



LABORATORY MANUAL

B.Tech. Semester- I/ II

PHYSICS LAB

Subject code: BSP-101P

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**DEPARTMENT OF APPLIED SCIENCE & HUMANITIES
DRONACHARYA COLLEGE OF ENGINEERING
KHENTAWAS, FARRUKH NAGAR, GURUGRAM (HARYANA)**

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Vision and Mission of the Institute

Vision:

“To impart Quality Education, to give an enviable growth to seekers of learning, to groom them as World Class Engineers and managers competent to match the expending expectations of the Corporate World has been ever enlarging vision extending to new horizons of Dronacharya College of Engineering.”

Mission:

M1. To prepare students for full and ethical participation in a diverse society and encourage lifelong learning by following the principle of ‘Shiksha evam Sahayata’ i.e. Education & Help.

M2. To impart high-quality education, knowledge and technology through rigorous academic programs, cutting-edge research, & Industry collaborations, with a focus on producing engineers& managers who are socially responsible, globally aware, & equipped to address complex challenges.

M3. Educate students in the best practices of the field as well as integrate the latest research into the academics.

M4. Provide quality learning experiences through effective classroom practices, innovative teaching practices and opportunities for meaningful interactions between students and faculty.

M5. To devise and implement program of education in technology that are relevant to the changing needs of society, in terms of breadth of diversity and depth of specialization.

Vision and Mission of the Department

Vision:

To lay a strong foundation for the first-year students of the engineering discipline in the area of Applied Sciences and Humanities with a view to make them capable of innovating and inventing engineering solutions and also develop students as capable and responsible citizens of our nation.

Mission:

- To build strong fundamental knowledge and ability for application in students and make them capable to apply knowledge of mathematics and science to the solution of complex engineering problems.
- To impart knowledge, leading to understanding between engineering and other core areas of Applied Sciences and Humanities.
- To provide students the basic tools of analysis, as well as the knowledge of the principles on which engineering is based.
- To strive to inculcate the scientific temper and the spirit of enquiry in the students.
- To make students achieve a superior level in communication and presentation skills.
- To foster values and ethics and make students responsible citizens of India.
- To pursue inter-disciplinary research for the larger good of the society.

Programme Educational Objectives (PEOs)

- PEO1:** To provide students with a sound knowledge of mathematical, scientific and engineering fundamentals required to solve real world problems.
- PEO2:** To develop research oriented analytical ability among students and to prepare them for making technical contribution to the society.
- PEO3:** To prepare students with effective communication skills, professional ethics and managerial skills.
- PEO4:** To prepare students with the ability to upgrade their skills and knowledge for life-long learning.
- PEO5:** At the end of the program, the students will develop a strong analytical skill and will be able to study critically a physics problem, solve the problem using different tools and present the result/conclusion.
- PEO6:** Demonstrate conceptual understanding of fundamental physics principles. Communicate physics reasoning in oral and in written form. Solve physics problems using qualitative and quantitative reasoning including sophisticated mathematical techniques.
- PEO7:** Practice in professions requiring a fundamental understanding of the principles of physics and engineering.
- PEO8:** Maintain professional proficiency in rapidly-advancing scientific and technical areas.
- PEO9:** Pursue advanced degrees in physics, engineering, and other professional fields.

Programme Outcomes (POs)

- PO1:** Be able to apply knowledge of mathematics, science, and engineering.
- PO2:** Be able to design and conduct experiments, as well as to analyze and interpret data.
- PO3:** Be able to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
- PO4:** Be able to function on multidisciplinary teams.
- PO5:** Be able to identify, formulate, and solve engineering problems.
- PO6:** Be able to demonstrate an understanding of professional and ethical responsibility.
- PO7:** Be able to communicate effectively in oral form.
- PO8:** Be able to communicate effectively in written form.
- PO9:** Have the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.
- PO10:** Recognize the need for and have an ability to engage in life-long learning.
- PO11:** Be able to demonstrate knowledge of contemporary issues.
- PO12:** Be able to use the techniques, skills, and modern engineering tools necessary for engineering practice

Programme Specific Outcomes (PSOs)

PSO-1: Students would be able to explain the basic concepts of Quantum Mechanics and the band theory of solids.

PSO-2: To enable students to learn and to apply the basic concepts of properties of matter in day to day life.

PSO-3: To learn the types of Semiconductors and the role of carrier concentrations in conductivity. Understand the behavior of materials at low temperatures and the applications of Super conductivity.

PSO-4: Understand the use of Semiconductor Physics in Engineering Science, and apply the concepts to evaluate capacitance, resistance in various semiconductor device systems.

PSO-5: The student will get a basic understanding of Nanotechnology. The course will give idea of synthesis, characterization of Nano materials and electrical & optical properties, application of Nano systems.

University Syllabus

Note: At least 8 experiments are to be performed by the students.

List of Subject related Experiments:

1. To study the forward and reverse characteristics of P-N junction diode.
2. To study the characteristics of Solar cell and find out the fill factor..
3. To study the reverse characteristics and voltage regulation using Zener Diode.
4. To determine Planks constant using photocell.
5. To measure e/m of electron using helical method.
6. To find capacitance of condenser using fleshing and quenching experiment.
7. To find temperature co-efficient of platinum using Callender Griffith bridge.
8. To find out low resistance by Carey Foster bridge.
9. To find resistance of galvanometer by post office box.
10. To measure resistance using four probe method.
11. To compare the capacitance of two capacitors using De'Sauty Bridge

Course Outcomes (COs)

Upon successful completion of the course, the students will be able to:

C101.1: Develop skills to impart practical knowledge in real time solution.

C101.2: Understand principle, concept, working and application of new technology and comparison of results with theoretical calculations.

C101.3: Design new instruments with practical knowledge.

C101.4: Gain knowledge of new concept in the solution of practical oriented problems and to understand more deep knowledge about the solution to theoretical problems.

C101.5: Understand measurement technology, usage of new instruments and real time applications in engineering studies.

CO-PO Mapping

| | PO1 | PO2 | PO3 | PO4 | PO5 | PO6 | PO7 | PO8 | PO9 | PO10 | PO11 | PO12 |
|-------------|-----|----------|----------|----------|----------|-----|-----|----------|----------|----------|----------|----------|
| C101.1 | | 2 | | | 2 | | | 2 | 2 | 2 | 2 | 2 |
| C101.2 | | | 2 | | 2 | | | 2 | 2 | 2 | 2 | 2 |
| C101.3 | | | | 2 | 2 | | | 2 | 2 | 2 | 2 | 2 |
| C101.4 | | | | 2 | 2 | | | 2 | 2 | 2 | 2 | 2 |
| C101.5 | | | | 2 | 2 | | | 2 | 2 | 2 | 2 | 2 |
| C101 | | 2 | 2 | 2 | 2 | | | 2 | 2 | 2 | 2 | 2 |

CO-PSO Mapping

| | PSO1 | PSO2 | PSO3 |
|-------------|----------|----------|------|
| C101.1 | 2 | 2 | |
| C101.2 | | 2 | |
| C101.3 | | 2 | |
| C101.4 | | 2 | |
| C101.5 | | 2 | |
| C101 | 2 | 2 | |

Course Overview

Engineering Physics Lab provides an experimental foundation for the theoretical concepts introduced in the lectures. It also discusses how to make careful experimental observations and how to think about and draw conclusions from such data. The students understand the role of direct observation in physics and to distinguish between inferences based on theory and the outcomes of experiments. It introduces the concepts and techniques which have a wide application in experimental science but have not been introduced in the standard courses. Finally the students are able to write a technical report which communicates scientific information in a clear and concise manner.

List of Experiments mapped with COs

| Sl No. | List of Experiments | Course Outcome | Page No. |
|---------------|--|-----------------------|-----------------|
| 1 | To study the forward and reverse characteristics of P-N junction diode. | C101.1 | 1-7 |
| 2 | To study the characteristics of Solar cell and find out the fill factor. | C101.1 | 8-16 |
| 3 | To study the reverse characteristics and voltage regulation using Zener Diode. | C101.3 | 17-21 |
| 4 | To determine Planks constant using photocell. | C101.1 | 22-27 |
| 5 | To measure e/m of electron using helical method. | C101.2 | 28-37 |
| 6 | To find capacitance of condenser using fleshing and quenching experiment. | C101.5 | 38-42 |
| 7 | To find temperature co-efficient of platinum using Callender Griffith bridge. | C101.5 | 43-47 |
| 8 | To find out low resistance by Carey Foster bridge. | C101.4 | 48-54 |
| 9 | To find resistance of galvanometer by post office box. | C101.4 | 55-58 |
| 10 | To measure resistance using four probe method. | C101.4 | 59-68 |
| 11 | To compare the capacitance of two capacitors using De'Sauty Bridge | C101.4 | 69-74 |

DOs and DON'Ts

PHYSICS LABORATORY

- 1.) Do not consume any food or drink in the laboratory. Any food or drink brought to the lab must remain in the students carrying bag until they leave.
- 2.) Do wear appropriate clothing to laboratory. This includes shoes that are not open toed (No sandals, slippers, etc.). Please wear clothing to lab that you don't care if it gets dirty. We don't have a lot of chemicals but you will have to kneel on the floor to make measurements and some of the equipment can have greasy rotation points.
- 3.) Do place all sensitive electronic equipment safely on your table or within your bag under your table so that expensive damage can be avoided.
- 4.) Do not modify or damage the laboratory equipment in any way unless the modification is directed by the instructor. This does not include the changing of a lab setup as prescribed by the procedures in the carrying out of measurements.
- s) Do use care when loosening and tighten screws and bolts. Treat the equipment as if it were your own.
- 6.) Do not force any of the equipment. If an excessive amount of force is necessary then tell your instructor.
- 7.) In case the fire alarm sounds, please do exit the building by the nearest safe exit. If the fire is in the room leave everything behind. If the fire is not in the room and immediate danger is not apparent, then quickly and quietly pack your bag and exit the room or just leave the stuff behind. The instructor will lock the doors on the way out to ensure security.
- 8.) In the case of any other emergency, do follow the instructions of the laboratory instructor and all safety personal that may have responded to the scene.
- 9.) Do handle all laboratory apparatus according to their instructions.
- 10.) After using the apparatus, do clean them properly and placed them back to their proper places

General Safety Precautions

Precautions (In case of Injury or Electric Shock)

1. To break the victim with live electric source, use an insulator such as fire wood or plastic to break the contact. Do not touch the victim with bare hands to avoid the risk of electrifying yourself.
2. Unplug the risk of faulty equipment. If main circuit breaker is accessible, turn the circuit off.
3. If the victim is unconscious, start resuscitation immediately, use your hands to press the chest in and out to continue breathing function. Use mouth-to-mouth resuscitation if necessary.
4. Immediately call medical emergency and security. Remember! Time is critical; be best.

Precautions (In case of Fire)

1. Turn the equipment off. If power switch is not immediately accessible, take plug off.
2. If fire continues, try to curb the fire, if possible, by using the fire extinguisher or by covering it with a heavy cloth if possible isolate the burning equipment from the other surrounding equipment.
3. Sound the fire alarm by activating the nearest alarm switch located in the hallway.
4. Call security and emergency department immediately:

Emergency : **Reception**

Security : **Main Gate**

Guidelines to students for report preparation

All students are required to maintain a record of the experiments conducted by them. Guidelines for its preparation are as follows:-

- 1) All files must contain a title page followed by an index page. *The files will not be signed by the faculty without an entry in the index page.*
- 2) Student's Name, Roll number and date of conduction of experiment must be written on all pages.
- 3) For each experiment, the record must contain the following
 - (i) Aim/Objective of the experiment
 - (ii) Pre-experiment work (as given by the faculty)
 - (iii) Lab assignment questions and their solutions
 - (iv) Test Cases (if applicable to the course)
 - (v) Results/ output

Note:

1. Students must bring their lab record along with them whenever they come for the lab.
2. Students must ensure that their lab record is regularly evaluated.

Physics Lab (BSP-101P)

Lab Assessment Criteria

An estimated 10 lab classes are conducted in a semester for each lab course. These lab classes are assessed continuously. Each lab experiment is evaluated based on 5 assessment criteria as shown in following table. Assessed performance in each experiment is used to compute CO attainment as well as internal marks in the lab course.

| Grading Criteria | Exemplary (4) | Competent (3) | Needs Improvement (2) | Poor (1) |
|--|---|---|---|---|
| AC1: Pre-Lab written work (this may be assessed through viva) | Complete procedure with underlined concept is properly written | Underlined concept is written but procedure is incomplete | Not able to write concept and procedure | Underlined concept is not clearly understood |
| AC2: Program Writing/ Modeling | Assigned problem is properly analyzed, correct solution designed, appropriate language constructs/ tools are applied, Program/solution written is readable | Assigned problem is properly analyzed, correct solution designed, appropriate language constructs/ tools are applied | Assigned problem is properly analyzed & correct solution designed | Assigned problem is properly analyzed |
| AC3: Identification & Removal of errors/ bugs | Able to identify errors/ bugs and remove them | Able to identify errors/ bugs and remove them with little bit of guidance | Is dependent totally on someone for identification of errors/ bugs and their removal | Unable to understand the reason for errors/ bugs even after they are explicitly pointed out |
| AC4: Execution & Demonstration | All variants of input /output are tested, Solution is well demonstrated and implemented concept is clearly explained | All variants of input /output are not tested, However, solution is well demonstrated and implemented concept is clearly explained | Only few variants of input /output are tested, Solution is well demonstrated but implemented concept is not clearly explained | Solution is not well demonstrated and implemented concept is not clearly explained |
| AC5: Lab Record Assessment | All assigned problems are well recorded with objective, design constructs and solution along with Performance analysis using all variants of input and output | More than 70 % of the assigned problems are well recorded with objective, design contracts and solution along with Performance analysis is done with all variants of input and output | Less than 70 % of the assigned problems are well recorded with objective, design contracts and solution along with Performance analysis is done with all variants of input and output | |

LAB EXPERIMENTS

LAB EXPERIMENT 1

P-N JUNCTION DIODE CHARACTERISTICS

AIM: To study the forward and reverse characteristics of P-N junction diode.

1. To plot Volt-Ampere Characteristics of Silicon P-N Junction Diode.
2. To find cut-in Voltage for Silicon P-N Junction diode.
3. To find static and dynamic resistances in both forward and reverse biased conditions for Si P-N Junction diode.

| Name | Qty |
|-------------------------------------|-----|
| Diodes IN 4007(Si) | 1 |
| Resistor 1K Ω , 10K Ω | 1 |

| Name | Range | Qty |
|------------------------|--------------------|-----|
| Bread Board | - | 1 |
| Regulated Power Supply | 0-30V DC | 1 |
| Digital Ammeter | 0-200 μ A/20mA | 1 |
| Digital Voltmeter | 0-2V/20V DC | 1 |
| Connecting Wires | | |

Components and Equipment's:

Theory:

Donor impurities (pentavalent) are introduced into one-side and acceptor impurities into the other side of a single crystal of an intrinsic semiconductor to form a p-n diode with a Junction called depletion region (this region is depleted off the charge carriers). This region gives rise to a potential barrier V called ***Cut- in Voltage***. This is the voltage across the diode at which it starts conducting. It can conduct beyond this Potential.

The P-N junction supports uni-directional current flow. If +ve terminal of the input supply is connected to anode (P-side) and –ve terminal of the input supply is connected to cathode (N- side) then diode is said to be forward biased. In this condition the height of the potential barrier at the junction is lowered by an amount equal to given forward biasing voltage. Both the holes from p-side and electrons from n-side cross the junction simultaneously and constitute a forward current (***injected minority current*** – due to holes crossing the junction and entering N-side of the diode, due to electrons crossing the junction and entering P-side of the diode). Assuming current flowing through the diode to be very large, the diode can be approximated as short-circuited switch.

If –ve terminal of the input supply is connected to anode (p-side) and +ve terminal of the input supply is connected to cathode (n-side) then the diode is said to be reverse biased. In this condition an amount equal to reverse biasing voltage increases the height of the potential barrier at the junction. Both the holes on p-side and electrons on n-side tend to move away from the junction thereby increasing the depleted region. However the process cannot continue indefinitely, thus a small current called ***reverse saturation current*** continues to flow in the diode. This small current is due to thermally generated carriers. Assuming current flowing through the diode to be negligible, the diode can be approximated as an open circuited switch.

Circuit Diagram

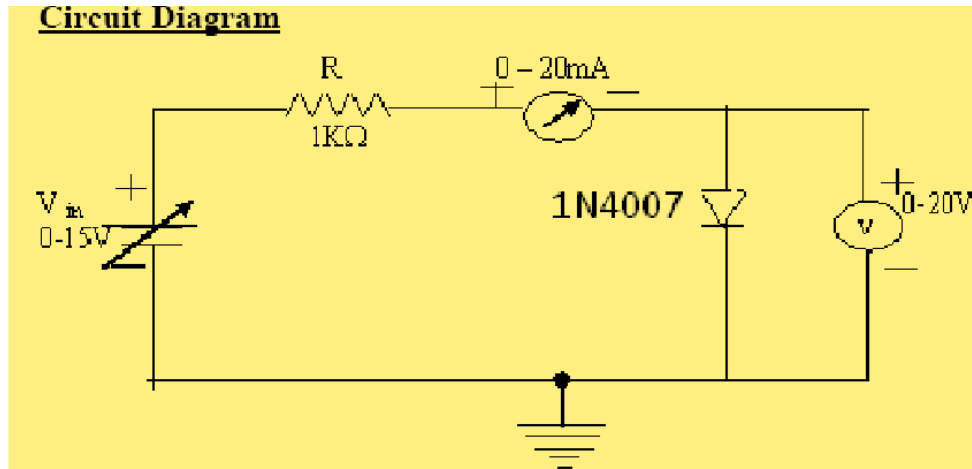
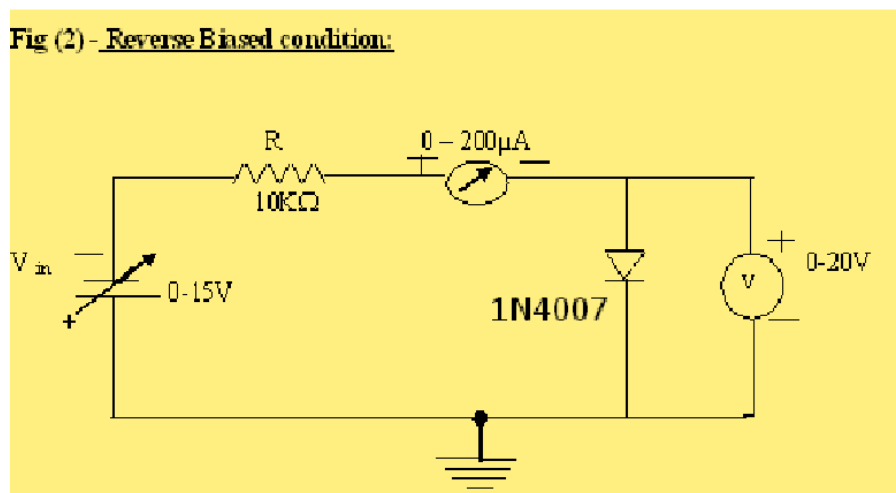


Fig (2) - Reverse Biased condition:



Procedure:

Forward Biased Condition:

1. Connect the circuit as shown in figure (1) using silicon PN Junction diode.
2. Vary V_f gradually in steps of 0.1 volts upto 5volts and note down the corresponding readings of I_f .
3. Step Size is not fixed because of nonlinear curve and vary the X-axis variable (i.e. if output variation is more, decrease input step size and vice versa).
4. Tabulate different forward currents obtained for different forward voltages.

Reverse biased condition:

1. Connect the circuit as shown in figure (2) using silicon PN Junction diode.
2. Vary V_r gradually in steps of 0.5 volts upto 8 volts and note down the corresponding readings of I_r .
3. Tabulate different reverse currents obtained for different reverse voltages. ($I_r = V_R / R$, where V_R is the voltage across 10K Ω resistor)

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Observations

Si diode in forward biased conditions:

| Sl. No | RPS Voltage | Forward Voltage across the diode V_f (volts) | Forward current through the diode I_f (mA) |
|--------|-------------|--|--|
| | | | |

Si diode in reverse biased conditions:

| Sl. No | RPS Voltage | Reverse Voltage across the diode V_r (volts) | Reverse current through the diode I_r (μ A) |
|--------|-------------|--|--|
| | | | |

Graph (Instructions):

1. Take a graph sheet and divide it into 4 equal parts. Mark origin at the center of the graph sheet.
2. Now mark + ve x-axis as V_f

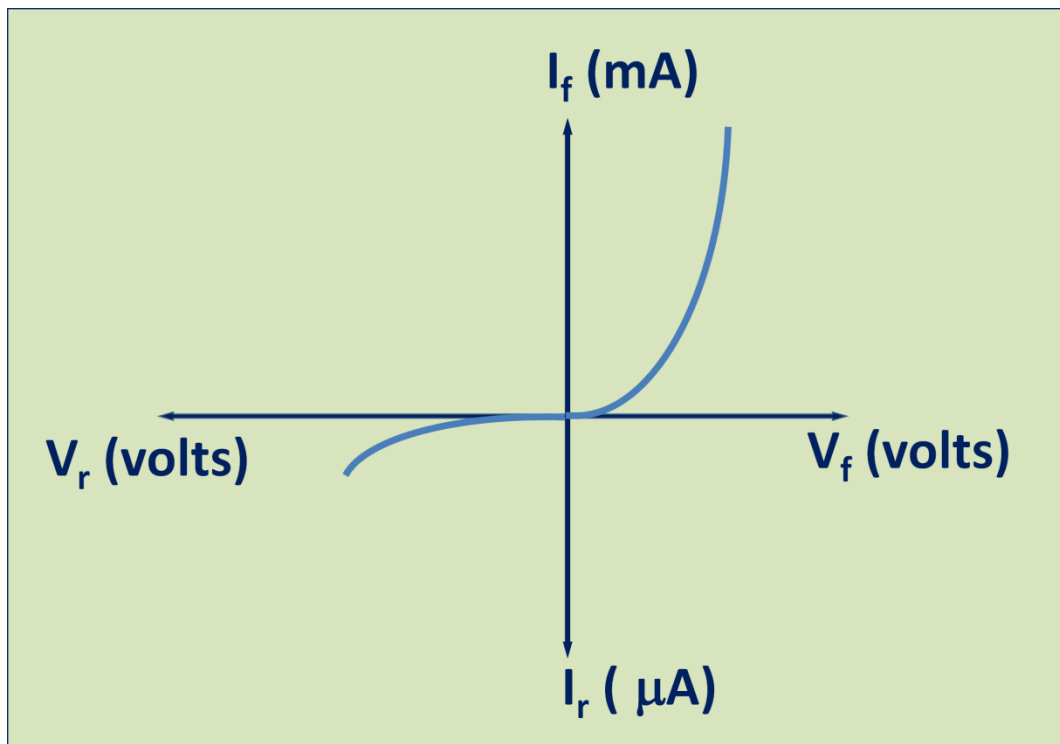
- Ve x-axis as V_r

+ Ve y-axis as I_f

- ve y-axis as I_r .

3. Mark the readings tabulated for Si forward biased condition in first Quadrant and Si reverse biased condition in third Quadrant.

Calculations from Graph:



Static forward Resistance $R_{dc} = V_f / I_f \Omega$ Dynamic forward Resistance $r_{ac} = \Delta V_f$

$\Delta I_f \Omega$

Static Reverse Resistance $R_{dc} = V_r / I_r \Omega$

Dynamic Reverse Resistance $r_{ac} = \Delta V_r / \Delta I_r \Omega$

Precautions:

1. While doing the experiment do not exceed the ratings of the diode. This may lead to damage the diode.
2. Connect voltmeter and Ammeter in correct polarities as shown in the circuit diagram.
3. Do not switch **ON** the power supply unless you have checked the circuit connections as per the circuit diagram.

Physics Lab (BSP-101P)

Result:

1. Cut in voltage = V
2. Static forward resistance = Ω
3. Dynamic forward resistance = Ω

Physics Lab (BSP-101P)

Quiz with Answers:

Q1. In which devices diode is used?

Ans: we use diodes in many electronic devices as a switch when in active region.

- these works in forward direction .
- they act as an open switch inn revers direction.

Q2. Can we replace the avalanche diode any other diode? If yes or not ,give the logical reason?

Ans- no we can't replace an avalanche diode by any other diode because it give a constant output in reverse bias condition.

Q3. What are the two types of semiconductors?

The two types of semiconductors are:

Intrinsic Semiconductor

Extrinsic Semiconductor

Q4. Who made the first semiconductor diode?

Answer: Ferdinand Braun

Q5. Who discovered the PN junction?

Answer: Russell Ohl

LAB EXPERIMENT 2

SOLAR CELL CHARACTERISTICS

AIM: To study the characteristics of Solar cell and find out the fill factor.

OBJECT

To study the characteristics of solar cell, the following studies can be carried out.

1. Illumination Characteristics.
2. Current Voltage Characteristics.
3. Power Load Characteristics.
4. Area Characteristics.
5. Spectral Characteristics.

OPTIONAL

1. Distance Vs Open Circuit Voltage.
2. Distance Vs Short Circuit Current.
3. Measurement of Short Circuit Current (I_{ESC}) with biasing the solar cell and compare it with the theoretical value obtained from current voltage characteristics curves.

THEORY:

Solar cells are basically solid-state devices. It is basically a p-n junction, which converts sunlight (solar energy) into electrical energy through a three-step process:

- 1. Generation of carrier pairs (electron hole pairs)**
- 2. Separation of electrons and holes**
- 3. Collection of separated carriers**

The details of each of the three processes are beyond the scope of this manual. Pl see text books. When a solar cell is illuminated, the photons incidents on the cell generate electrons-hole pairs. By diffusion in the material the electron and holes reach the junction. At the junction the barrier field separates the positive and negative charges carriers. Under the action of the electric field, the electrons (minority carriers) from p region are swept into n region. Similarly, the holes from n region are swept into p region. It leads to an increase in the number of holes on the p side and of the electrons on the n side of the junction. The accumulation of charges on the two sides of the

Physics Lab (BSP-101P)

junction produces an emf, which is called a photo emf. The photo emf is known as open circuit voltage. It is proportional to the illumination (mW/cm^2 or lumen/cm^2) and on the size of the illuminated area. When an external circuit is connected across the solar cell terminals, the minority carriers return to their original sides through the external circuit, causing the current to flow through the circuit. Thus the solar cell behaves as a battery with n side as the negative terminal and p side as positive terminal. The photo emf or voltage can be measured with a voltmeter. The process of generation of photovoltaic voltage is shown in Fig.

(1) The conversion of optical energy is known as photovoltaic effect. Hence a solar cell is also called a photovoltaic cell.

All solar cell materials used till date are semiconductors in crystalline or amorphous forms. A common characteristic of these materials is that they possess a band gap i.e. a discontinuity or rather a range of forbidden values in the energy spectrum. Mostly, solar cells are fabricated from silicon single crystals; Silicon is not transparent for visible light. Therefore, the surface layer of the cell, which is of p type, is made extremely thin to enable maximum light to penetrate the junction. It is desired the absorption of light takes place at the junction region such that the generated electron holes pairs can be separated by the junction fields before they are lost by recombination. To enhance the transmission of the light into the material an anti-reflection coating is given over p type layer. Thin metallic films vacuum deposited suitably on both the sides of the cell act as electrodes. An open circuit voltage of peak value of 0.6 V is generated by a solar cell. Silicon wafer of 1" dia to 4" dia are used to fabricate solar cells. In order to enhance the total voltage and current output, a number of P-n junction are formed on a wafer, using a mesh type or finger like electrode structure. To increase power output, solar cells are arrayed into a series chain or parallel chain and are interconnected. Such an arrangement is called a solar panel. In normal use single solar cell is rarely used, as its output is very low.

(i) **Illumination Characteristic**

The Illumination Characteristic of a solar cell is shown in the Fig. (2). It is seen that the current through the solar cell increases as the intensity of the light falling on the solar cell increases.

(ii) **Current Voltage Characteristic**

The output characteristic (current voltage characteristics) of a solar cell is shown in the Fig. (3) it is seen that in the open circuit, the output voltage of the cell is ≈ 0.6 V and the current is zero. If the panel is short circuited, the current is maximum while the output voltage of the cell becomes zero. In both the cases, the output power is zero. It is seen from the curve that the voltage varies depending on the current drawn.

(iii) **Power Load Characteristics**

To derive maximum power from the panel, an appropriate load is to be connected across it. The value of the load that allows the cell to give maximum output power is obtained by drawing a power load characteristics, as shown in the Fig. (4). It is seen that a load other than $(R_L)_{\text{max}}$ will produce less power.

(iv) **Area Characteristics:**

The power delivered is proportional to the surface area of the solar panel exposed to the light. It is governed by the relation,

$$P = K A$$

Where,

P is the total
power available

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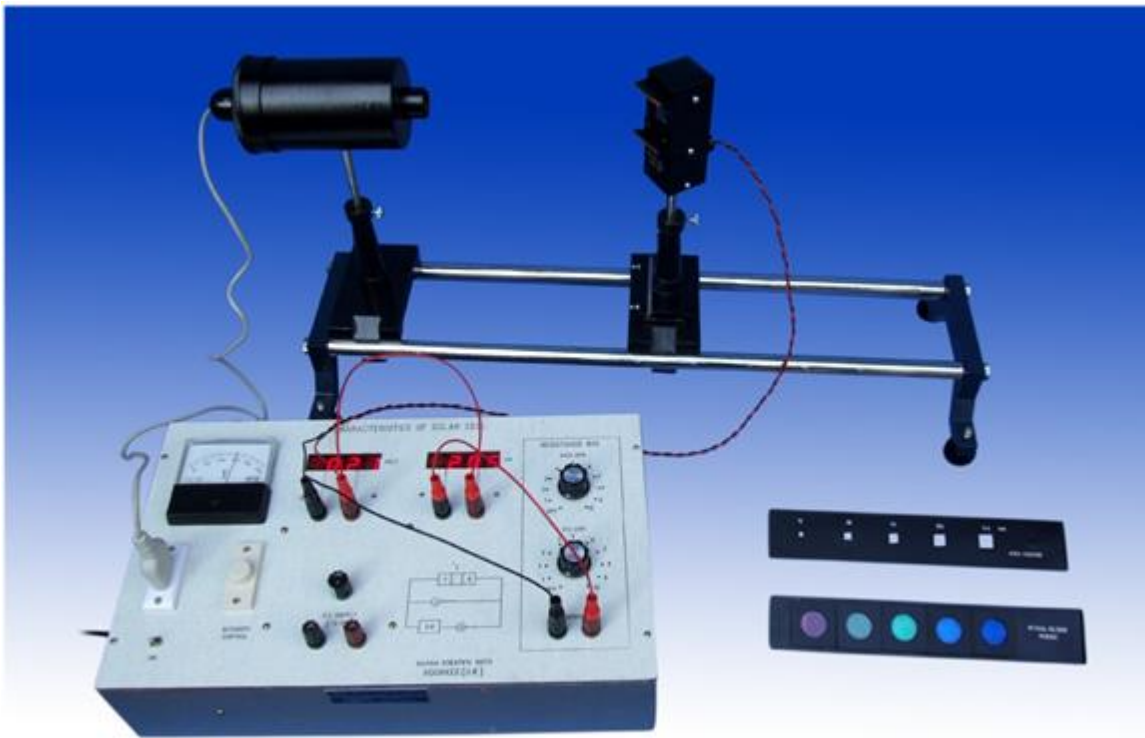
A is the area of
the Cell

K is a constant.

The dependence of P on A is shown in the Fig. (5)

(v) **Spectral Characteristics:**

The response of a solar cell to light depends on the wavelength of the incident light also. In the sunlight, different colors have different intensities. The variation of power on wavelength is shown in the Fig.(6)



PROCEDURE

(a) **Illumination Characteristics**

1. Make the circuit as shown in fig. 7. A 100 W lamp is arranged over the solar cell such that the light falls on it at normal. The intensity control is kept at its minimum say at 50 volts and the lamp is switched on.
2. Adjust the resistance box at zero ohm (i.e. both the knobs marked X10 and X100 ohm must be set

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at off position) note the short circuit current and make table as shown below.

3. Increase the intensity of the lamp in steps say 100, 150, 200 volts and note the corresponding current for each setting of the voltage, record these readings in the table.

Note: Intensity is taken as proportional to the A.C. voltage given to the lamp

- a. Plot a graph between Current and the Intensity.

Table – 1

| S.No. | Intensity (volts) | Current (mA) |
|-------|-------------------|--------------|
| 1. | | |
| 2. | | |
| 3. | | |

(b) Current Voltage Characteristics

1. The intensity of the lamp is kept at the minimum say 100 V. disconnect the load resistance (i.e. R.B. is at infinity) and note the open circuit voltage.
2. Adjust the resistance box (R.B.) at zero ohm (i.e. both the knob of the resistance box marked X10 and X100 ohm must be set at off position) and note the short circuit current.
3. Set the load dial at 100 ohms. Note the corresponding voltage and current make the table as shown below and record these readings in the table. Vary the load in steps up to 1100 ohms and note the corresponding voltage and current for each setting of the load in table
4. The intensity of the lamp is increased say 150 V. The load is again varied from 100 to 1100 ohms and note the corresponding voltage and the currents, record the value in the table. The open circuit voltage and the short circuit current are also determined and recorded.
5. The intensity of the lamp is set at 200 V, and repeat step 4. Record these readings in the table.
6. Plot a graph for Current Vs Voltage.

Table – 2

| S.No. | R _L Ohms | Intensity, I ₁ | | Intensity, I ₂ | | Intensity, I ₃ | |
|-------|------------------------|---------------------------|-------------|---------------------------|-------------|---------------------------|-------------|
| | | Voltage(V) | Current(mA) | Voltage(V) | Current(mA) | Voltage(V) | Current(mA) |
| 1. | 100 | | | | | | |
| 2. | 200 | | | | | | |
| 3. | | | | | | | |

(c) Power Load Characteristics

Using the sets of the reading obtained in the table 2 above, calculate the output power of the cell. Make table as shown below and record the readings in the table.

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1. Plot a graph for Power Vs Load. Measure the value of the optimum load that draws maximum power from the cell.

Table – 3

| S.No. | R _L Ohms | Intensity, I ₁ = 100 V | Intensity, I ₂ = 150 V | Intensity, I ₃ = 200 V |
|-------|------------------------|--------------------------------------|--------------------------------------|--------------------------------------|
| | | Power mW | Power mW | Power mW |
| 1. | 100 | | | |
| 2. | 200 | | | |
| 3. | | | | |

(d) Area Characteristics:

1. Set the intensity of the lamp at a convenient level say 200V. Adjust the load at the optimum value.
2. Place the chopper plate having different slot areas, in front of the solar cell in the grove provided.
3. Adjust one of the slot say 16 mm² over the solar cell; it reduces the surface area, which is illuminated. The voltage and the current readings are noted in the table. Note the corresponding voltage and current readings make table as shown below and record the readings in the table.
4. Adjust the other slots say 36, 64, 100, 144 mm² over the solar cell and note the corresponding current and voltage for each slot area and record the readings in the table.
5. Plot a graph for Power Vs Area. Measure the slope of the curve.

Table – 4

| S.No. | Slot Area mm ² | Voltage, V volts | Current, I amp | Power P = VI mW |
|-------|---------------------------|------------------|----------------|-----------------|
| 1. | | | | |
| 2. | | | | |
| 3. | | | | |
| 4. | | | | |

(e) Spectral Characteristics:

1. Set the intensity of the lamp to a convenient level say 200 V. Adjust the load at the optimum value.
2. Put the different colors filter over the solar cell and for each filter the note voltage and the current and record these readings in the table.
3. The wavelength corresponding to each color is noted and calculate the output power
4. Plot a graph for Power Vs Wavelength.

Table – 5

| S.No. | Filter Colors | Peak Wavelength Transmitted, A° | Voltage, V volts | Current, I amp | Power P = VI mW |
|-------|---------------|------------------------------------|---------------------|-------------------|--------------------|
| 1. | | | | | |

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| | | | | | |
|----|--|--|--|--|--|
| 2. | | | | | |
| 3. | | | | | |

OPTION-

Distance Vs Open Circuit Voltage:

Repeat step 1 of the current voltage characteristics and vary the distance between the source and the photocell and note the open circuit voltage for each position of the cell from the source say at 15, 18, 21, 24, 27, 30 cm.

Distance Vs Short Circuit Current:

Repeat step 2 of the current voltage characteristics and vary the distance between the source and the photocell and note the short circuit current for each position of the cell from the source say at 15, 18, 21, 24, 27, 30 cm.

Experimental Measurement of Short Circuit Current:

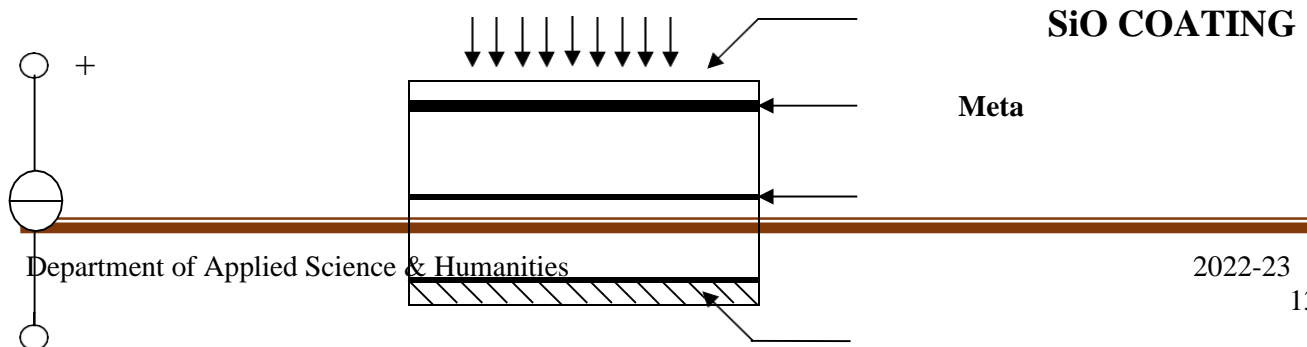
Make the circuit as shown in the fig. 7(b) using R_2 and the multimeter. Set the lamp voltage say at 100 volts. Adjust the supply voltage at 1.5 volts and vary R_2 till the voltmeter V reads Zero voltage. In this position the cell and the battery try to send current through R.B. and when both currents are equal no current will pass through

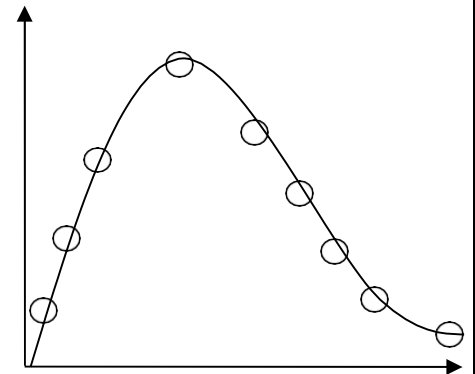
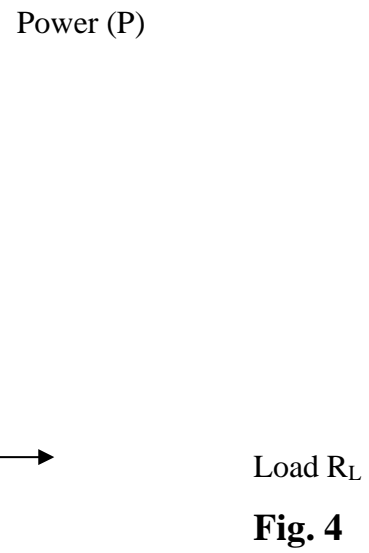
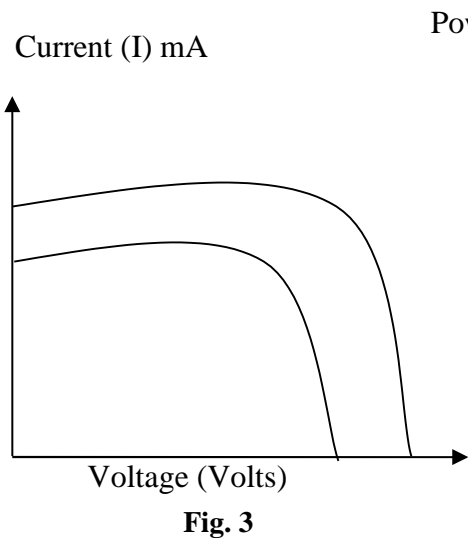
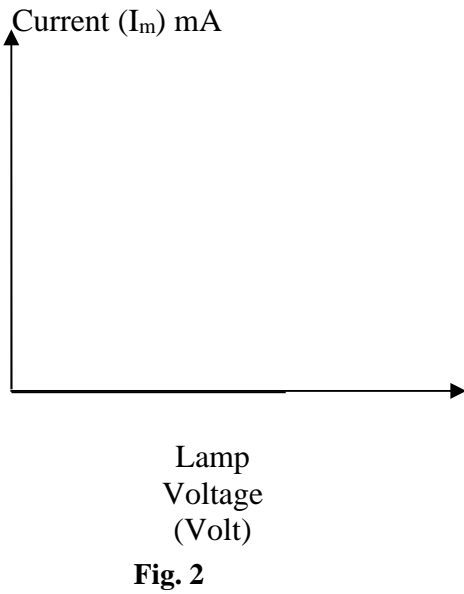
R.B. and thus no voltage drop across it as measured by the voltmeter. In this case, the current obtained through multimeter gives the short circuit current. Repeat the experiment for different values of lamp voltage say 150, 200 volts and note the corresponding short circuit current. Make table as shown below:

Table - 6

| S.No. | Lamp Voltage | Experimental value of Short circuit current I_{ESC} | Theoretical value of Short circuit current obtained from V-I characteristics curve. |
|-------|--------------|---|---|
| 1. | | | |
| 2. | | | |
| 3. | | | |

Compare the Experimental value of Short Circuit Current I_{ESC} with the Theoretical value.





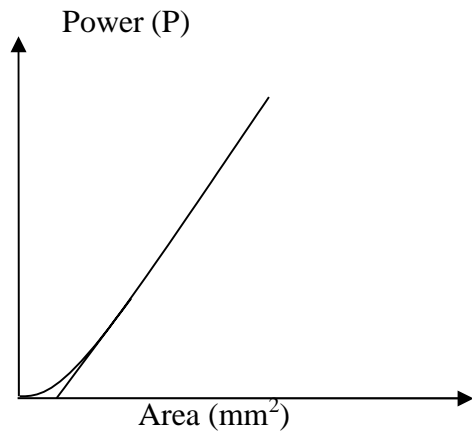


Fig. 5

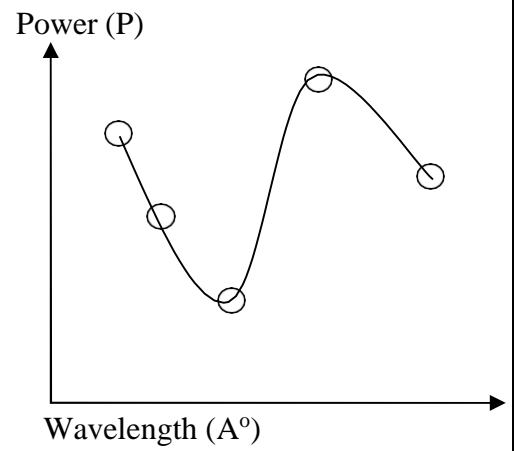


Fig.
6

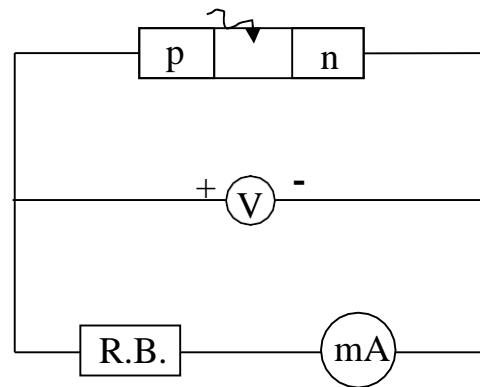
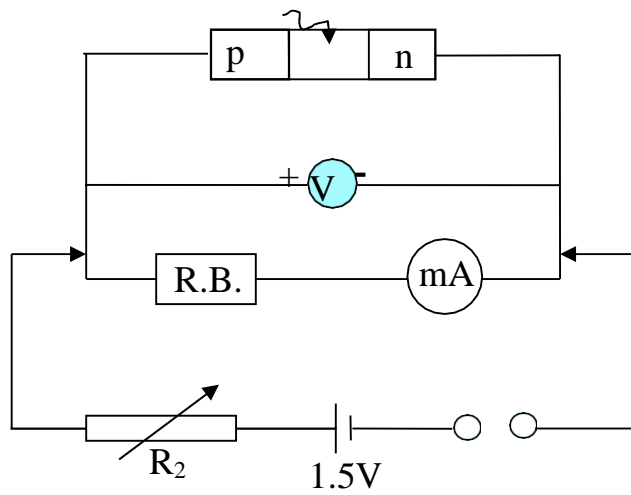


Fig. 7(a)

Quiz with Answers:

Q1. What is solar cell?

Ans: 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.

Q2. How does a solar cell work?

Ans: By utilizing the photovoltaic effect, it converts light energy into electrical current.

Q3. What material is commonly used in solar cells?

Ans: Silicon is the most widely used material for solar cells.

Q4. What is the efficiency of typical solar cells?

Ans: Efficiency ranges from 15% to 25% for most commercial solar cells.

Q5. What are the main types of solar cells?

Ans: Crystalline silicon, thin-film, and organic solar cells are common types.

LAB EXPERIMENT 3

ZENER DIODE CHARACTERISTICS

AIM: To study the reverse characteristics and voltage regulation using Zener Diode.

APPARATUS: Circuit board comprises 0-10 V D.C. at 10 mA, continuously variable regulated power supply, integral current limiting resistor, Digital voltmeter, digital current meter ZENER diode, Patch chords.

THEORY: The circuit diagram to plot the VI characteristics of a Zener diode is shown. Zener diode is a special diode with increased amounts of doping. This is to compensate for the damage that occurs in the case of a $p-n$ junction diode when the reverse bias exceeds the breakdown voltage and thereby current increases at a rapid rate.

Applying a positive potential to the anode and a negative potential to the cathode of the Zener diode establishes a forward bias condition. The forward characteristic of the Zener diode is same as that of a $p-n$ junction diode i.e. as the applied potential increases the current increases exponentially. Applying a negative potential to the anode and positive potential to the cathode reverse biases the Zener diode.

As the reverse bias increases, the current increases rapidly in a direction opposite to that of the positive voltage region. Thus under reverse bias condition breakdown occurs. It occurs because there is a strong electric field in the region of the junction that can disrupt the bonding forces within the atom and generate carriers. The breakdown voltage depends upon the amount of doping. For a heavily doped diode depletion layer will be thin and breakdown occurs at low reverse voltage and the breakdown voltage is sharp where as a lightly doped diode has a higher breakdown voltage. This explains the Zener diode characteristics in the reverse bias region.

The maximum reverse bias potential that can be applied before entering the Zener region is called the Peak Inverse Voltage referred to as PIV rating or the Peak Reverse Voltage Rating (PRV rating).

REVERSE BIASED CHARACTERISTICS OF A DIODE.

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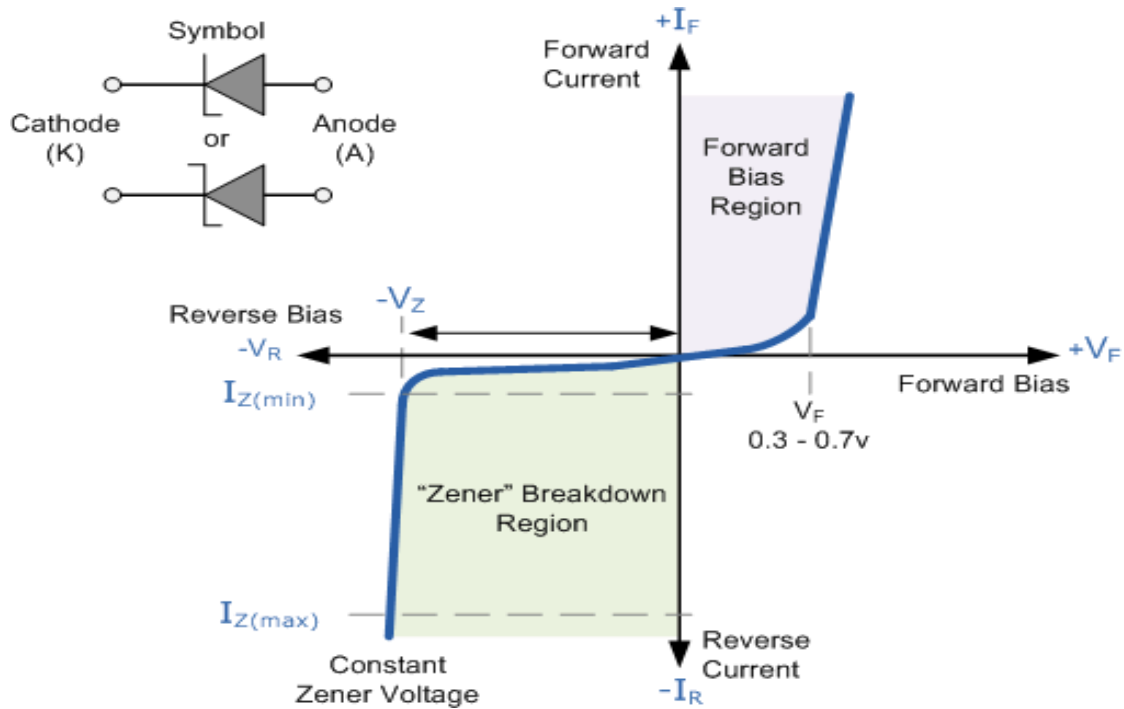
The **Zener Diode** is used in its "reverse bias" or reverse breakdown mode, i.e. the diodes anode connects to the negative supply.

From the I-V characteristics curve above, we can see that the Zener diode has a region in its reverse bias characteristics of almost a constant negative voltage regardless of the value of the current flowing through the diode and remains nearly constant even with large changes in current as long as the Zener diodes current remains between the breakdown current $I_{Z(\min)}$ and the maximum current rating $I_{Z(\max)}$. The fact that the voltage across the diode in the breakdown region is almost constant turns out to be an important application of the Zener diode as a voltage regulator.

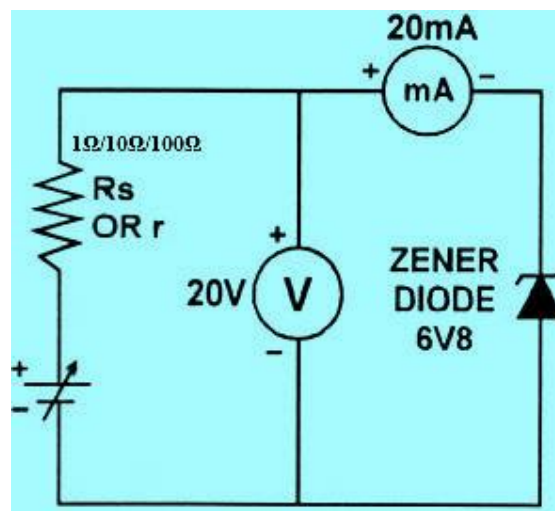
If the reverse bias applied to a p-n junction diode is increased, a point will be reached at which the junction breaks down and the current flowing in the reverse voltage at which this occurs and the breakdown mechanism involved, depends on the construction of the diode. In a conventional rectifier diode, reverse breakdown should not occur within the voltage rating of the diode (which may be several hundred volts). When reverse breakdown occurs in rectifier it destroys the diode. Such breakdown is also known as "AVALANCHE BREAKDOWN". The "avalanche breakdown" mechanism predominates in diodes having reverse breakdown voltages above about 8V.

Devices can be made with reverse breakdown voltages below about 3 V. This type of breakdown is known as "ZENER BREAKDOWN". When reverse breakdown occurs at voltages in the range 3 to 8, then both Zener and avalanche breakdown mechanism are involved. It is customary to describe diodes that are continuously operated in the reverse breakdown mode as ZENER diode, even though the actual breakdown mechanism may be of the avalanche type. Breakdown voltages of commercially available diodes range from about 1 to 1000. Zener diodes are used in the reverse biased mode to give stable fixed voltage references in practical circuits.

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CIRCUIT DIAGRAM:



PROCEDURE:

1. Connect the circuit for reverse bias of Zener diode as shown in the figure Fig.
2. Switch ON the board. Slowly increase the 0-10 V supply and note down the readings of voltmeter for the supply voltage and voltage across the diode.

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3. Plot the voltage and current readings on a graph paper by taking voltage on the negative X- axis and current on the negative Y-axis. The plot will look like the reverse bias characteristics shown in Fig.
4. We observe that negligible current flows through the Zener diode till the Zener voltage i.e. 6V is reached. Thereafter on increasing the applied voltage there is almost no variation in the voltage across the Zener diode.

OBSERVATION TABLE:

Value of series resistance $R =$ _____ ohm

| Sr. No. | Applied Voltage $V_{in}(\text{volt})$ | Resistive Voltage (V_R) (mV) | Current (mA) $I = V_R/R$ | Voltage across Diode $V_Z = V_{in} - (V_R * 10^{-3})$ |
|---------|--|--|--------------------------------|--|
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RESULT: The reverse biased characteristics of Zener diode has been plotted in the graph.

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The breakdown voltage of Zener diode is found as__volt The dynamic resistance of Zener diode is found as _____ ohm

Quiz with Answers:

Q1. What is a Zener diode?

Ans: A semiconductor device designed to work in reverse breakdown, allowing current to flow in the opposite direction.

Q2. What is the main function of a Zener diode?

Ans: To regulate voltage and maintain a constant voltage level in electronic circuits.

Q3. How does a Zener diode differ from a regular diode?

Ans: Zener diodes are specifically designed to operate in the breakdown region, while regular diodes do not.

Q4. What is the breakdown voltage of a Zener diode?

Ans: It is a specific voltage at which the diode starts conducting in reverse-bias mode.

Q5. What happens when a Zener diode is in breakdown?

Ans: It allows a controlled amount of current to flow, maintaining a constant voltage across the diode.

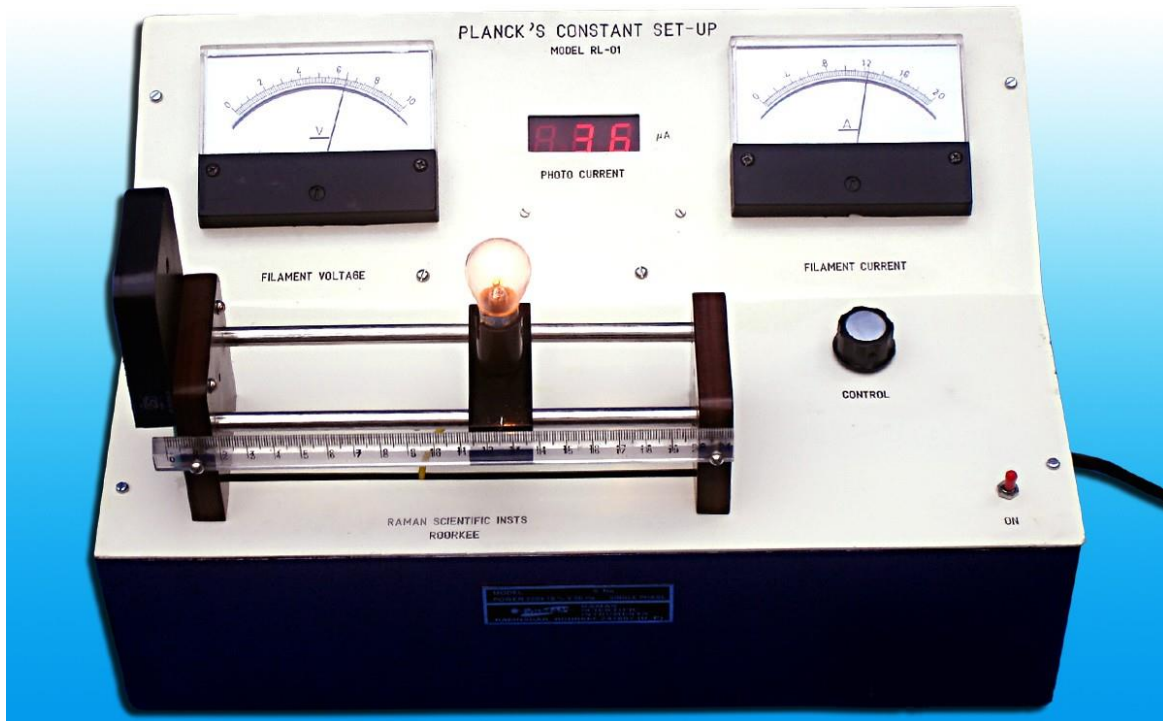
LAB EXPERIMENT 4

PLANCK'S CONSTANT CHARACTERISTICS

Aim: To determine Planks constant using photocell.

Apparatus used: The complete experimental arrangement as shown in figure (1) consists of filament bulb, its power supply (0-12 V d.c.) , A solar cell fitted on mini optical bench, one Ammeter (0- 2 A) and one voltmeter (0-10 V) to read filament current and voltage, one digital D.C. Microammeter (0-200 μ A.).

Planck's Constant Set-Up



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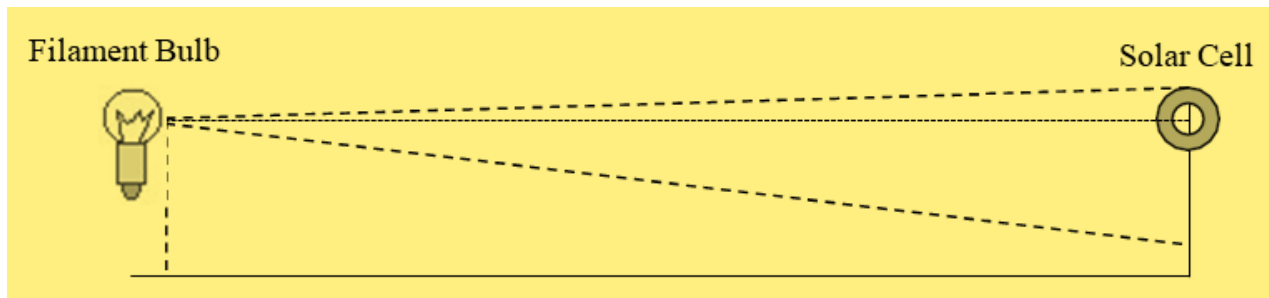


Figure 1(a)

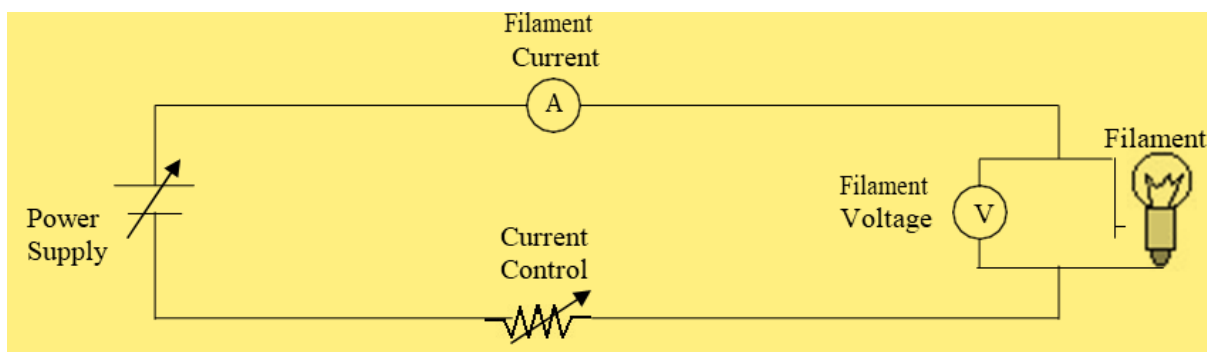


Figure 1(b)

METHOD:-

(a) To determine the value of R_g and R_t/R_g with the V-I characteristics of Bulb.

1. To find R_g the resistance of the filament bulb when it just starts glowing: Connect the set-up with the mains and switched it ON. Apply filament current by the power supply control knob marked CONTROL on the panel such that the filament just starts glowing. Note the corresponding filament current and voltage and record these readings in table-I as shown below. Take at least three readings to get the better value of R_g . Refer fig. 3

TABLE: - I For R_g , the resistance of the filament when it just starts glowing.

| S.No. | Filament Current I Amp. | Filament Voltage V Volt | R_g Ohm | Average R_g |
|-------|----------------------------|----------------------------|-----------|---------------|
| 1. | | | | |
| 2. | | | | |
| 3. | | | | |

1. To find R_t/R_g from the V-I characteristics of bulb: Further increase the filament current in steps

TABLE: - II For V-I Characteristics of the Filament bulb

| S.No. | Filament Current I Amp. | Filament Voltage V Volt | R_t Ohm | R_t / R_g |
|-------|----------------------------|----------------------------|-----------|-------------|
| 1. | | | | |
| 2. | | | | |
| 3. | | | | |
| 4. | | | | |

of 0.1 amp. and note the corresponding values of filament voltage for each value of filament current. Record all these readings in table-II as shown below.

2. Calculate R_t and R_t / R_g for each value of filament current and voltage.

(b) Observations of θ and to determine the value of Planck's constant 'h'

3. Adjust the filament bulb at some distance 'd' from the solar cell on mini optical bench.
4. Increase the filament current to such extent that the digital micro ammeter reads some photo-current say mini $2 \mu A$ to $3 \mu A$. Note this value of filament current and photocurrent and record it in table- II as shown below.
5. Increase the filament current in steps of 0.1 amp. As in previous case and note the corresponding photo-current for each value of filament current. Record these readings in table- III.
6. Note the value of R_t / R_g for each value of filament current from table-II and record these readings in table -III.
7. Note the corresponding temperatures for each value of R_t / R_g from graph no I or table-IV for R_t / R_g Vs Temp T °K for tungsten.
8. Calculate $\log \square$ and $1/T$ °K.
9. Plot graph between $\log \square$ Vs $1/T$ °K and find the slope of the curve.
10. Repeat the experiment at different value of 'd' between the bulb and solar cell.

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Table-III For θ

For distance between the filament bulb and solar cell $d =$ cm
Wavelength $\lambda = 6000 \text{ \AA}$

| S.No. | Filament Current I Amp. | Filament voltage V volt | Corresponding R_t/R_g from table or graph. | Photo-current μA | log θ | T $^\circ\text{K}$ from graph R_t/R_g Vs T $^\circ\text{K}$ | $\frac{1}{T^\circ K} \times 10^{-4}$ |
|-------|-------------------------|-------------------------|--|-----------------------------|--------------|---|--------------------------------------|
| 1. | | | | | | | |
| 2. | | | | | | | |
| 3. | | | | | | | |
| 4. | | | | | | | |

Activ
Go to

Calculations:

From equation (7)

$$h = 2.303 \frac{\lambda_0 K}{c} \times \frac{\log \theta}{T^\circ K} \times 10^{-4}$$

Where $\lambda_0 = 6000 \text{ \AA}$ mean wavelength of light

$k = 1.38 \times 10^{-16} \text{ erg/deg.}$ Boltzmann's constant

$c = 3 \times 10^{10} \text{ meter/sec.}$ velocity of light

$$\frac{\log \theta}{\frac{1}{T}} = \text{Slope of the curve.}$$

Results:

The experimentally observed values of Planck's constant 'h' = erg/sec.

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The standard value of Planck's constant

'h' =

The experimentally observed value of h is always within 10 to 15% of the standard value.

Table –IV

Relation between R_t/R_g and Temperature K for Tungsten Filament

| S. No. | Temperature (K) | R_t/R_g |
|--------|-----------------|-----------|
| 01. | 0273 | 0.25 |
| 02. | 0300 | 0.29 |
| 03. | 0400 | 0.43 |
| 04. | 0500 | 0.55 |
| 05. | 0600 | 0.71 |
| 06. | 0700 | 0.85 |
| 07. | 0800 | 0.99 |
| 08. | 0900 | 1.15 |
| 09. | 1000 | 1.29 |
| 10. | 1100 | 1.45 |
| 11. | 1200 | 1.61 |
| 12. | 1300 | 1.79 |
| 13. | 1400 | 1.95 |
| 14. | 1500 | 2.11 |
| 15. | 1600 | 2.30 |
| 16. | 1700 | 2.46 |
| 17. | 1800 | 2.65 |
| 18. | 1900 | 2.85 |
| 19. | 2000 | 3.05 |
| 20. | 2100 | 3.26 |
| 21. | 2200 | 3.46 |
| 22. | 2300 | 3.66 |
| 23. | 2400 | 3.85 |

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Quiz with Answers:

Q1. What is Planck's constant?

Ans: Planck's constant (h) is a fundamental constant that relates the energy of a photon to its frequency.

Q2. How is Planck's constant measured using a photocell?

Ans: By measuring the relationship between the light's frequency and the kinetic energy of emitted photoelectrons.

Q3. What is the significance of Planck's constant in the context of a photocell?

Ans: It helps determine the energy of photons absorbed by the photocell, influencing the emission of electrons.

Q4. How does Planck's constant enable the understanding of the photoelectric effect in photocells? Ans: It explains the discrete nature of energy levels in quantum systems and validates Einstein's explanation of the photoelectric effect.

Q5. What are the units of Planck's constant?

Ans: The units of Planck's constant are energy times time, typically joule-seconds ($J \cdot s$) or electron volt-seconds ($eV \cdot s$).

LAB EXPERIMENT 5

e/m CHARACTERISTICS

Aim: To measure e/m of electron using helical method.

AIM: - To determine the value of e/m for an electron by Thomson's method using bar magnets.

APPARATUS USED :- A cathode ray tube fitted on a wooden stand provided with two arms perpendicular to the axis of the tube and having scales with zero at the point where the central line of the arms cuts the axis of the tube; a power supply unit capable of giving the accelerating D.c. voltage for the cathode ray tube and the deflecting D.C. voltage for the electric field through a reversing key with suitable voltmeters, two bar magnets, a compass box, a compass needle, etc.

THEORY :- The value of e/m can be determined by the method originally used by Prof. J.J. Thomson

The apparatus consists of a cathode ray tube which has three essential parts.

- (i) The electron gun. This part consist of the cathode K and the anode A. It produces, accelerated and focuses the electrons into a fine beam so as to produce a small bright spot on the fluorescent screen S.
- (ii) The screen. The screen S is coated with some fluorescent material like zinc sulphide etc. so that a greenish blue spot of light is observed where the electron beam impinges upon the screen. A transparent mm graph is attached to the screen to note the exact position of the fluorescent spot.

Measurement of e/m and Electronic Charge

- (iii) The electric and magnetic deflecting system. Two plates P and Q are fitted in the tube symmetrically on either side of the electron beam so that an electric field perpendicular to the plane of the paper can be applied between them.

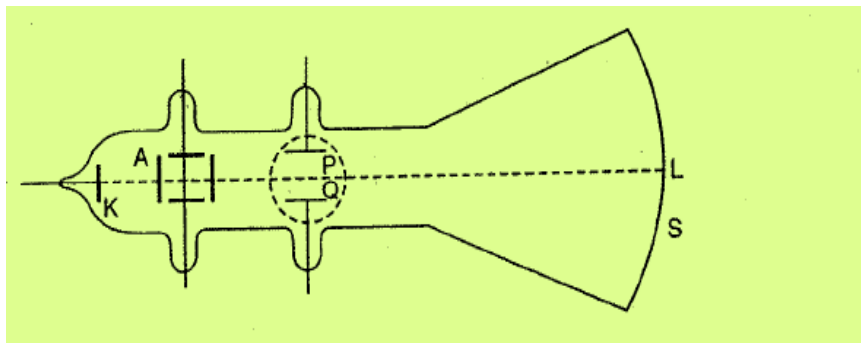


Figure 1.

A magnetic field can also be applied at the same place in a direction perpendicular to the direction of the electric field i.e. in the plane of the paper. Thus the deflection of the cathode rays due to the electric as well as the magnetic, field takes place in a direction perpendicular to the plane of the paper.

To apply the magnetic field the cathode ray tube is fitted on a wooden stand provided with two arms, one on either side perpendicular to the direction of the electron beam. A scale is marked on each arm which gives the distance from the axis of the cathode ray tube. When two bar magnets are placed with their lengths parallel to the arms with their opposite poles towards the cathode ray tube, these produce a uniform magnetic field exactly at the same place where an electric field produced when a potential difference is applied between the plates P and Q.

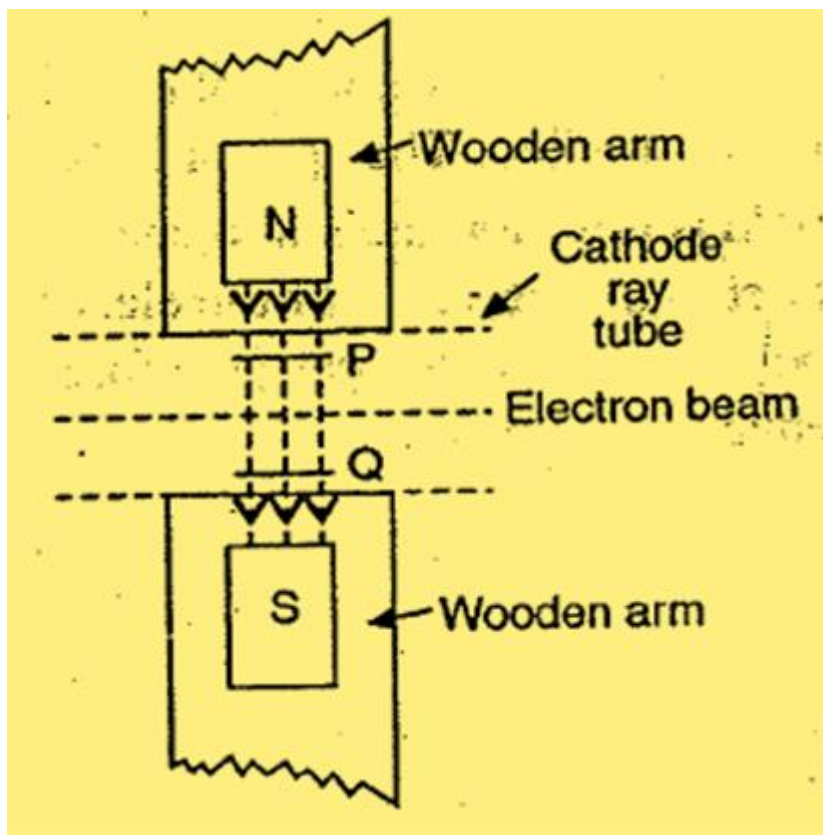


Figure 2

Theory. Let E be intensity of the electric field applied between the plates P and Q in a direction perpendicular to the plane of the paper then the force acting on the electron of charge $e = Ee$

This force acts at right angles to the direction of motion of the electron. The electron, therefore, moves along a circular path within the electric field and on leaving the field flies off tangentially to the path meeting the screen at M_1 or M_2 depending up to the direction of the electric field as shown in Fig. 3. (a) and (b). When a magnetic field B is applied in the plane of the paper perpendicular to the direction of the beam as show in in figure 4. (a) then according to Fleming's left hand rule the beam is deflected upward cut of the paper in a direction perpendicular to both, the direction of motion of the electron and that of the field.

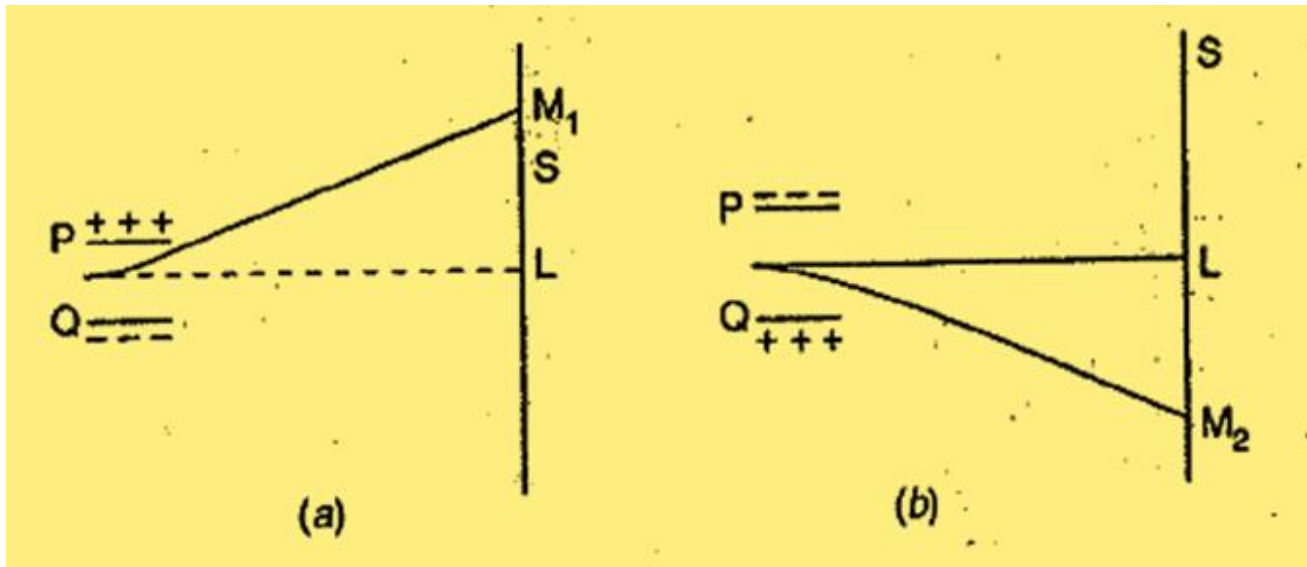


Figure 3

When the magnetic field is applied as shown in Figure 4. (b) the electron beam is deflected downward into the paper. If v is the velocity of the electrons in the beam, then magnitude of the force acting on each electron = $B e.v$. As this force also acts at right angles to the direction of motion of the electron, the electron moves along a circular path in the magnetic field and on leaving the field flies off tangentially meeting the screen at M_1 or M_2 as explained above.

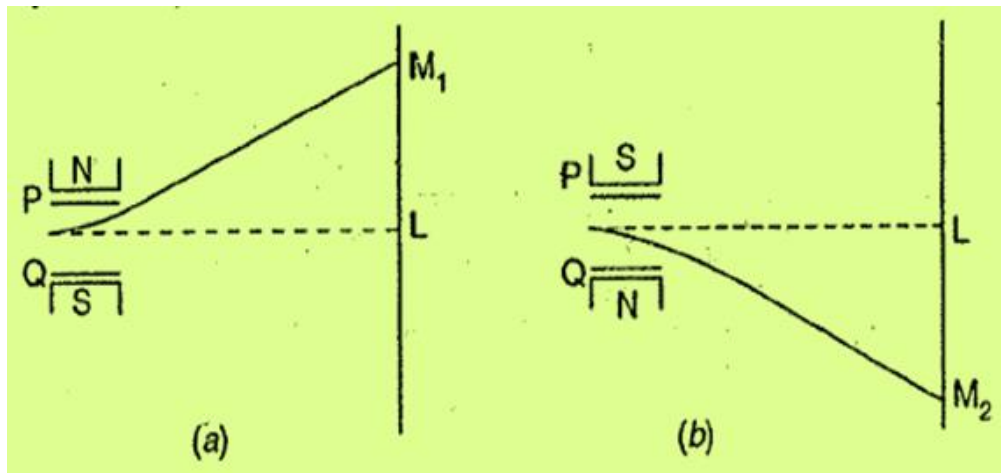


Figure - 4

If r is the radius of the circular path along which the electron moves in the magnetic field, then

$$mv^2$$

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$$B e v = \frac{m v^2}{r}$$

r

Or

To find the velocity of electron v : To find the value of V , one of the fields say the magnetic field is first applied. The spot of light moves from its initial position to the position say M_1 . The electric field is now applied simultaneously so as to produce deflection of the electron beam in the opposite direction. The value of the electric field is so adjusted that the spot of light comes back to its initial position. In such a case the forces acting on the electron due to the electric and magnetic fields are equal and opposite.

$$e E = B e v$$

$$\text{Or } v = \frac{E}{B}$$

Substituting in (i), we have

$$\frac{e E}{m r B^2} = \frac{E}{B} \quad \dots\dots\dots(ii)$$

To find the radius r of circular path. To find the value of r , the radius of the circular path in the magnetic field, note the position of the luminous spot on the screen when no field is applied and again when a field B is applied. Let the deflection of the spot be $y = LM_2$ as shown. The circular path of the beam OR in the magnetic field is as shown in Figure 2. The beam leaves the magnetic field at R tangentially to the path and meets the screen at M_2 so that $M_2 R$ produced meets OX in T . Draw OC and RC perpendiculars to OL and RM_2 respectively meeting at C , then C is the centre of the circular arc OR and $OC = CR$ radius of the circle = r

$$\text{Now } \angle OCR = \angle LTM_2 = \theta$$

$$\tan \theta = \frac{LM_2}{LT} = \frac{OX}{OC}$$

$$r = OC = \frac{LT}{\tan \theta}$$

Now OX is very nearly equal to the length of the region in which the magnetic field is applied. This is also equal to the length of the region in which the electric field is applied. I.e. the length of the plates P and Q . Let it be l (This is generally given by the makers).

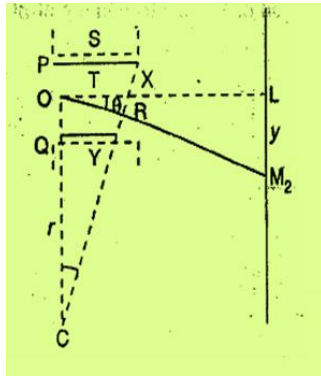


Figure 5

Measurement of e/m and Electronic Charge

LT is the distance of the centre of the screen from the centre of the region of the magnetic field (or electric field). Let is be = L

$$\square \quad r = \frac{Ll}{y} \quad \text{---}$$

Substituting in (ii), we have

$$\frac{e}{m} = \frac{yE}{LB^2} \quad \text{---} \quad \dots$$

(iii)

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The electric field $E = \frac{V}{d}$ where V is the potential difference applied between the plates P and Q and d the distance between the plates (d is also given by the markers). Substituting in (iii), we have

$$\frac{e}{m} = \frac{yV}{LdB^2}$$

When V is in volts, B in Tesla and y , L , I , and d in meters e/m is in Coulomb/kg.

PROCEDURE :

- (1) Draw the North South line using a compass needle. Also draw the East-West line. Place the cathode ray tube fitted in the wooden frame with its axis along the North South line so that the arms of the frame lie along the East West line.
- (2) Connect the cathode ray tube to the power supply unit. Switch on the current and wait till a luminous bright spot appears on the screen. Adjust the brightness and focus controls so as to get a sharp bright point spot in the middle of the screen. Note the initial position of the spot on the scale fitted on the screen.
- (3) Now apply a suitable deflecting voltage so that the luminous spot is deflected by about 0.5 to 1.0 cm. Note the deflecting voltage V and the position of the spot. Measure the distance through which the spot has moved and let it be y .
- (4) Place the bar magnets symmetrically on either side of the cathode ray tube along the arms of the wooden stand on which the tube is fitted such that their opposite poles face each other and their common axis is exactly at right angles to the axis of the cathode ray tube. Adjust the polarity as well as the distance of the magnets so that the luminous spot comes back to its initial position. When the adjustment is perfect note the distance of the poles of the magnets on the side nearer to the cathode ray tube. Let the distances be r_1 and r_2 .
- (5) Remove the bar magnet, switch off the electric field applied to the deflecting plates and again note the initial position of the luminous spot. Reverse the polarity of the potential difference applied to the electric deflecting plates with the help of the reversing switch fitted in the power supply unit thereby reversing the electric field. Again note the final position of the luminous spot and calculate y .
- (6) Again place the bar magnets on the arms of the wooden stand as in the previous step and adjust their polarity as well as the distance so comes back to its initial position. When the adjustment is perfect again note the distances of the poles of the magnets on the side nearer to the cathode ray tube. Let the distances be r'_1 and r'_2 . Switch off the power supply.
- (7) To find the value of the magnetic field B , carefully remove the magnets and the cathode ray tube from the wooden stand. Place the compass box (of a deflection magnetometer or tangent galvanometer) such that its centre lies exactly on the point where the common axis of the bar magnets and the axis of the cathode ray tube intersect. Rotate the compass box about its vertical axis so that the pointer lies along the $\square\square\square$ line.
- (8) Place the magnets exactly in the same positions as in step 4 at distances r_1 and r_2 . This produces a deflection in the magnetometer compass box and the two ends of the pointer give the deflection.

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Let the readings be θ_1 and θ_2 .

- (9) Now place the magnets exactly, in the same positions as in step 5 at distances r'_1 and r'_2 and again note the deflections θ'_1 and θ'_2 from the two ends of the pointer of the compass box. The mean of these four deflection $\theta_1, \theta_2, \theta'_1, \theta'_2$ gives the mean deflection θ . If B_H is the horizontal component of earth's magnetic field, then $B = B_H \tan \theta$
- (10) Take two more sets of observations by changing the value of V and hence that of the electric field.

Observations. (Data provided on the cathode ray tube by the manufactures).

Length of the deflecting plate P or Q = 1 = m
 Distance of the screen from the center of the plates L = m
 Distance between the deflecting plate P and Q d = m

| Sl. No. | Applied Voltage V | DIRECT FIELD | | | | | | | | REVERSED FIELD | | | | | | | |
|---------|-------------------|------------------|-------|---------------------|----------------------------|-------|------|-------|---------|------------------|----------------------|---------|----------------------------|------|--------|--|--|
| | | Position of Spot | | | Magnetic pole and Distance | | | | | Position of Spot | | | Magnetic Pole and Distance | | | | |
| | | Initial | final | Deflection y in met | Pole | r_1 | Pole | r_1 | Initial | Final | Deflection y in met. | Pole | r'_1 | Pole | r'_2 | | |
| 1 | $V_1 =$ | | | | | | | | | | | $Y_1 =$ | | | | | |
| 2 | $V_2 =$ | | | | | | | | | | | $Y_2 =$ | | | | | |
| 3 | $V_3 =$ | | | | | | | | | | | $Y_3 =$ | | | | | |

Horizontal component of earth's field $B_H = \frac{Wb}{sq.m}$ (Tesla)

For determination of B

| Sl. No. | Applied Voltage V | Reading of two ends of pointer when mag. Poles are at r_1 and r_2 | | Reading of two ends of pointer when mag. Poles are at r'_1 and r'_2 | | Mean θ | B = $B_H \tan \theta$ |
|---------|-------------------|---|--|---|--|---------------|-----------------------|
| | | | | | | | |
| 1 | V_1 | | | | | | B_1 |
| 2 | V_2 | | | | | | B_2 |
| 3 | V_3 | | | | | | B_3 |

CALCULATIONS:

$$(i) \quad e/m = \frac{y_1 V_1}{L l d B_1^2} = C \text{ kg}^{-1}$$

$$(ii) \quad e/m = \frac{y_2 V_2}{L l d B_2^2} = C \text{ kg}^{-1}$$

$$(iii) \quad e/m = \frac{y_3 V_3}{L l d B_3^2} = C \text{ kg}^{-1}$$

Measurement of e/m and Electronic charge

$$(iii) \quad e/m = \frac{y_3 V_3}{L l d B_3^2} = C \text{ kg}^{-1}$$

$$\text{Mean } e/m = C \text{ kg}^{-1}$$

PRECAUTIONS:

- (1) The cathode ray tube must be set in the north south direction.
- (2) The luminous spot on the screen should be sharp, bright and in the middle.
- (3) The deflecting voltage must produce a deflection of the order of 0.5 to 1.0 cm.
- (4) The axis of the bar magnets and the axis of the cathode ray tube must be exactly at right angles and in a horizontal plane.
- (5) The deflecting voltage must be reversed to produce the deflection of the spot of light in the opposite direction and the magnetic field must also be reversed to bring it back to initial position.
- (6) The cathode ray tube must be handled carefully.

Quiz with answers:

Q1. What is the helical method?

Ans: A technique to measure the charge-to-mass ratio (e/m) of electrons by observing the motion of electrons in a magnetic field.

Q2. How does the helical method work?

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Ans: Electrons are accelerated in a cathode ray tube and then pass through a magnetic field, resulting in a helical path.

Q3. What is the relationship between e/m and the helical path radius?

Ans: The e/m ratio is proportional to the ratio of the electron's charge (e) to the radius (r) of its helical path.

Q4. What are the required measurements for the helical method?

Ans: The magnetic field strength, accelerating voltage, and the radius of the helical path.

Q5. What is the significance of measuring e/m using the helical method?

Ans: It provided early experimental evidence for the existence of charged subatomic particles like electrons

LAB EXPERIMENT 6

FLASHING AND QUENCHING CHARACTERISTICS

Aim: To find capacitance of condenser using flashing and quenching experiment.

APPARATUS USED : A capacitor of unknown capacitance, capacitors of known capacitance (say 0.1, 0.2, 0.5 μF), a neon flashing lamp, a resistance of about 1 meg ohm, regulated D.C. power supply capable of giving upto 150 volts and 5 keys.

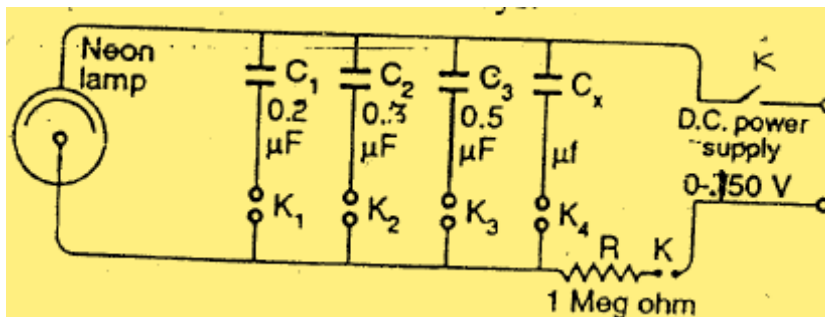


Figure (1)

Note : Neon lamps intended to be connected direct to H.T. have a ballast resistor of about 2000 ohm sealed into the cap to limit the current. This must be removed for this experiment. Alternatively small neon flash bulbs without any resistor sealed in are available from radio dealers.

THEORY :

Flashing and quenching of a neon bulb. A neon bulb is placed in parallel with a capacitor and connected to D.C. supply which can be continuously increased from 0 to 150 volt through a high resistance of about 1 meg. Ohm. The voltage is slowly increased to a value say V_1 when the lamp flashes and begins to glow. As soon as the neon lamp flashes, it becomes conducting and the capacitor begins to discharge through it. It continues to do so until the extinction (or quenching) potential V_2 is reached when the neon lamp ceases to glow and stops conducting. The capacitor then again begins to charge till the flashing potential V_1 is reached when again the lamp flashes and begins to glow. The process is repeated, During the time the capacitor is charging the neon lamp does not glow. In other words, the total time t between two consecutive flashes is equal to the time taken by the voltage first to fall from the flashing potential V_1 to quenching potential V_2 (discharge) and then to rise from V_2 to V_1 (charging). This flashing and quenching time can be determined by noting the time taken by the lamp to produce say 20 consecutive flashes and quenches.

If t_1 is the time taken by the capacitor voltage to fall from V_1 to V_2 and t_2 is the time taken by the voltage to rise from V_2 to V_1 , then

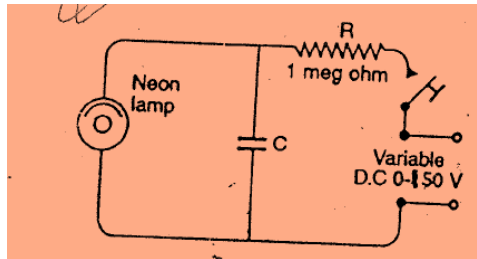
$$V_2 = V_1 e^{-t_1/CR}$$

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Or

t_1

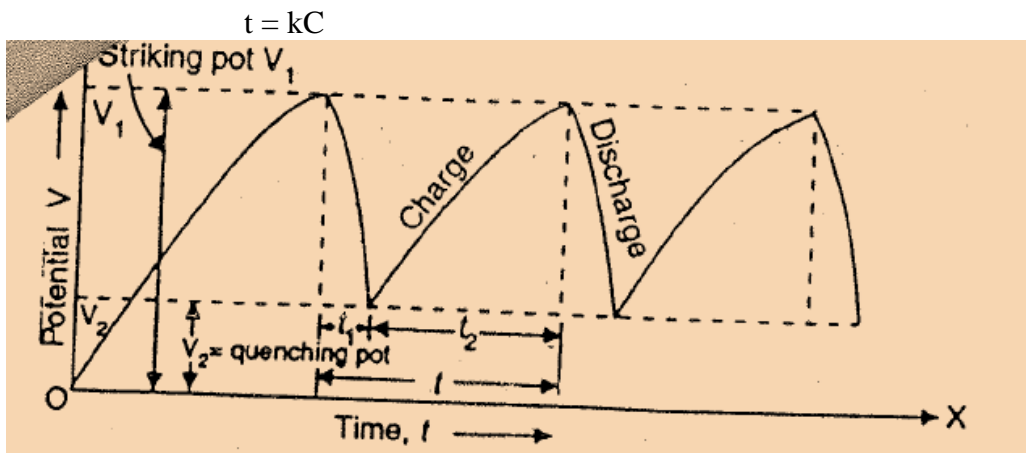
$$t_1 = CR \log_e \frac{V_2}{V_1}$$



□

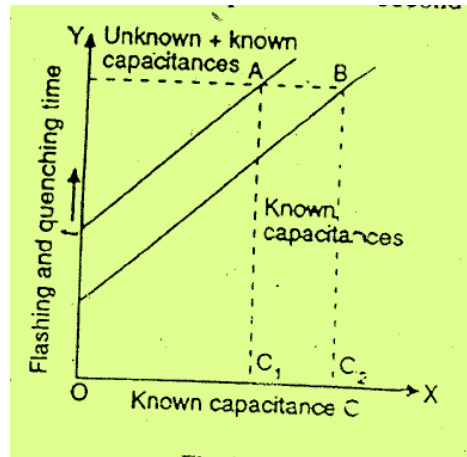
As R , V_2 and V_1 have constant fixed values, the function within brackets is a constant., Let it be = k

□



Determination of capacitance: To find the value of an unknown capacitance a second graph is plotted by noting the flashing and quenching time for the sum of the unknown capacitance and each of the unknown capacitances. The two graphs are parallel straight lines as shown. To calculate the value of the unknown capacitance draw a straight line AB parallel to X -axis corresponding to any value of flashing and quenching time cutting the two graphs at A and B respectively. If C_1 and C_2 are the values of the known capacitances corresponding to the points A and B respectively C_x the unknown capacitance and C_s the stray capacitance of the circuit then.

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Total capacitance corresponding to point A

$$= C_s + C_1 + C_x$$

And total capacitance corresponding to point B

$$= C_x + C_2$$

Since the flashing and quenching time for both is the same $K(C_s +$

$$C_1 + C_x) = k (C_x + C_2)$$

Or $C_x = C_2 - C_1$

PROCEDURE :

1. Draw a diagram showing the scheme of connections as in Figure (1) and make connections accordingly.

2. Connect the capacitance C_1 in the circuit by putting in the key K_1 . Put in the key K and increase the power supply voltage slowly till the neon lamp just begins to flash. As it is connected in parallel.

Remove the key K to disconnect the power supply. Put in the key K_4 so that the capacitors C_1 and C_x (of unknown capacitance) are connected in parallel and total capacitance is equal to their sum $C_1 + C_x$. Again put in the key K (see that the power supply voltage remains constant). Note the time of 20 flashes. Remove the keys K , K_4 and K_1 .

3. Repeat the experiment with capacitors C_2 alone and $(C_2 + C_x)$; C_3 alone and $(C_3 + C_x)$. Now put in the keys K_1 and K_2 so that the total capacitance $(C_1 + C_2)$ is in the circuit. Repeat the experiment with $(C_1 + C_2)$ and then with $[(C_1 + C_2) + C_x]$. Similarly repeat the experiment with $(C_1 + C_3)$ and $[(C_1 + C_3) + C_x]$, $(C_1 + C_2 + C_3)$ and $[(C_1 + C_2 + C_3) + C_x]$

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OBSERVATION :

| 1 Sl.No. | 2 Known Capacitance | 3 Time for 20 Flashes without C_x | 4 Flashing and Quenching time t | 5 Time for 20 Flashes with C_x | 6 Flashing and Quenching time t |
|-------------|--|--|------------------------------------|-------------------------------------|------------------------------------|
| | $C_1 =$ $C_2 =$ $C_3 =$ $C_1 + C_2 =$ $C_1 + C_3 =$ $C_1 + C_2 + C_3 =$ | | | | |

1. Plot two graphs (i) between values of capacitance in column 2 taken along X-axis and flashing and quenching time t in column 4 (without unknown capacitance) and (ii) between values of capacitance in column 2 and quenching and flashing time t in column 6 (with unknown capacitance) taken along the Y-axis. For three different values of flashing and quenching time draw three straight lines. Parallel to X-axis cutting the two graphs at A and B, C and D, and E and F respectively.

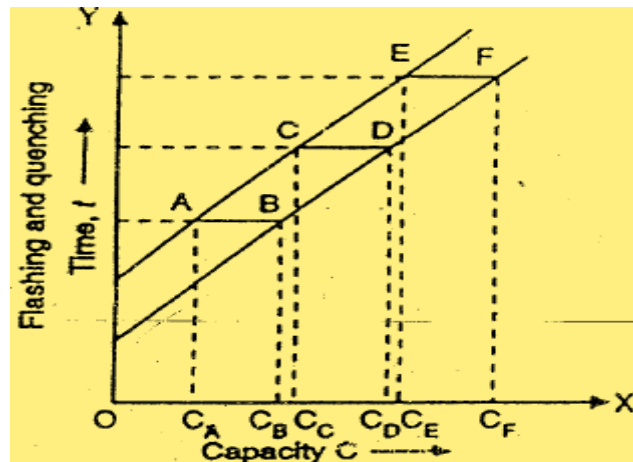


Figure (2)

The unknown capacitance $C_x = AB = C_B - C_A$

$$= CD = C_D - C_C$$

$$= EF = C_F - C_E$$

Mean $C_x = \mu F$

PRECAUTIONS

1. The voltage from the D.C. power supply should remain constant throughout the experiment.
2. The resistor sealed in the cap of the neon lamp should be removed before using it for the experiment, otherwise a bulb without resistor should be used.

Quiz with Answers:

Q1. What is the flashing and quenching experiment?

Ans: It is an experiment used to find the capacitance of a capacitor by charging and discharging it repeatedly through a neon lamp.

Q2. How does the flashing and quenching experiment work?

Ans: The capacitor is charged, and when it reaches a certain voltage, it discharges through the neon lamp, causing the lamp to flash and quench repeatedly.

Q3. What role does the neon lamp play in the experiment?

Ans: The neon lamp acts as an indicator, flashing when the capacitor discharges and quenching when the capacitor charges again.

Q4. How can the flashing and quenching rates be used to determine capacitance?

Ans: The flashing and quenching rates are related to the time constants of the RC circuit, which depend on the capacitor's capacitance.

Q5. What other components are required for the experiment?

Ans: Apart from the capacitor and the neon lamp, a resistor and a DC power supply are needed.

Q6. How is capacitance calculated from the experiment?

Ans: Using the flashing and quenching rates, the capacitance can be determined from the time constants and the known value of the resistor.

LAB EXPERIMENT 7

CALENDAR AND GRIFFITH CHARACTERISTICS

AIM: To determine the temperature coefficient of resistance of platinum by means of Callendar and Griffith's pattern bridge.

APPARATUS : Platinum resistance thermometer, Callendar and Griffith's pattern bridge, a Leclanche cell, a galvanometer, beaker (600 c.c. capacity), electric stove, a decimal-ohm dial box, a mercury thermometer and connection wires.

THEORY : Callendar and Griffith's pattern bridge. For work at the undergraduate level such a piece of apparatus is manufactured. By Instrument & Chemicals Ltd. Ambala. The circuit diagram of the bridge is given in figure 1.

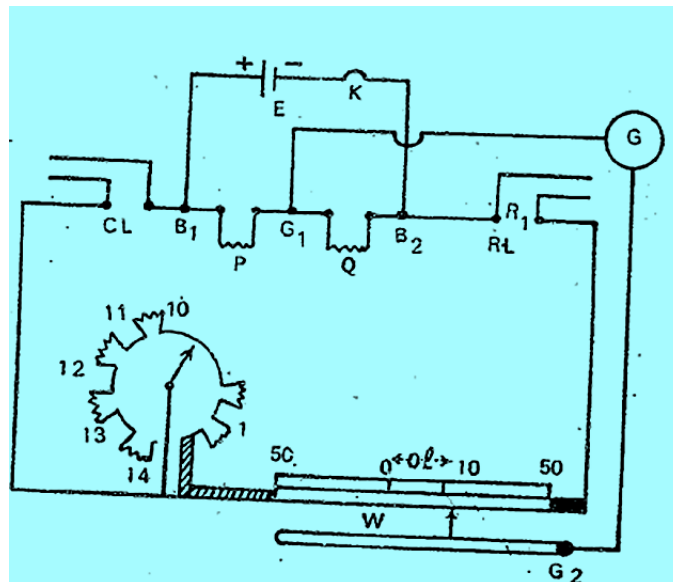


Figure 1

The ratio coils P and Q have equal resistance, so that the ratio is 1:1. CL and RL are the gaps for connecting the compensating and the resistance leads of the thermometer. R is a dial pattern resistance, each coil having a resistance of one ohm. In series with this is a stretched wire W, also of resistance one ohm. The scale for the reading of the length of the wire is graduated with zero in the middle and 50 division marks at either end. Thus the value $\frac{1}{100}$, the resistance per unit length of the bridge wire is 1/100 ohms per unit length.

Suppose with connections as shown in the figure above, the null point is at a length l measured from middle points of the wire. Let R_1 be the required resistance of the platinum wire, say at room temperature t_1 and R the resistance introduced in the dial box.

Then

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$$\frac{P}{Q} = 1 + \frac{y + R + 50l}{y + R_1 + 50l}$$

Where ρ is the resistance per unit length of the bridge wire and y is the resistance of the leads. From the above equation we have

$$y + R_1 + 50l = y + R + 50l$$

$$R_1 = R + 2l\rho \quad (a)$$

Where ρ is known, R_1 can be calculated from the observed values of R .

Similarly, if R_2 be the resistance of the platinum wire of the thermometer at a temperature t_2 , then $R_2 = R + 2l\rho$

$$+ 2l^1\rho \quad (b)$$

Knowing R_1 and R_2 , ρ can be calculated from the relation.

$$\rho = \frac{R_2 - R_1}{R_2 t_2 - R_1 t_1}$$

PROCEDURE :

(I) Determination of electrical Zero of the bridge.

Connect the Laclanche cell through a key K across the terminals B_1 and B_2 and the galvanometer across G_1 , G_2 . Put the dial box R at zero. Close the gaps CL and RL by thick copper strips.

Insert the plug of the key K of the cell circuit and determine the position of the null point by pressing the jockey in the neighborhood of the middle of the wire. Note this position. This gives the position of the electrical zero of the bridge wire. For an accurate bridge it should be at zero of the scale – this zero of the scale being at the middle point of the wire and 50 division marks on either side being at the ends of the wire. The difference between the zero of the scale and the electrical zero may be termed as the zero error of the bridge. Due correction must be applied in subsequent observations.

(II) Determination of ρ , the resistance per unit length of the bridge wire.

Remove the copper strip from the gap CL . Connect a decimal ohm resistance box across CL . The dial box R stands at zero. Insert r of, say, 0.3 ohm in the gap CL , by rotating the dial of the decimal ohm box and locate the null point on the bridge wire. Measure the length from the zero of the scale. Correct this length for the zero error of the bridge by subtracting from this length the zero error of the bridge with its appropriate sign. Let this corrected length be L_1 units.

Then evidently, since R

$$= 0, R = 0.3 = 2L_1\rho$$

$$\text{Or } \rho = \frac{r}{2L_1} = \frac{0.3}{2L_1} \text{ ohm per unit length}$$

Repeat the observations by introducing resistance of value 0.4, 0.5, 0.6 ohm from the decimal – ohm dial

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box across CL. Calculate \square from each set and find its mean value.

(III) Determination of R_1 and R_2 .

Disconnect the decimal ohm dial box from the gap CL and the copper strip from the gap RL. Connect the compensation leads of the platinum resistance thermometer across CL and its resistance leads across RL.

Introduction a resistance of 2 ohms in the dial box R and locate the balance point on the bridge wire. (Usually the resistance of the thermometer lies between 2 and 3 ohms). Correct this length for the zero error of the bridge wire and knowing the values of R, L and \square , calculate R_1 from equation a.

By changing the value of R to 3 ohms, redetermine the value of R_1 . It may be noticed here that with R equal to 2 ohms, the balance point was on the positive side of the scale (i.e., on to the right of zero of the scale) whereas with R equal to three ohms, the balance point is obtained on the left hand side of the zero, i.e. on the negative side of the scale. In the latter case R_1 will be calculated from the relation

$$R_1 = R - 2l\square$$

Find the mean value of R_1 . Record the room temperature t_1 °C. Thus the resistance R_1 of the platinum coil is known at a temperature t_1 °C.

Next place the platinum resistance thermometer in a large beaker or container with water. Allow the water to boil by heating the container over an electric stove. Also put a mercury thermometer to record the temperature t_2 of boiling water.

When water in the container has been boiling for about ten minutes or so, introduce a resistance of 3 ohms in the dial, box R and locate the new balance point on the bridge wire, which will now be again on the positive side of scale. Repeat this observation after every two minutes, and when the reading does not change it can be assumed that the platinum coil has attained the temperature t_2 °C of boiling water, as recorded by the mercury thermometer. Note this length for the balance point and correct it for zero error. From a knowledge of the resistance R (3 ohms), the corrected length l^1 for balance and Calculate R_2 from the equation (b)

Put R at 4 ohms and redetermine the value of R_2 . Compute the mean value of R_2 from those two determinations.

SOURCE OF ERROR AND PRECAUTIONS

- 1) The decimal ohm box should be preferably of dial pattern and should be connected by short, thick wires.
- 2) The cell circuit should be made on by the plug key only when observations are being taken; for the rest of the time, the plug should be out of the key. This would prevent unnecessary heating of the resistance coils due to the passage of current.
- 3) The galvanometer should be shunted by a low resistance wire to avoid excessive deflections in it when the bridge is out of balance the shunt should be removed when the exact position of the null point is being determined.

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4) The jockey should be pressed gently over the bridge wire; and the contact between the jockey and the bridge wire should not be made while the jockey is being moved along.

5) To ascertain that the platinum coil has attained the temperature of boiling water, the position of the balance point must be found out every minute or every two minutes; if there is no shift in the balance point it can be assumed that the platinum coil has attained the temperature of boiling water. If there is any shift, it should be of a negligible order, a mm. or so. The mean of such close lengths should be taken to obtain the length for balance of the bridge.

CALCULATION FOR R_1 and R_2

Calculation for R_1 and R_2

$$\begin{aligned} \text{From Set 1, } R_1 &= R + 2(l \pm Z) \\ &= \\ &= \text{ ohm} \end{aligned}$$

$$\begin{aligned} \text{From set 2, } R_1 &= R - 2(l \pm Z) \\ &= \\ &= \text{ ohm} \end{aligned}$$

Mean value of $R_1 =$ ohm

Similarly,

$$\begin{aligned} \text{Mean value of } R_2 &= \\ &= \text{ ohm} \end{aligned}$$

Hence

$$\begin{aligned} \alpha &= \frac{R_2 - R_1}{R_2 t_2 - R_1 t_1} \\ &= \\ &= \text{ per } ^\circ\text{C} \end{aligned}$$

RESULT

The temperature coefficient of resistance for platinum =

per $^\circ\text{C}$. Standard value of $\alpha =$ per $^\circ\text{C}$

Percentage error =

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Quiz with Answers:

Q1. What is the Callendar and Griffith's pattern bridge?

Ans: It is a Wheatstone bridge used to measure the temperature coefficient of resistance of a material.

Q2. How does the bridge measure the temperature coefficient of resistance?

Ans: By comparing the change in resistance of the platinum element with temperature variations.

Q3. What is the temperature coefficient of resistance (TCR)?

Ans: The TCR is the rate of change of resistance per degree Celsius of temperature change.

Q4. How is the TCR of platinum determined using the bridge?

Ans: By balancing the bridge and measuring the resistance change of the platinum element at different temperatures.

Q5. What is the significance of using platinum in this experiment?

Ans: Platinum has a relatively stable TCR over a wide temperature range, making it suitable for accurate measurements.

Q6. What are the required components for the experiment?

Ans: A Wheatstone bridge setup, a calibrated resistance, a platinum element, and a temperature-controlled environment.

LAB EXPERIMENT 8

CAREY FOSTER CHARACTERISTICS

Aim: To find out low resistance by Carey Foster bridge

Aim of the Experiment: To determine (a) the resistance per unit length of the wire of a Carey- Foster bridge and then to (b) find the resistivity of the material of a given wire.

Apparatus Required: Carey- Foster Bridge, Laclanche cell, Weston galvanometer, standard one – ohm coil, 2 low resistance boxes, plug key, thick copper strip, connecting wires.

Theory of Carey-Foster bridge: The Carey- Foster bridge is a modified form of the meter bridge (shown in Fig. 1). The Carey- Foster bridge is especially suited for the comparison of two nearly equal resistances whose difference is less than the resistance of the bridge wire.

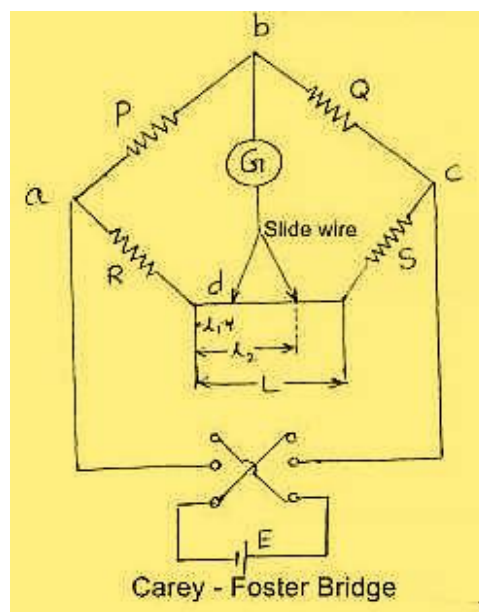


Fig. 2: Circuit diagram of Carey Foster’s bridge

As shown in the Fig. 2, two nearly equal resistances P and Q are connected in the inner gaps of the bridge, and two low resistances X and Y which are to be compared are connected in the outer gaps of the bridge. If l_1 be the position of the null point, we have from the Wheatstone bridge principle

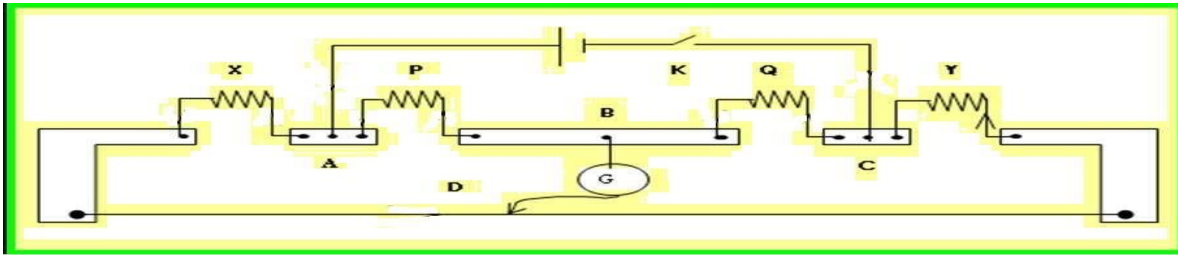


Fig. 1: Schematic representation of Carey-Foster bridge experimental set-up

$$P = \frac{X+a(s_1+\alpha)}{F+a(100-s_1+p)} \quad (1)$$

$$Q = \frac{Y+a(s_2+\alpha)}{F+a(100-s_2+p)}$$

or

$$\frac{P}{Q} + 1 = \frac{X+y+a(100+\alpha+p)}{F+a(100-s_1+p)} \quad (2)$$

$$\frac{P}{Q} + 1 = \frac{X+y+a(100+\alpha+p)}{F+a(100-s_2+p)}$$

where, a is the resistance per unit length of the bridge wire, α and Q are the end corrections (in cm) at the left and right ends of the bridge wire respectively.

If the resistances X and Y are interchanged and l_2 be the position of the new null point, we have

$$P = \frac{F+a(s_2+\alpha)}{X+a(100-s_2+p)} \quad (3)$$

$$Q = \frac{Y+a(s_1+\alpha)}{X+a(100-s_2+p)}$$

$$\frac{P}{Q} + 1 = \frac{X+y+a(100+\alpha+p)}{X+a(100-s_2+p)} \quad (4)$$

$$\frac{P}{Q} + 1 = \frac{X+y+a(100+\alpha+p)}{X+a(100-s_2+p)}$$

Comparing equations (2) and (4) we see that the fraction on the right hand side are equal and since their numerators are identical their denominators must also be equal. Hence equating the denominators of the right hand sides of equation (2) and (4), we have

$$Y + a(100 - l_1 + p) = X + a(100 - l_2 + p) \quad (5)$$

$$X - Y = a(l_2 - l_1) \tag{6}$$

[In the above procedure the end-corrections are eliminated from the working equations]

Part A: To find a, the resistance per unit length of the bridge wire:

Equation (6) can be used to find a, the resistance per unit length of the bridge wire, if the values of X and Y are known. Let X = a thick copper strip be connected in the outer left gap and Y = the standard 1 Ω be connected in the outer right gap of the bridge, and let l₁ and l₂ respectively be the null points on the bridge wire, before and after interchanging X and Y in the outer gaps. Then we have from Eq. (6) by putting X = 0 and Y = 1 Ω,

$$1 = a(l_1 - l_2) \tag{7}$$

Part B: To find the resistivity ρ of the material of a given wire

Now, replace the copper strip with the wire of unknown resistance = X connected initially in the outer left gap and the standard 1 Ω resistance = Y in the outer right gap of the bridge. Then if l₁^u and l₂^u respectively be the readings on the scale of the positions of the null point before and after interchanging X and Y, we have, from equation (6):

$$X - Y = a(l_2^u - l_1^u) \tag{8}$$

$$X = a(l_1^u - l_2^u) + Y \tag{9}$$

This equation can be used to calculate X, if a is determined from equation (7).

Then if L is the length and ‘a’ the cross-sectional area of the wire, the resistivity ρ is related to X by

$$X = \rho \frac{L}{a} \tag{10}$$

or

$$\rho = \frac{Xa}{L} \text{ Ohm-cm.} \tag{11}$$

Procedure for Part A: To find a, the resistance per unit length of the bridge wire:

Connect a thick copper strip (X = 0) in the outer left gap and a standard 1-ohm resistance (Y = 1 Ω) in the outer right gap of a Carey- Foster bridge as shown in Fig. 1. Connect the two low resistance

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boxes P & Q in the inner gaps as shown. A jockey is connected through the galvanometer as shown. Finally connect the Lachlanche cell and include a plug key K in the circuit. Select nearly equal values of P and Q in the resistance boxes and find the null point l_1 for each of about 10 sets of P

and Q. (Note that P and Q need not be exactly equal. Choose values for P, Q such as 3,3; 3, 4; 4, 3; 4, 4; 4, 5; 5, 4; 5, 5; etc.).

Now connect the thick copper strip (X) in the outer right gap and the standard 1-ohm resistance (Y) in the outer left gap of the bridge and find l_2 for each of these sets of P and Q. Follow the observation table. Calculate the value of a for each set of observations separately from equation (7) and then find the mean value of a.

Observations:

Resistance per unit length:

$$a = \frac{1}{(l_1 - l_2)} \Omega/\text{CN}$$

Table 1: Determination of a, resistance per unit length of the bridge wire

| S.No. | P (ohm) | Q (ohm) | Position of balance point with X in the | | $(l_1 - l_2)$ (cm) | a (ohm/cm) | Mean a (ohm/cm) |
|-------|---------|---------|---|-------------------------|-----------------------|---------------|--------------------|
| | | | Left gap l_1 (cm) | Right gap l_2 (cm) | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

Results:

Mean value of a =ohm/cm

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Procedure for Part A: To find the resistivity ρ of the material of a given wire:

To find the resistance of the given wire and hence its resistivity, replace the copper strip by the given wire and repeat the above procedure. Find the resistance of the given wire using Eq (6).

Measure the length of the wire and find its diameter using a micrometer screw gauge. Calculate the resistivity using equation (11).

Length of the wire $L = \dots\dots\dots$ cm

Diameter at three different points on the wire, along perpendicular diameters at each point

Table 2: Determination of resistance and resistivity of the unknown wire (usually Nichrome)

| S.No. | P (ohm) | Q (ohm) | Position of balance point with X in the | | $(l_2^u - l_1^u)$ (cm) | a (ohm/cm) | Mean a (ohm/cm) |
|-------|---------|---------|---|---------------------------|---------------------------|---------------|--------------------|
| | | | Left gap l_1^u (cm) | Right gap l_2^u (cm) | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

Results and discussion:

Mean value of the resistance of the given wire is found to be ...

The resistivity ρ of the material of the given wire is

Resistivity of nichrome at room temperature $\sim 100 - 150 \times 10^8 \rho . m$

Percentage of error:

Sources of error and precautions:

1. The ends of the connecting wires should be clean and all connections should be tight.
2. The resistances in the four arms of the bridge should be nearly equal, so that the bridge may have high

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sensitivity.

3. A plug key should be included in the cell circuit and should be closed only when observations are being made.
4. The galvanometer may be shunted by a low resistance wire to avoid excessive deflection in it when the bridge is out of balance. The exact position of the null point should be determined with full galvanometer sensitivity by removing the shunt wire from it.
5. The jockey should always be pressed gently and the contact between the jockey and the bridge wire should not be made while the jockey is being moved along.

Nichrome is a non-magnetic alloy of nickel, chromium, and often iron, usually used as a resistance wire. Patented in 1905, it is the oldest documented form of resistance heating alloy. A common alloy is 80% nickel and 20% chromium, by mass, but there are many others to accommodate various applications. It is silvery- grey in colour, is corrosion-resistant, and has a high melting point of about 1,400 °C (2,550 °F). Due to its resistance to oxidation and stability at high temperatures, it is widely used in electric heating elements.

Resistivity of nichrome at room temperature $\sim 1.0 - 1.5 \times 10^6 \Omega \cdot m$ (From Wiki)

Quiz with Answers:

Q1. What is the Carey Foster bridge?

Ans: It is a modified version of the Wheatstone bridge used to measure low resistances.

Q2. How does the Carey Foster bridge work?

Ans: It balances the ratio of two known resistances against the ratio of the unknown low resistance and a standard resistor.

Q3. What is the significance of using the Carey Foster bridge for low resistance measurement?

Ans: It provides higher sensitivity and accuracy for measuring low resistances compared to standard Wheatstone bridges.

Q4. What are the required components for the Carey Foster bridge experiment?

Ans: A galvanometer, a standard resistor, two known resistors, and the unknown low resistance.

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Q5. How is the bridge balanced in the experiment?

Ans: By adjusting the known resistances until the galvanometer shows zero deflection.

LAB EXPERIMENT 9

POST OFFICE BOX CHARACTERISTICS

Aim: To find resistance of galvanometer by post office box.

1. Apparatus required: Post Office box, galvanometer, power supply (2v), Resistance box, connecting wires.

2. Theory: A post office box is a compact form of the Wheatstone's bridge. In the instrument each of the arms AB & BC contains three of 10, 100 and 1000 Ω respectively as shown in Fig.1.

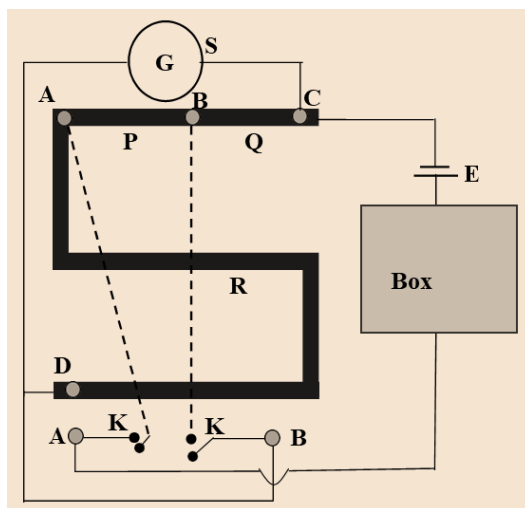


Figure 1

These are called ratio arms. The arm AD is the other ratio arm R. The key K1 is connected to the point A and the key K2 to the point B internally as shown by the lines drawn on the ebonite plate. The unknown, S, is connected between C & D, the battery, E, between C & A through the key K1 and the galvanometer, G, between D & B through the key K2. The circuit is now exactly the same as shown in Fig.2.

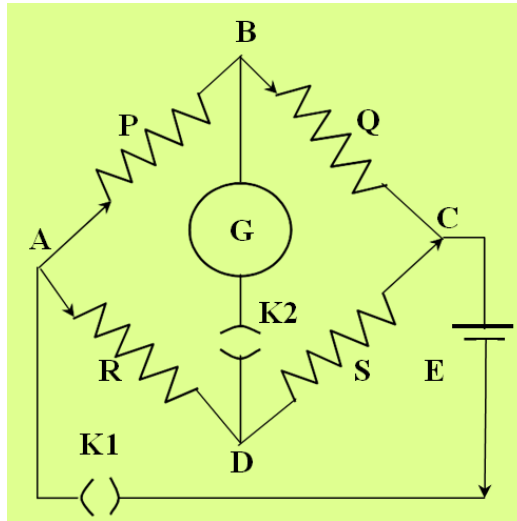


Figure 2

Hence,

$$\frac{P}{Q} = \frac{R}{S} \Rightarrow \frac{P}{R} = \frac{Q}{S}$$

In the Kelvin's method the same galvanometer whose has to be measured, is also used as an indicator for obtaining the balance point.

The galvanometer acts as its own indicator for obtaining the balance point a shown in Fig.3.

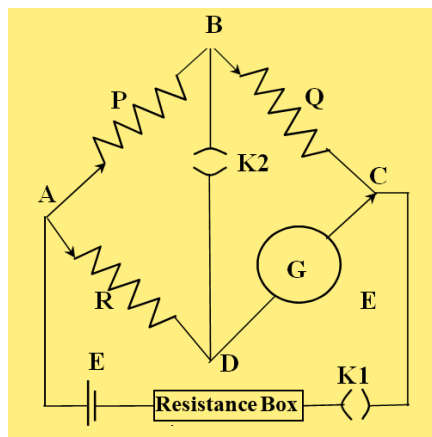


Figure 3

Physics Lab (BSP-101P)

3. Observations:

| Sr. No. | Ratio arms | | Values of R (Ω) for which deflection increases instead of decreasing | G (Ω) lies between $G = R \cdot \frac{Q}{P}$ |
|------------|----------------|----------------|--|--|
| | P (Ω) | Q (Ω) | | |
| | | | | |

1. Procedure:

- (i). Make connections as in Fig.1.
- (ii). Take resistance from box and keep other plugs tight.
- (iii). Keeping R = 0, insert 10 Ω s in P & Q. Press tapping key K1 and adjust from resistance box so that deflection is between 10 & 30.
- (iv). Insert 10 Ω in R, press tapping K1 and note deflection in galvanometer. If deflection decreases on tapping key K2, go on repeating the observation by increasing R in steps so that on pressing K1 first and then tapping K2, the deflection increases. The value of galvanometer lies between last two values of R.
- (v). Keeping Q = 10 Ω make P = 100 Ω . Starts with 10 times the lower value of R obtained in earlier step and increase it in steps, so that on pressing K1 first and then K2, the deflection increases instead of decreasing. Note last two values of R.
- (vi). Keeping Q = 10 Ω make P = 1000 Ω . Starts with 10 times the lower value of R obtained in earlier step and increase it in steps, so that on pressing K1 first and then K2, the deflection increases instead of decreasing. Note last two values of R.

Result: The resistance of the Galvanometer is Ω .

Quiz with Answers:

Q1. What is a post office box?

Ans: A device used to measure the resistance of a galvanometer or other low-resistance components.

Q2. How does a post office box measure the galvanometer resistance?

Ans: By balancing the unknown resistance with known standard resistors until there is no deflection in the galvanometer.

Q3. What are the components needed for the post office box experiment?

Physics Lab (BSP-101P)

Ans: Known standard resistors, a galvanometer, a battery, and connecting wires.

Q4. How is the galvanometer resistance calculated using the post office box?

Ans: The galvanometer resistance is equal to the ratio of the product of known resistors and the balancing resistor.

Q5. What is the significance of measuring the galvanometer resistance?

Ans: It ensures accurate measurements in various electrical experiments where the galvanometer is used as a sensitive indicator.

Q6. How is the balance achieved in the post office box experiment?

Ans: By adjusting the known resistors and the balancing resistor until the galvanometer shows zero deflection.

LAB EXPERIMENT 10

FOUR POIT PROBE CHARACTERISTICS

Aim: To measure resistance using four probe method.

Four Probe Method

Aim:

Study the temperature dependence of resistivity of a semiconductor (Four probe method) and to determine band gap of experimental material (Ge).

Apparatus Required:

Four probe apparatus, sample (a Ge crystal in form of a chip), oven, thermometer (260°) constant power supply, oven power supply, panel meters for measurement of current and voltage.

Formula Used : Resistivity of a semiconductor is

$$\rho = A \exp \left(\frac{E_g}{2k_B T} \right)$$

Where E_g is Band Gap in eV

k_B is Boltzman constant = 8.617×10^{-5} eVK⁻¹

and T is absolute Temperature

Principle :

Ohm's law: If physical conditions (like temperature, mechanical stress) remains unchanged, then potential difference across two ends of a conductor is proportional to current flowing through it

$$V \propto I$$

$$V = IR$$

The constant of proportionality, R, is called resistance of the conductor.

Resistivity: At a constant temperature, the resistance, R, of a conductor is (i) proportional to its length and (ii) inversely proportional to its area of cross-section,

$$R = \rho \frac{L}{A}$$

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The constant of proportionality, ρ , is called resistivity of material of the conductor. Resistivity of a material is equal to the resistance offered by a wire of this material of unit length and unit cross-sectional area. Unit of resistance is ohm (Ω), and unit of resistivity is ohm-meter ($\Omega\text{-m}$)

Four probe method: The 4-point probe set up (Fig.I & Fig.II) consists of four equally spaced tungsten metal tips with finite radius. Each tip is supported by springs on the end to minimize sample damage during probing. The four metal tips are part of an auto-mechanical stage which travels up and down during measurements. A high impedance current source is used to supply current through the outer two probes, a voltmeter measures the voltage across the inner two probes to determine the sample resistivity. Typical probe spacing ~ 2 mm. These inner probes draw no current because of the high input impedance voltmeter in the circuit. Thus unwanted voltage drop ($I R$ drop) at point B and point C caused by contact resistance between probes and the sample is eliminated from the potential measurements. Since these contact resistances are very sensitive to pressure and to surface condition (such as oxidation of either surface).

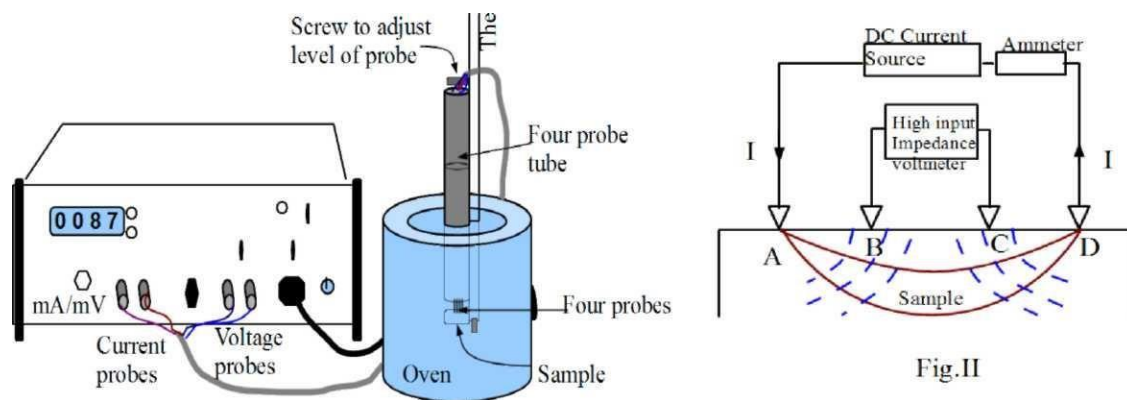


Fig.I Schematic diagram of a Four Probe

Resistivity of Germanium (semiconductor) crystals or slices:

In order to use this four probe method in germanium crystals or slices it is necessary to assume that: The resistivity of the material is uniform in the area of measurement and a non conducting boundary is produced when the surface of the crystal is in contact with an insulator. The derivation of equations given below are involved. For each case it is assumed that the probes are equally spaced (spacing = s).

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Case I: Resistivity Measurements on a Large Sample:

We assume that the metal tip is infinitesimal and sample are semi infinite in lateral dimensions. For bulk samples where the sample thickness, $W \gg S$, the probe spacing, we assume a spherical protrusion of current emanating from the outer probe tips. The resistivity is computed to be

$$\rho_o = \left(\frac{V}{I}\right) * 2\pi s$$

where

V = floating potential difference between the inner probes, unit: volt

I = current through the outer pair of probes, unit: ampere

s = spacing between point probes, unit: meter

ρ_0 = resistivity, unit: ohm meter

Case II: Resistivity Measurements on a Thin Slice-Nonconducting Bottom Surface:

For the case of a nonconducting bottom on a slice the resistivity is computed from

$$\rho = \frac{\rho_o}{G_7\left(\frac{W}{S}\right)}$$

$G_7\left(\frac{W}{S}\right)$ can be calculated from graph (1) or from Table (1) given below or using formula

$$G_7(w/s) = \frac{2s}{w} \log_e 2$$

Table 1

| S.No. | W/S | $G_7(W/S)$ | S.No. | W/S | $G_7(W/S)$ |
|-------|-------|------------|-------|-------|------------|
| 1. | 0.100 | 13.863 | 6. | 1.000 | 1.504 |
| 2. | 0.141 | 9.704 | 7. | 1.414 | 1.223 |
| 3. | 0.200 | 9.631 | 8. | 2.000 | 1.094 |
| 4. | 0.330 | 4.159 | 9. | 3.333 | 1.0228 |
| 5. | 0.500 | 2.780 | 10. | 5.000 | 1.0070 |

Temperature dependence of resistivity of a semiconductor:

Intrinsic semi-conduction The process in which thermally or optically excited electrons contribute to the conduction is called intrinsic semi-conduction. In the absence of photonic excitation, intrinsic semi-conduction takes place at temperatures above 0 K as sufficient thermal agitation is required to transfer electrons from the valence band to the conduction band. Conductivity for intrinsic semi-conduction. The total electrical conductivity is the sum of the conductivities of the valence and conduction band carriers, which are holes and electrons, respectively. It can be expressed as

$$\sigma = e(n_e\mu_e + n_h\mu_h) \quad (1)$$

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where n_e , μ_e are the electron's concentration and mobility,
and n_h , μ_h are the hole's concentration and mobility, respectively.

Drift mobility determines the average drift velocity in the presence of an applied external field. It also depends on the temperature. The mobility is a quantity that directly relates the drift velocity v_d of charge carriers to the applied electric field E across the material, i.e.,

$$\mu = v_d / E \dots\dots\dots (2)$$

In the intrinsic region the number of electrons is equal to the number of holes, $n_e = n_h = n_i$, so Equation (1) implies that,

$$\sigma = e n_i (\mu_e + \mu_h) \dots\dots\dots (3)$$

The electron density (electrons/volume) in the conduction band is obtained by integrating (density of states \times probability of occupancy of states) from the bottom to top of the conduction band. The detailed calculations reveal that

$$n_i = N T^{\frac{3}{2}} \exp\left(-\frac{E_g}{2k_B T}\right) \dots\dots\dots (4)$$

Where N is a constant substituting n_i in eq (3)

$$\sigma = e (\mu_e + \mu_h) N T^{\frac{3}{2}} \exp\left(-\frac{E_g}{2k_B T}\right) \dots\dots\dots (5)$$

This shows that conductivity depends on temperature it decreases exponentially with decrease in temperature.

Temperature dependence of resistivity

$$\rho = \frac{\exp\left(\frac{E_g}{2k_B T}\right)}{e (\mu_e + \mu_h) N T^{\frac{3}{2}}} \dots\dots\dots (6)$$

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$$\rho = A \exp\left(\frac{E_g}{2k_B T}\right) \quad (7)$$

Where A is a constant Taking Log

$$\ln \rho = \ln A + \frac{E_g}{2k_B T} \quad (8)$$

or

$$\log \rho = C + \frac{1}{2.3026} * \frac{E_g}{2k_B T} \quad (9)$$

where C is a constant . Rewriting eq (9)

$$\log \rho = C + \frac{1}{2.3026 * 10^3} * \left(\frac{E_g}{2k_B}\right) \left(\frac{1000}{T}\right).$$

where C is a constant . Rewriting eq (9)

$$\log \rho = C + \frac{1}{2.3026 * 10^3} * \left(\frac{E_g}{2k_B}\right) \left(\frac{1000}{T}\right).$$

Therefore, if a graph is plotted $\log \rho$ vs $\left(\frac{1000}{T}\right)$ it should be a straight line and band gap E_g can be determined from its slope as follows :

1. Slope = $\frac{AC}{BC} = \frac{1}{2.3026 * 10^3} * \frac{E_g}{2k_B}$,
2. Band gap $E_g = 2.3026 * 10^3 * 2 * k_B * \text{slope eV}$, (Take Boltzman constant $k_B = 8.617 * 10^{-5} \text{ eVK}^{-1}$).

Method :

- (1) The setting of 4-point probes on the semiconductor chip is a delicate process. So first understand well the working of the apparatus. The semiconductor chip and probe set is costly.
- (2) Note the values of probe spacing (S) and the thickness (W) of the semiconductor chip. Note the type of semiconductor (germanium or something else).
- (3) Make the circuit as shown in Fig.1. Put the sample in the oven (normally already placed by lab instructor) at

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room temperature.

- (4) Pass a milliampere range current (say 5 mA) in the sample using constant current power supply.
- (5) The reading of the current through the sample is measured using milliammeter provided for this purpose. The voltage is measured by a high impedance milli voltmeter connected to the inner probes. The readings can be taken alternately on digital meter provided for this purpose.
- (6) Note temperature of sample (oven) using thermometer inserted in the oven for this purpose.
- (7) The oven temperature is increased a little, and its temperature noted after reaching steady state. Again the constant current reading (advised to be kept the same) and the corresponding voltage readings are taken.
- (8) Repeat the procedure for different temperatures. Note the data in the observation table.
- (9) For each temperature, calculate the resistivity by using the relation.

$$\rho = \frac{\rho_0}{G_7 \left(\frac{W}{S}\right)} = \left(\frac{V}{I}\right) \left(\frac{2\pi S}{G_7 \left(\frac{W}{S}\right)}\right)$$

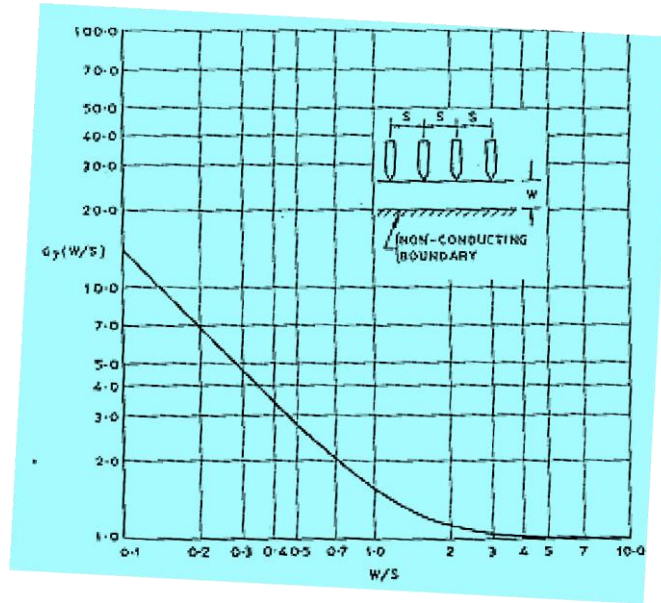
- (10) Compute $\log \rho$ and $10^3 / T$ and write it in the observation table.
- (11) Plot a graph between $\log \rho$ and $10^3 / T$. It is a straight line. Find its slope.
- (12) Calculate the band gap using formula

$$E_g = 2.3026 \cdot 10^3 \cdot 2 \cdot k_B \cdot \text{slope eV}$$

Use Boltzman constant $k_B = 8.617 \cdot 10^{-5} \text{ eVK}^{-1}$

$$(k_B = 1.3806 \cdot 10^{-23} \text{ JK}^{-1} \text{ and } 1\text{eV} = 1.6 \cdot 10^{-19} \text{ J})$$

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Graph 1

Observations:

1. Semiconductor chip material = Germanium
2. Spacing (distance) between the probes, $s = 2.0 \text{ mm} = \dots\dots\dots \text{m}$.
3. Thickness of the sample, $w = 0.5 \text{ mm} = \dots\dots\dots \text{m}$.

Table : Voltage across the inner probes for a constant current at different sample temperatures

Current (I) =mA

| S.No. | Temperature T (K) | Voltage across inner probes (mV) | $\frac{1000}{T} K^{-1}$ (calculated) | Resistivity ρ $\rho = \left(\frac{V}{I}\right) \left(\frac{2\pi s}{G_T \left(\frac{w}{s}\right)}\right)$ (ohm-cm) | Log ρ (calculated) |
|-------|------------------------|--|---|--|-------------------------|
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| .. | | | | | |
| .. | | | | | |

Calculations:

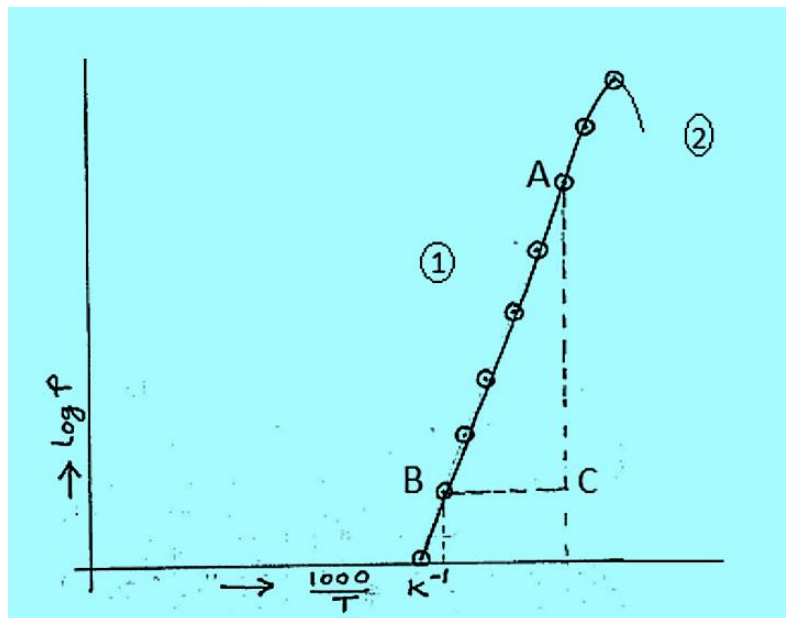
1. For the given sample $\left(\frac{W}{S}\right) = \dots\dots\dots$
2. The correction factor $G_7(w/s) = (\text{from table 1 or graph 1})$ or calculate $G_7(W/S)$ as follows:

$$G_7(w/s) = \frac{2 * s}{w} \ln 2$$

3. Calculation of $T (K^{-1})$, ρ (ohm-m) and $\log \rho$

$$\rho = \frac{\rho_0}{G_7\left(\frac{W}{S}\right)} = \left(\frac{V}{I}\right) \left(\frac{2\pi S}{G_7\left(\frac{W}{S}\right)}\right)$$

4. The graph between $\frac{1000}{T}$ and $\log \rho$ is plotted as shown in graph (2)
5. Slope of the straight line is $\frac{AC}{BC}$



Graph 2 Variation of $\log \rho$ with $\frac{1000}{T}$

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Explanation of Graph-2

The resistivity of a Germanium crystal as a function of inverse temperature. For this sample when $T < T' \text{ } ^\circ\text{K}$ i.e. region (2), conduction is mainly due to the impurity carriers (extrinsic region). For $T > T' \text{ } ^\circ\text{K}$ conduction is due to electrons transferred to the conduction band and the corresponding holes created in the valence band (this is the intrinsic region).

Result:

1. The temperature dependence of the resistivity of semiconductor (germanium) chip is as shown in the graph (2) . The resistivity decreases exponentially with the increase in T . That is as at low temperatures resistivity is more and at high temperatures the resistivity is less.
2. The energy band gap for the given semiconductor (germanium) is =eV.

Precautions:

1. The surface of the semiconductor should be flat.
2. All the four probes should be collinear.
3. The adjustment of 4-point probes should be done gently, as the semiconductor chip is brittle.
4. The voltage should be measured using inner probes only using a high impedance millivoltmeter.
5. Temperature of the oven should not exceed the limits set by manufacturer of the probes and chip.

Quiz with Answers:

Q1. What is the four-probe method?

Ans: A technique used to accurately measure the resistance of a sample by using four evenly spaced electrical contacts.

Q2. How does the four-probe method work?

Ans: Two outer probes apply a current to the sample, while two inner probes measure the voltage drop, allowing precise resistance calculation.

Q3. What is the advantage of using the four-probe method?

Ans: It eliminates the errors introduced by contact resistances, providing more accurate resistance measurements.

Q4. What type of materials can be measured using this method?

Ans: Both conductive and semiconducting materials can be measured accurately.

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Q5. What are the essential requirements for the four-probe method?

Ans: High precision probes, low contact resistance, and a stable current source are needed.

Q6. Can the four-probe method measure low resistance values?

Ans: Yes, it is well-suited for measuring low resistance samples due to its ability to minimize contact resistance effects.

LAB EXPERIMENT 11

DE SAUTY BRIDGE CHARACTERISTICS

Aim: To compare the capacitance of two capacitors using De'Sauty Bridge

APPARATUS:

Desauty's bridge has been designed on a training board New Tech Type – NTI – 113. It consists of two variable Capacitors C_1 and C_2 . Each can be varied in step of $0.01\mu\text{F}$ i.e. $\times 0.01 \mu\text{F}$ upto $0.1 \mu\text{F}$. Two resistances R_1 and R_2 of bridge may be varied in steps of (i) $\times 100 \Omega$ upto $1 \text{ k}\Omega$ (ii) $\times 1\text{k}\Omega$ upto $10 \text{ k}\Omega$ Fixed frequency oscillator and headphone or galvanometer fitted with diode are connected in between the terminals marked for this purpose.

THEORY:

When the bridge is balanced i.e. Potentials at B and D are equal i.e.

$$V_B = V_D$$

$$\text{or } V_A - V_B = V_A - V_D$$

If i_1 and i_2 are the alternating currents passing in arms ABC and ADC then $R_1 i_1 = R_2 i_2$ (1)

Similarly

$$V_B - V_C = V_D - V_C$$

or

$$i_1 = \frac{i_2}{j\omega C_1} = \frac{i_2}{j\omega C_2} \dots\dots\dots(2)$$

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when $\omega = 2\pi f$ is frequency of fixed frequency oscillator

Dividing (1) by (2)

$$R_1 i_1 X_{j\omega C_1} = R_2 i_2 X_{j\omega C_2}$$

$$\frac{i_1}{i_2} = \frac{R_2 C_2}{R_1 C_1}$$

or $R_1 C_1 = R_2 C_2$

or $\frac{C_1}{C_2} = \frac{R_2}{R_1}$ (3)

Using this formula determining the values of R_1 and R_2 the ratio between two Capacities i.e. C_1/C_2 calculated. If one capacity is known the other can be calculated.

PROCEDURE:

COMPARISON OF TWO CAPACITIES

1. Complete the circuit as shown in Fig. 2.
2. Set C_1 and C_2 at some values.
3. Adjusting the values of R_1 and R_2 obtain null point i.e. the sound in head phone or deflection in Galvanometer should be minimum.
4. Change the values of R_1 , R_2 and take different sets.
5. Note the values in O.T. and calculate the ratio C_1/C_2 using formula (3).

OBSERVATION TABLE:

$C_1 = \dots\dots\dots \mu\text{F}, C_2 = \dots\dots\dots \mu\text{F}$

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| S.No. | R ₁ Ω | R ₂ Ω | $\frac{C_1}{C_2} = \frac{R_2}{R_1}$ |
|-------|---------------------|---------------------|-------------------------------------|
| 1. | | | |
| 2. | | | |
| 3. | | | |
| 4. | | | |
| 5. | | | |
| 6. | | | |

Mean Value of

$$\frac{C_1}{C_2} = \dots\dots\dots$$

RESULT:

Ratio of two Capacities $C_1/C_2 = \dots\dots\dots$

Correct Value of $C_1/C_2 = \dots\dots\dots$

PRECAUTIONS:

1. Initially output of fixed frequency oscillator should be kept low. Near null point it should be increased.
2. If head phone is used there must be silence in the neighboring.
3. For sensitivity of bridge the impedance in all four arms should be nearly equal.
4. Plug type resistance boxes should not be used.

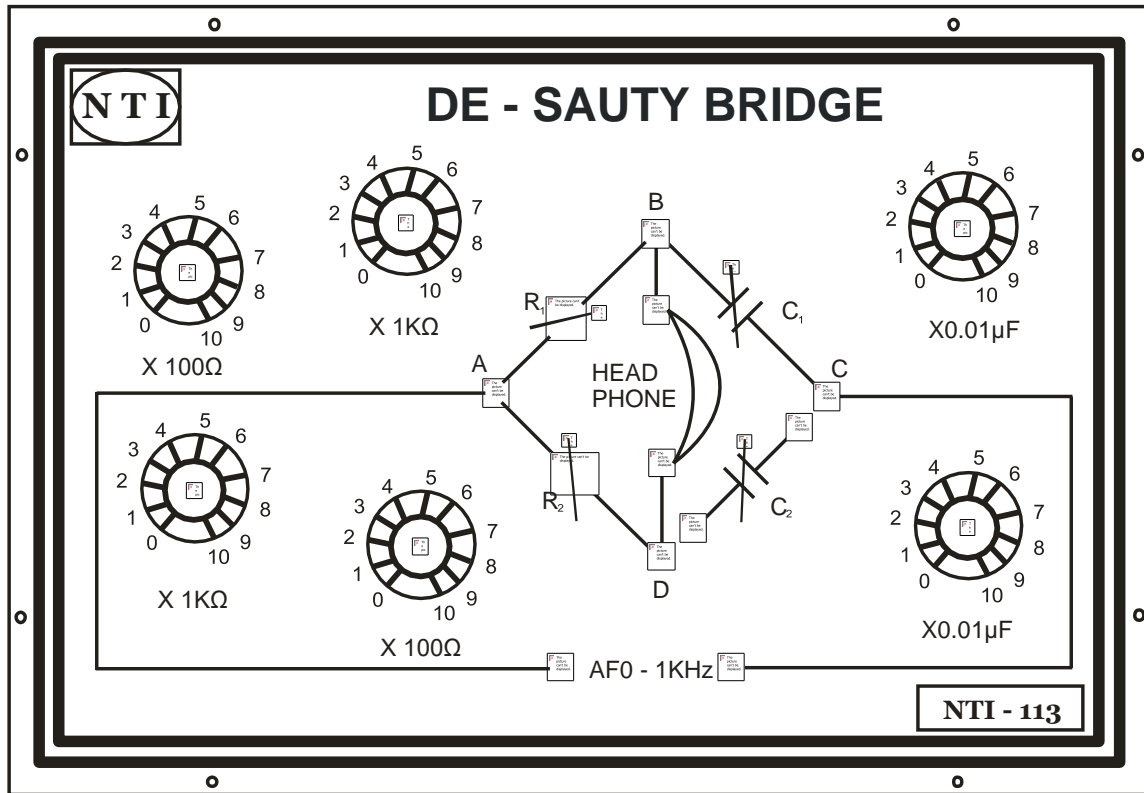


Fig. (1) Panel Diagram for DE-SAUTY BRIDGE

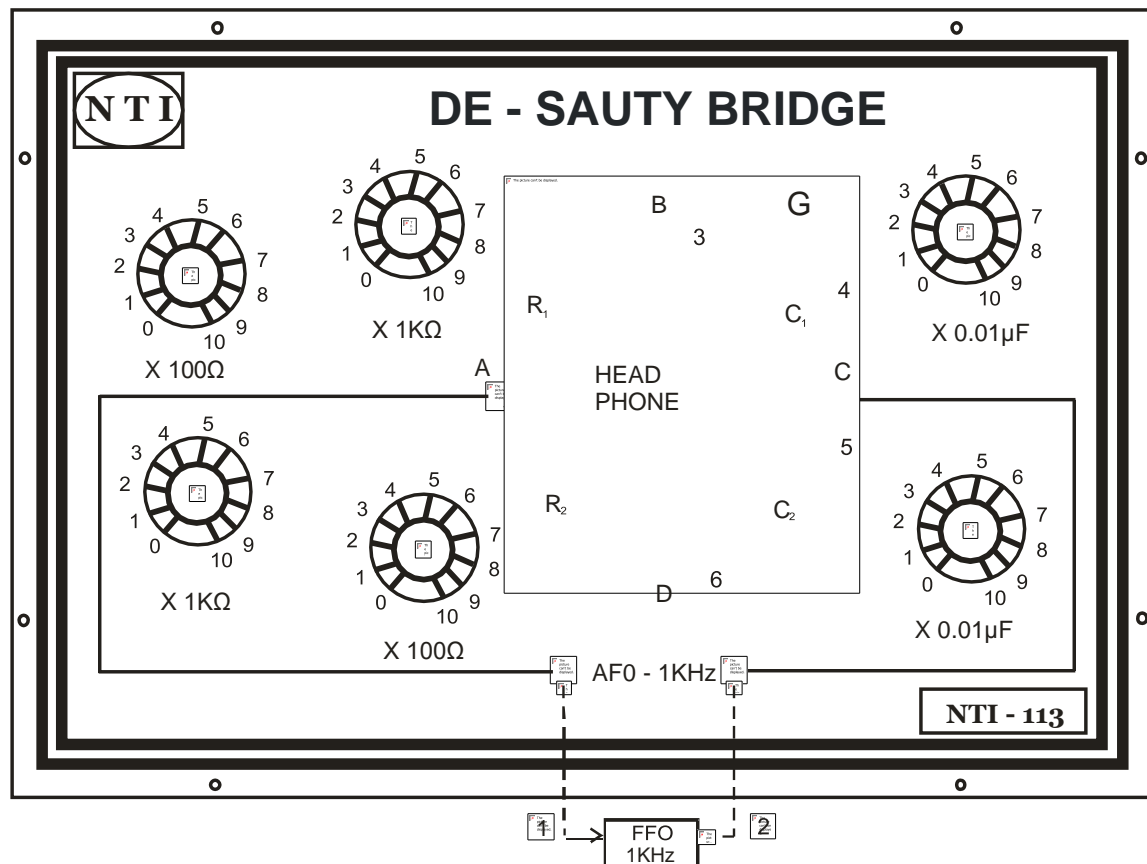


Fig. (2) Connections for DE-SAUTY BRIDGE

Quiz with Answers:

Q1. What is the De'Sauty Bridge used for?

Ans: To compare the capacitance of two capacitors.

Q2. How does the De'Sauty Bridge work?

Ans: It balances the ratio of the known capacitance and a standard resistor against the ratio of the unknown capacitance and a variable resistor.

Q3. What components are required for the De'Sauty Bridge experiment?

Ans: Two capacitors (unknown and known), a variable resistor, a standard resistor, and a galvanometer.

Q4. How is the bridge balanced in the experiment?

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Ans: By adjusting the variable resistor until the galvanometer shows zero deflection.

Q5. What is the principle behind the bridge operation?

Ans: The bridge balances the voltage drop across the two branches, making the galvanometer null, indicating a balanced configuration.

Q6. How is capacitance compared using the De'Sauty Bridge?

Ans: By finding the ratio of the unknown capacitance to the known capacitance based on the balance condition.

Q7. What are the advantages of using the De'Sauty Bridge for capacitance comparison?

Ans: It provides a straightforward and accurate method for comparing the capacitance of two capacitors.

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Crosschecked

By

HOD Applied Science & Humanities

Please spare some time to provide your
valuable feedback.
