

Instruction Manual
PHYSICS LABORATORY
(ASP 202)



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Instructions to Students

Introduction

Physics is an experimental science. Advancements in physics throughout its history have come about mainly driven by experiments. For you, the physics lab will be an opportunity to have some fun with some hands-on experience with physics theories. Moreover, it will be an opportunity for you to develop and enhance your skills of experimental observation, data analysis and proper scientific documentation which are always important in a career in science and engineering. So please look forward to use your laboratory time for a gainful purpose.

This manual will provide the basic theoretical backgrounds and detail procedures of various experiments that you will perform in the lab. Before that, here are some specific instructions for you to follow while carrying out the experiments. It also outlines the approach that will be undertaken in conducting the lab. Please read carefully the followings.

Specific Instructions

1. ***You are expected to complete one experiment in each class.*** For that to happen, you will have to come to the laboratory with certain ***initial preparation***. The initial preparation will involve a prior study of the basic theory of the experiment you are going to take up as well as the procedure to perform it so as to have a rough idea of what to do. In addition, it will also involve a ***partial*** preparation of the lab report in advance as mentioned later in this section.
2. ***You must bring with you the following materials to the lab:*** This instruction manual, A4 size papers for writing the lab report, graph sheets if necessary, pen, pencil, measuring scale, calculator and any other stationary items required. On the very first day of your lab class, **bring also a file cover/folder with your name, roll no., branch name etc. written on it clearly and submit it to the instructor.** The folder will be used to store your laboratory reports regularly at the end of the classes. The folder with your reports will be kept in the laboratory and will be returned to you only after the course instructions are over.
3. The format of a lab report shall be as follows:
 - (a) The first sheet will contain your name, branch name, roll number, date and title of the experiment. The subsequent sheets will contain the followings in that order.
 - (b) The objective of the experiment, apparatus needed, and a brief theory with working formulas and figures or diagrams whenever necessary.
 - (c) Experimental observations. Data from experimental observations should be recorded in proper tabular format with well documented headings for the columns. The data

tables should be preceded by the least counts of the instruments used to take the data and numerical value of any constant, if any, used in the table.

- (d) Graphs whenever applicable.
 - (e) Relevant calculations, error analyses.
 - (f) Final results along with error estimates.
 - (g) Remarks if any.
 - (h) Please DO NOT write the procedure of experiment anywhere.
4. As part of the initial preparation mentioned earlier, ***you are required come to the lab ready with the items 3(a) and 3(b) above already written in your report sheets.*** This will save valuable lab time and help you to complete the rest of the experiment within the allotted time.
 5. After the completion of your data recording, switch off any power supply etc. used and put back the components of the apparatus in their proper places. Complete the rest of the relevant calculations and hand over the final report sheets to the instructor before leaving the lab.
 6. Last but not the least - ***please handle the instruments with care and maintain utmost discipline and decorum in the lab.***

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References

This manual was prepared with helps from several books, documentation provided by the equipments vendors, and from several documents shared by others on the website. Though it is not possible to mention all the individual sources, cited below is a list of books which students may also find helpful for further reading.

1. “*Fundamentals of Physics*”, D. Halliday, R. Resnick and J. Walker, John Wiley and Sons, Inc., New York, 2001.
2. “*Concepts of Modern Physics*”, A. Beiser, The McGraw-Hill Companies, Inc., New York, 2003.
3. “*Optics*”, A. Ghatak, Tata-McGraw Hill, New Delhi, 1992.
4. “*Practical Physics*”, G. L. Squires, Cambridge University Press, Cambridge, 1985.
5. “*Laboratory Experiments in College Physics*”, C. H. Bernard and C. D. Epp, John Wiley and Sons, Inc., New York, 1995.
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Experiment 1

Study of Hall Effect

Objective

To study Hall effect and determine the Hall coefficient and hence the number density of majority charge carriers of a semiconductor sample.

Apparatus

A Hall effect experimental setup with the following components: electromagnet with power supply, Hall probe, semiconductor sample, current supply with ammeter, voltmeter etc.

Theory

When an electrical current passes through a sample placed in a magnetic field, a voltage develops across the sample in a direction perpendicular to both the current and the magnetic field. This is known as Hall effect.

The basic experimental setup for study of Hall effect is shown in Fig. 1. A rectangular slab of a semiconducting sample with its *width* (w) along y -direction and *thickness* (d) along z -direction is placed in a magnetic field of strength B directed along the z -direction. Now

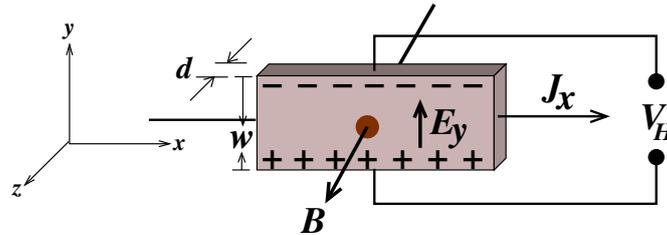


Fig. 1: Hall effect experiment (for +ve charge carriers)

an electric current, I_H is made to pass through the sample along its length by maintaining a potential difference along x -direction. The corresponding current density is,

$$J_x = \frac{I_H}{wd} \quad (1)$$

Suppose that the charge carriers are positive, each having charge $+q$, and are moving along $+x$ direction with velocity \vec{v} . Then the Lorentz force experienced by the carriers due to the magnetic field is,

$$\vec{F}_B = q(\vec{v} \times \vec{B}) = -(qvB)\hat{y} \quad (2)$$

This force \vec{F}_B along $-\hat{y}$ direction deflects the positive charge carriers towards the *bottom surface* of the sample. This makes the *bottom surface* positively charged while leaving the *top surface* negatively charged. This accumulation of charges near the bottom and top surfaces of the sample leads to the development of a transverse electric field $\vec{E} = E_y\hat{y}$ along the y -direction. Force due to this electric field, $q\vec{E}$ opposed the Lorentz force \vec{F}_B and prevents further charge accumulation. In the steady state condition, these two forces balance out each other and we get,

$$qE_y = qvB \quad (3)$$

Now we define a quantity called *Hall coefficient* R_H , as the ratio of the electric field E_y to the current density J_x multiplied by magnetic field B , that is

$$R_H = \frac{E_y}{J_x B} = \frac{1}{nq} \quad (4)$$

where we have used Eq. (3) and the fact that $J_x = nqv$, n being the number density (m^{-3}) of charge carriers.

In order to determine R_H , we proceed as follows. Writing $v = J_x/nq$ and multiplying both sides of Eq. (3) by wd , we get

$$E_y wd = \frac{J_x wd B}{nq} \quad (5)$$

But $Ew = V_H$, the voltage across the top and bottom surfaces called the Hall voltage and $J_x wd = I_H$. This gives,

$$V_H = \left(\frac{R_H B}{d} \right) I_H \quad (6)$$

Therefore, if we measure the Hall voltage V_H against Hall current I_H for a fixed magnetic field B and plot V_H versus I_H , the curve will be a straight line with the slope m being,

$$m = \frac{R_H B}{d} \quad (7)$$

The Hall coefficient R_H can be calculated from the value of this slope, m if the thickness d of the sample is known. Once R_H is determined, the carrier density n can be calculated using Eq. (4).

Now assume the situation where the charge carriers are negative with $q = -e$. In that case, for current direction along $+x$, the charges will be moving with velocity $\vec{v} = -v\hat{x}$. The Lorentz force, $\vec{F}_B = q(\vec{v} \times \vec{B}) = -(evB)\hat{y}$ will still be along negative y direction as before. However this time, the bottom surface acquires negative polarity and consequently, the sign of the Hall voltage V_H will be opposite to what was observed in case of positive charge. Thus for given directions of the Hall current and the magnetic field, we can determine the type of charge carriers (whether +ve or -ve) by looking at the sign of the Hall voltage V_H .

Experimental setup

The experimental setup is complete unit (Fig. 2) consisting of the followings - an electromagnet, constant current power supply, a Gauss and Tesla meter, a Hall current & voltage measurement unit and the sample connected with contact leads for passing Hall current and measuring Hall voltage.



Fig. 2: Hall effect measurement unit

Procedure

1. Keep the poles of the electromagnet apart by a distance of around 20 mm.
2. Connect the electromagnet with the constant current power supply and switch on power.
3. Set a suitable magnetic field (< 3 KGauss) by adjusting the magnetizing current. You can measure the magnetic field using the Hall probe. You will have to keep the magnetic field constant at, say $B = 1$ KG and $B = 2$ KG for two sets of measurements.
4. Insert the sample between the pole pieces of the electromagnet.
5. For the first set of measurement, set the magnetic field ($+B$) first at, say $B = 1$ KG and keep it constant.
6. Switch on the Hall current I_H through the sample and adjust it at around 5 mA. Measure the hall voltage V_H .
7. Increase the Hall current I_H at suitable steps (up to maximum 20 mA) and record V_H against each I_H .
8. Now reverse the direction of the magnetic field ($-B$) keeping its magnitude constant at the same value (1 KG in this case).
9. Record V_H against I_H for the same set values of I_H as taken for $+B$.
10. Now for each current I_H , calculate the average of two values of $V_H(+B)$ and $V_H(-B)$. This cancels out offset voltage due to any misalignment in the sample contacts.
11. Plot a curve of V_H versus I_H and find out its slope.
12. Calculate the Hall coefficient, R_H from the slope.
13. For the second set of measurement, increase the magnetic field ($+B$) to say $B = 2$ KG and keep it constant.
14. Repeat steps 6-12.
15. Finally calculate the average R_H and determine the number density n using Eq. (4).

Observations

Thickness of the sample, $d = \dots$

Table 1: Hall voltage V_H as a function of Hall current I_H , for $B = 1$ KG

Sl No.	I_H (in mA)	$V_{H1}(+B)$ (in mV)	$V_{H2}(-B)$ (in mV)	Mean $V_H = \frac{ V_{H1}-V_{H2} }{2}$	I_H (in A)	Mean V_H (in V)
1	5					
2	7					
3	9					
⋮						
8	...					
⋮						

Table 2: Hall voltage V_H as a function of Hall current I_H , for $B = 2$ KG

Sl No.	I_H (in mA)	$V_{H1}(+B)$ (in mV)	$V_{H2}(-B)$ (in mV)	Mean $V_H = \frac{ V_{H1}-V_{H2} }{2}$	I_H (in A)	Mean V_H (in V)
1	5					
2	7					
3	9					
⋮						
8	...					
⋮						

Graphs:

Plot two graphs of V_H versus I_H for the above two data tables and find its slopes.

Calculations:

From the slopes of the above two $I_H - V_H$ curves, calculate the Hall coefficient R_H and find the average of the two values obtained. Calculate the number density of majority charge carriers using Eq. (4) and assuming that q is equal to the charge of an electron.

Result:

Hall coefficient of the given sample, $R_H = \dots$

Number density of majority charge carriers, $n = \dots$ (m^{-3}).

Remark:

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Experiment 2

Determination of Planck's constant

Objective

To determine the value of Planck's constant using photoelectric effect.

Apparatus

Planck's constant experimental unit consisting of a vacuum photo tube, light source, color filters, regulated voltage power supply, voltmeter, ammeter etc.

Theory

The phenomenon of emission of electrons from the surface of a material when light falls on it, is known as the photoelectric effect. The emitted electrons are called photoelectrons. A typical experimental setup for observing the photoelectric effect is shown in Fig. 1. Light falls on a target metal plate T enclosed in a vacuum tube and as a result electrons are ejected from the

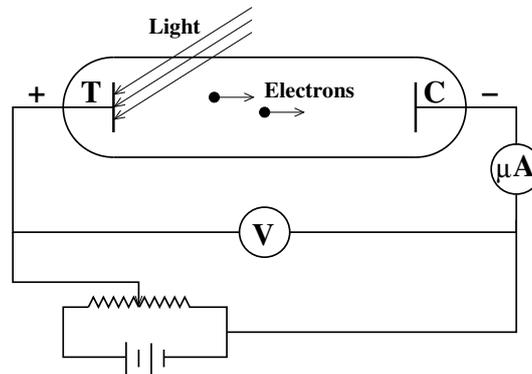


Fig. 1: Photoelectric effect experiment

surface of the plate. When the ejected electrons reach the collector electrode C placed opposite to T, an electric current, called photocurrent flows through the circuit. This photocurrent can be measured by an ammeter connected to the circuit. The kinetic energies of the emitted electrons can be estimated by applying a negative potential to the collector C and tuning the potential such that it is just enough to prevent the electrons from reaching the collector. This negative potential, V_0 to C at which the photocurrent becomes zero, is called the *stopping potential*. Obviously,

$$eV_0 = K_{max} \quad (1)$$

where e is the electronic charge and K_{max} is the maximum kinetic energy of the emitted electrons. The photoelectric effect was first explained by Einstein on the basis of quantum theory of light. According to it, light, i.e. electromagnetic radiation consists of discrete energy packets or energy quanta. Each energy packet behaves as particle and is called photon. The energy of a photon is given by,

$$E = hf \quad (2)$$

where h is called Planck's constant and f is the frequency of radiation. When the photons falls on metal surface, an electron can absorb the energy of a photon and acquire enough energy to escape the surface potential barrier ϕ (also called work function). The maximum kinetic energy with which the electron can eject out, according to the principle of energy conservation, is given by

$$K_{max} = hf - \phi \quad (3)$$

Since $K_{max} = eV_0$, the relationship can also be written as

$$eV_0 = hf - \phi \quad (4)$$

The above equation shows that a graph of V_0 versus f will be a straight line with the slope being equal to h/e . Thus, if V_0 is measured for different frequency f (colors) of incident light and V_0 is plotted as a function of f , the value of Planck's constant h can be determined from the slope of the line.

Experimental setup

The Planck's constant measurement unit is shown in Fig. 2. It consists of a light source, a photo vacuum tube, DC voltmeter, DC ammeter and connecting ports. Also supplied along with the unit are four filters of different colors, e.g. violet, blue 1, blue 2 and yellow. The circuit diagram for the connections is displayed in the panel.



Fig. 2: Planck's constant measurement unit

Procedure

1. Take the Planck's constant setup & fix the photo vacuum tube at particular position.
2. Complete the circuit connections as shown in the diagram in the panel of the unit.
3. Set the range of the DC voltmeter at 200 mV and the ammeter at $2 \mu\text{A}$.
4. Connect the mains cord and switch on the power supply and light source. Now you can observe some value of current on ammeter.
5. First insert the 'red' color filter in front of photo vacuum tube.
6. If the observed current is too low, then slide the photo vacuum tube towards light source till you get some appreciable current. Fix the photo tube at this distance (position 1).
7. Switch on the DC voltage source.
8. Now vary the DC voltage slowly by variable resistance pot and see the value of current. It should decrease as the voltage is increased.
9. When the current becomes zero, note the value of applied voltage by DC voltmeter. This is the stopping potential, V_0 for the given color.
10. Switch off the DC voltage source.
11. Repeat steps 7-10 for the other color filters, e.g. orange, yellow, green and blue respectively, keeping the position of the photo vacuum tube fixed.
12. Tabulate all the readings as indicated in Table 1.
13. Now reduce the distance between the light source and the photo vacuum tube to approximately half of what was taken in the above set of readings. This is position 2 of the photo tube.
14. Repeat steps 7-12 with the same set of color filters for position 2 of the photo tube.
15. The stopping potential, V_0 should be same for both the positions of the photo tube. Find the mean V_0 from the two values obtained for position 1 & 2 (see Table 1).
16. Plot a graph of V_0 versus f (in 10^{12} Hz).
17. Find the slope of the best straight line fit and from the slope, calculate h .

Observations

Velocity of ligh, $c = 3 \times 10^8 \text{ ms}^{-1}$.

Table 1: Determination of V_0 as a function of frequency, f .

Color of filter	Wavelength, λ ($\times 10^{-9}$ m)	Frequency, $f = c/\lambda$ ($\times 10^{12}$ Hz)	Stopping potential, V_0 (in V)		
			with the photo tube in position 1	with the photo tube in position 2	Mean V_0
Red	700				
Orange	620				
Yellow	580				
Green	530				
Blue	470				

Graph:

Plot a graph of V_0 versus f from data in Table 1.

Calculation:

Value of $e = 1.6 \times 10^{-19}$ C.

Slope of the V_0 - f graph, $\frac{h}{e} = \dots$

$h = \dots$

Result:

Value of Planck's constant from the experiment, $h = \dots$.

Remark:

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Experiment 3

Electrical resistivity and band gap of semiconductors

Objective

To determine the electrical resistivity of a semiconductor as a function of temperature by four probe method and determine the band gap of the semiconductor.

Apparatus

Four probe measurement unit with oven, semiconducting sample, current source, voltmeter, ammeter etc.

Theory

By Ohm's law, the electric field intensity, \vec{E} at a point in a material is proportional to the current density, \vec{J} that it induces at that point. The proportionality constant is called electrical resistivity, ρ of the material. That is,

$$\vec{E} = \rho \vec{J} \quad (1)$$

For a sample with a long wire like geometry with uniform cross-sectional area, ρ can be measured by simply passing a known current through the sample and measuring the voltage drop across it. This simple method has however several disadvantages. For example, it can not be applied to a sample with non-regular shapes, there could be errors due to contact resistance of the measuring leads, soldering the contact leads itself can be difficult for some samples etc. Also in case of semiconductors, the soldering process may results in injection of impurities into the sample thereby affecting its intrinsic electrical resistivity.

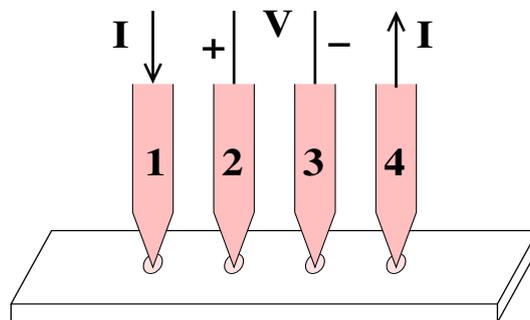


Fig. 1: Four probe experiment arrangement

Some of the above difficulties can be overcome by employing a technique called four probe method. Consider a flat semiconducting sample. In the four probe method, four pointed,

collinear, equally spaced probes are placed in pressure contact with the plane surface of the sample (Fig. 1). A current is injected into the sample through the outer two probes (1 & 4). The resulting electric potential distribution is measured via the two inner probes (2 & 3). The voltage drop, V across probes 2 & 3 for a current I through probes 1 & 4, is given by a simple expression, if certain conditions are satisfied. The surface of the sample is assumed to be flat with no surface leakage. The diameter of the contact between each probe and the sample should be small compared to the distance between the probes. Also the thickness, d of the sample is assumed to be much smaller than the distance, s between two probes. Under such conditions, it can be shown that,

$$V = \frac{I}{\pi d} \rho \ln 2 \quad (2)$$

Therefore resistivity of the sample is,

$$\rho = \frac{V \pi d}{I \ln 2} \quad (3)$$

Now the temperature variation of resistivity of a semiconductor is given by,

$$\rho = \rho_0 \exp\left(\frac{E_g}{kT}\right) \quad (4)$$

where E_g is the band gap of the semiconductor and k is Boltzmann's constant. Taking logarithm of both sides of the above equation,

$$\ln \rho = \frac{E_g}{10^3 \times k} \left(\frac{10^3}{T}\right) + \ln \rho_0 \quad (5)$$

The factor 10^3 above is inserted for convenience. Thus a plot of ' $\ln \rho$ ' as a function of $\frac{10^3}{T}$ is a straight line with the slope being equal to,

$$\text{slope} = \frac{E_g}{10^3 \times k} \quad (6)$$

Therefore, by determining the resistivity, ρ of the sample at various temperatures T , we can plot a graph of ' $\ln \rho$ ' versus $\frac{10^3}{T}$, and find the band gap from the slope of the graph.

Experimental setup



Fig. 2: Band gap measurement unit

The experimental setup (Fig. 2) consists of a measuring unit with current source, an LCD panel for reading current, voltage and temperature. A semiconductor sample connected with the four probe arrangement can be placed in an oven which can be heated by passing electrical current through it. The current source provides the probe current through the sample as well as the heating current to the oven.

Procedure

1. Connect the band gap measurement unit to mains.
2. The sample crystal is attached with the probe arrangement. Place it in the oven.
3. Connect four probe (eight pin connector) to the given eight pin socket of measurement unit.
4. Connect the heater terminals (three pin socket) of the oven to the measurement unit.
5. Set the oven toggle switch at off position and current adjustment at the minimum.
6. At starting, current & voltage will be zero. The LCD display will show the current and the voltage along with the oven temperature.
7. Set some suitable value of low current to the probe, say 5 mA. Keep this current constant throughout the experiment.
8. Note down the voltage (between probes 2 & 3) and the temperature of the oven from the display (Table 1).
9. Switch on the oven current supply. Now temperature will increase slowly.
10. Record the value of voltage corresponding to a fixed interval of temperature rise, say 5°C.
11. Take at least 8 readings for different values of temperatures.
12. Calculate the experimental resistivity using Eq. (3).
13. Express resistivity in units of Ohm-cm and temperature in Kelvin (K).
14. Plot $\ln \rho$ versus $10^3/T$. Find the best linear fit to the points (choose only the linear portion of the curve).
15. From the slope of the graph, calculate the band gap, E_g using Eq. (6).

Observations

Material of the given semiconductor sample = Germanium (Ge).

Thickness of the sample, $d = 0.23$ mm.

Distance between the probes, $s = 2.0$ mm.

Value of Boltzmann's constant, $k = 8.617 \times 10^{-5}$ eV/K.

Set constant current through the sample, $I = \dots$.

Table 1: Resistivity ρ as a function of temperature T

Sl No.	Temperature (in °C)	Temperature, T (in °K)	Voltage, V (in V)	Resistivity, ρ (in Ohm-cm)	$\frac{10^3}{T}$	$\ln \rho$
1						
2						
3						
⋮						
8	...					
⋮						

Graph:

Plot a graphs of $\ln \rho$ versus $10^3/T$. Find the best linear fit to the points.

Calculations:

From the slope of the $\ln \rho - 10^3/T$ curve, calculate the band gap, E_g using Eq. (6).

Result:

Band gap of the given semiconductor sample is $E_g = \dots$.

Remark:

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Experiment 4

Verification of Stefan-Boltzmann Law

Objective

To verify Stefan-Boltzmann law of thermal radiation by electrical method.

Apparatus

Complete unit of Stefan's law experimental setup consisting of an electrical circuit (Fig. 1) containing elements such as an electrical bulb with tungsten filament, voltage source, voltmeter, variable resistance etc.

Theory

The Stefan-Boltzmann law states that the energy radiated by a black body per second per unit surface area is given by,

$$P_{\text{rad}} = \sigma T^4 \quad (\text{W/m}^2) \quad (1)$$

where T is the absolute temperature of the body and σ is called the Stefan-Boltzmann constant. If the body is not 'perfectly black', then the relationship is given by,

$$P_{\text{rad}} = \sigma \varepsilon T^4 \quad (\text{W/m}^2) \quad (2)$$

where ε is called emissivity of the body ($\varepsilon < 1$).

Now consider a tungsten filament in an electric bulb being heated by passing electrical current through it. Let T be the absolute temperature of the filament and T_s be that of the surroundings. The filament emits thermal radiation due to its own temperature as well as absorbs some from the surroundings. The net rate of heat loss by the filament due to thermal radiation is,

$$E = A\sigma\varepsilon(T^\gamma - T_s^\gamma) = C(T^\gamma - T_s^\gamma) \quad (3)$$

where A is the surface area of the filament, $C = A\sigma\varepsilon$ and the index $\gamma = 4$. If $T_s \ll T$, then we can safely neglect the second term and write,

$$E = CT^\gamma \quad (4)$$

The above energy loss by the filament due to radiation can be equated with the power dissipated by the electrical source in the filament resistance under the following circumstances. If the bulb is completely evacuated, there is no loss of heat by convection. Secondly, since the filament is in contact with a bad thermal conductor at the base of the bulb, the heat lost by conduction is small. Moreover the conduction heat depends linearly upon the temperature and

hence at very high temperature it will be much smaller than the radiated heat which goes as the fourth power of temperature. Therefore we can assume that the electrical power dissipated in the filament is lost completely in the form of thermal radiation and hence,

$$E = P = VI \quad (5)$$

Where P is the electrical power dissipated by the voltage source and is given by the voltage, V multiplied by the electric current I . Eq. (5) can be used to estimate the energy radiated by the filament. Thus we can study the Stefan-Boltzmann law by measuring the power radiated as a function of temperature, if we can estimate the temperature of the filament.

The filament temperature can be estimated from its electrical resistance, R as follows. The relationship between the resistance and temperature of a tungsten filament can be expressed by the following empirical formula,

$$R_t = R_0(1 + \alpha t + \beta t^2) \quad (6)$$

where t is the temperature in $^{\circ}\text{C}$. R_t and R_0 are the resistances at temperatures t $^{\circ}\text{C}$ and 0 $^{\circ}\text{C}$, respectively. The temperature coefficients α and β for tungsten are given by,

$$\alpha = 5.21 \times 10^{-3} \text{ } ^{\circ}\text{C}^{-1} \quad \text{and} \quad \beta = 7.2 \times 10^{-7} \text{ } ^{\circ}\text{C}^{-2} \quad (7)$$

In order to determine R_0 , we use the known fact that the temperature of a tungsten filament when it *just starts glowing* is $t_g \sim 527$ $^{\circ}\text{C}$. Let R_g be its corresponding resistance. Using the numerical values of this temperature t_g and the constants α , β in Eq. (6), we get

$$R_0 = \frac{R_g}{3.95} \quad (8)$$

R_g is determined by noting the voltage V_g and the current I_g at the *glowing point*, $R_g = V_g/I_g$. Now we can calculate the ratio R_t/R_0 and solve Eq. (6) for t in terms of R_t/R_0 , to get

$$t = \frac{-\alpha + \sqrt{\alpha^2 - 4\beta(1 - R_t/R_0)}}{2\beta} \quad (9)$$

The other solution is discarded because it will give rise to a negative t whereas Eq. (6) is valid for only $t > 0$ $^{\circ}\text{C}$. Thus once the value of R_t/R_0 is determined, we can estimate the temperature, t $^{\circ}\text{C}$ of the filament using Eq. (9). The corresponding absolute temperature is readily obtained by,

$$T = t + 273 \text{ } (^{\circ}\text{K}) \quad (10)$$

Now we can verify the Stefan-Boltzmann law as follows. Taking logarithm of both sides of Eq. (4), we get

$$\ln E = \gamma \ln T + C', \quad C' = \ln C = \text{constant} \quad (11)$$

Therefore a graph of the quantity $\ln E$ as a function $\ln T$ is a straight line with the slope being γ . By estimating E as a function of T for a number of different values of T using means described above, we can plot the above graph and find its slope. The graph should be a straight line and the slope should be $\gamma = 4$.

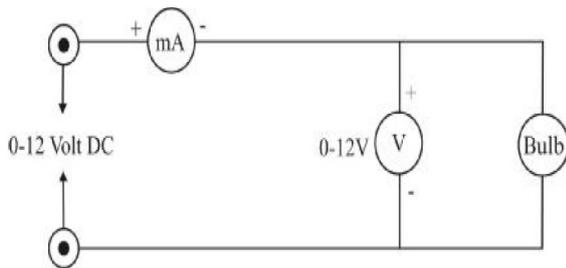


Fig. 1: Circuit diagram



Fig. 2: Stefan's law trainer

Experimental setup

The experimental setup is a complete unit consisting of an electrical circuit containing elements such as an electrical bulb with tungsten filament, voltage source, voltmeter, variable resistance etc. (Fig. 2).

Procedure

I. To find the resistance of the bulb filament at 0°C

1. Connect the main cords to the mains.
2. Connect the circuit as shown in Fig. 1 through patch cords.
3. Switch on the unit.
4. Increase the DC voltage with the help of the variable resistance till the bulb begins to glow (i.e. the filament appears faint red).
5. Note the readings of V_g and I_g , i.e. the voltage and current at the time when the *filament just begins to glow*.
6. Calculate $R_g = V_g/I_g$.
7. Then calculate the resistance R_0 of the filament at 0°C by using Eq. (8).

II. To find the radiant power, E emitted by the filament as a function of temperature, T and verify Stefan-Boltzmann law

1. Starting again from a lower voltage, increase the DC voltage gradually till the bulb just begins to glow.
2. Note down the reading of current (in mA) corresponding to the given voltage (in volt) from the given ammeter and voltmeter.
3. Now increasing the voltage further, note down the readings of current at different values of voltages.
4. Tabulate all readings in the given observation table.

5. Calculate $R_t = V/I$ for different voltages i.e., for different temperatures t .
6. Calculate R_t/R_0 for all values of R_t and then determine temperature T of the filament using Eq. (9) and (10).
7. Calculate the energy radiated/sec (E) by the filament at each temperature by using Eq. (5).
8. Finally plot a graph between $\ln E$ versus $\ln T$. Find its slope γ and verify whether it satisfies the Stefan-Boltzmann law.

Observations

Determination of R_0 , the resistance of the filament at 0°C

Voltage across the filament at the *glowing point*, $V_g = \dots$

Current through the filament at the *glowing point*, $I_g = \dots$

$$R_g = \frac{V_g}{I_g} = \dots \text{ (in } \Omega \text{)}$$

$$R_0 = \frac{R_g}{3.95} = \dots \text{ (in } \Omega \text{)}$$

Table 1: Determination of power, E radiated by the filament as a function of temperature, T

Sl No.	Voltage, V (in Volt)	Current, I (in mA)	I (in A)	Res., $R_t =$ V/I (in Ω)	R_t/R_0	Temp., t (in $^\circ\text{C}$)	Temp., T (in $^\circ\text{K}$)	Radiated Power, $E = VI$ (in W)	$\ln(T)$	$\ln(E)$
1										
2										
3										
\vdots										
10										
\vdots										

Graph:

Plot a graph of $\ln E$ versus $\ln T$ and find out its slope, γ .

Result:

Remark:

—

Experiment 5

Post office box

Objective

To determine the value of an unknown resistance using Post Office box.

Apparatus

A Post Office box unit consisting of a Wheatstone bridge with variables resistances, galvanometer, voltage source, connecting wires etc.

Theory

A post office (PO) box operates on the same principle as Wheatstone's bridge which consists of four resistances R_1 , R_2 , R_3 and R_4 that are connected to each other as shown in the circuit diagram in Fig. 1. In this circuit, E is a voltage source, G is a galvanometer and K_1 and K_2 are two keys. If the values of the resistances are adjusted so that no current flows through the galvanometer (balance condition), then the resistances R_1 , R_2 , R_3 and R_4 satisfy the relationship,

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \quad (1)$$

A PO box is a compact form of the Wheatstone bridge where the resistances with bridge arms

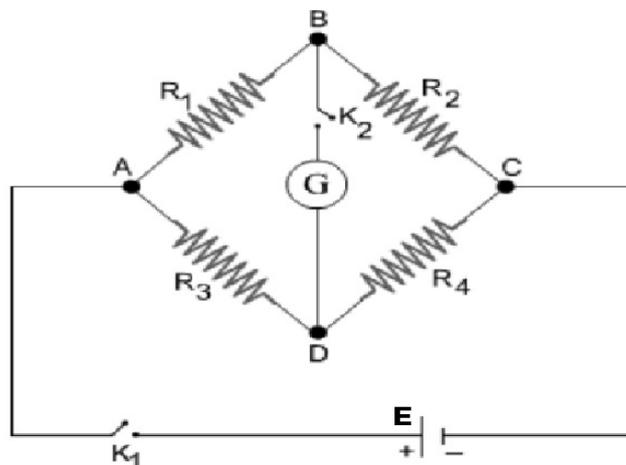


Fig. 1: Wheatstone's bridge

are inbuilt in a single unit and can be varied conveniently. Two of its arms have resistances which can be set to be at values 0Ω , 10Ω , 100Ω and 1000Ω alternately. These two arms are

used establish the ratio between the two sides of the bridge and are called ratio arms. A third bridge arm is connected to a variable resistance which can be given a value from 0 to about 10 k Ω in convenient steps. The fourth arm can be connected to an unknown resistance whose value needs to be determined. If $R_4 = R_x$ is the unknown resistance in the fourth arm and R_1, R_2, R_3 are the other three resistances when the Wheatstone bridge is in balanced condition, then from Eq. (1) we get,

$$R_x = \frac{R_2}{R_1} R_3 \quad (2)$$

Experimental setup

The PO box experimental unit is as shown in Fig. 2. It has a DC voltage source, a galvanometer,

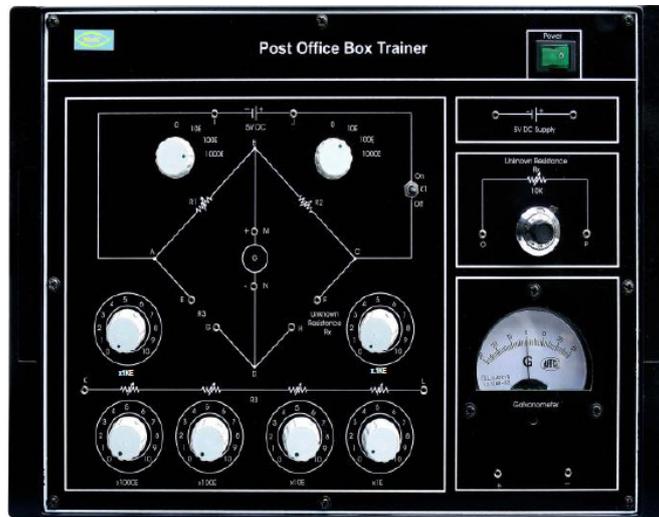


Fig. 2: PO Box

Wheatstone bridge arms with resistances R_1, R_2, R_3 and R_x . R_1 and R_2 are the ratio arms each of which can be set at 0 Ω , 10 Ω , 100 Ω and 1000 Ω . R_3 is connected at a variable resistance which consists of six resistances in series. These six resistances are identified by the six dial knobs near the arm R_3 . Each of these six resistances can be varied with the help of the knobs and given values as indicated in the panels. The total resistance R_3 is the series combination of all these six individual resistances. The arm R_x can be connected to a variable potentiometer resistor which acts as an unknown resistance.

Procedure

1. Connect the -ve terminal of the DC voltage to 'I' terminal and the +ve terminal to 'J' terminal of the bridge (Fig. 2).
2. Connect Galvanometer's +ve and -ve terminals to M and N terminals respectively.
3. Connect K & L terminals of variable resistance to E & G (R_3) terminals of bridge.
4. Connect O & P terminals of unknown resistance to H & F (R_x) terminals of bridge.

5. Set all rotaries at 0Ω .
6. Keep the key K_1 in 'Off' position.
7. Switch 'On' power.
8. Set the resistance R_x at an some value (preferably below $1\text{ k}\Omega$) by rotating its dial Knob.
9. Then set resistances R_1 and R_2 at 10Ω .
10. Switch on the key K_1 and observe the deflection on galvanometer.
11. Adjust the value of R_3 in steps of 0.1Ω , 1Ω , 10Ω , 100Ω , 1000Ω , $10\text{k}\Omega$ as per the requirement beginning from zero, till the null point is obtained in the galvanometer.
12. Note down the value of R_3 in the given observation table.
13. Change the ratio R_1/R_2 to $1/10$ by setting $R_1 = 10\Omega$ and $R_2 = 100\Omega$. Repeat steps 11-12.
14. Change the ratio R_1/R_2 to $1/100$ by setting $R_1 = 10\Omega$ and $R_2 = 1000\Omega$. Repeat steps 11-12.
15. Change the ratio R_1/R_2 to 10 by setting $R_1 = 100\Omega$ and $R_2 = 10\Omega$. Repeat steps 11-12.
16. Change the ratio R_1/R_2 to 100 by setting $R_1 = 1000\Omega$ and $R_2 = 10\Omega$. Repeat steps 11-12.
17. For each of ratios R_1/R_2 , calculate R_x using Eq. (2).
18. Find the mean R_x from the above values.
19. Determine the theoretical value of R_x with the help of dial knob as follows. Here the dial knob can rotates 10 times corresponding to 0 to 10 numbers, it is said to be main scale reading. A unit main scale reading corresponds to 1000Ω . Its each rotation has 50 divisions and is said to be circular scale reading (least count = 10Ω). For example, if there are 5 rotations by main scale it means the resistance on main scale is $5 \times 1000\Omega$. If the circular scale is at 30, it means the additional resistance on the circular scale is $30 \times 10\Omega$. And the value of R_x is $5000\Omega + 300\Omega = 5300\Omega$.
20. Compare the the theoretical value of R_x with the experimentally obtained value.

Observations

Table 1: Determination of R_x for different values of the ratio R_1/R_2

Sl No.	R_1 (Ω)	R_2 (Ω)	R_3 (Ω)							$R_x = \frac{R_2}{R_1} \times R_3$ (Ω)
			$\times 0.1$	$\times 1.0$	$\times 10$	$\times 100$	$\times 1000$	$\times 10\text{ k}$	Total (R_3)	
1	10	10								
2	10	100								
3	10	1000								
4	100	10								
5	1000	10								

For determination of theoretical value of R_x :

Main scale reading of the dial knob, $m = \dots$.

Circular scale reading of the dial knob, $c = \dots$.

Theoretical $R_x = (m \times 1000 + c \times 10)\Omega = \dots\Omega$.

Calculations:

1. Calculate the mean experimental value of R_x from Table 1.
2. Calculate the theoretical value of R_x .
3. Calculate the percentage deviation of the experimental value from its theoretical value.

Result:

Value of unknown resistance, $R_x = \dots$

Its theoretical value is = \dots

The experimental value is deviated by $\dots\%$ from the theoretical value.

Remark:

—

Experiment 6

Carey Foster bridge

Objective

To determine the resistance per unit length of a Carey Foster bridge wire and hence determine the value of an unknown low resistance.

Apparatus

Carey Foster bridge, galvanometer, two equal resistances (10 Ω each), voltage source, connecting wires etc.

Theory

The Carey Foster bridge is an electrical circuit that can be used to measure very low resistances. It works on the same principle as Wheatstone's bridge, which consists of four resistances R_1 , R_2 , R_3 and R_4 that are connected to each other as shown in the circuit diagram in Fig. 1. In this circuit, E is a voltage source, G is a galvanometer and K_1 and K_2 are two keys. If the values of the resistances are adjusted so that no current flows through the galvanometer (balance condition), then the resistances R_1 , R_2 , R_3 and R_4 satisfy the relationship,

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \quad (1)$$

In a meter bridge, two of the resistors, say R_3 and R_4 are replaced by a resistance wire of

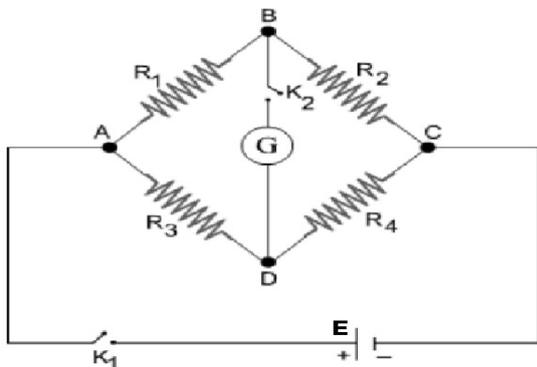


Fig. 1: Wheatstone's bridge

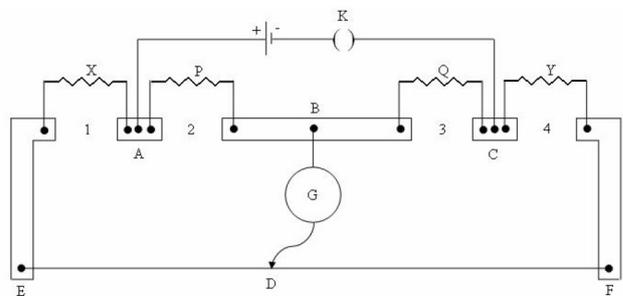


Fig. 2: Carey Foster bridge circuit diagram

one meter length and uniform cross sectional area fixed on a meter scale. Point D is a sliding contact that can be moved along the wire, thus varying the magnitudes of R_3 and R_4 . The Carey Foster bridge is a modified form of the meter bridge in which the effective length of the

wire is considerably increased by connecting a resistance in series with each end of the wire. This increases accuracy of the bridge.

The circuit diagram for the Carey Foster bridge is shown in Fig. 2. Two standard low resistances, P and Q , of $10\ \Omega$ each are connected in the inner gaps 2 and 3. A known resistance, i.e., a fractional resistance box X and the unknown resistance Y whose resistance is to be determined are connected in the outer gaps 1 and 4, respectively. A one meter long resistance wire of uniform area of cross section is soldered to the ends of two copper strips. Since the wire has uniform cross-sectional area, the resistance per unit length is the same along the wire. A galvanometer G is connected between terminal B and the jockey D , which is in sliding contact that with the bridge wire. A voltage source is connected between terminals A and C .

The four points A , B , C and D in Fig. 2 exactly corresponds to the similarly labeled points in the Wheatstone's bridge circuit in Fig. 1. Therefore if the balance point is located at a distance l_1 from E , then we get

$$\frac{P}{Q} = \frac{X + \alpha + l_1\rho}{Y + \beta + (100 - l_1)\rho} \quad (2)$$

where ρ is the resistance per unit length of the wire, and α and β are the resistances due to end corrections at the left and right ends. If now the positions of X and Y are interchanged and the balance point is found at a distance l_2 from E , then

$$\frac{P}{Q} = \frac{Y + \alpha + l_2\rho}{X + \beta + (100 - l_2)\rho} \quad (3)$$

From Eq. (2) and (3), we obtain

$$\frac{X + \alpha + l_1\rho}{Y + \beta + (100 - l_1)\rho} = \frac{Y + \alpha + l_2\rho}{X + \beta + (100 - l_2)\rho} \quad (4)$$

Adding 1 on both sides and simplifying,

$$\frac{X + Y + \alpha + \beta + 100\rho}{Y + \beta + (100 - l_1)\rho} = \frac{X + Y + \alpha + \beta + 100\rho}{X + \beta + (100 - l_2)\rho} \quad (5)$$

which gives,

$$Y + \beta + (100 - l_1)\rho = X + \beta + (100 - l_2)\rho$$

$$\text{or, } Y = X - (l_2 - l_1)\rho \quad (6)$$

Thus once we know l_1 , l_2 , ρ and X then the unknown resistance Y can be determined using Eq. (6). In order to determine ρ , put $Y = 0$ in Eq. (6) so as to get,

$$\rho = \frac{X}{l_2 - l_1} \quad (7)$$

Thus ρ can be determined by short circuiting Y and measuring l_1 and l_2 .

Procedure

I. To find the resistance per unit length of the wire, ρ

1. Make the circuit connections as shown in Fig. 2. Make sure that all connections are tight.

2. Connect the given resistances P and Q ($10\ \Omega$ each) in gaps 2 and 3. In this part, X is a fractional resistance box and Y is a short circuit (zero resistance).
3. Switch on power voltage source so that current flows through the circuit.
4. First set the resistance X at zero and see if the galvanometer shows opposite deflections when the jockey is pressed at the two ends of the wire. Also check whether the null point is located around the middle of the bridge wire. If it is so, then the connections are likely correct.
5. Now set a small resistance in X , say $X = 0.1\ \Omega$.
6. Locate the balance point. Record the distance of the balance point from the left end (point E) of the wire as length l_1 .
7. Reverse the direction of current flow by interchanging the connections to the voltage source and again record the balance point l_1 for the reverse current. Take average of l_1 for direct and reverse current (see Table 1) in order to eliminate the effect of any thermo emf.
8. Increase resistance X in steps of $0.1\ \Omega$ and repeat steps 6-7 each time.
9. Interchange the positions of X and the zero resistance Y and repeat steps 6-7 for the same set of resistance values for X . The corresponding balance point distance measured from the same end of the bridge wire should be recorded as l_2 in the data table.

II. To find an unknown low resistance Y

1. Remove the short circuit and set the resistance Y at a small value as unknown resistance.
2. Repeat the entire sequence of steps 5-9 in part I of the procedure and fill up Table 2.

Observations

Table 1: Determination of ρ of the Carey Foster bridge wire (with $Y = 0$)

Sl No.	X (Ω)	Position of balance point with $Y (= 0)$ in the						$l_2 - l_1$ (cm)	$\rho = X/(l_2 - l_1)$ (Ωcm^{-1})
		right gap, l_1 (cm)			left gap, l_2 (cm)				
		direct current	reverse current	mean l_1	direct current	reverse current	mean l_2		
1	0.1								
2	0.2								
3	0.3								
⋮									
8	...								
⋮									

Table 2: Determination of the unknown low resistance, Y

Sl No.	X (Ω)	Position of balance point with Y in the						$l_2 - l_1$ (cm)	$Y = X - \rho(l_2 - l_1)$ (Ω)
		right gap, l_1 (cm)			left gap, l_2 (cm)				
		direct current	reverse current	mean l_1	direct current	reverse current	mean l_2		
1	0.1								
2	0.2								
3	0.3								
\vdots									
8	...								
\vdots									

Calculations:

1. Calculate the value of $(l_2 - l_1)$ for each value of X in Table 1.
2. Calculate ρ of the bridge wire for each value of X in Table 1 using Eq. (7).
3. Calculate the mean ρ from the values obtained in Table 1 for different X .
4. Using this mean value of ρ in Eq. (6), calculate the unknown resistance Y for each row in Table 2.
5. Use these results to calculate the mean value of Y .

Result:

Resistance per unit length of bridge wire, $\rho = \dots$

Value of the unknown low resistance, $Y = \dots$

Remark:

—

Experiment 7

Determination of Young's modulus of elasticity

Objective

To determine the Young's modulus of elasticity of the material of a sample beam by bending.

Apparatus

Sample beam supported at its two ends and loaded at the middle, a stand, weights, weight holder, spherometer etc.

Theory

Elasticity is the property of materials by virtue of which it tend to resist a deforming force and recover from a change of size or shape of the body on removal of the deforming force. When the deforming force is applied to a body in such a manner that its length is changed, then a *longitudinal strain* is produced in the body. Due to the elastic property, an internal restoring force is produced along the length of the body which opposes the deforming force. The magnitude of this force per unit cross-sectional area is called the *normal stress*. If the body is of length L and have uniform cross-sectional area A , and if a force F acting along the length of the body changes the length by l , then

$$\text{Longitudinal strain} = \frac{l}{L}, \quad \text{Normal stress} = \frac{F}{A} \quad (1)$$

The Young's modulus of elasticity of the material of the body is defined as,

$$Y = \frac{\text{Normal stress}}{\text{Longitudinal strain}} \quad (\text{Newton/m}^2) \quad (2)$$

Now consider a material in the form of a rectangular beam supported horizontally by two knife edges at its two ends (Fig. 1). Let L be the length of the beam between the two points of contacts with the knife edges, ' b ' be its breadth and ' d ' be its depth. Let the beam be loaded at

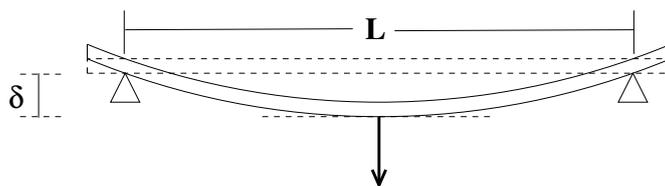


Fig. 1: Beam supported at its two ends and loaded at the middle.

the middle point by a weight $W = Mg$, where M is the mass of the load and g is the acceleration due to gravity. The load produces a downward bending in the beam (Fig. 1). Let δ be the depression, i.e. downward displacement from the original position of the middle point of the beam. Then it can be shown that the Young's modulus of elasticity of the material of the beam is,

$$Y = \frac{MgL^3}{4bd^3\delta} \quad (3)$$

From the above equation we can write,

$$\delta = \frac{MgL^3}{4bd^3Y} \quad (4)$$

Now if δ_1 and δ_2 are the depressions corresponding to loads M_1 and M_2 respectively, then

$$\delta_2 - \delta_1 = \frac{gL^3}{4bd^3Y}(M_2 - M_1)$$

Or,
$$Y = \frac{gL^3}{4bd^3} \frac{\Delta M}{\Delta \delta} \quad (5)$$

where $\Delta\delta = \delta_2 - \delta_1$ and $\Delta M = M_2 - M_1$. Therefore, given a beam with arrangements as shown in Fig. 1, the Young's modulus of elasticity Y can be determined by measuring δ as a function of M and using any of the Eq. (3) or Eq. (5).

Experimental setup

The experimental setup consists of a stand which can support the sample beam horizontally at its two ends (Fig. 2). The beam can be loaded at the middle by means of a weight holder. A spherometer mounted on a separate stand is used to measure the depression of the beam. The spherometer is connected with buzzer indicator which turns on when the tip of the spherometer leg touches the beam. There are three different sample beams with specifications as follows.



Fig. 2: Experimental setup for Young's modulus measurement

Sample beam specifications:

Sample beam	Material	Length (in cm)	Breadth (in cm)	Depth (in cm)
1	Iron	100	2.5	0.6
2	Brass	100	2.6	0.5
3	Aluminum	100	2.55	0.5

Procedure

1. Make sure that the sample beam placed horizontally on the stand is tightened to the stand properly.
2. Tighten the weight holder at the center of sample with the help of screw. The weight holder is free of any load at this point.
3. Place the spherometer stand near the center of sample.
4. Adjust the spherometer screw such that its main scale reading is nearly zero.
5. Adjust the height of the spherometer in its stand such that the spherometer leg just touches the top surface at the middle of the beam.
6. Once the adjustments have been done, turn the spherometer screw a little *upward* such that its leg now loses contact with the beam
7. Switch on power to the buzzer.
8. Now rotate the spherometer screw *downward* slowly and carefully such that the tip of its leg *just touches* the beam. At this point the buzzer circuit becomes complete and the buzzer begins to blow.
9. As soon as the buzzer begins to blow, stop rotating the spherometer screw and switch off power to the buzzer.
10. Note down the spherometer main scale reading, m and circular scale reading, s . The total reading is ' $m+s \times L.C.$ ', where $L.C.$ is the least count of the spherometer (see Table 1). Call this reading under no load condition as y_0 .
11. Now place a 500 gm weight on the weight holder with a T-pin at the bottom. At this stage, the spherometer leg loses contact with the sample beam.
12. Switch on power to the buzzer.
13. Rotate the spherometer screw *downward* slowly and carefully again, until the buzzer begins to blow. As soon as the buzzer begins to blow, stop rotating the spherometer screw and switch off power to the buzzer.
14. Note down the spherometer readings again and evaluate the total y_1 .
15. Calculate the depression, $\delta_1 = y_1 - y_0$ for the given load $M = 500$ gm and tabulate the value as shown in Table 1.
16. Place more 500 gm weights one by one for total weight up to 2.0 Kg. In each case, determine the depression δ_n produced as indicated in steps 12-16.
17. Steps 7-16 above give the depression δ_n of the beam as a function of load M for *increasing load*. Now determine δ_n for the same values of M , but this time with *decreasing load* as follows.
18. With the previous total load still on the weight holder, rotate the spherometer screw upward so that there is *sufficient* gap between the tip of the spherometer leg and the beam. At the point, the buzzer is in switched off condition.

19. Switch on power to the buzzer.
20. Remove one 500 gm load from the holder. The middle point of the beam moves upward.
21. Rotate the spherometer screw downward slowly and carefully, until the buzzer begins to blow. As soon as the buzzer begins to blow, stop rotating the spherometer screw and switch off power to the buzzer.
22. Determine the total reading y'_n for the n -th value of load M and determine the corresponding depression δ_n .
23. Keep removing more loads one by one until there is no more load and in each case determine y'_n and hence the corresponding depression δ_n for the load M present in the holder by following the same procedure as indicated in steps 18-22.
24. Calculate the mean depression δ_n for each load M from the values obtained for load increasing and load decreasing readings.
25. Insert the values mean depressions δ_n and the corresponding loads M obtained above in Table 2.
26. Find the difference in depression $\Delta\delta$ for a particular constant weight difference, say $\Delta M = 0.5$ Kg as indicated in Table 2.
27. Calculate mean $\Delta\delta$ from the values obtained in step 26.
28. Calculate Young's modulus of elasticity, Y by using these values of $\Delta\delta$ and ΔM in Eq. (5).

Observations

From the supplied technical specifications for the sample beam,

Material of the sample beam = ...

Length, $L = \dots$

Breadth, $b = \dots$

Depth, $d = \dots$

Least count of the spherometer is, $L.C. = \dots$ mm.

Abbreviations used:

MSR = Main scale reading, CSR = Circular scale reading

Table 1: Determination of depression δ of the beam a function of load M .

Sl No., n	Load M (in Kg)	Spherometer readings and depression of the beam for								Mean δ_n ($\times 10^{-3}$ m)
		load increasing				load decreasing				
		MSR m (mm)	CSR s	Total $y_n = m + s \times L.C.$ (mm)	$\delta_n = (y_n - y_0)$ (mm)	MSR m (mm)	CSR s	Total $y'_n = m + s \times L.C.$ (mm)	$\delta_n = (y'_n - y'_0)$ (mm)	
0	0.0									
1	0.5									
2	1.0									
3	1.5									
4	2.0									

Table 2: Determination of $\Delta\delta$ for a constant load difference ΔM

Sl No.	Load M (in Kg)	Depression δ_n (in mm)	Constant load difference ΔM (in Kg)	$\Delta\delta$ (in mm)	Mean $\Delta\delta$ (in mm)	Mean $\Delta\delta$ (in m)
0	0.0	$\delta_0 = 0.0$	0.5	—		
1	0.5	$\delta_1 = \dots$		$\delta_1 - \delta_0 = \dots$		
2	1.0	$\delta_2 = \dots$		$\delta_2 - \delta_1 = \dots$		
3	1.5	$\delta_3 = \dots$		$\delta_3 - \delta_2 = \dots$		
4	2.0	$\delta_4 = \dots$		$\delta_4 - \delta_3 = \dots$		

Calculation:

Calculate Y using Eq. (5) by taking the values of $\Delta\delta$ and ΔM from Table 2.

Result:

Young's modulus of elasticity of '*material name*' is, $Y = \dots \text{ Nm}^{-2}$.

Remark:

—

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Experiment 8

Newton's ring experiment

Objective

To determine the wavelength of sodium light by measuring the diameters of Newton's rings.

Apparatus

Newton's ring assembly, microscope with horizontal measurement, sodium vapor lamp etc.

Theory

Newton's ring experiment involves producing an interference pattern of a light beam by getting it reflected from the two surfaces of a circular thin film whose thickness varies radially from a central point. The schematics of the arrangement is shown in Fig. 1. It consists of plano-convex lens (L) placed on top a plane glass plate (P). The lower surface of the lens and the upper surface of the glass plate encloses an air film whose thickness increases radially from the point of contact (C) of these two surfaces. A parallel beam of light from the source falls on another

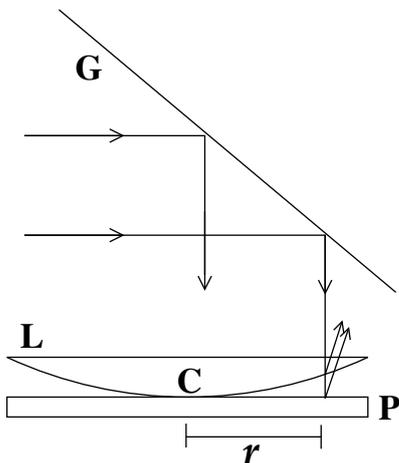


Fig. 1: Newton's ring experiment

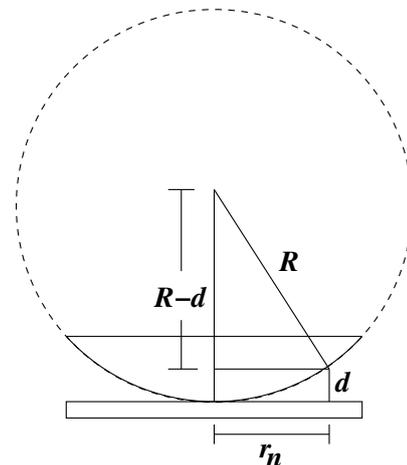


Fig. 2: Radius of a Newton's ring

glass plate (G) at an angle of 45° . The plate reflects parts of the incident light towards the air film between L and P. This beam gets reflected from the upper and lower surface of the air film and produces an interference pattern which can be observed from above by a microscope. Due to the circular symmetry of the film thickness, the interference pattern consists of concentric circular dark and bright fringes and are called Newton's rings.

Now consider a ray of light incident nearly normally on the air film at a point at distance ' r ' from the central point C. Let ' d ' be the thickness of the film at this radial distance. The

ray gets reflected partially from the top surface of the film without any phase change. Part of the ray enters the air film and get reflected from the bottom surface with a phase change of π . An additional phase difference occurs due to the optical path difference of $2\mu d$ between these two components, where μ is the refractive index of the film. For air, $\mu = 1$. The conditions for destructive and constructive interference are therefore,

$$2d = n\lambda, \quad n = 0, 1, 2, \dots \quad (\text{for minima}) \quad (1)$$

$$2d = \left(n + \frac{1}{2}\right)\lambda, \quad n = 0, 1, 2, \dots \quad (\text{for maxima}) \quad (2)$$

where λ is the wavelength of the light. The radius of the circular fringes can be obtained as follows. Let r_n be the radius of the n -th dark ring. From the construction of Fig. 2,

$$r_n^2 = R^2 - (R - d)^2 \approx 2Rd \quad (3)$$

where R is the radius of the spherical surface of the plano-convex lens. Since $R \gg d$, we have neglected the d^2 term from the above expression. From Eq. (1) and (3),

$$r_n^2 = n\lambda R \quad (4)$$

In experiments, it is easier to measure the diameter of a ring more accurately than to measure the radius. Therefore we express the above relation in terms of diameter. If D_n is the diameter of the n -th dark ring and D_{n+p} is that of the $(n + p)$ -th ring, then we get from Eq. (4),

$$\lambda = \frac{D_{n+p}^2 - D_n^2}{4pR} \quad (5)$$

Thus the wavelength, λ of the incident light can be determined by measuring the diameters of the Newton's ring formed.

Experimental setup



Fig. 3: Newton's ring experimental setup

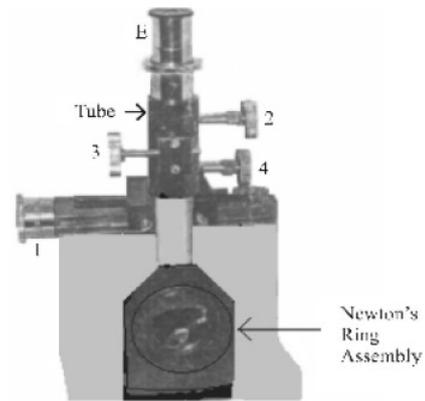


Fig. 4: Newton's ring microscope

The experimental setup (Fig. 3) consists of a Newton's ring microscope (Fig. 4) which has two parts. There is a traveling microscope to observe and measure the diameter of the Newton's rings. The other part is a detachable Newton's ring assembly with a plano-convex lens on top of a glass plate. Another glass plate reflects light from the source towards the lens. There is a sodium vapor lamp which acts as a source of monochromatic light.

Procedure

1. Position the Newton's ring microscope and the sodium vapor lamp enclosure such that the enclosure opening directly faces the inclined glass plate (G in Fig. 1). The plate should be inclined at 45° with horizontal.
2. Connect the 'Power supply for Na Lamp' to the mains. Then connect the cord of the light source box to the 'Power supply for Na Lamp'. Then switch on the power supply.
3. Wait for some time till the lamp glow bright yellowish.
4. Determine the least count of the traveling microscope. The least count is the pitch of the screw divided by the number of circular scale divisions.
5. Adjust the microscope position follows. There are two knobs (2 & 4 in Fig. 4) provided in one side of the microscope for coarse lateral and coarse vertical movement of the microscope *frame*. Use these two knobs to bring the microscope frame on top of the Newton's ring lens.
6. There is another knob (1 in Fig. 4) in the other side of the microscope for finer vertical movement of the microscope *tube*. Use this finer knob to move the microscope tube to and fro vertically in order to have a clear view of the Newton's rings. Try to obtain a good contrast between the bright and dark circular fringes.
7. Bring the cross-wire of the microscope on top of the central dark fringe with the help of the traveling microscope screw knob (1 in Fig. 4).
8. Slide the cross-wire to the left till the cross-wire line which is perpendicular to the left-right direction, lies tangentially at the 20-th dark ring. Note down the main and circular scale readings (see Table 1).
9. Now slowly slide the microscope to the right and note down the readings when the cross-wire line lies tangentially at the 16-th, 12-th, 8-th and 4-th dark ring respectively.
10. Keep sliding the microscope to the right and again note down the readings when the vertical cross-wire lies tangentially at the 4-th, 8-th, 12-th, 16-th and 20-th dark ring respectively.
11. Calculate the diameter, D_n of each ring from the difference of the *right side* and *left side* readings for a particular (n -th) ring.
12. Calculate the difference $D_{n+p}^2 - D_n^2$ for two rings with $p = 4$. The value of n will be $n = 4, 8, 12, 16$.
13. Calculate the wavelength, λ using Eq. (5) for the pairs of rings considered above. Finally calculate the mean wavelength.

Observations

Radius of curvature of the convex surface of the plano-convex lens, $R = 200$ cm

Least count of the traveling microscope screw, $L.C. = \dots$ cm.

Abbreviations used:

MSR = Main scale reading, CSR = Circular scale reading

Table 1: Determination of wavelength, λ from Newton's ring experiment.

Ring No., n	Microscope readings with the cross-wire						Diameter of the ring $D_n = b_n - a_n$ (cm)	$D_{n+p}^2 - D_n^2$ for $p = 4$ (cm^2)	$\lambda = \frac{D_{n+p}^2 - D_n^2}{4pR}$ (in \AA)	Mean λ (\AA)
	on the left of center			on the right of center						
	MSR m (cm)	CSR s	Total $a_n = m + s \times L.C.$ (cm)	MSR m (cm)	CSR s	Total $b_n = m + s \times L.C.$ (cm)				
4										
8										
12										
16										
20							—			

Calculation:

Calculate λ considering the different pairs of rings in Table 1 and find the mean λ .

Result:

Wavelength of sodium light is, $\lambda = \dots \text{\AA}$.

Remark:

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Experiment 9

Diffraction grating experiment

Objective

To determine the wavelength of laser using Diffraction grating.

Apparatus

Diffraction grating, laser light source, viewing screen, optical bench, stands etc.

Theory

A diffraction grating is a transparent plate ruled with a very large number of closely spaced parallel opaque grooves. In principle, a grating can be thought of as a set of large number of identical equally spaced thin slits separated by opaque strips. Light passing through a grating produces a diffraction pattern on a screen which can be analyzed to find the positions of bright and dark regions. Consider a plane wavefront incident on a grating surface. Portions of the

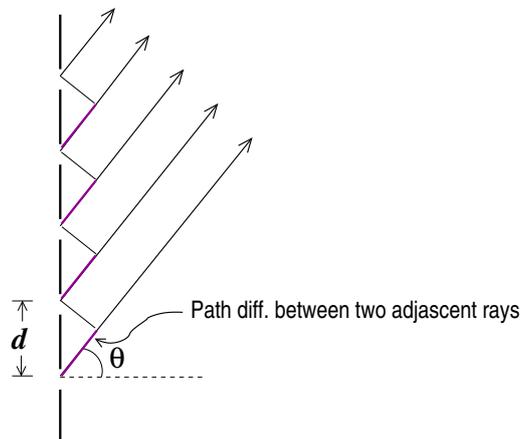


Fig. 1: Path difference in diffraction grating

wavefront falling on the slits will be transmitted through the grating. Now each point on a wavefront falling on a slit will act as a source of secondary wavefront. Rays coming out from these points interfere with each other producing a diffraction pattern on a viewing screen placed behind the grating. Moreover, beams coming from different slits also interfere with each other producing a net intensity distribution of light which is resultant of both the diffraction effect due each single slit and interference effect due to all the N slits. Now consider a setting in which the viewing screen is placed at 'large distance' from the grating (Fraunhofer diffraction class) so that the interfering rays can be considered almost parallel (Fig. 1). Consider parallel

rays emerging at an angle θ with the horizontal line from identical points in each slit as shown in Fig. 1. The path difference between two such adjacent rays will be ' $d \sin \theta$ ', where d is the distance between two slits. It can be shown that the intensity of the resultant wave obtained as a result of superposition of all such rays (emerging from all points from all slit wavefronts) is given by,

$$I = I_0 \frac{\sin^2 \beta}{\beta^2} \frac{\sin^2 N\gamma}{\sin^2 \gamma} \quad (1)$$

where I_0 is a constant. β and γ are given by

$$\beta = \frac{\pi b \sin \theta}{\lambda}, \quad \gamma = \frac{\pi d \sin \theta}{\lambda} \quad (2)$$

where b is the slit width and λ is the wavelength of light used. Thus the intensity, I will vary as a function of angle θ . For very large N , points of highest intensity, called principal maxima will be obtained when $\gamma = m\pi$, that is when,

$$\pi d \sin \theta_m = m\lambda, \quad m = 0, \pm 1, \pm 2, \dots \quad (\text{principal maxima}) \quad (3)$$

The maxima for $m = 0, \pm 1, \pm 2, \dots$ are called zeroth order, first order, second order maxima and so on, respectively. If y_m is the distance of the m -th principal maxima from the central maximum, and D ($\gg y_m$) is the distance between the grating and the screen, then the corresponding diffraction angle can be estimated using,

$$\theta_m = \frac{y_m}{D} \quad (\text{radian}) \quad (4)$$

In addition to the above principal maxima, there will be a number of minima and secondary maxima between two such principal maxima. Thus we can determine the wavelength, λ of the incident light from Eq. (3) by measuring the diffraction angle of various order principal maxima obtained.

Experimental setup



Fig. 2: Diffraction grating experimental setup

The experimental setup (Fig. 2) consists of an optics bench, mounted on which are a laser source, a diffraction grating and a viewing screen with two measuring scales engraved perpendicularly on it.

Procedure

1. Mount the laser source on the sliding stand at 0cm mark of the optics bench.
2. Place the grating mounted on a stand at a suitable distance from the source so that laser light falls normally on it.
3. Place the viewing screen mounted on another stand at the other end of the bench. The screen should also face the laser source normally.
4. Adjust the heights of all the three elements so that they are aligned at a same height.
5. Switch on the laser source. See that the laser light falls on the transparent portion of the grating.
6. Adjust the distance between the diffraction grating and the screen so that the light beam after passing through grating produces several bright spots on the screen.
7. Adjust the position of Laser so that the diffraction spots fall along the scale of screen.
8. Adjust the position of screen and the grating so that the diffraction spots are sharp and bright.
9. The brightest spot at the mid point is the central maxima and symmetrically situated on both sides of the central maxima there are multiple spots of diminishing intensity.
10. The first bright spot on either side of the central maxima is the first order maxima. Measure the distance between the center of central maxima and center of first bright spot on the screen (Table 1).
11. The second bright spot on either side of the central maxima is the second order maxima. Measure the distance between the center of central maxima and center of second bright spot on the screen.
12. Repeat the same procedure for 3rd and 4th order maxima.
13. Calculate the distance between two slits, d from the number of lines per cm (N_0) of the diffraction grating.
14. Note down the distance, D between grating and screen.
15. Calculate the diffraction angle θ_m of the m -th principal maximum using Eq. (4).
16. Calculate λ using Eq. (3) for each order of maxima considered above and find the mean value.

Observations

Number of lines of the diffraction grating per cm, $N_0 = 3000$.

Distance between two grating slits, $d = \frac{1}{N_0} = \dots$ cm.

Distance between the grating and the screen, $D = \dots$ cm.

Table 1: Determination of wavelength, λ using diffraction grating.

Sl No.	Order of the maxima (m)	Distance of the m -th maximum from center			Diffraction angle, $\theta_m = y_m/D$ (rad)	$\sin \theta_m$	Wavelength, $\lambda = \frac{\pi d \sin \theta_m}{m}$ (cm)	Mean λ (in Å)
		on the left of center y'_m (cm)	on the right of center y''_m (cm)	Mean, $y_m = (y'_m + y''_m)/2$ (cm)				
1	1							
2	2							
3	3							
4	4							

Calculation:

Calculate λ considering the different m in Table 1 and find the mean λ .

Result:

Wavelength of the used laser light is, $\lambda = \dots \text{Å}$.

Remark:

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