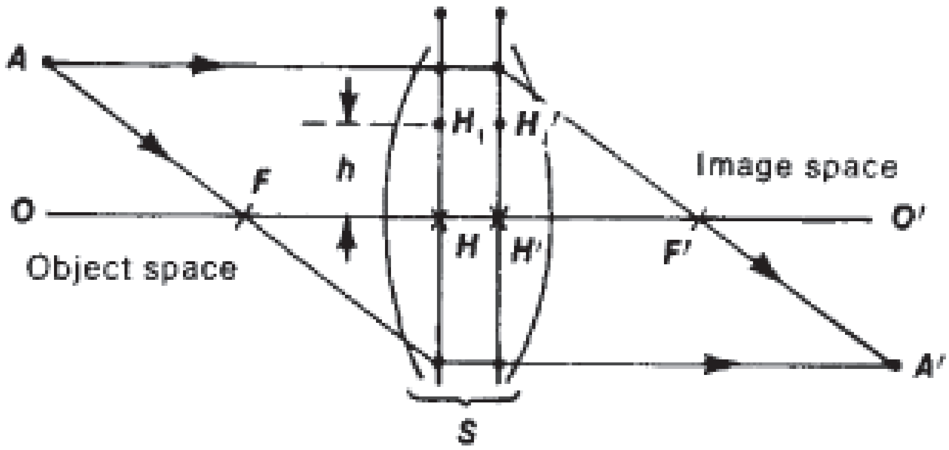


Figure 5: Position of the image *A'* of an arbitrary point *A* projected by an optical system S can be found if the cardinal points *F, F', H*, and *H'* of the system are known: a ray passing through the front focus *F* is directed by the system parallel to its optical axis *OO'*, and a ray that is incident upon the system parallel to the axis *OO'* is directed through the back focus *F'* after refraction

There are four cardinal points in an optical system: the front and back foci *F* and *F'* and the front and back principal points *H* and *H'*. The back focus is the image of an infinitely remote point located on the optical axis in the object space, and the front focus is the image in the object space of an infinitely remote point in the image space. The principal points are the points of intersection with the optical axis of the principal planes, which are the planes for which the optical system *S* produces full-size mutual images (every point H_1 located in the principal plane HH_1 at a distance *h* from the axis *OO'* appears in the other principal plane $H' H'_1$ as the point H'_1 at the same distance *h* from the axis as point H_1).

The distance from point *H* to point *F* is called the front focal distance (negative in the figure), and the distance from point H' to point *F'* is called the back focal distance (positive in the figure).

The construction of an image *A'* of an arbitrary point *A* for a centered optical system using the points *F, H, H'*, and *F'* is shown in Figure 4.

5.11 GLOSSARY

Concave Lens – Concave lenses are thinner at the middle. Rays of light that pass through the lens are spread out (they diverge). A concave lens is a diverging lens. When parallel rays of light pass through a concave lens the refracted rays diverge so that they appear to come from one point called the principal focus.

A bi-concave lens is symmetrical across both its horizontal and vertical axis.

Convex Lens – Convex lenses are thicker at the middle. Rays of light that pass through the lens are brought closer together (they converge). A convex lens is a converging lens.

A bi-convex lens is symmetrical across both its horizontal and vertical axis.

Focal Length – The focal length of an optical system is a measure of how strongly the system converges or diverges light. For an optical system in air, it is the distance over which initially collimated (parallel) rays are brought to a focus. A system with a shorter focal length has greater optical power than one with a long focal length; that is, it bends the rays more sharply, bringing them to a focus in a shorter distance.

Nodal Slide – The nodal slide is an instrument used for locating and measuring the cardinal points of a lens or a system of lenses.

Principal Axis – a line passing through the centre of curvature of a lens or spherical mirror and parallel to the axis of symmetry.

Reflection – Reflection is the change in direction of a wavefront at an interface between two different media so that the wavefront returns into the medium from which it originated. Common examples include the reflection of light, sound and water waves.

Refraction – Refraction is the change in direction of wave propagation due to a change in its transmission medium. The phenomenon is explained by the conservation of energy and the conservation of momentum.

Refractive Index – In optics, the refractive index or index of refraction of a material is a dimensionless number that describes how light propagates through that medium.

5.12 REFERENCES

1. Introduction to Physics, Cutnell, Johnson, Young, Stadler – Wiley India, 2017

2. Engineering Physics Practical, S. K. Gupta – Krishna Prakashan Media, Meerut, 2010

5.13 VIVA-VOCE QUESTIONS AND ANSWERS

1. What are cardinal points of an optical system?

Ans: There are six cardinal points of an optical system, namely:

a) Two focal points
b) Two principal points
c) And two nodal points

2. What is the importance of cardinal points of the coaxial optical system?

Ans: By the knowledge of cardinal points, one can treat the optical system of coaxial lenses as a single lens and the position and size of the image of an object may directly be obtained by using simple formulae developed for thin lenses without considering refraction through each component of the system separately.

3. Under what condition, the six cardinal points of an optical system reduces to four?

Ans: If the medium on either side of the optical system and also between the lenses is same (or air), the nodal points coincide with the principal points. Hence, the six cardinal points reduces to four.

EXPERIMENT 6: HARTMANN'S FORMULA USING PRISM SPECTROMETER

CONTENTS

6.1 OBJECTIVES

To verify Hartmann's dispersion formula using a constant deviation spectrometer.

6.2 INTRODUCTION

Hartmann's dispersion formula is a semi-empirical formula relating the index of refraction n and wavelengths λ. It is also referred to as Cornu-Hartmann formula.

6.3 APPARATUS

Constant deviation spectrometer, mercury lamp, sodium lamp, reading lamp and reading lens.

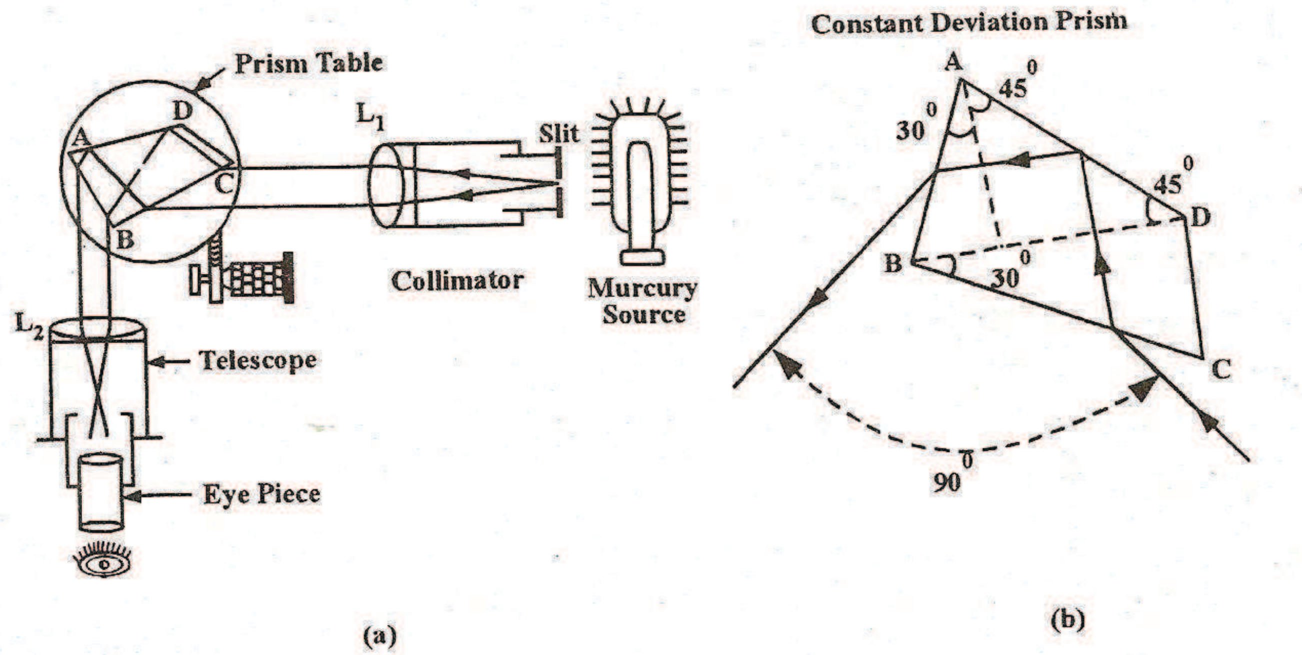


Figure 1: (a) Constant Deviation Spectrometer; (b) Constant Deviation Prism.

6.4 THEORY AND FORMULA USED

Hartmann suggested an equation for the wavelength of the spectral line which is at a distance x from a fixed mark in the spectrum and is known as Hartmann's dispersion formula.

It is given by

$$\lambda = A + \frac{B}{x - C}$$

where A, B and C are constants.

6.5 PROCEDURE

8. Place the sodium lamp before the collimator. Open the slit widely and see it through the telescope tube (without eye piece).
9. Adjust the position and height of the lamp to get the image in the center of he prism face.
10. Remove the dust particles if any and narrow the slit to have a fine pencil of rays.
11. Set the wavelength drum at 5890 A^0 (D_1 or D_2 marked on the drum). Focus the eye piece. If the image of the spectral line viewed in the eye piece is far removed from the center of the field of view of the eye piece, the constant deviation prism requires setting. If the image of the spectral line is near the center, do not move the prism. A minor adjustment by means of screws provided with the eye piece is sufficient. The spectrometer is now set up.
12. Replace the sodium lamp by the mercury lamp, which provides a number of lines of accurately known wavelengths in the visible spectrum. Note these wavelengths from the standard tables.
13. Rotate the wavelength drum to bring the spectral lines in turn to coincide with the cross-wire or the pointer in the field of view of the eye piece. Read and record the wavelengths of the visible spectral lines on the drum. Now compare these wavelengths with the standard wavelengths noted from the table.
14. With the help of the drum, adjust the spectrum in the field of view (if whole of the spectrum does not come in the field of view, divide it into two parts). Note down the position of the lines on the micrometer scale attached with the eye piece.

6.6 OBSERVATION

Table for the measurement of wavelength of spectral lines and their positions

Wavelength of spectral lines	Positions of spectral lines
$\lambda_1 =$	$x_1 =$
$\lambda_2 =$	$x_2 =$
$\lambda_3 =$	$x_3 =$

6.7 CALCULATION

Consider three conveniently spaced lines of known wavelengths λ_1, λ_2 and λ_3. Their positions x_1, x_2 and x_3 are noted on the micrometer scale attached with the eye piece (or a travelling microscope).

Using the relation

$$\lambda_1 = A + \frac{B}{x_1 - C}, \quad \lambda_2 = A + \frac{B}{x_2 - C}, \quad \lambda_3 = A + \frac{B}{x_2 - C}$$

A, B and C are calculated.

Now using the values of A, B and C, the wavelengths of other spectral lines are calculated with the Hartmann's dispersion formula by substituting the observed values of x for these lines.

6.8 RESULT

The wavelengths so obtained are compared with the drum's readings and the values given in the standard tables. Since, the values are very close to the required or expected values, hence the Hartmann's formula is verified.

6.9 PRECAUTIONS AND SOURCES OF ERROR

7. The mechanical and optical adjustments of the telescope must be made carefully and correctly.
8. While taking observations, the prism table and telescope must keep clamped.
9. The prism should be placed properly and correctly on the prism table.
10. Telescope should be rotated in the same direction.
11. While taking observations, the prism table and the telescope should never be unclamped together.

6.10 SUMMARY

A simple interpolation formula for the prismatic spectrum was proposed by J. Hartmann in Astrophysical Journal, vol. 8, p.218. In this experiment, we compare the wavelengths obtained with the drum's readings and the values given in the standard tables. Because, the values are very close to the required or expected values, the Hartmann's formula is deemed to be true.

6.11 GLOSSARY

Collimator – A collimator is a device that narrows a beam of particles or waves. To narrow can mean either to cause the directions of motion to become more aligned in a specific direction (i.e., make collimated light or parallel rays), or to cause the spatial cross section of the beam to become smaller (beam limiting device).

Dispersion – the separation of white light into colours or of any radiation according to wavelength.

Prism – Prisms can be made from any material that is transparent to the wavelengths for which they are designed. Typical materials include glass, plastic, and fluorite. A dispersive prism can be used to break light up into its constituent spectral colors (the colors of the rainbow).

Refraction – Refraction is the change in direction of wave propagation due to a change in its transmission medium. The phenomenon is explained by the conservation of energy and the conservation of momentum.

Refractive Index – In optics, the refractive index or index of refraction of a material is a dimensionless number that describes how light propagates through that medium.

Semi-empirical – partly empirical; especially involving assumptions, approximations, or generalizations designed to simplify calculation or to yield a result in accord with observation.

Spectral Line – A spectral line is a dark or bright line in an otherwise uniform and continuous spectrum, resulting from emission or absorption of light in a narrow frequency range, compared with the nearby frequencies. Spectral lines are often used to identify atoms and molecules.

Spectrometer – an apparatus used for recording and measuring spectra, especially as a method of analysis.

Spectrum – Spectrum, in optics, the arrangement according to wavelength of visible, ultraviolet, and infrared light. An instrument designed for visual observation of spectra is called a spectroscope; an instrument that photographs or maps spectra is a spectrograph.

Wavelength – the distance between successive crests of a wave, especially points in a sound wave or electromagnetic wave.

6.12 REFERENCES

1. Introduction to Physics, Cutnell, Johnson, Young, Stadler – Wiley India, 2017

2. University Practical Physics, D. C. Tayal – Himalaya Publishing House, 2000

6.13 VIVA-VOCE QUESTIONS AND ANSWERS

1. Can we identify each element with a constant deviation spectrometer?

Ans: An unknown element can be identified with its characteristic spectral lines.

2. What is the use of a spectrometer and what are its main components?

Ans: The spectrometer is an instrument used to obtain a pure spectrum. It has three components:

(a) Collimator
(b) Telescope
(c) Prism Table

3. What is a travelling microscope?

Ans: A travelling microscope is an instrument for measuring length with a resolution typically in the order of 0.01mm. The precision is such that better-quality instruments have measuring scales made from Invar to avoid misreadings due to thermal effects. The instrument comprises a microscope mounted on two rails fixed to, or part of a very rigid bed. The position of the microscope can be varied coarsely by sliding along the rails, or finely by turning a screw. The eyepiece is fitted with fine cross-hairs to fix a precise position, which is then read off the vernier scale.

4. How are spectra classified?

Ans: Spectra may be classified according to the nature of their origin, i.e., emission or absorption.

An emission spectrum consists of all the radiations emitted by atoms or molecules, whereas in an absorption spectrum, portions of a continuous spectrum (light containing all wavelengths) are missing because they have been absorbed by the medium through which the light has passed; the missing wavelengths appear as dark lines or gaps.

The spectrum of incandescent solids is said to be continuous because all wavelengths are present. The spectrum of incandescent gases, on the other hand, is called a line spectrum because only a few wavelengths are emitted. These wavelengths appear to be a series of parallel lines because a slit is used as the light-imaging device. Line spectra are characteristic of the elements that emit the radiation. Line spectra are also called atomic spectra because the lines represent wavelengths radiated from atoms when electrons change from one energy level to another. Band spectra is the name given to groups of lines so closely spaced that each group appears to be a band, e.g., nitrogen spectrum. Band spectra, or molecular spectra, are produced by molecules radiating their rotational or vibrational energies, or both simultaneously.

EXPERIMENT 7: VERIFICATION OF CAUCHY'S DISPERSION FORMULA

CONTENTS

7.1 OBJECTIVES

To find the refractive index and Cauchy's constants of a prism using spectrometer.

7.2 INTRODUCTION

Cauchy's equation is an empirical relationship between the refractive index and wavelength of light for a particular transparent material. It is named for the mathematician Augustin-Louis Cauchy, who defined it in 1836.

Principle: It is based on the phenomenon of dispersion of light, is split or dispersed into different colors, when it passes through a prism. Shorter wavelengths (like blue) bend the most while longer wavelengths (like red) bend the least.

7.3 APPARATUS

Spectrometer, prism, mercury lamp, spirit level.

Spectrometer Design:

<u>The Collimator:</u> The collimator C consists of two hollow concentric metal tubes, one being longer than other. The longer tube carries an achromatic lens L at one end and the smaller tube at the other end. The smaller tube is provided with a slit at the outer end and can be moved in our out the longer tube with the help of rack and pinion arrangement. The slit is adjusted in the focal plane of the lens L to obtain a pencil of parallel rays from the collimator when light is allowed to be incident upon the slit. The collimator is also provided with two screws for adjusting inclination of the axis of the collimator. This is rigidly fixed to the main part of the apparatus.

<u>The Prism Table:</u> It is a circular table supported horizontally in the center of the instrument and the position can be read with the help of two verniers attached to it and moving over a graduated circular scale carried by the telescope. The leveling of the prism table is made with the help of three screws provided at the lower surface. The table can be raised or lowered and clamped in any desired position with the help of a screw. The prism table is also provided with tangent screws for a slow motion. There are concentric circles and straight lines parallel to the line joining two of the leveling screws on the prism table.

<u>The Telescope:</u> The telescope consists of similar tubes as in case of collimator carrying achromatic objective lens O at one end and eyepiece E on the another side end. The eyepiece tube can be taken in or out with the help of rack and pinion arrangement. Two cross wire are focused on the focus of the eyepiece. The telescope can be clamped to the main body of the instrument and can be moved slightly by tangent screws. The telescope is attached to the main scale and when it rotates, the graduated scale rotates with it. The inclination of telescope is adjusted by two screws provided at the lower surface.

7.4 THEORY AND FORMULA USED

(i) The refractive index of the material of the prism is given by the formula.

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

(ii) Variation of refractive index with wavelength may be represented by the Cauchy's relation

$$\mu = A + \frac{B}{\lambda^2}$$

Where A and B are the Cauchy's constant and can be determined as

$$B = \mu_1 - \mu_2 / \frac{1}{\lambda_1^2} - \frac{1}{\lambda_2^2} \text{..........}cm^2, A = \mu_1 - \frac{B}{\lambda_1^2} = \mu_2 - \frac{B}{\lambda_2^2} \text{....}cm^2$$

7.5 PROCEDURE

1. Adjust the spectrometer for parallel rays.
2. Determine the least count of the spectrometer.
3. Place the prism on the prism table with its refracting edge at the centre and towards the collimator as shown in Fig. 1.
4. The light reflected from each of the two polished faces is observed through the telescope. The image of the slit so formed is focused on the cross-wire and the two positions of the telescope are noted. The difference of the two readings gives twice the angle of the prism i.e. 2α.
5. Now place the prism such that its centre coincides with the centre of the prism table and the light falls on one of the polished face (Fig.2).

6. The spectrum obtained out of the other face is observed through the telescope. Set the telescope at particular color. Rotate the prism table in one direction adjusting the telescope simultaneously to keep the spectral line in view. On continuing this rotation in the same direction, a position will come where the spectral lines recede in the opposite direction. This position where the spectrum turns away is the minimum deviation position for this color. Lock the prism table and note the readings of the verniers.
7. Set the telescope crosswire on another color and again note the vernier readings. Take this observation for various colors.
8. Removal the prism and see the slit directly through the telescope. Set the slit on the crosswire and note the readings of the verniers.
9. The difference in minimum deviation positions of various colors and direct positions of the slit give the angles of minimum deviation for corresponding colors.

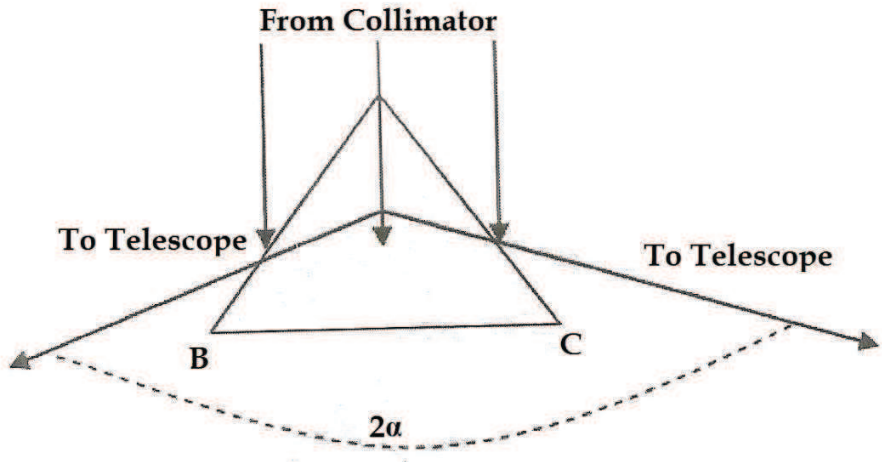


Figure 5

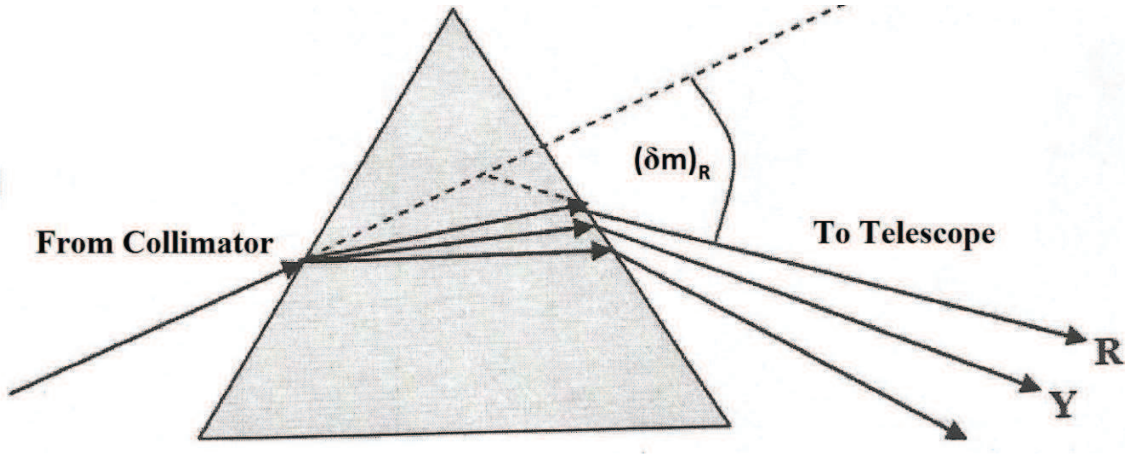


Figure 6

7.6 OBSERVATION

(a) Determination of the least count of the Spectrometer.
Value of one Main Scale Division x = Degree
Total number of divisions in circular scale, n =
Hence, least count of the microscope screw = x/n = Degree

(b) Table for the angle of Prism (A)

Verniers	Telescope Readings for Reflection from						Difference 2A=b-a Degree	Angle of Prism(A) Degree	Mean A Degree
	First face (a) Degree			Second face (b) Degree					
	M.S.	V.S.	Total Degree	M.S.	V.S.	Total Degree			
V1									
V2									

(c) Table for angle of minimum deviation (δm)

Color	Vernier	Telescope Readings for						Difference δm = b-a Degree	Mean δm Degree
		Dispersed image			Direct image				
		M.S.	V.S.	Total Degree	M.S.	V.S.	Total Degree		
Blue	V1								

	V2								
Green	**V1**								
	V2								

7.7 CALCULATIONS

Using formula from equation (3) we can calculate the values of refractive index, μ, for all the colors. Refractive index for the material of the prism for different wavelengths is given in the following table

Sr. No.	**Color**	**Standard Wavelength λ in Å**	**Refractive index, μ**
1	Blue	4693	
2	Green	5461	

Using any two values of wavelengths and μ for two colors, we get the values of B and A by using equations (2a) and (2b) respectively.

7.8 RESULT

(i) The refractive indices of the material of prism for various colors are in table above.
(ii) The Cauchy's constants are A = and B =

7.9 PRECAUTIONS AND SOURCES OF ERROR

(i) Spectrometer leveling and adjustments should be properly done.
(ii) The slit should be sharp and vertical
(iii) The position of angle of minimum deviation should be accurately determined.
(iv) The refracting surfaces of the prism should not be touched with fingers.

7.10 SUMMARY

When an electromagnetic wave is incident on an atom or a molecule, the periodic electric force of the wave sets the bound charges into vibratory motion. The frequency with which these charges are forced to vibrate is equal to the frequency of the wave. The phase of this motion as compared to the impressed electric force will depend on the impressed frequency. It will vary with the difference between the impressed frequency and the natural frequency of the charges.

Dispersion can be explained with the concept of secondary waves that are produced by the induced oscillations of the bound charges. When a beam of light propagates through a transparent medium (solid or liquid), the amount of lateral scattering is extremely small. The scattered waves travelling in a lateral direction produce destructive interference.

However, the secondary waves travelling in the same direction as the incident beam superimpose on one another. The resultant vibration will depend on the phase difference between the primary and the secondary waves. This superimposition, changes the phase of the primary waves and this is equivalent to a change in the wave velocity. Wave velocity is defined as the speed at which a condition of equal phases is propagated. Hence the variation in phase due to interference, changes the velocity of the wave through the medium. The phase of the oscillations and hence that of the secondary waves depends upon the impressed frequency. It is clear, therefore, that the velocity of light in the medium varies with the frequency of light. Also refractive index depends upon the velocity of light in the medium. Therefore the refractive index of the medium varies with the frequency (wavelength) of light.

Cauchy's equation is an empirical relationship between the refractive index and wavelength of light for a particular transparent material. It is named for the mathematician Augustin-Louis Cauchy, who defined it in 1836. The theory of light-matter interaction on which Cauchy based this equation was later found to be incorrect. In particular, the equation is only valid for regions of normal dispersion in the visible wavelength region. In the infrared, the equation becomes inaccurate, and it cannot represent regions of anomalous dispersion. Despite this, its mathematical simplicity makes it useful in some applications.

The Sellmeier equation is a later development of Cauchy's work that handles anomalously dispersive regions, and more accurately models a material's refractive index across the ultraviolet, visible, and infrared spectrum.

7.11 GLOSSARY

Dispersion – the separation of white light into colors or of any radiation according to wavelength. It is the phenomenon in which the phase velocity of a wave depends on its frequency.

Prism – Prisms can be made from any material that is transparent to the wavelengths for which they are designed. Typical materials include glass, plastic, and fluorite. A dispersive prism can be used to break light up into its constituent spectral colors (the colors of the rainbow).

Refraction – Refraction is the change in direction of wave propagation due to a change in its transmission medium. The phenomenon is explained by the conservation of energy and the conservation of momentum.

Refractive Index – In optics, the refractive index or index of refraction of a material is a dimensionless number that describes how light propagates through that medium.

Spectrometer – an apparatus used for recording and measuring spectra, especially as a method of analysis.

Spectrum – Spectrum, in optics, the arrangement according to wavelength of visible, ultraviolet, and infrared light. An instrument designed for visual observation of spectra is called a spectroscope; an instrument that photographs or maps spectra is a spectrograph.

Wavelength – the distance between successive crests of a wave, especially points in a sound wave or electromagnetic wave.

Wave Interference – In physics, interference is a phenomenon in which two waves superpose to form a resultant wave of greater, lower, or the same amplitude.

7.12 REFERENCES

1. Introduction to Physics, Cutnell, Johnson, Young, Stadler – Wiley India, 2017s

2. University Practical Physics, D. C. Tayal – Himalaya Publishing House, 2000

7.13 VIVA-VOCE QUESTIONS AND ANSWERS

1. What are the values of A and B in the Cauchy's dispersion formula depend on?

Ans: The values of A and B, the Cauchy's constants, depend on the medium and can be determined for a material by fitting the equation to measured refractive indices at known wavelengths.

2. Does the refractive index of a medium decreases or increases with an increase in the wavelength of light?

Ans: It is evident that the refractive index of the medium decreases with increase in wavelength of light.

3. What are some of the desirable and undesirable effects of dispersion vis-à-vis optical applications?

Ans: Material dispersion can be a desirable or undesirable effect in optical applications.

The dispersion of light by glass prisms is used to construct spectrometers and spectroradiometers. Holographic gratings are also used, as they allow more accurate discrimination of wavelengths.

However, in lenses, dispersion causes chromatic aberration, an undesired effect that may degrade images in microscopes, telescopes, and photographic objectives. In optics, chromatic aberration (abbreviated CA; also called chromatic distortion and spherochromatism) is an effect resulting from dispersion in which there is a failure of a lens to focus all colors to the same convergence point. It occurs because lenses have different refractive indices for different wavelengths of light. The refractive index of transparent materials decreases with increasing wavelength in degrees unique to each.

EXPERIMENT 8: DISPERSIVE POWER OF A PRISM

CONTENTS

8.1 OBJECT IVES

To determine the dispersive power of the material of the prism with the help of a spectrometer.

8.2 INTRODUCTION

Dispersive power is basically a measure of the amount of difference in the refraction of the highest and lowest wavelengths that enter the prism. This is expressed in the angle between the two extreme wavelengths (i.e. Red and Violet). The greater the dispersive power, the greater the angle between them, and vice-versa.

8.3 APPARATUS

Spectrometer, mercury lamp (white light source), prism, spirit level, electric lamp and reading lamp.

8.4 THEORY AND FORMULA USED

If μ_v, μ_r and μ_y be the refractive indices of the material of the prism for violet, red and yellow colors, respectively, then the dispersive power ω of the material of prism is given by

$$\omega = \frac{\mu_v - \mu_r}{\mu_y - 1}$$

The refractive index of the material of prism for a particular wavelength is given by

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

where A is the refracting angle of the prism and δ_m is the angle of minimum deviation for the ray of given wavelength.

Therefore, the determination of dispersive power of a material of prism involves the measurements of refracting angle of the prism A and the angles of minimum deviation δ_m for violet, yellow and red colors.

8.5 PROCEDURE

1. DO NOT PLACE THE PRISM ON THE SPECTROMETER YET.
2. First check leveling of the spectrometer base, prism table, collimator and telescope. If needed, level them using the adjustment screws and a spirit level.
3. The collimator is adjusted for parallel beam of light and the telescope for focusing the parallel beam by Schuster's method (details of which is given in another experiment). But the present set up may not require it.
4. **Adjusting the telescope:** While looking through the telescope, slide the eyepiece in and out until the crosswire comes into sharp focus. Point the telescope at some distant object and view it through the telescope. Turn the focus knob of telescope until the image is sharp. The telescope is now focused for parallel light rays. DO NOT change the focus of the telescope henceforth.
5. Ensure the Hg lamp is fully illuminated and placed close to the slit of the collimator. Check that the slit is partially open.
6. **Adjusting the collimator:** Align the telescope directly opposite the collimator and look through the telescope, to see a focused image of the slit. If necessary, adjust the slit width until the image of the slit as seen through the telescope is sharply focused on the crosswire. The collimator is then set to produce parallel light from the slit.
7. Determine the vernier constant of the spectrometer. Report all the angles in degree unit. Details about reading angles in spectrometer are given in the manual for finding angle of minimum deviation.

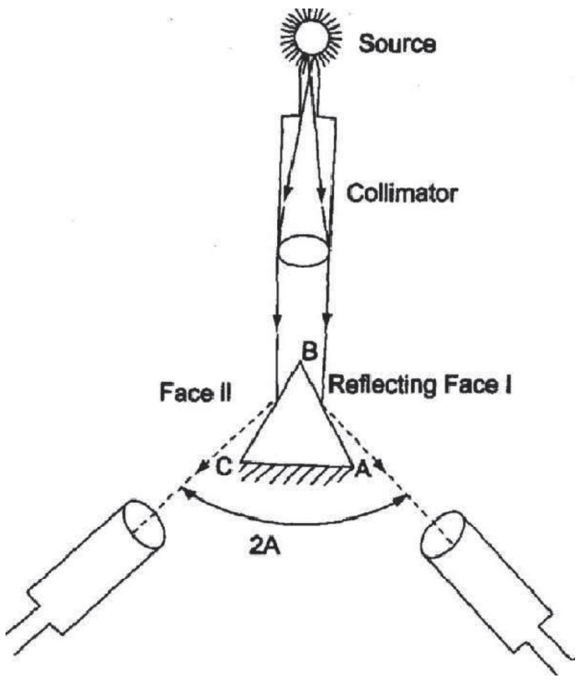


Figure 7

8. **Angle of prism:** (Refer Fig. 1)

- Place the prism such that its vertex is at the center of the prism table, directly in line with the illuminated slit.
- The opaque face (AC) should face towards you so that light from the collimator is reflected at the two faces AB and AC.
- Rotate and adjust the telescope to position I where the image of the slit reflected at AB is centered on the crosswire. Record the angular positions on each vernier.
- Now, turn the telescope to position II for the image reflected at AC and record again the angular positions on each vernier.
- Take three independent sets of readings for telescope position I and II on each vernier. Let the mean of these three sets of readings of the two verniers V_1 and V_2 are respectively,

telescope position I: α_1 , α_2
telescope position II: β_1 , β_2

- Then the mean angle of the prism A is obtained using $2A = (A_1 + A_2)/2$, where $A_1 = \alpha_1 \sim \beta_1$ and $A_2 = \alpha_2 \sim \beta_2$

9. **Direct ray reading:** Remove the prism from the spectrometer and align the telescope so that the direct image of the slit is seen through the telescope centered on the crosswire. Record the angular position of the telescope on the two verniers as D_1 and D_2. This will be the reference angular position for any measurements later.

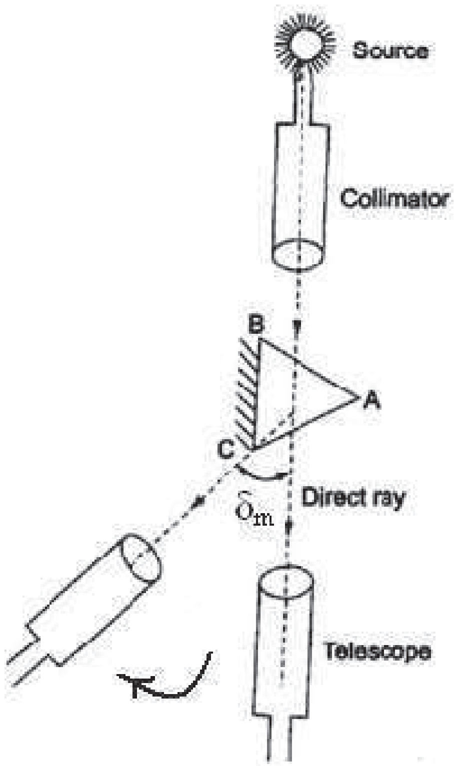


Figure 8

10. **Angle of minimum deviation:** (Refer Fig. 2)

- Replace the prism on the spectrometer table so that it is oriented as shown in Fig. 2.
- Locate the image of the spectrum with naked eye. Then rotate the telescope to bring the spectrum in the field of view.
- Gently turn the prism table back and forth. As you do so, the spectrum should appear to migrate in one direction until a point at which it reverses its direction.
- Lock the prism table. Now, using fine adjustment screw of the telescope fix the crosswire on one of the spectral lines of wavelength λ_1 at an extreme end.

. Then move the prism table using fine adjustment screw so that the angle where the line starts reversing its direction is precisely located. Take three such independent readings. Let the mean of these readings on the two verniers V_1 and V_2 for λ_1 are θ_1 and θ'_1. Calculate the mean value of $\delta_m(\lambda_1)$ as follows:

$$\delta m(\lambda_1) = \frac{1}{2}[(\theta_1 \sim D_1) + (\theta'_1 \sim D_2)]$$

- Similarly, note down the angles of minimum deviation for all the spectral lines, whose wavelengths and colors are given in the chart.

11. Calculate the refractive index for each wavelength and then determine the dispersive power.

8.6 OBSERVATION

Table 1: Determination of vernier constant (VC) of the spectrometer

Value of 1 small main scale division (MSD) = ………
……. vernier scale divisions = ….. main scale divisions
Hence, 1 vernier scale division = ………… main scale division (VSD)
Vernier Constant (VC) = (1 – VSD) x MSD = ………

Table-1. Determination of the angle of the prism

Vernier	obs	Reflection image1				Reflection image 2				2A (degree)	Mean 2A (degree)	A (degree)
		Main scale (M)	Vernier (V)	T = M + VC x V	Mean T (degree)	Main scale (M)	Vernier (V)	T = M + (VC x V)	Mean T (degree)			
V_1	1 2 3				$\alpha_1 =$				$\beta_1 =$	$A_1 = \alpha_1 \sim \beta_1$	$2A = (A_1 + A_2)/2$	
V_2	1 2 3				$\alpha_2 =$				$\beta_2 =$	$A_2 = \alpha_2 \sim \beta_2$		

Table-2. Direct ray reading

Vernier	Obs.	Main scale (M)	Vernier (V)	T = M + (VC x V)	Mean (degree)
V_1	1 2 3				D_1
V_2	1 2 3				D_2

Table-3. Angle of minimum deviation for various λ

Color / λ(nm)	Vernier	Obs	Main Scale(M)	Vernier (V)	T = M + (VC x V)	Mean (degree)	$\delta_m(\lambda_n)$ (degree)	Mean $\delta_m(\lambda_n)$ (degree)
Color λ_1	V_1	1				θ_1	$\theta_1 \sim D_1$	$\delta_m(\lambda_1) =$ ....
		2						
		3						
	V_2	1				θ'_1	$\theta'_1 \sim D_2$	
		2						
		3						
.	.	.						.
.	.	.						.
.	.	.						.
Color λ_N	V_1	1				θ_n	$\theta_n \sim D_1$	$\delta_m(\lambda_N) =$ ....
		2						
		3						
	V_2	1				θ'_n	$\theta'_n \sim D_2$	
		2						
		3						

8.7 CALCULATIONS

Dispersive power of the prism =

$$\omega = \frac{\mu_v - \mu_r}{\mu_y - 1}$$

8.8 RESULT

(i) The dispersive power of the prism is _________.

8.9 PRECAUTIONS AND SOURCES OF ERROR

1. Do not touch the refracting surfaces by hand. Place the prism on the prism table or remove it from the prism table by holding it with fingers at the top and bottom faces. The reflecting surfaces of the prism should be cleaned with a piece of cloth soaked in alcohol.

2. Rotate the adjustment screws slowly. Do not force any movement. If something is not moving check the clamping screw. Use fine adjustment screw after locking the clamping screw.

3. Take the readings without any parallax errors.

8.10 SUMMARY

The difference between the refractive indices of a transparent material for a specific blue light and a specific red light is known as the dispersion of the material. The usual choices of blue and red lights are the so-called “F” and “C” lines of hydrogen in the solar spectrum, named by Fraunhofer, with wavelengths 4861 and 6563 angstroms (the angstrom unit, abbreviated Å, is 10−8 centimeter), respectively.

It is generally more significant, however, to compare the dispersion with the mean refractive index of the material for some intermediate color such as the sodium “D” Fraunhofer line of wavelength 5893 angstroms. The dispersive power (ω) of the material is then defined as the ratio of the difference between the “F” and “C” indices and the “D” index reduced by 1.

8.11 GLOSSARY

Dispersion – the separation of white light into colors or of any radiation according to wavelength. It is the phenomenon in which the phase velocity of a wave depends on its frequency.

Dispersive Power – a measure of the amount of difference in the refraction of the highest and lowest wavelengths that enter the prism. This is expressed in the angle between the two extreme wavelengths (i.e. rED and Violet). The greater the dispersive power, the greater the angle between them, and vice-versa.

Prism – Prisms can be made from any material that is transparent to the wavelengths for which they are designed. Typical materials include glass, plastic, and fluorite. A dispersive prism can be used to break light up into its constituent spectral colors (the colors of the rainbow).

Refraction – Refraction is the change in direction of wave propagation due to a change in its transmission medium. The phenomenon is explained by the conservation of energy and the conservation of momentum.

Refractive Index – In optics, the refractive index or index of refraction of a material is a dimensionless number that describes how light propagates through that medium.

Spectrometer – an apparatus used for recording and measuring spectra, especially as a method of analysis.

Spectrum – Spectrum, in optics, the arrangement according to wavelength of visible, ultraviolet, and infrared light. An instrument designed for visual observation of spectra is called a spectroscope; an instrument that photographs or maps spectra is a spectrograph.

Wavelength – the distance between successive crests of a wave, especially points in a sound wave or electromagnetic wave.

8.12 REFERENCES

1. Introduction to Physics, Cutnell, Johnson, Young, Stadler – Wiley India, 2017

2. University Practical Physics, D. C. Tayal – Himalaya Publishing House, 2000

8.13 VIVA-VOCE QUESTIONS AND ANSWERS

1. What is total internal reflection? How is it useful?

Ans: When a ray of light emerges obliquely from glass into air, the angle of refraction between ray and normal is greater than the angle of incidence inside the glass, and at a sufficiently high obliquity the angle of refraction can actually reach 90°. In this case the emerging ray travels along the glass surface, and the sine of the angle of incidence inside the glass, known as the critical angle, is then equal to the reciprocal of the refractive index of the material.

At angles of incidence greater than the critical angle, the ray never emerges, and total internal reflection occurs.

Light is totally internally reflected in many types of reflecting prism and in fiber optics, in which long fibers of high-index glass clad with a thin layer of lower index glass are assembled side-by-side in precise order. The light admitted into one end of each fiber is transmitted along it without loss by thousands of successive internal reflections at the interlayer between the glass and the cladding. Hence, an image projected upon one end of the bundle will be dissected and transmitted to the other end, where it can be examined through a magnifier or photographed. Many modern medical instruments, such as cystoscopes and bronchoscopes, depend for their action on this principle. Single thick fibers (actually glass rods) are sometimes used to transmit light around corners to an otherwise inaccessible location.

2. What happens to the dispersive power of a prism immersed in water?

Ans: By immersing the prism in water, you effectively reduce the difference in the refractive indices of the two media (because *refractive index of glass* > refractive index of *water* > refractive index of *air*) which results in a smaller $\Delta\theta$ (or smaller *refraction*).

EXPERIMENT 9: DISPERSIVE POWER OF A GRATING

CONTENTS

9.1 OBJECTIVES

Measurement of the wavelength separation of sodium D-lines using a diffraction grating and to calculate the angular dispersive power of the grating.

9.2 INTRODUCTION

In optics, a diffraction grating is an optical component with a periodic structure that splits and diffracts light into several beams travelling in different directions. The emerging coloration is a form of structural coloration. The directions of these beams depend on the spacing of the grating and the wavelength of the light so that the grating acts as the dispersive element. Because of this, gratings are commonly used in monochromators and spectrometers.

For practical applications, gratings generally have ridges or rulings on their surface rather than dark lines. Such gratings can be either transmissive or reflective. Gratings that modulate the phase rather than the amplitude of the incident light are also produced, frequently using holography.

The principles of diffraction gratings were discovered by James Gregory, about a year after Newton's prism experiments, initially with items such as bird feathers. The first man-made diffraction grating was made around 1785 by Philadelphia inventor David Rittenhouse, who strung hairs between two finely threaded screws. This was similar to notable German physicist Joseph von Fraunhofer's wire diffraction grating in 1821.

Diffraction can create "rainbow" colors when illuminated by a wide spectrum (e.g., continuous) light source. The sparkling effects from the closely spaced narrow tracks on optical storage disks such as CDs or DVDs are an example, while the similar rainbow effects caused by thin layers of oil (or gasoline, etc.) on water are not caused by a grating, but rather by interference effects in reflections from the closely spaced transmissive layers. A grating has parallel lines, while a CD has a spiral of finely-spaced data tracks. Diffraction colors also appear when one looks at a bright point source through a translucent fine-pitch umbrella-fabric covering. Decorative patterned plastic films based on reflective grating patches are very inexpensive, and are commonplace.

9.3 APPARATUS

Spectrometer, prism, a diffraction grating of known grating element, spirit level, electric lamp, electric lamp and reading lens.

9.4 THEORY AND FORMULA USED

The sodium spectrum is dominated by the bright doublet known as the sodium D-lines at 589.0 and 589.6 nanometers. Using an appropriate diffraction grating the wavelength separation of these two lines can be determined. A schematic for diffraction of sodium light (Na-D lines) with a plane transmission grating is shown in Fig. 1.

Diffraction Grating:
An arrangement consisting of a large number of parallel slits of the same width and separated by equal opaque spaces is known as diffraction grating. It is usually made by ruling equidistant, extremely close tine grooves with a diamond point on an optically plane glass plate. A photographic replica of a plate made in this way is often used as a commercial transmission grating.

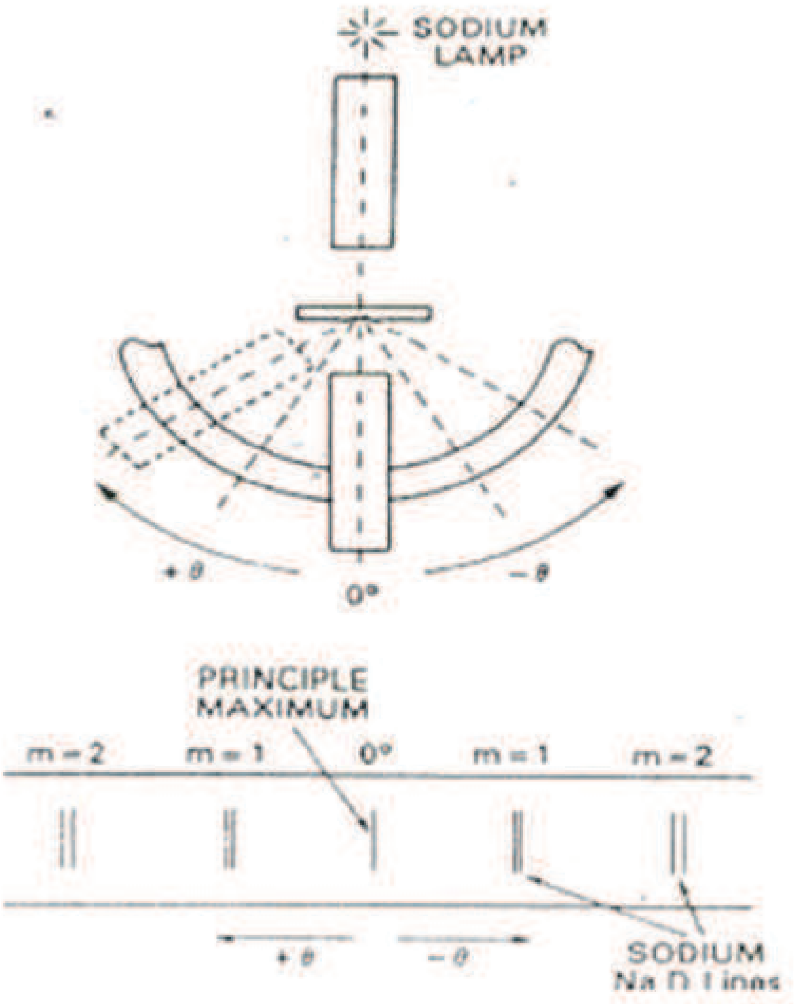


Figure 9: Schematic for diffraction of sodium Na-D lines setup

For N parallel slits, each with a width e, separated by an opaque space of width b. the diffraction pattern consists of diffraction modulated interference fringes. The quantity (e+b) is called the grating element and N (= 1/ (e+b)) is the number of slits per unit length, which could typically be 300 to 12000 lines per inch. For a large number of slits, the diffraction pattern consists of extremely sharp (practically narrow lines) principal maxima, together with weak secondary maxima in between the principal maxima. The various principal maxima are called orders.

For polychromatic incident light falling normally on a plane transmission grating the principal maxima for each spectral color are given by

$$(e+b)\sin\theta = \pm m\lambda \qquad (1)$$

Where m is the order of principal maximum and θ is the angle of diffraction.
Angular dispersive power:

The angular dispersive power of the grating is defined as the rate of change of angle of diffraction with the change in wavelength. It is obtained by differentiating Eqn. 1 and is given by

$$\frac{d\theta}{d\lambda} = \frac{m}{(e+b)\cos\theta} \qquad (2)$$

9.5 PROCEDURE

1. Adjust the spectrometer. Determine the vernier constant of the spectrometer.
2. Now remove the prism from the turntable. The next step is to adjust the grating on the turntable so that its lines are vertical, i.e. parallel to the axis of rotation or the turntable. Moreover, the light from the collimator should fall normally on the grating. To achieve this, the telescope is brought directly in line with the collimator so that the centre of the direct image of the slit falls on the intersection of the cross-wires. In this setting of the telescope, its vernier reading is taken; let it be φ.
3. The telescope is now turned through 90° from this position in either direction so that the reading of the vernier becomes $(\varphi + 90^0)$ or $(\varphi - 90^0)$. Now the axis of telescope is at right angles to the direction of rays of light emerging from the collimator. The telescope is clamped in this position.
4. The grating of known grating element is then mounted on the grating holder, which is fixed on the turntable in such a way that the ruled surface of the grating is perpendicular to the line joining two of the leveling screws (say Q and R).
5. The table is now rotated in the proper direction till the reflected image of the slit from the grating surface coincides with the intersection of the cross-wires of the telescope.
6. With the help of two leveling screws (Q and R), perpendicular to which grating is fixed on the table, the image is adjusted to be symmetrical on the horizontal cross- wires. The plane of the

grating, in this setting, makes an angle of 45° with the incident rays as well as with the telescope axis.

7. The reading of vernier is now taken and with its help, the turntable is rotated through 45^0 from this position so that the ruled surface becomes exactly normal to the incident rays. The turntable is now firmly clamped.

8. The final adjustment is to set the lines of the grating exactly parallel to the axis of rotation of the telescope. The telescope is rotated and adjusted to view the first order diffraction pattern. The third leveling screw (P) of the prism table is now worked to get the fringes (spectral lines) symmetrically positioned with respect to the horizontal cross-wire.

9. If this adjustment is perfect, the centers of all the spectral lines on either side of the direct one will be found to lie on the intersection of the cross-wires as the telescope is turned to view them one after another. The rulings on the grating are now parallel to the axis rotation of the telescope. The grating spectrometer is now fully to make the measurements. Do not disturb any of the setting of the spectrometer henceforth throughout the experiment.

10. Look through the telescope to notice the first or second order (whichever you see is completely resolved) D lines of sodium. That means you will see two yellow lines on both sides of the direct image (which is a single line) of the slit at the center. Note down the positions of the cross wire for each line on one side using the two verniers on the spectrometer. Use a torch, if needed, to read the verniers. Repeat the above step by turning the telescope to the other side too. Determine the diffraction angle, α, for all the two spectral lines.

11. Take two sets of reading for each D-line and calculate the corresponding wavelength λ_1 and λ_2 using Eq. 1.

9.6 OBSERVATION

Number of lines on grating = --------
Grating element = ----------
Order, m=----

Sodium Doublet	Left side						Right side						Vernier 1 2θ(deg)	Vernier 2 2θ(deg)	Avg. θ(deg)	λ
	Vernier 1(deg)			Vernier 2(deg)			Vernier 1(deg)			Vernier2(deg)						
	MSR	VSR	TOTAL	MSR	VSR	TOTAL	MSR	VSR	TOTAL	MSR	VSR	TOTAL				
D1															θ_1=..	λ_1=..
D2															θ_2=..	λ_2=..

9.7 CALCULATIONS

1. Calculate λ_1 and λ_2 and the uncertainty of the result.

2. Calculate the difference $\lambda_2 \sim \lambda_1$ and compare with the literature value.

3. Calculate the angular dispersive power.

9.8 RESULT

(i) The dispersive power of the grating is _________.

9.9 PRECAUTIONS AND SOURCES OF ERROR

1. Once the collimator and the telescope are adjusted for parallel rays, their focusing should not be disturbed throughout the experiment.
2. Once the grating is properly adjusted on the turntable it should be locked.
3. While taking measurements at different positions of the telescope. It must always be in locked condition.
4. While rotating the telescope arm if the vernier crosses over 0º (360º) on the circular main scale take the angular difference appropriately.

9.10 SUMMARY

Dispersive power of a grating is defined as the ratio of the difference in the angle of diffraction of any two neighboring spectral lines to the difference in the wavelength between the two spectral lines. It can also be defined as the diffraction in the angle of diffraction per unit change in wavelength.

In grating spectrum, red color is deviated (diffracted) most and violet least. The sequence of the colors in grating spectrum is reversed than that of prism spectrum.

9.11 GLOSSARY

Diffraction Grating – an optical component with a periodic structure that splits and diffracts light into several beams travelling in different directions.

Dispersion – the separation of white light into colors or of any radiation according to wavelength. It is the phenomenon in which the phase velocity of a wave depends on its frequency.

Dispersive Power – a measure of the amount of difference in the refraction of the highest and lowest wavelengths that enter the prism. This is expressed in the angle between the two extreme wavelengths (i.e. rED and Violet). The greater the dispersive power, the greater the angle between them, and vice-versa.

Refraction – Refraction is the change in direction of wave propagation due to a change in its transmission medium. The phenomenon is explained by the conservation of energy and the conservation of momentum.

Refractive Index – In optics, the refractive index or index of refraction of a material is a dimensionless number that describes how light propagates through that medium.

Spectrum – Spectrum, in optics, the arrangement according to wavelength of visible, ultraviolet, and infrared light. An instrument designed for visual observation of spectra is called a spectroscope; an instrument that photographs or maps spectra is a spectrograph.

Wavelength – the distance between successive crests of a wave, especially points in a sound wave or electromagnetic wave.

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9.13 VIVA-VOCE QUESTIONS AND ANSWERS

1. What is the main difference between the spectrum obtained by grating and that due to a prism?

Ans: In grating spectrum, red color is deviated (diffracted) most and violet least. The sequence of the colors in grating spectrum is reversed than that of prism spectrum.

2. How many types of gratings are known to you?

Ans: There are two types of gratings:

(a) Transmission grating
(b) Reflection grating

3. Why are transmission gratings less angle sensitive than reflection gratings?

Ans: The main difference can be seen in Figure 2. All the angles are measured relative to the normal of the grating. First we will consider the 0th order diffraction order for both types of gratings while tilting the grating slightly. For the 0th order diffraction the diffraction angle (β) equals the angle of incidence (α).

For a reflective grating, the 0th order is obviously reflected back from the surface just as if the grating was a plane mirror so, when the grating is tilted the 0th order diffraction shifts by twice the angular tilt. The higher order diffractions basically follow the 0th order diffraction so, the mth order diffraction also shifts angularly by twice the tilt angle of the grating.

For a transmission grating however, the 0th order goes straight through the grating and is not affected by tilting the grating. Again, since the higher order diffractions follow the 0th order diffraction, the mth order diffraction is almost unaffected by tilting the grating.

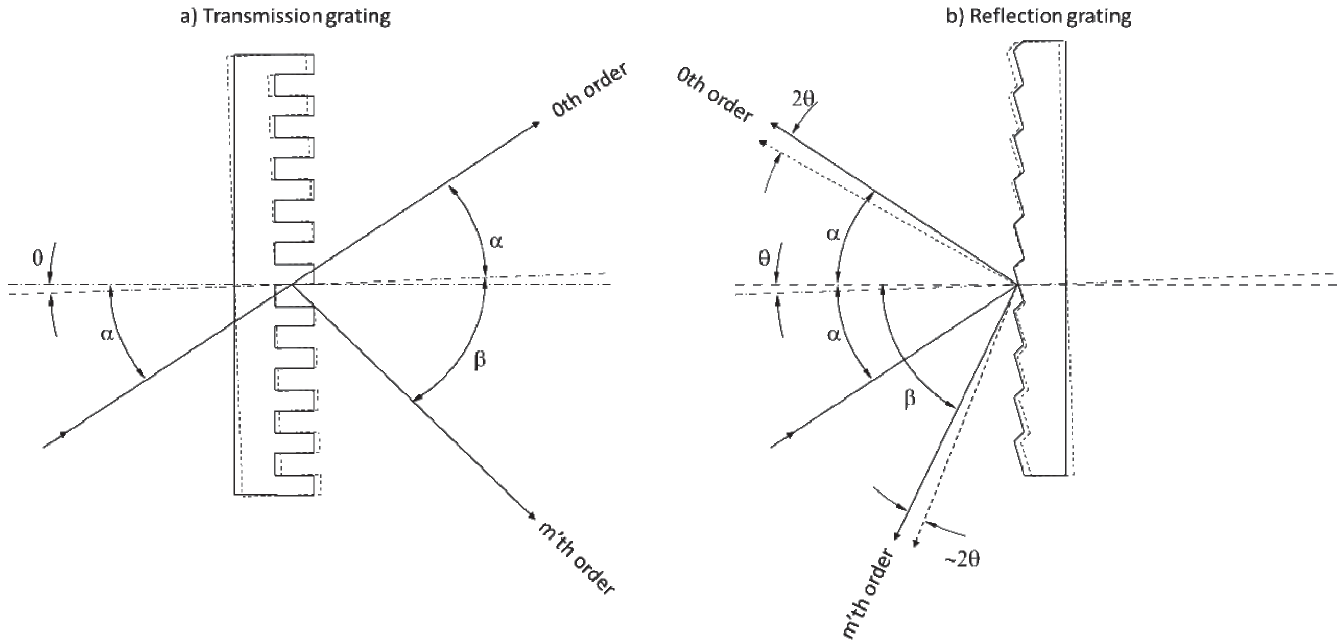

Figure 10

4. On what factors does the dispersive power depend?

Ans: The dispersive power of a grating depends on the following factors:

(a) The dispersive power of a grating is directly proportional to the order of spectrum (n, i.e. higher orders are dispersed more than the lower orders).
(b) The dispersive power of a grating is inversely proportional to the grating element, i.e. smaller the grating element (a + b), more is the dispersive power.
(c) The dispersive power of a grating is inversely proportional to the cosine of the angle of diffraction, i.e. the larger the angle of diffraction, more is the dispersive power, i.e. the dispersion is more in the red region than the violet region.

EXPERIMENT 10: ZONE PLATE EXPERIMENT

CONTENTS

10.1 OBJECTIVES

To construct Fresnel's zone and to determine the focal length of zone plates.

10.2 INTRODUCTION

A zone plate is a device used to focus light or other things exhibiting wave character. Unlike lenses or curved mirrors however, zone plates use diffraction instead of refraction or reflection. Based on analysis by Augustin-Jean Fresnel, they are sometimes called Fresnel zone plates in his honor. The zone plate's focusing ability is an extension of the Arago spot phenomenon caused by diffraction from an opaque disc.

A zone plate consists of a set of radially symmetric rings, known as Fresnel zones, which alternate between opaque and transparent. Light hitting the zone plate will diffract around the opaque zones. The zones can be spaced so that the diffracted light constructively interferes at the desired focus, creating an image there.

10.3 APPARATUS

He-Ne Laser, zone plate, lens holder, lens, object holder, ground glass screen, polarizing filter, optical bench, slide mount.

10.4 THEORY AND FORMULA USED

A zone plate is illuminated with parallel laser light. The focal points of several orders of the zone plate are projected on a ground glass screen.

According to Fresnel, interference of waves diffracted by obstacles may be treated simply by splitting the primary wave front into so called zones. The optical path difference from the common boundaries of a zone pair up to a point of observation P is always $\lambda/2$. Secondary waves originating from neighboring zones impinge in P with opposed phases, thus extinguishing each other except for a part coming from the first zone.

Using a so called zone plate, which consists of alternating transparent and opaque circles, it is possible to let either the odd or the even zones exert an influence at a point of observation P. If the number of zones is 2k, the amplitude A at point P is (under the justified assumption that the secondary waves have the same amplitude, due to the fact that the areas of the single zones are equal):

$$A = A_1 + A_3 + A_5 + ... + A_{2k-1}; \quad A \sim kA_1 \qquad (1)$$

At the point of observation P, the amplitude A without zone plate is 1/2 A_1 (contribution of half of the first zone). Using a zone plate, it is thus possible to increase light intensity at P by a factor of $4k^2$. This means that the zone plate acts as a focusing lens.

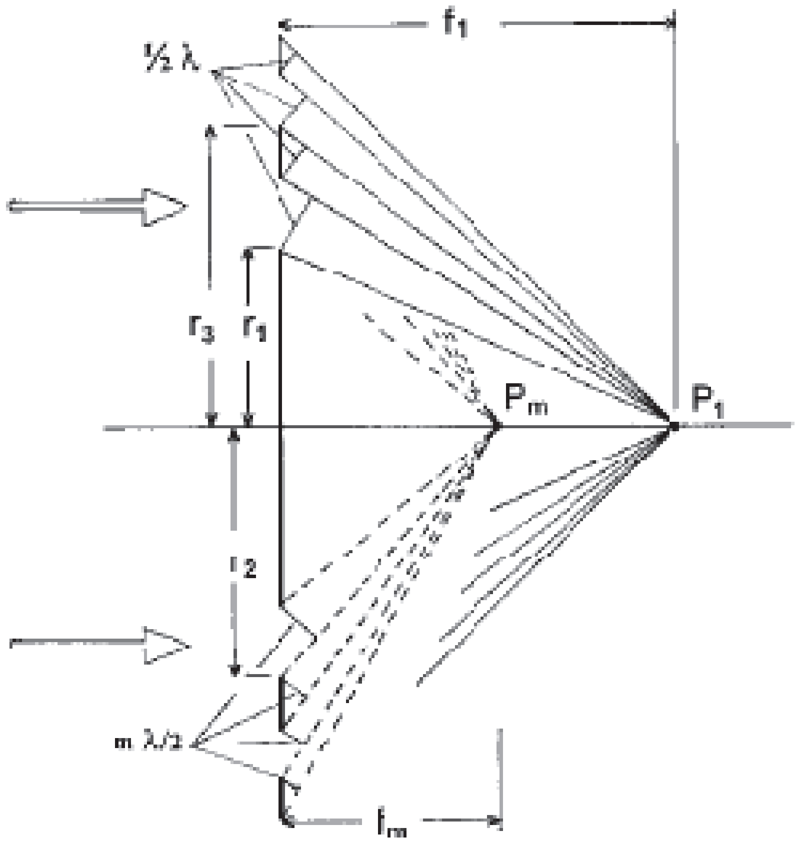

Figure 11: Geometry of the Zone Plate

In Figure 1, the first rings of a zone plate illuminated by a plane wave (parallel beam) are shown.

Assuming the distance between P and the centre of the zone plate to be f_1, in case of constructive interference at P, the following holds for radii rn (n=1,2,3 ...):

$$r_n^2 = \left(f + n\frac{\lambda}{2}\right)^2 - f^2 = f^2 + nf\lambda + n^2\frac{\lambda^2}{4} = nf\lambda; \quad \text{with } nf\lambda \gg n^2\frac{\lambda^2}{4} \qquad (2)$$

For the radii r_n of the zone plate and the focal length f we thus have:

$$r_n = (nf\lambda)^{1/2}; \; f = r_n^2 \cdot \frac{1}{n\lambda} \qquad (3)$$

If the point of observation P is shifted along OP towards the zone plate, alternating brightness and darkness are observed, which means that the zone plate has several focal points.

$$f_m = f_1/m \quad (m = 1, 3, 5, 7, ...) \qquad (4)$$

The existence of these focal points of higher order is due to the difference in the optical path of the zone rays of 3/2λ, 5/2λ, 7/2λ, 9/2λ ...

The zone plate used for the experiment has 20 zones, the radius of the first dark central circle is $r_1 = 0.6$ mm. The following radii are found to be:

$$r_n = n^{1/2} \cdot 0.6 \text{ mm} \qquad (5)$$

10.5 PROCEDURE

Figure 2 shows the complete experimental set-up.

1. The slide mount for the laser is placed at the head of the optical bench.
2. To start with, the laser beam is widened with lenses L_1, L_2 and L_3 to a diameter of approx. 5 mm (cf. Figure 3).
3. Careful shifting of lenses L_2 and L_3 allows making the laser beam parallel over a length of several meters (maximum 10 m). The correct values for the different focal lengths of the zone plate can only be obtained under this condition. For this purpose, a piece of black cardboard, into which a hole is punched with a desk punch and which is used as a test diaphragm, proves useful.
4. The other components should then be mounted; making sure the zone plate is well illuminated.
5. The image of the zone plate is observed on the ground glass plate, which is located nearly at the end of the optical bench at the beginning, with magnifying lens L_4.
6. Moving the ground glass screen and L_4 in the direction of the zone plate simultaneously, the different focal points of the zone plate are searched for and the corresponding focal lengths are determined.
7. The polarizing filter, which is used to reduce the brightness of the image, is set together with the ground glass screen in the same mounting frame.

Figure 12: Experimental set-up to determine the different focal lengths of a zone plate

$f(L_1) = +\ 20mm$ ZP = zone plate
$f(L_2) = -\ 50mm$ S = ground glass screen
$f(L_3) = +\ 100mm$ P = Polarisation filter
$f(L_4) = +\ 50mm$

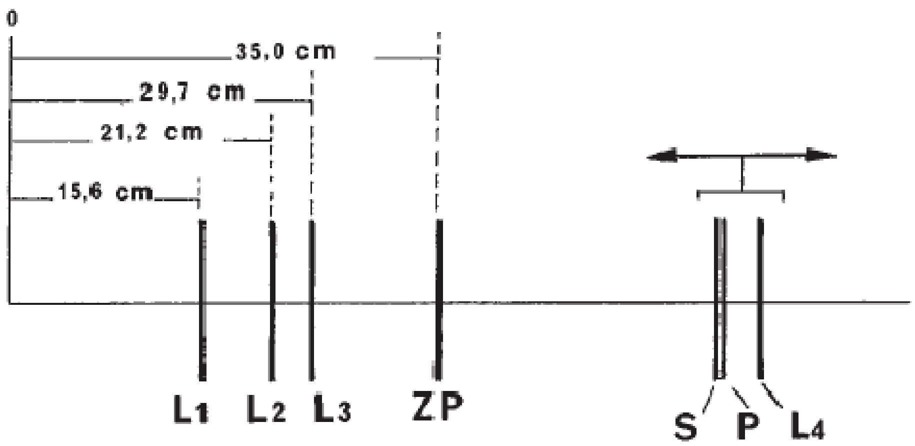

Figure 3: Position of the optical components

10.6 OBSERVATION

In Table 1, the averaged experimental values are compared to the values calculated according to (3), (4) and (5) and with λ = 632.8 nm.

Table 1

m	f(theor.)/cm	f(exp.)/cm	n	r(theor.)/mm	r(exp.)/mm
1			1		
3			2		
5			3		
7			4		
9			5		

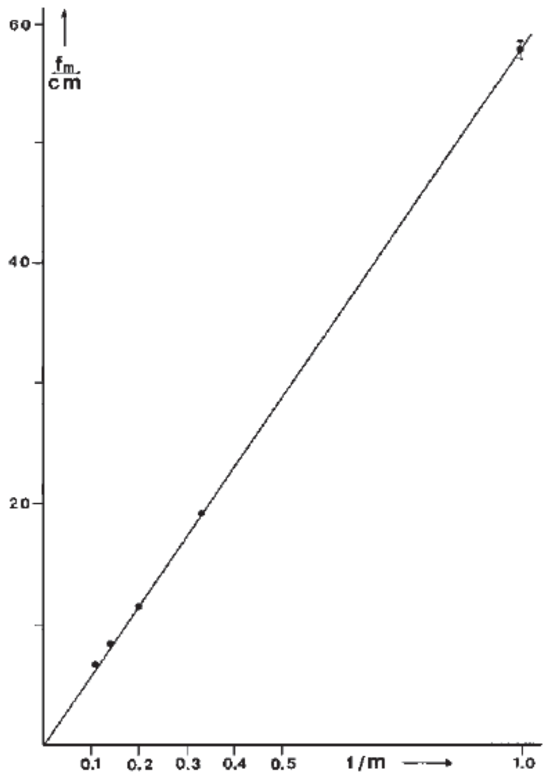

Figure 4: **Focal length of first and higher order of the zone plate as a function of the reciprocal value of the order.**

10.7 CALCULATIONS

Figure 4 shows the empirical focal lengths as a function of the inverse value of the order of the focal points.

10.8 RESULT

Since, the graph follows a straight line; we can infer that focal lengths are inversely proportional to the order of focal points.

10.9 PRECAUTIONS AND SOURCES OF ERROR

1. Never look directly into a non-attenuated laser beam.
2. The zone plate should be well illuminated.

10.10 SUMMARY

A zone plate is a diffractive optic that consists of several radially symmetric rings called *zones*. Zones alternate between opaque and transparent, and are spaced so that light transmitted by the transparent zones constructively interferes at the desired focus. One common use of a zone plate is to bring light from a distant source to focus. In this scenario, the incident wave can be approximated as a plane wave.

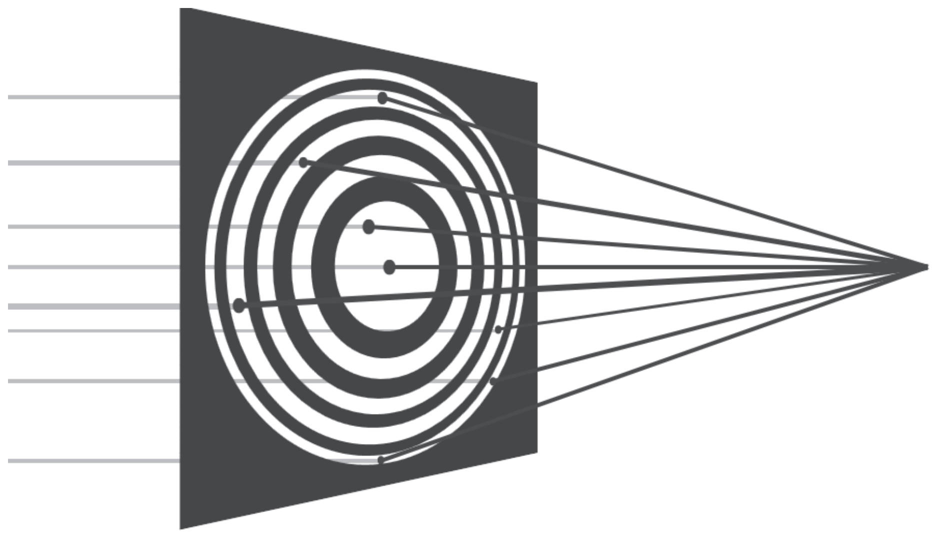

Figure 5

10.11 GLOSSARY

Diffraction – It refers to various phenomena that occur when a wave encounters an obstacle or a slit. It is defined as the bending of light around the corners of an obstacle or aperture into the region of geometrical shadow of the obstacle.

In classical physics, the diffraction phenomenon is described as the interference of waves according to the Huygens–Fresnel principle. These characteristic behaviors are exhibited when a wave encounters an obstacle or a slit that is comparable in size to its wavelength. Similar effects occur when a light wave travels through a medium with a varying refractive index, or when a sound wave travels through a medium with varying acoustic impedance. Diffraction occurs with all waves, including sound waves, water waves, and electromagnetic waves such as visible light, X-rays and radio waves.

Focal Length – The focal length of an optical system is a measure of how strongly the system converges or diverges light. For an optical system in air, it is the distance over which initially collimated (parallel) rays are brought to a focus. A system with a shorter focal length has greater optical power than one with a long focal length; that is, it bends the rays more sharply, bringing them to a focus in a shorter distance.

Refraction – Refraction is the change in direction of wave propagation due to a change in its transmission medium. The phenomenon is explained by the conservation of energy and the conservation of momentum.

Refractive Index – In optics, the refractive index or index of refraction of a material is a dimensionless number that describes how light propagates through that medium.

Spectrum – Spectrum, in optics, the arrangement according to wavelength of visible, ultraviolet, and infrared light. An instrument designed for visual observation of spectra is called a spectroscope; an instrument that photographs or maps spectra is a spectrograph.

Wavelength – the distance between successive crests of a wave, especially points in a sound wave or electromagnetic wave.

Zone Plate – A zone plate is a device used to focus light or other things exhibiting wave character. Unlike lenses or curved mirrors however, zone plates use diffraction instead of refraction or reflection.

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10.13 VIVA-VOCE QUESTIONS AND ANSWERS

1. What is meant by Fresnel zones?

Ans: A zone plate consists of a set of radially symmetric rings (example shown in Figure 6), known as Fresnel zones, which alternate between opaque and transparent.

Figure 5

2. What are some of the applications of zone plates?

Ans: Following are some of the applications of zone plates:

(a) Physics: There are many wavelengths of light outside of the visible area of the electromagnetic spectrum where traditional lens materials like glass are not transparent, and so lenses are more difficult to manufacture. Likewise, there are many wavelengths for which there are no materials with a refractive index significantly larger than one. X-rays, for example, are only weakly refracted by glass or other materials, and so require a different technique for focusing. Zone plates eliminate the need for finding transparent, refractive, easy-to-manufacture materials for every region of the spectrum. The same zone plate will focus light of many wavelengths to different foci, which means they can also be used to filter out unwanted wavelengths while focusing the light of interest.

Other waves such as sound waves and, due to quantum mechanics, matter waves can be focused in the same way. Wave plates have been used to focus beams of neutrons and helium atoms.

(b) Photography: Zone plates are also used in photography in place of a lens or pinhole for a glowing, soft-focus image. One advantage over pinholes (aside from the unique, fuzzy look achieved with zone plates) is that the transparent area is larger than that of a comparable pinhole. The result is that the effective f-number of a zone plate is lower than for the corresponding pinhole and the exposure time can be decreased. Common f-numbers for a pinhole camera range from f/150 to f/200 or higher, whereas zone plates are frequently f/40 and lower. This makes hand held shots feasible at the higher ISO settings available with newer DSLR cameras.

(c) Gun sights: Zone plates have been proposed as a cheap alternative to more expensive optical sights or targeting lasers.

(d) Lenses: Zone plates may be used as imaging lenses with a single focus as long as the type of grating used is sinusoidal in nature.

(e) Reflection: A zone plate used as a reflector will allow radio waves to be focused as if by a parabolic reflector. This allows the reflector to be flat, and so easier to make. It also allows an appropriately patterned Fresnel reflector to be mounted flush to the side of a building, avoiding the wind loading that a parabaloid would be subject to.

(f) Software testing: A bitmap representation of a zone plate image may be used for testing various image processing algorithms, such as:

- Image interpolation and image re-sampling;
- Image filtering.

EXPERIMENT 11: TO VERIFY STEFAN'S LAW

CONTENTS

11.1 OBJECTIVES

After performing this experiment, you should be able to

- What is meant by a black body
- Describe Stefan's law
- Understand the power P radiated by the body at absolute temperature T
- Understand the resistance of conductor depends on temperature 't'
- Verify Stefan's law experimentally

11.2 INTRODUCTION

The Stefan–Boltzmann law describes the power radiated from a black body in terms of its temperature. Specifically, the Stefan–Boltzmann law states that the total energy radiated per unit surface area of a black body across all wavelengths per unit time, is directly proportional to the fourth power of the black body's absolute temperature T. The constant of proportionality σ, called the Stefan–Boltzmann constant.

A body that does not absorb all incident radiation (sometimes known as a grey body) emits less total energy than a black body and is characterized by an emissivity. To find the total power radiated from an object, multiply by its surface area.

11.3 APPARATUS USED

Electric bulb (having tungsten filament) of 6V & 6W, 6V battery, DC Voltmeter (0-10V), DC ammeter (0-1 A) and Rheostat (100Ω).

11.4 THEORY AND FORMULA USED

A black body is a substance which emits all radiation falls on it, of whatever wavelength they may be it. The emitted radiation by black body is independent of nature of substance and it purely depends on the temperature of the body.

According to Stefan's law the rate of emission of radiant energy by unit area of perfectly black body is directly proportional to the fourth power of its absolute temperature.

So $$E = \sigma T^4 \qquad (1)$$

where E is net amount of radiant energy per second per unit area by the body at absolute temperature T. σ is Stefan's constant

If the black body at absolute temperature T is surrounded by another black body at absolute temperature T_0. The body will radiate at absolute temperature T and absorbed radiation at absolute temperature T_0. So the Stefan's law is

$$E = \sigma\left(T^4 - T_0^4\right) \qquad (2)$$

A similar relation in equation (2) can also hold for the bodies which are not black bodies. In such case we can write

$$P = C\left(T^{\alpha} - T_0^{\alpha}\right) \qquad (3)$$

Where P is power radiated by the body at absolute temperature T is surrounded by another black body at absolute temperature T_0.

If $T >> T_0$, the relation is $P = CT^{\alpha}$

Or $$\log_{10} P = \alpha \log_{10} T + \log_{10} C \qquad (4)$$

Thus the graph between $\log_{10}P$ and $\log_{10}T$ should be straight line whose slope is α, which should close to 4.

For the verification of Stefan's law, we take tungsten bulb as radiating body, so we have to measure following two parameters.

(1) Power radiated by the tungsten bulb in steady state the electric power VI neglecting power loss through the gas inside the bulb.
(2) In experiment we need temperature of tungsten filament. We measure the resistance of tungsten filament to find its temperature

As we know that resistance of conductor depends on temperature't' as

$$R_t = R_0\left(1 + \alpha t + \beta t^2\right)$$

The temperature coefficients α & β are known for tungsten filament and we also know that the tungsten filament glows at temperature at 800^0K. So the resistance of tungsten filament at 0^0C can be found and which is

$$R_{0^0 c} = \frac{R_g}{3.9} \qquad R_g \text{ is resistant at } 800^0\text{K (at just glow)}$$

So by calculating $\frac{R_t}{R_0}$, the temperature of tungsten filament can be found.

11.5 ABOUT APPARATUS

The apparatus in the experiment is a simple electric circuit as shown in figure 1. The 6V battery is connected to the electric bulb with rheostat. For the measurement of current and voltage the DC Voltmeter (0-10V) & DC ammeter (0-1 A) are connected.

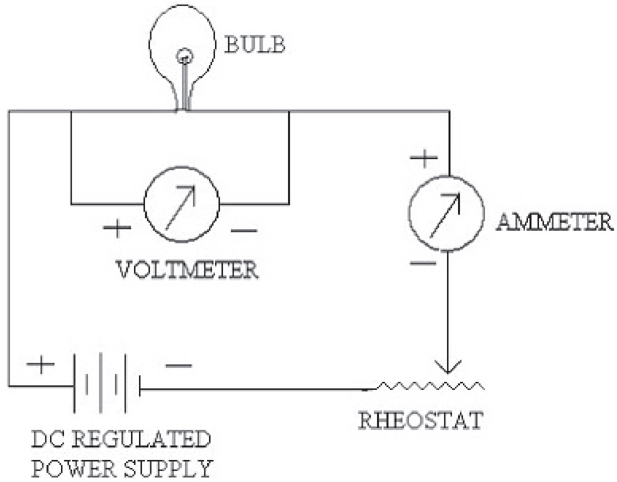

Figure 1

11.6 PROCEDURE

Let us perform the experiment in following steps.

1. Make connection as shown in figure 1.
2. Find the 'gust glows' condition of tungsten filament of bulb by adjusting the current with rheostat. Repeat the same by increasing and decreasing the current. Then the every value of V (voltage) and I (current) ,the ratio will gives R_g.
3. Find R_0 by the relation $R_{0^0c} = \frac{R_g}{3.9}$.
4. The current is increased from a value below glow stage to high enough to get dazzling white light. Take all values of V (voltage) and I(current).
5. From V and I values, we deduce power P as P = VI.
6. By calculating $\frac{R_t}{R_0}$, we deduce the temperature 'T' of tungsten filament.
7. Draw the graph between $\log_{10}P$ and $\log_{10}T$, which is straight line.
8. Find the slope of graph between $\log_{10}P$ and $\log_{10}T$.

11.7 OBSERVATION

Table1. Determination of R_g (Temperature of filament $\approx 800^0$K)

S.N.	Voltage V (In volt)	Current I (amp.)	R_g=V/I (In ohm)	Average R_g
1				
2				
3				
4				
5				

Table2. Determination of power dissipated P for different temperature T of filament.

S.N.	Voltage V (In volt)	Current I (amp.)	Resistance R_t=V/I (In ohm)	R_t/R_0	Temperature T from graph in K given in table3 and fig 3	$\log_{10}T$	Power P=VI	$\log_{10}P$
1								
2								
3								
4								
5								
6								

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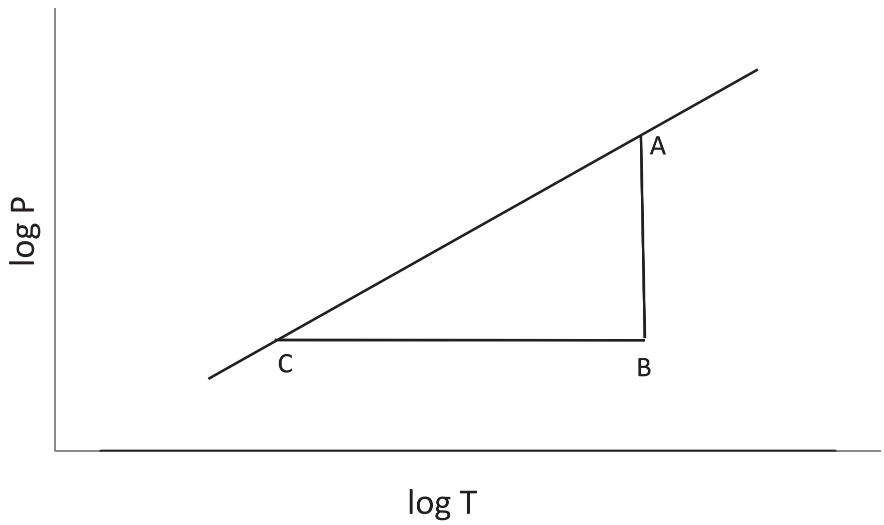
11.8 CALCULATION AND DISCUSSION

The relation between power and temperature of tungsten filament is given by

$$\log_{10} P = \alpha \log_{10} T + \log_{10} C$$

So the graph between $\log_{10}P$ and $\log_{10}T$ as shown in figure 2 is straight line and slope of the straight line should be close 4.



11.9 RESULT

The slope of line of the graph between $\log_{10}P$ and $\log_{10}T$ is straight line and slope of the straight line comes out ……….... Hence Stefan's law is verified.

11.10 PRECAUTION AND SOURCE OF ERROR

1. Sensitive voltmeter and sensitive ammeter sould be used.
2. Value of R_g shuld be determined at just glow position of the filament, so that the correct value of R_0 can be calculated.
3. There should not be any fluctuation on the power.
4. Temperature corresponding to the value of R_g/R_0 from the graph should be taken carefully.

11.11 REQUIRED TABLE AND GRAPH

Table 3

Temperature In ^oC	R_t/R_0	Temperature In ^oC	R_t/R_0
0	1.00	1100	7.60
100	1.53	1200	8.26
200	2.07	1300	8.90
300	2.13	1400	9.70
400	3.22	1500	10.43
500	3.80	1600	11.17
600	4.40	1700	11.42
700	5.00	1800	12.67
800	5.64	1900	13.50
900	6.37	2000	14.30
1000	6.94		

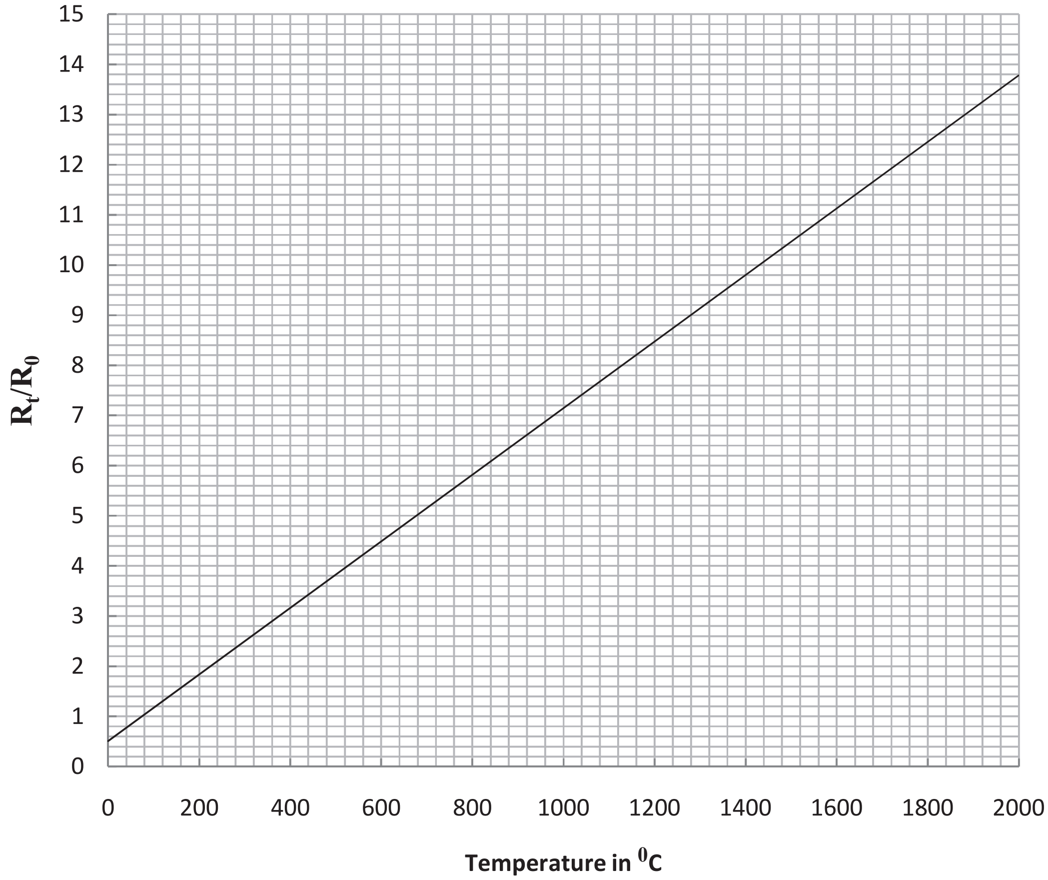


Figure 2: Graph between temperature and R_t / R_0 of table 3.

11.12 SUMMARY:

1. A black body is a substance which emits all radiation falls on it, of whatever wavelength they may be it. The emitted radiation by black body is independent of nature of substance and it purely depends on the temperature of the body.
2. According to Stefan's law, $E = \sigma T^4$.
3. If P is power radiated by the body at absolute temperature T is surrounded by another black body at absolute temperature T_0 then

   $$\log_{10} P = \alpha \log_{10} T + \log_{10} C$$

4. The resistance R of a conductor depends on temperature't' as

   $$R_t = R_0\left(1 + \alpha t + \beta t^2\right)$$

   where temperature coefficients α & β are known for tungsten filament and the resistance of tungsten filament at 0^0C can be found and which is

   $$R_{0^0 c} = \frac{R_g}{3.9}$$ R_g is resistant at 800^0K (at just glow)

   So by calculating $\frac{R_t}{R_0}$, the temperature of tungsten filament can be found.

5. After getting temperature and power P we can make a graph and if this graph comes straight line, the Stefan's law is verified.

11.13 GLOSSARY

` Black body: a substance which emits all radiation falls on it

Radiant energy: Energy of electromagnetic radiation emitted by a body

Resistance: the difficulty to pass an electric current through that conductor

Absolute temperature: 0 K or -273^0 C

Filament: a conducting wire or thread with a high melting point, forming part of an electric bulb

11.14 REFERENCES

1. C. L. Arora, *B.Sc. Practical Physics*, S. Chand publication, Delhi

2. C.L. Arora and P.S. Hemne, *Physics for Degree students (BSc Second year)*, S. Chand publication, Delhi

3. Indu Prakash, Ram Krishna, A K Jha, *A text Book of Practical Physics*, Kitab Mahal Publication Delhi.

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4. *https://en.wikipedia.org*.

11.15 VIVA-VOCE QUESTIONS

Question1.What is a black body?
Answer: A body which absorbs all incident radiations, irrespective of frequency, is called a black body.
Question2. State Stefan's law?
Answer: According to Stefan's law the rate of emission of radiant energy by unit area of perfectly black body is directly proportional to the fourth power of its absolute temperature.

i.e. $E = \sigma T^4$

Question3.What is a R_g ?
Answer. R_g is resistance of tungsten filament in just glow stage i.e. at 800^0K.
Question4. In the experiment how temperature of tungsten filament is found at 0^0C ?
Answer: After finding R_g, R_0 is found by the relation $R_{0^0 c} = \frac{R_g}{3.9}$

EXPERIMENT 12: DETERMINE MECHANICAL EQUIVALENT OF HEAT (J) BY SEARLE'S METHOD.

CONTENTS

12.1 OBJECTIVES

After performing this experiment, you should be able to understand

- Meaning of mechanical equivalent of heat
- How work is converted into heat
- Working of Searle's fiction cone apparatus
- Methods of minimizing heat loss.
- Cause of production of heat in the experiment

12.2 INTRODUCTION

Mechanical equivalent of heat relates two energies i.e. work energy and heat energy. In practice we can produce heat by rubbing our hands, vice versa the heat can do work as in case of heat engine. Mechanical equivalent is defined as the amount of work done to produce a unit quantity of heat. In other words whenever a mechanical work is completely transformed into heat, the amount of heat produced is directly proportional to the amount of work done.

There are many procedures to find Mechanical equivalent of heat. In this experiment we convert work produced by friction into work.

12.3 APPARATUS USED

Electric bulb (having tungsten filament of 6V & 6W), 6V battery, DC Voltmeter (0-10V), DC ammeter (0-1 A) and Rheostat (100Ω).

12.4 THEORY AND FORMULA USED

Mechanical equivalent of heat can be defined as the amount of work done to produce a unit quantity of heat. In other words whenever a mechanical work is completely transformed into heat, the amount of heat produced is directly proportional to the amount of work done.

$W \propto Q$ Where W is Amount of Work, Q is units of heat.
$W = J\,Q$

In the above equation constant J is known as Mechanical equivalent of heat or Joule's equivalent.
In Searle's friction cone method the following formula is used

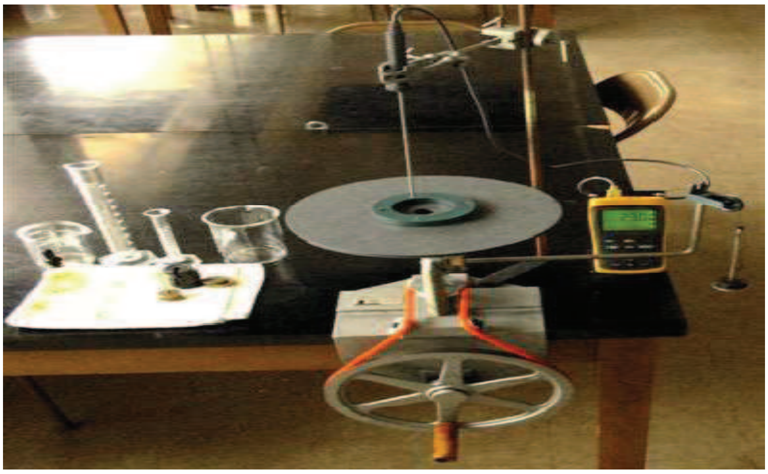
$$J = \frac{2\pi nMgR}{(m_1 s_1 + m_2)(\theta_2 - \vartheta_1)}$$

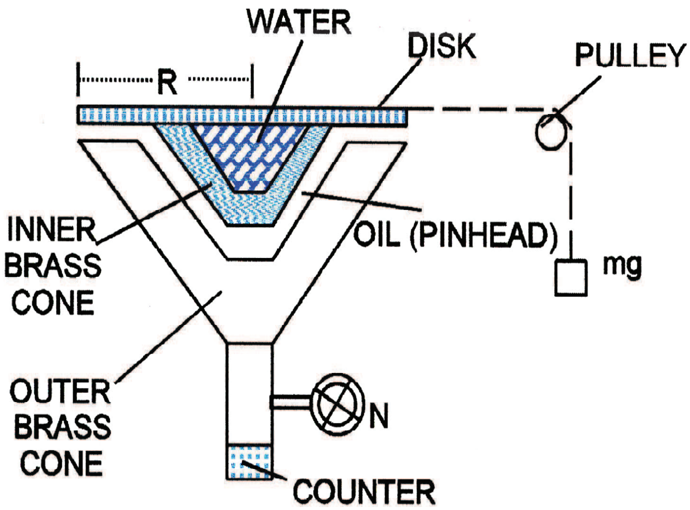
Where n - number of revolution suffered by the outer cone
Mg - applied force

R	-	Radius of disc
m_1	-	mass of two cones and stirrer
s_1	-	specific heat of material of cones
m_2	-	mass of water in the cone
θ_1	-	initial temperature of water in cone
θ_2	-	final temperature of water in cone

12.5 ABOUT APPARATUS

Searle's fiction cone apparatus as shown in figure 1 & figure 2, consists of two metal cones which fit closely one into the other. Two cones are fitted in metal box linked with cork for preventing loss of heat. The outer cone is fixed at bottom to a spindle for rotating by means with wheel. A counter attached with apparatus counts the revolution. The load Mg applied by means of a wooden disc fitted to upper end of inner cone, so revolution of inner cone is prevented. The disc has a hole in its centre through which a thermometer in inserted to record the temperature of liquid (water) filled in inner cone of the apparatus.





12.6 PROCEDURE

Let us perform the experiment in following steps.

1. Note the mass of the two cones i.e. inner and outer cones.
2. Using pipette fill the inner cone by water about 2/3 of cone.
3. Measuring the volume of water, Find the mass of water in inner cone.
4. Place outer cone over Cone by putting drop of oil between them.
5. Insert thermometer in inner cone.
6. Adjust the load and speed of wheel such that the inner cone remains stationary i.e. the weight neither goes up nor comes down.
7. Note the load Mg applied.
8. Note the initial temperature (θ_1) of water in inner cone and initial reading of counter and start the stop watch.
9. Rotate the wheel with constant speed and raise the temperature of water by 5^0C to 8^0C
10. Now note the final reading of temperature (θ_2) of water in inner cone and stop the stop watch
11. Noting final reading of counter, find number of revolution of wheel.
12. To make radiation corrections, the apparatus is allowed to cool for the same time (Time for which revolution is made). Then note the fall in temperature ($\delta\theta$). $\delta\theta/2$ is added in final temperature to give corrected temperature $\theta_2 + \delta\theta/2$.

12.7 OBSERVATION

S.N.	Quantity measured	Observes values
1	Mass of cones (m_1)	
2	Mass of water in inner cone (m_2)	
3	Initial temperature of water in cone (θ_1)	
4	Initial reading of counter (n_1)	
5	Applied load on hanger (M)	
6	Final temperature of water in cone(θ_2)	
7	Time taken in raising the temperature of water in inner cone (t)	
8	Final reading of counter(n_2)	
9	Fall of temperature of water in time t ($\delta\theta$).	
10	Specific heat of material of cone (s_1)	
11	Radius of groove of the disc (R)	

12.8 CALCULATION AND DISCUSSION

1. Fall of temperature $\left(\theta_2 - \theta_1 + \frac{\delta\theta}{2}\right)$=………^{0}C
2. Number of revolutions made by the cones $n = n_2 - n_1$ = …….

3. $J = \dfrac{2\pi nMgR}{(m_1 s_1 + m_2)(\theta_2 - \vartheta_1)}$ =……..erg/cal.

12.9 RESULT

The mechanical equivalent of heat=……………erg/cal.

12.10 STANDARD VALUE OF 'J':

The standard value mechanical equivalent of heat is 4.18 x 10^7 erg/cal.

12.11 PERCENTAGE ERROR

12.12 PRECAUTION AND SOURCE OF ERROR:

1. The cones should be properly lubricated before starting the experiment.
2. The cord in which load is attach must always tangential to disc.
3. Pulleys should be frictionless.
4. Sensitive thermometer should be used.

12.13 SUMMARY

1. Mechanical equivalent of heat can be defined as the amount of work done to produce a unit quantity of heat.
2. By friction, the work can be converted into heat.
3. The working of Searle's fiction cone apparatus is to convert frictional energy to heat energy.

12.14 GLOSSARY

Black body: a substance which emits all radiation falls on it.

Radiant energy: The energy of electromagnetic radiation emitted by a body.

Resistance: the difficulty to pass an electric current through that conductor

Absolute temperature: 0^0 K or -273^0 C.

Filament: A conducting wire or thread with a high melting point, forming part of an electric bulb.

12.15 REFERENCES

1. C. L. Arora, *B.Sc. Practical Physics*, S. Chand publication, Delhi

2. C.L. Arora and P.S. Hemne, *Physics for Degree students (BSc Second year)*, S. Chand publication, Delhi

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4. *https://wikipedia.org*

12.16 VIVA-VOCE QUESTIONS

Question1.What is meant by mechanical equivalent of heat 'J' and what is its unit?
Answer: The ratio of amount of work done (W) to heat produce (H) is called mechanical equivalent of heat. Inn MKS its unit is joule/calorie.
Question2.How much work is required to produce 1 calorie of heat?
Answer: 4.2 joule.
Question3.What is the cause of production of heat in this experiment?
Answer: Friction. When the outer cone rotates over inner cone, it develops heat.
Question4.Why 'J' is called mechanical equivalent of heat?
Answer: The 'J' relates mechanical work to heat energy.
Question5.How we can be minimize heat loss in this experiment?
Answer: The heat loss is minimized by surrounding the cones by some insulating material and corrected by adding fall of temperature ($\delta\theta/2$) to the final temperature.

EXPERIMENT 13: TO DETERMINE THE COEFFICIENT OF THERMAL CONDUCTIVITY OF GOOD CONDUCTOR (A METAL) BY SEARLE'S METHOD.

CONTENTS

13.1 OBJECTIVES

After performing this experiment, you should be able to

- Thermal Conductivity and coefficient of thermal conductivity
- Difference between good conductor and bad conductor of heat
- Method of transferring heat from one point to other
- Method of minimizing heat loss.

13.2 INTRODUCTION

Thermal conductivity refers to the intrinsic ability of a material to transfer heat. It is one of the three methods of heat transfer, the other two being convection and radiation. Thermal conductivity occurs through molecular agitation and contact, and does not result in the bulk movement of the solid itself. Heat moves along a temperature gradient, from an area of high temperature and high molecular energy to an area with a lower temperature and lower molecular energy. This transfer will continue until thermal equilibrium is reached.

13.3 APPRATUS USED

Searle's conductivity apparatus, Stop watch, constant water flow arrangement, steam generator and four sensitive thermometers T_1, T_2, T_3 & T_4.

13.4 THEORY AND FORMULA USED

Thermal conductivity refers to the intrinsic ability of a material to transfer heat. It is one of the three methods of heat transfer, the other two being convection and radiation. Thermal conductivity occurs through molecular agitation and contact, and does not result in the bulk movement of the solid itself. Heat moves along a temperature gradient, from an area of high temperature and high molecular energy to an area with a lower temperature and lower molecular energy. This transfer will continue until thermal equilibrium is reached.

If heat 'Q' is entering the metallic tube in time 't' , A is cross sectional area, 'd' is distance between two points on tube to which heat transferred and $(\theta_1 - \theta_2)$ is temperature gradient then

$$Q = KA\frac{\theta_1 - \theta_2}{d}t \text{, where 'K' is coefficient of thermal conductivity.} \qquad (1)$$

If this heat 'Q' warms up a 'm' mass of water from temperature (θ_4) to (θ_3)that enter in the tube. Then

$$Q = ms(\theta_3 - \theta_4) \text{, where ' s' is specific heat of water.} \qquad (2)$$

Equating equation (1), (2) and putting value of s we get formula for the coefficient of thermal conductivity K for good conductor (a metal)

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

Where A - Area of cross section of cylindrical tube.
d - Distance between two fixed points of tube (conductor).
θ_1, θ_2 - Steady temperature of two fixed points on tube (conductor).
m - Mass of water collected per second.
θ_3, θ_4 - Steady temperature of water at exit and at entrance respectively.

13.5 ABOUT APPARATUS

Searle's apparatus is as shown in figure 1 is a cylindrical tube of metal. One end of the cylindrical tube is heated by steam from boiler and other end of the tube is cooled by circulating cold water from constant water flow arrangement. Water from constant water flow arrangement is adjusted to come out in drop from exit side. For the measurement of temperature of water at entrance and exit, arrangement for thermometers has been made in the apparatus. The temperature of fixed points of tube is measured by inserting thermometers on holes of tube. The apparatus is kept in a wooden box for minimizing heat losses.

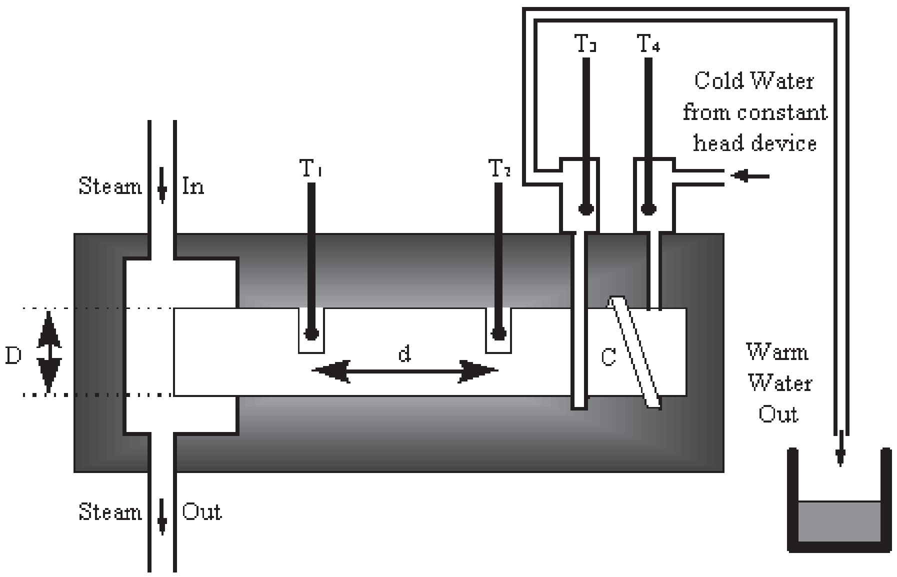

Figure 1

13.6 PROCEDURE

Let us perform the experiment in following steps.

1. Measure distance between two fixed points of tube.
2. Determine the diameter of tube.
3. Pass the steam from boiler to steam chamber to heat the one end of tube.
4. Allow the water flow in the tube from other end from constant pressure arrangement and adjust the water so that it comes in drops at exit point of the apparatus.
5. Insert the thermometers at respective position on tube.
6. Attain the steady state respective position on tube i.e. temperature become constant.
7. Collect the water in clean Beaker for 5 minutes and calculate mass of water per second. Mass is calculated by knowing volume of water coming out.
8. Determining above calculate the coefficient of thermal conductivity K of tube (good conductor).

13.7 OBSERVATION

1. The distance between two fixed points on tube = …………. cm.

2. Table for determination of diameter (D) of tube

   Least count of vernier callipers = ………….. cm.

   Zero error of the vernier callipers= ± ………….. cm.

S. N.	Reading along any direction			Reading along a perpendicular direction			Mean diameter (Uncorrected) (X+Y)/2	Mean diameter (corrected)	Mean diameter (corrected)
	M.S. Reading	V.S. Reading	Total Reading (X)	M.S. Reading	V.S. Reading	Total Reading (Y)			
1									
2									
3									
4									
5									

3. Table for determine steady state of respective place of tube:

S.N.	**Time in minutes**	**Thermometer Reading**			
		Steady temperature of one fixed point attach the steam boiler on tube θ_1	**Steady temperature of other fixed point on tube** θ_2	**Steady temperature at exit point of cooled water** θ_3	**Steady temperature at entrance point of water** θ_4
1	**1**				
2	**2**				
3	**3**				
4	**4**				
5	**5**				
6	**6**				
7	**7**				
8	**8**				
9	**….**				
10	**….**				
11	**….**				
12	**….**				
13	**….**				
14	**….**				

Steady state temperatures from above table

θ_1=………..^{0}C

θ_2=………..^{0}C

θ_3=………..^{0}C
θ_4=………..^{0}C

4. Mass of collected water:

   Mass of collected water in 5 minute=…………..gm

   Mass of collected water in 1 second=…………..gm

13.8 CALCULATION AND DISCUSSION

The coefficient of thermal conductivity K for good conductor (a metal) is given by the formula

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

After putting the observed values from observation table 1, 2, 3 & 4, the coefficient of thermal conductivity K is calculated and from its value the material is listed in category of good conductor or bad conductor.

13.9 RESULT

The coefficient of thermal conductivity of given metal (good conductor) is ………..cal/cm/^{0}C/sec.

13.10 STANDARD RESULT

The value of coefficient of thermal conductivity of given metal (good conductor) is ………..cal/cm/^{0}C/sec.

13.11 PERCENTAGE ERROR

13.12 PRECAUTION AND SOURCE OF ERROR

1. Water from constant water flow arrangement should come out in drop from exit side.
2. Steady state of respective place of tube is taken carefully.
3. Water should be collected after attaining the steady state of thermometer.
4. The diameter of should be determine accurately.

13.13 REQUIRED TABLE

The Standard values of thermal conductivity of different material

Substance	Thermal conductivity in C.G.S. units	Substance	Thermal conductivity in C.G.S. units
Aluminium	0.504	Iron (wrough)	0.144
Bismuth	0.0194	Lead	0.083
Copper	0.918	Platinum	0.166
Gold	0.7	Silver	0.974
Tungsten	0.35	Steel	0.115

13.14 SUMMARY

1. Thermal conductivity refers to the intrinsic ability of a material to transfer heat. It is one of the three methods of heat transfer, the other two being convection and radiation. Thermal conductivity occurs through molecular agitation and contact, and does not result in the bulk movement of the solid itself.
2. If heat 'Q' is entering the metallic tube in time 't' , A is cross sectional area, 'd' is distance between two points on tube to which heat transferred and $(\theta_1 - \theta_2)$ is temperature gradient then

$$Q = KA\frac{\theta_1 - \theta_2}{d}t$$, where 'K' is coefficient of thermal conductivity

3. One end of metallic tube is heated by passing steam from steam chamber. This heat flows through metallic tube which transfers to cold water coming from chamber having constant pressure arrangement. This heat raises the temperature of water. By observing change in temperature of water, we can calculate thermal conductivity of water.

4. In present experiment, the method of transferring heat along the metallic tube is conduction and for minimizing heat loss the apparatus is kept in wooden box.

13.15 GLOSSARY

Thermal Conductivity: Measure of how a material conducts the transfer of heat from it.

Good conductor of heat: Materials in which heat can flow.

Steam chamber: Enclosed space containing steam.

Specific heat: Heat required to increase the temperature of unit mass substance by 1^0 C.

13.16 REFERENCES

1. C. L. Arora, *B.Sc. Practical Physics*, S. Chand publication, Delhi

2. C.L. Arora and P.S. Hemne, *Physics for Degree students (BSc Second year)*, S. Chand publication, Delhi

3. Indu Prakash, Ram Krishna, A K Jha, *A text Book of Practical Physics*, Kitab Mahal Publication Delhi.

5. S.L.Gupta, V.Kumar, *Practical Physics*, Pragati prakashan, Meerut.

4. *https://en.wikipedia.org.*

13.17 VIVA-VOCE QUESTIONS

Question1: What do you understand by thermal conductivity?
Answer: It is measure of how a material conducts the transfer of heat from it. Thermal conductivity is defined as quantity of heat flowing per second through unit area of cross section of a material, of unit thickness, when the difference of temperature is unity.
Question2: What is unit thermal conductivity?
Answer: cal/cm/^{0}C/sec.
Question3: What is steady state?
Answer: In the steady state the temperature of each point of rod becomes constant, i.e. it does not rise further. The heat transmitted from one point to another does not raise their temperature but part of it is radiated and rest transmitted to next section.
Question4: How the heat is transmitted in this experiment?
Answer: By conduction.
Question5: Can this method be used for determining thermal conductivity of bad conductor?
Answer: No, because in bad conductors, heat conduction is very small and temperature difference will not be worth recording.
Question6: What should be conductivity of perfect conductor of heat?
Answer: Infinite.

EXPERIMENT 14: TO DETERMINE THE TEMPERATURE COEFFICIENT RESISTANCE OF PLATINUM RESISTANCE THERMOMETER BY USING CAREY FOSTER'S BRIDGE

CONTENTS

14.1 OBJECTIVES

After performing this experiment, you should be able to

- what is the principle of Carey Foster's bridge
- to know Wheatstone bridge
- relate how the resistance vary with temperature
- determine the temperature coefficient of platinum
- describe the application of platinum resistance thermometer

14.2 INTRODUCTION

Platinum resistance thermometer is a device which is used to determine the variation in electrical resistance of platinum with variation in temperature. The resistance of platinum wire free from impurities has a linear resistance-temperature relationship. Platinum resistance thermometers are used in industrial application at temperature below 600^0C. When the temperature becomes higher than 600^0C it becomes difficult to prevent the platinum from being contaminated by impurities from the metal covering of the thermometer.

Carey Foster bridge is a bridge circuit used to measure medium resistances or to measure small difference between two large resistances. It is a modified form of Wheatstone bridge. This bridge can be used to calibrate a resistance temperature device. Platinum resistance thermometer requires a small current to pass through it to determine its resistance at different temperatures.

14.3 APPARATUS USED

Carey Foster's Bridge, Two equal resistances of about 2 ohms each, two thick copper strip, a fractional resistance box, a cell/ battery, galvanometer, Platinum resistance thermometer, water bath, thermometer, one way key, connecting wires, jockey.

14.4 THEORY AND FORMULA USED:

The resistance of pure platinum wire increases with temperature according to the relation

$$R_T = R_0 (1+\alpha T)$$

Where R_0 = resistance of wire at 0^0C, R_T = resistance of wire at temperature T ^{0}C and 'α' is a constant, called the temperature coefficient of resistance for platinum.

α can be calculated by measuring the resistance of the Platinum resistance thermometer at any two temperatures as described below.

Let R_1 and R_2 be the resistance of the Platinum resistance thermometer at temperature T_1 and T_1, then

$$R_1 = R_0 (1+\alpha T_1)$$

and $$R_2 = R_0 (1+\alpha T_2)$$

On solving above two equations we get

$$\alpha = (R_2 - R_1) / (T_2R_1 - T_1R_2)$$

14.5 ABOUT APPARATUS

The electrical resistance of metal wire increases linearly with temperature. So, electric resistance may be used as a thermometric property to define a temperature scale. A platinum wire is often used in this thermometer because platinum has high melting point and its temperature coefficient of resistance (α) is constant and large.

Platinum resistance thermometer consists of a fine platinum wire wound in a non-inductive way on a mica frame M (as shown in figure 1).The ends of this wire are soldered to points A and C from which two thick leads run along the length of the glass tube and are connected to two terminals (P,P) fixed on the cap of the tube. These are the platinum wire leads. By the side of these leads, another set of leads run parallel and are connected to the terminals (C,C) fixed on the cap of the tube. These are called compensating leads and are platinum wire are separated from each other mica separators (D, D). The electrical resistance of the (P, P) leads is same as that of the (C, C) leads.

Platinum resistance thermometer requires a small current to pass through it to determine its resistance at different temperature. Platinum resistance thermometer can be used in the temperature range -170^{0}C to 200^{0}C.

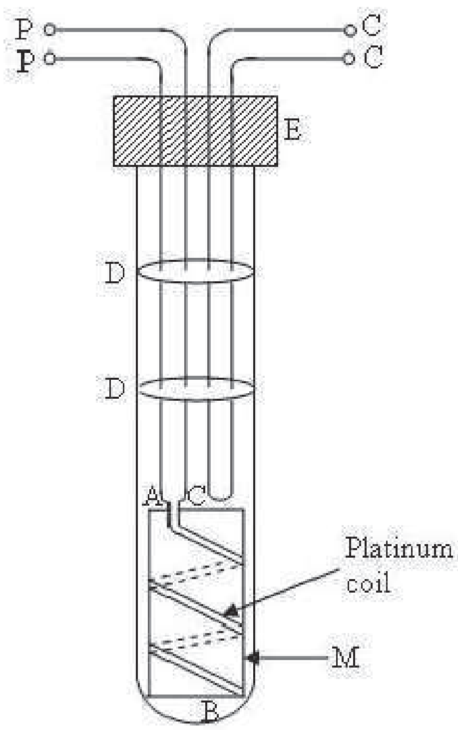

Figure 1: PlatinumResistance Thermometer

14.6 PROCEDURE

Let us perform the experiment in following steps.

1. Connect the circuit as shown in figure .
2. Put the PTR in water bath and connect the PP leads in gap 1 and the compensating leads (C, C) in gap 4 in series with a fractional resistance box X. The wires used to connect the (P, P) and (C, C) leads should be cut from the same bunch and should be of equal length.
3. Connect the two standard resistances P and Q in the inner gap 2 and 3 and also, the galvanometer with a jockey.
4. Put some ice in water bath and note the temperature T_1. Ensure that the PRT is surrounded by ice with a little water so as to fill all air space between the ice pieces.
5. Introduce a suitable resistance from the fractional resistance box X and note down the balancing length from one end as l_1 . The balancing point should be determined only after the PRT has acquired a steady temperature failing which, the position of balance point on the bridge wire will not be stable. Also record the same for reverse current by interchanging the terminals of the battery
6. Interchange the resistances in the outer arms (gap 1 and 4) and note l_2 from the same end for direct as well as reverse current.
7. Calculate $R_1 = X + \rho (l_2 - l_1)$; that is resistance of the PRT at temperature T_1.
8. Now, remove the ice and put the PRT in water at room temperature, say T_2. Note down and record T_2 in the observation table.
9. Determine the resistance of PRT at T_2 (that is R_2) by repeating the steps 5 to 7 as above.
10. Now, heat the water for some time till the PRT acquires a constant temperature T_3 . Note down T_3 and repeat the steps 5 to 7 to determine the resistance at T_3.
11. Repeat step 10 for at least five more temperatures.

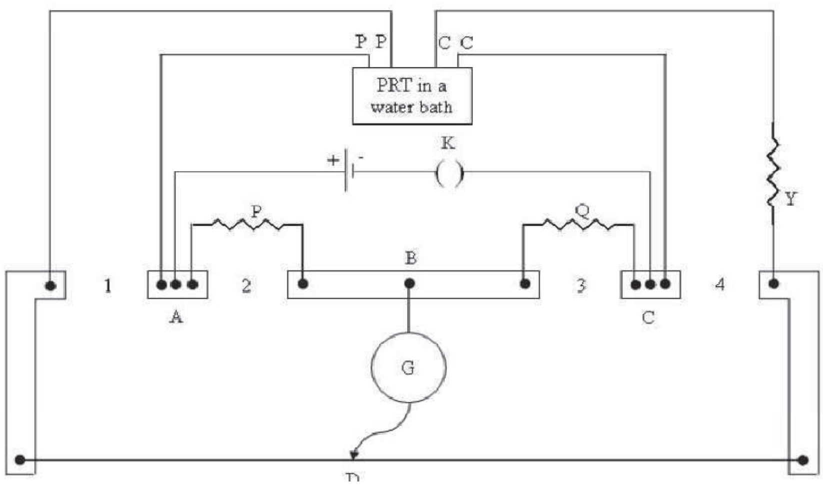

Figure 2: Circuit for determination of resistance of PRT at different temperatures.

14.7 OBSERVATION

Resistance per unit length of the Carey Foster's bridge wire (ρ) = ……………Ω/cm

Fractional resistance = 0.5 or 1.0 Ω

Table1. determination of resistance of PRT at different temperature.

S.N.	Temp. of water (^{0}C)	Position of balance point with PP leads in the						$(l_2 - l_1)$ (cm)	$R_T = X + \rho (l_2 - l_1)\Omega$
		Right gap (l_1 in cm)			Left gap (l_2 in cm)				
		Direct current	Reverse current	Mean	Direct current	Reverse current	Mean		
1									
2									
3									
4									
5									
6									

14.8 CALCULATION AND DISCUSSION

Plot a graph (Figure 3) between the temperature (in ^{0}C) and the resistance of PRT (in Ω) that is the calibration curve of PRT. The variation in resistance of PRT as a function of temperature has been studied and calibration curve for the given resistance temperature device has been drawn, which is a straight line.

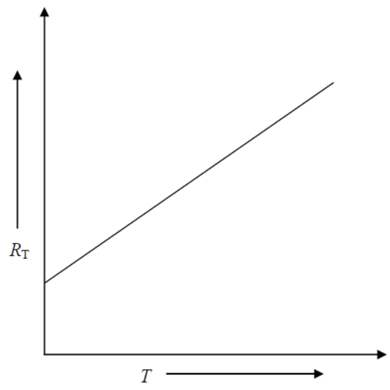

Figure 3 Graph showing change in resistance with temperature

From the graph, α can be calculated as following

$\alpha_1 = (R_2 – R_1)/(T_2 R_1 – T_1 R_2)$

$\alpha_2 = (R_3 – R_2)/(T_3 R_2 – T_2 R_3)$

$\alpha_3 = (R_1 – R_3)/(T_3 R_1 – T_1 R_3)$

A number of values of 'α' can be calculated by choosing any two points on the temperature scale and the corresponding resistances.
Mean value of 'α' can be taken as the mean of all the calculated values.

14.9 RESULT

The temperature coefficient of resistance for platinum using PRT is found to be …………**$^0C^{-1}$.**

Standard value of 'α' for platinum is 37 x 10^{-4} $^0C^{-1}$.

14.10 PRECAUTION AND SOURCE OF ERROR

1. The ends of connecting wires, thick copper strips and leads should be well cleaned. Connection should be made tight.
2. Jockey should be pressed gently on bridge wire.
3. The bridge wire may get heated up due to continuous passage of current for a long time, which will change its resistance.
4. The balance point for the measurement of resistance should be determined only when the temperature acquired by PRT is steady.

14.11 SUMMARY

1. Platinum resistance thermometer is that device, by which one can determine the unknown temperature because resistance of platinum varies linearly.
2. For various values of resistance of platinum wire at different temperature, the graph between temperature and resistance is a straight line.
3. The straight line of the graph shows linear dependence of resistance on temperature.
4. For different values of resistance at different temperature, which are obtained from graph, on substituting the corresponding values in the relation

$$\alpha = (R_2 - R_1)/(T_2 R_1 - T_1 R_2)$$

one can calculate the temperature coefficient of of resistance of platinum.

14.12 GLOSSARY

Balance point: a point on the bridge wire that produces zero deflection in the galvanometer when the jockey knife edge is in contact. Also known as a null point

Jockey: a metal knife edge that can move along the bridge wire of a Carey Foster's bridge and is used to locate the null point.

Low resistance: a resistance in the range of 1-5 ohm.

Resistance: the opposition offered to the flow of current by an object. The SI unit of resistance of is ohm.

Specific resistance: the resistance per unit length of the wire. The SI unit of specific resistance of is ohm per meter.

14.13 REFERENCES

1. C. L. Arora, *B.Sc. Practical Physics*, S. Chand publication, Delhi

2. C.L. Arora and P.S. Hemne, *Physics for Degree students (BSc Second year)*, S. Chand publication, Delhi

3. Indu Prakash, Ram Krishna, A. K. Jha, *A text Book of Practical Physics*, Kitab Mahal Publication Delhi.

4. *https://en.wikipedia.org*

14.14 VIVA-VOCE QUESTIONS

Question1. What is the temperature coefficient of resistance?

Answer: Temperature coefficient of resistance is increase in resistance per unit resistance per unit rise in temperature.

Question2. What is the relation between resistance and temperature for platinum wire?
Answer: Resistance is linearly depends on temperature.

Question3. Why the temperature above 1200 ^{0}C cannot be measured accurately by a PRT.

Answer: This is because platinum begins to evaporate above 1200 ^{0}C.

Question4. On which principle Carey Foster's Bridge based?

Answer: It is based on the principle of Wheat stone's bridge.

Question5. What is balanced point of a Carey Foster's Bridge?

Answer: A point on the bridge wire that produces zero deflection in the galvanometer when the jockey edge is in contact with it. It is also known as 'null point'.

Question6. What is the use of determining of α ?

Answer: We can determine any temperature by recording the change in resistance of the material.

Question7. Why platinum wire is chosen for this experiment?

Answer: Because for platinum, variation in resistance with temperature is large and uniform.

EXPERIMENT 15: TO VERIFY NEWTON'S LAW OF COOLING

CONTENTS

15.1 OBJECTIVES

After performing this experiment, you should be able to

- describe Newton's law of cooling
- Know that each body radiates heat and absorbs heat radiated by the other
- understand that radiation by surface occurs at all temperatures
- understand the Principle of calorimeter

15.2 INTRODUCTION

Each body radiates heat and absorbs heat radiated by others. The hotter body radiates more and receives less. Radiation by surface occurs at all temperatures. Higher the temperature difference with surroundings, higher is the rate of heat radiation. Newton's law of cooling states that the rate of cooling decreases with the passes of time and is proportional to difference of temperature between body and surrounding.

15.3 APPARATUS USED

A copper calorimeter, two Celsius thermometers, a stirrer, a stop watch, hot plate.

15.4 THEORY AND FORMULA USED

The rate at which a body loses by radition depends on (i) the temperature of body, (ii) the temperature of surounding medium and (iii) the nature and extent of the exposed surface.

According Newton's law of cooling, the rate of loss of heat is proportional to temperature difference between the body and its surroundings.

For a body of mass 'm' and specific heat 's' at its initial temperature 'θ' higher than its surronding's temperature θ_0. If dQ is amount of heat lost by the hot body to its surrounding in small interval of time dt, then rate of loss of heat is dQ/dt.

Following Newton's law of cooling we have

$$dQ/dt = -K(\theta-\theta_0) \qquad (1)$$

Also $$dQ/dt = ms\,(d\theta/dt) \qquad (2)$$

From equations (1) and (2)the rate of fall of temperature is given by

$$d\theta/dt = -K(\theta-\theta_0)/ms \qquad (3)$$

let K/ms ,which is constant is replaced by another constant k , than

$$d\theta = -k(\theta-\theta_0)\,dt$$

On integrating, we get

$$\log_e(\theta-\theta_0) = -kt + c$$

$$2.303\log_{10}(\theta-\theta_0) = -kt + c \qquad (4)$$

Here 'c' is integration constant.

Equation (4) shows that the graph between $\log_{10}(\theta-\theta_0)$ and 't' is a straight line, so plotting the graph will be used to verify Newton's law of cooling.

$$2.303\log_{10}(\theta-\theta_0) = -kt + c$$

Where θ = temperature of body

θ_0 = temperature of surrounding

k is constant and c is constant of integration .

15.5 ABOUT APPARATUS

Newton's low of cooling can be verified with the help of experimental setup shown in figure. The setup consist of double walled vessel (V) containing water in between the two walls. A copper calorimeter (C) containing hot water is placed inside the doubled walled vessel. Temperature of water in calorimeter and that of water between double walls of container is recorded by two thermoters.

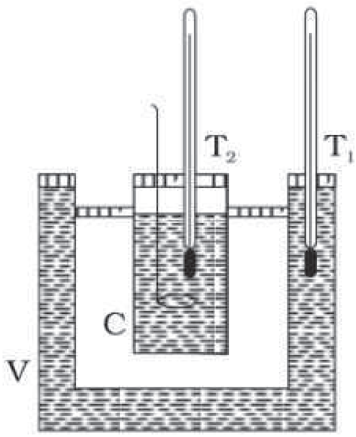

Figure1: Calorimeter

15.6 PROCEDURE:

Let us perform the experiment in following steps.

1. Find the least count of both thermometers. Measure room temperature(θ_0)with the help of one (say T_1) of the thermometers.
2. Pour water into the double – walled container at room temperature. Insert the other thermometer(T_2) in water contained in it.
3. Heat some water separately to a temperature of about 50^0C above the room temperature. Pour hot water in calorimeter.
4. Put the calorimeter back in the enclosure and cover it with the lid having holes. Insert the thermometer T1and the stirrer in the calorimeter through the holes provided in the lid.
5. Note the initial temperature of water between enclosure of double wall with the thermometerT_2, when the difference of readings of two thermometers T_1 and T_2 is about 40^0C. Note the initial reading of the thermometer T_1.

6. Keep on stirring the water constantly. Note the reading the temperature T_1 , first after about every 30 seconds , then after about one minute and finally after two minutes duration.
7. Record observations in tabular form. Find the excess of temperature (θ-θ_0) and also $\log_{10}$ (θ-θ_0) for each reading by using logarithmic tables.
8. Plot the graph between time't', taken along x-axis and $\log_{10}$(θ-θ_0) taken along y-axis. Interpret the graph.

15.7 OBSERVATION

Least count of stop watch = ……. Second
Least count of both the thermometers = ……. ^{0}C
Initial temperature of water in the enclosure θ_1 = ….. ^{0}C
Final temperature of water in the enclosure θ_2 = ….. ^{0}C
Mean temperature of water in the enclosure θ_0= (θ_1+θ_2)/2 = …… ^{0}C

Table1: For measuring the change in temperature of water with time

S.N.	Time (t) in seconds	Temperature of hot water θ_2 ^{0}C	Excess Temperature of hot water (θ- θ_0) ^{0}C	$\log_{10}$(θ- θ_0)
1				
2				
3				
4				
5				
6				

15.8 PLOTTING GRAPH

1. Plot a graph between (θ-θ_0) and't' as shown in figure 2 taking 't' along x-axis and (θ-θ_0) along y-axis . This is called cooling curve.
2. Plot a second graph between $\log_{10}$ (θ-θ_0) and time't' as shown in figure 3, taken 't' along x-axis and $\log_{10}$(θ-θ_0) along y-axis.

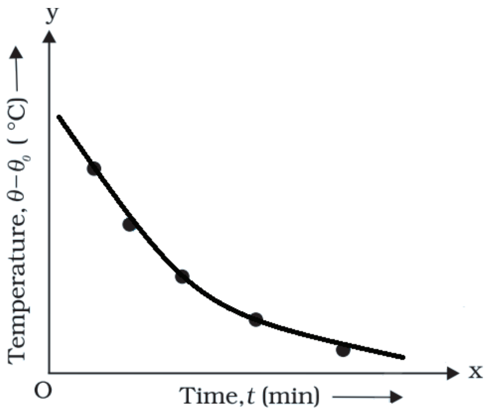

Figure 2

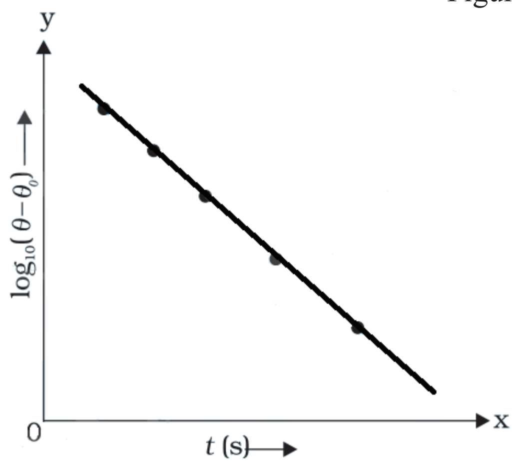

Figure 3

15.9 RESULT

The cooling curve is an exponential decay curve. It is observed from the graph that the logarithm of the excess of temperature of hot body over that of its surroundings varies linearly with time as the body cools, which verify Newton's law of cooling.

15.10 PRECAUTION AND SOURCE OF ERROR

1. Water in the calorimeter should be gently stirred continuously.
2. Make sure that the openings for inserting thermometer are air tight and no heat is lost to the surroundings through these.
3. The accuracy of result depends mainly on the simultaneous measurement of temperature of hot water and the time.
4. The temperature of the water in enclosure is not constant.
5. If the opening for the thermometer is not airtight, some loss of heat can occur.

15.11 SUMMARY

1. When a hot body placed in surrounding which is at lower temperature, it losses heat to the surrounding.
2. According to Newton's law of cooling $dQ/dt = -K (\theta-\theta_0)$
3. Graph between difference of temperature $(\theta-\theta_0)$ and time (t) is exponential.
4. A graph drawn between $\log_{10}(\theta-\theta_0)$ and time (t) is a straight line having negative slope.
5. With points 3 and 4, we conclude that Newton's law of cooling hold good.

15.12 GLOSSARY

1. Calorimeter: a device used to study loss and gain of heat
2. Radiant energy: energy of electromagnetic radiation emitted by a body
3. Specific heat: the property of substance which determines the change in temperature of the substance when a given quantity of heat is absorbed by it.
4. Thermometer: instrument use to measure temperature

15.13 REFERENCES

1. C. L. Arora, *B.Sc. Practical Physics*, S. Chand publication, Delhi

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4. https://en.wikipedia.org

15.14 VIVA-VOCE QUESTIONS

Question1.What is Newton's law of cooling?

Answer: The rate of cooling of a body is directly proportional to the temperature difference between the body and its surroundings , provided that the temperature difference is small .

Question2. Calorimeters are made of metals not glass. Why?

Answer: This is because metals are good conductors of heat and have low specific heat capacity.

Question3.Which object will cool faster when kept in open air, the one at 200^0C or the one at 100^0C? Why?

Answer: The object at 200^0C will cool faster than the object at 100^0C. This is in accordance with
Newton's law of cooling.

Question 4 .What is the significance of Newton's law of cooling curve?

Answer: The rate of cooling decreases as the difference of temperature between the body and surrounding decreases.

Question5.What is meant by the rate of cooling?

Answer: It is fall in temperature of a body per second.