

1. Aim

To determine the **resistivity and conductivity of a semiconductor/material** using the **four-probe method**.

2. Apparatus Required

- Four-probe experimental setup
- Semiconductor/sample wafer
- Constant current source
- Digital voltmeter/microvoltmeter
- Four equally spaced probes
- Heating arrangement/temperature controller
- Thermometer or temperature sensor
- Connecting wires

3. Principle

In the four-probe method, four sharp probes are placed in a straight line on the surface of the sample.

- The **outer two probes** carry a known current I .
- The **inner two probes** measure the potential difference V .
- Since the voltage measurement circuit draws negligible current, errors due to contact resistance are minimized.

For a sufficiently large, thin sample:

$$\rho = 2\pi sIV$$

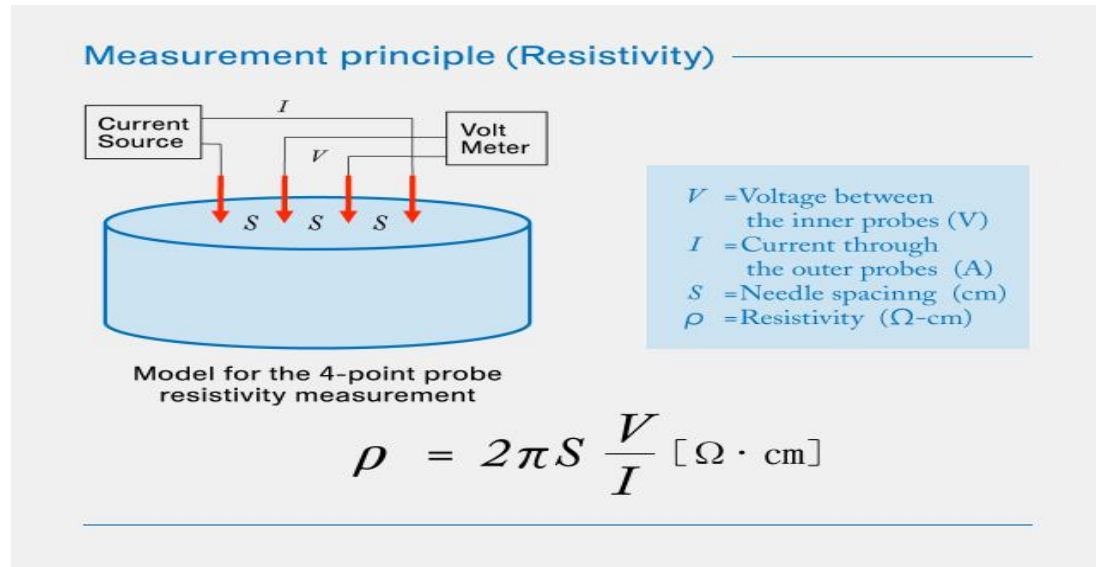
where:

- ρ = resistivity of the sample
- s = spacing between adjacent probes
- V = potential difference between inner probes
- I = current through outer probes

Conductivity is:

$$\sigma = \rho^{-1}$$

4. Experimental Setup



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The four probes are arranged linearly and equally spaced. The outer probes are connected to the current source, while the inner probes are connected to the voltmeter.

5. Procedure

1. Place the semiconductor sample properly on the sample holder.
2. Ensure that all four probes make **gentle and proper contact** with the sample surface.
3. Connect the **outer probes** to the constant-current source.
4. Connect the **inner probes** to the digital voltmeter/microvoltmeter.
5. Switch on the experimental setup.
6. Set a small, known current I through the outer probes.
7. Note the corresponding voltage V between the inner probes.
8. Repeat the measurement for different values of current.
9. If temperature dependence is required, heat the sample gradually and record the temperature T , current I , and voltage V at each temperature.
10. Calculate V/I for each observation.
11. Calculate the resistivity using:

$$\rho = 2\pi S \frac{V}{I}$$

12. Calculate conductivity using:

$$\sigma = \frac{1}{\rho}$$

6. Observation Table

S. No.	Current I (mA)	Voltage V (mV)	V/I	Temperature T (°C)	Resistivity ρ
1					
2					
3					
4					
5					

7. Calculations

For each observation:

IV = measured resistance

Then,

$$\rho = 2\pi s IV$$

and

$$\sigma = \rho^{-1}$$

If temperature variation is studied, a graph of **$\log \rho$ versus $1/T$** may be plotted to study the temperature dependence of the semiconductor.

8. Precautions

1. Ensure that all four probes are **equally spaced**.
2. The probes should make proper but not excessive contact with the sample.
3. Do not use excessively high current, as it may heat the sample.
4. Take voltage readings only after the reading becomes stable.
5. Check the polarity and connections before switching on the power supply.
6. Avoid disturbing the probe arrangement during the experiment.
7. Use the correct probe spacing s in calculations.
8. If temperature measurements are being taken, allow the sample to reach thermal equilibrium before recording readings.

9. Result

The **resistivity ρ** and **conductivity σ** of the given semiconductor/material are determined using the four-probe method.

Formula for result:

$$\rho = 2\pi sIV \quad \sigma = \rho l$$

SOP: Franck–Hertz Experiment

1. Aim

To study the **Franck–Hertz experiment** and determine the **first excitation potential of mercury (or the gas filled in the given tube)** by observing the periodic variation of collector current with accelerating voltage.

2. Apparatus Required

- Franck–Hertz experimental setup
- Franck–Hertz tube containing mercury vapour/neon
- Heating arrangement
- DC power supply
- Accelerating-voltage supply
- Retarding-voltage supply
- Microammeter/current meter
- Digital voltmeter
- Connecting wires

3. Principle

The Franck–Hertz experiment demonstrates the **quantized energy levels of atoms**.

Electrons emitted by the cathode are accelerated through the gas-filled tube. As the accelerating voltage increases, electrons gain kinetic energy and collide with gas atoms.

At certain definite energies, the electrons undergo **inelastic collisions** with atoms and lose a fixed amount of energy corresponding to the excitation energy of the atom. Consequently, the collector current decreases periodically.

The excitation energy is related to the excitation potential by:

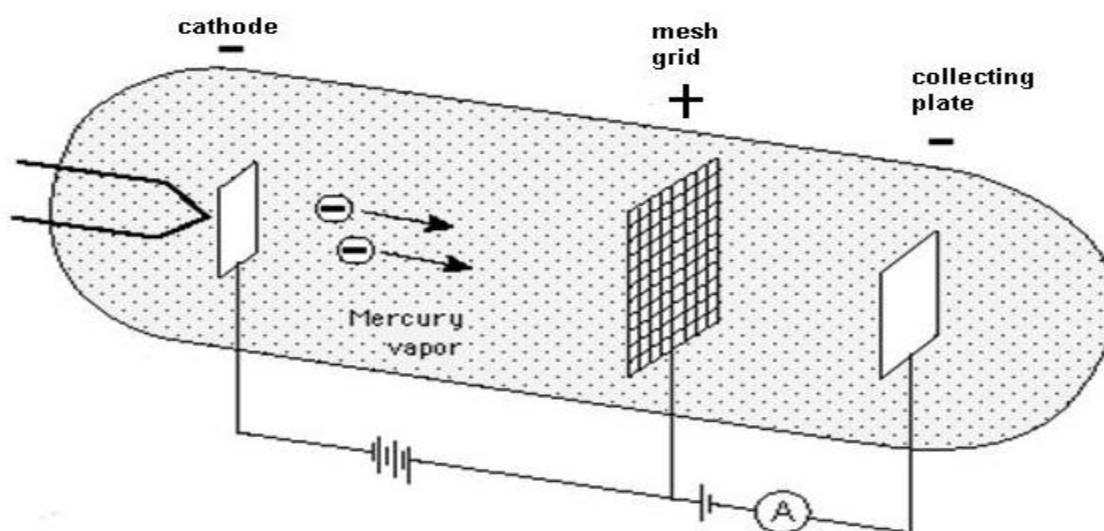
$$E = eV$$

Hence,

$$E_{\text{exc}} = eV_{\text{exc}}$$

For mercury, the first excitation potential is approximately **4.9 V**.

4. Experimental Setup



The Franck–Hertz tube consists essentially of a heated cathode, an accelerating grid and a collector electrode (Plate). Electrons emitted from the cathode are accelerated towards the collector through the gas/vapour inside the tube.

5. Procedure

1. Check all electrical connections according to the circuit diagram provided with the apparatus.
2. Switch ON the Franck–Hertz apparatus.

3. Set the tube temperature to the required value and allow the tube to attain thermal equilibrium.
4. Keep the **retarding voltage** between the grid and collector at the specified constant value.
5. Set the accelerating voltage to its minimum value.
6. Note the corresponding collector current.
7. Increase the accelerating voltage gradually in small, equal steps.
8. Record the collector current for each value of accelerating voltage.
9. Continue taking readings until several maxima and minima of collector current are obtained.
10. Plot a graph between **collector current I_c** and **accelerating voltage V** .
11. Identify the successive maxima or minima in the graph.
12. Determine the voltage difference between successive corresponding maxima/minima.
13. Calculate the average excitation potential using:

$$V_{exc} = N V_2 - V_1 + V_3 - V_2 + \dots$$

14. For mercury, the value should be close to **4.9 V**.

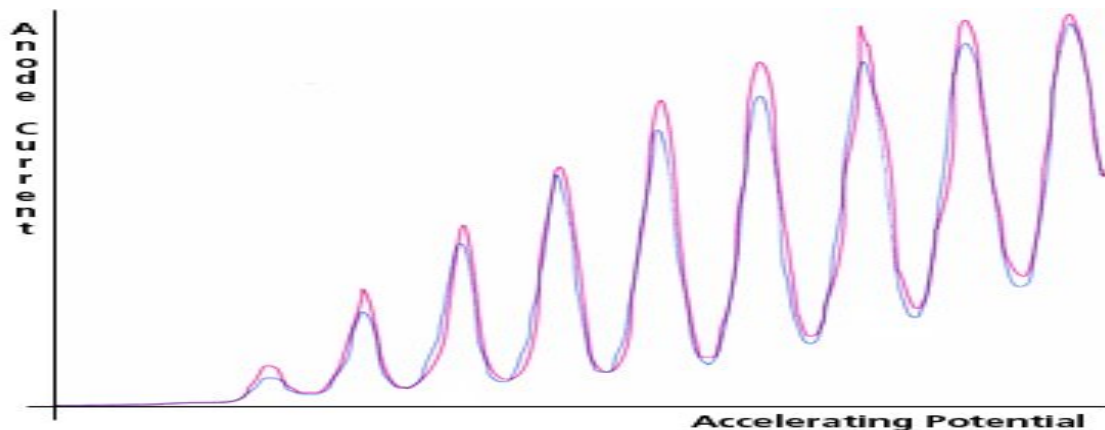
15. Calculate the excitation energy using:

$$E_{exc} = e V_{exc}.$$

6. Observation Table

S. No.	Accelerating Voltage V (V)	Collector Current I_c (μA)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

7. Graph



Plot:

Y-axis: Anode or collector current I_c

X-axis: Accelerating voltage or Potential V

The graph should show a series of **maxima and minima**.

The approximate separation between successive maxima (or successive minima) gives the **first excitation potential**.

8. Calculations

If the positions of successive maxima are $V_1, V_2, V_3, \dots$, then:

$$\Delta V_1 = V_2 - V_1$$

$$\Delta V_2 = V_3 - V_2$$

and so on.

Therefore,

$$V_{\text{exc}} = N\Delta V_1 + \Delta V_2 + \Delta V_3 + \dots$$

The excitation energy is:

$$E_{\text{exc}} = eV_{\text{exc}}$$

In electron-volts, the numerical value is simply:

$$E_{\text{exc}}(\text{eV}) = V_{\text{exc}}(\text{V})$$

9. Precautions

1. Check all connections before switching ON the apparatus.
2. Allow sufficient time for the tube to reach the required operating temperature.
3. Keep the retarding voltage constant during observations.
4. Increase the accelerating voltage gradually.
5. Do not exceed the specified voltage limits of the Franck–Hertz tube.
6. Take readings only after the current becomes stable.

7. Avoid parallax error while taking analog meter readings.
8. Do not disturb the tube during the experiment.
9. Obtain several maxima/minima for better accuracy.
10. Switch OFF the apparatus after completing the experiment.

10. Sources of Error

- Fluctuation in accelerating voltage
- Variation in tube temperature
- Contact potential between electrodes
- Instrumental errors
- Non-uniformity of gas/vapour pressure
- Difficulty in locating exact maxima and minima
- Space-charge effects

11. Result

The first excitation potential of the gas in the Franck–Hertz tube is found to be:

$V_{\text{exc}} = \underline{\hspace{2cm}} \text{ V}$

For a mercury-filled tube, the expected value is approximately:

$V_{\text{exc}} \approx 4.9 \text{ V}$ [blob:https://web.whatsapp.com/dfbfdac1-181a-4dd6-b7bc-bdf578d9ad4b](https://web.whatsapp.com/dfbfdac1-181a-4dd6-b7bc-bdf578d9ad4b)

Thus, the experiment verifies the **quantized energy levels of atoms** and provides experimental evidence for the discrete excitation energies of atoms.

SOP: Hall Effect Experiment

1. Aim

To study the **Hall Effect** and determine:

- Hall coefficient R_H
- Carrier concentration n
- Nature/type of charge carriers in the given semiconductor.

2. Apparatus Required

- Hall Effect set up
- Semiconductor Hall probe/sample
- Electromagnet
- DC power supply
- Constant-current source
- Digital voltmeter/millivoltmeter
- Gauss meter/teslameter
- Connecting wires
- Micrometer/vernier caliper for measuring sample dimensions

3. Principle/Theory

When a current-carrying semiconductor is placed in a magnetic field perpendicular to the direction of current, a voltage develops across the specimen in a direction perpendicular to both the current and magnetic field. This voltage is called **Hall voltage**.

If:

- I = current through the specimen
- B = magnetic field
- t = thickness of the specimen
- V_H = Hall voltage

then, $V_H = R_H t I B$

Therefore, $R_H = IBV_H t$

For a single type of charge carrier, $R_H = nq l$

Hence, carrier concentration is $n = q R_H l$

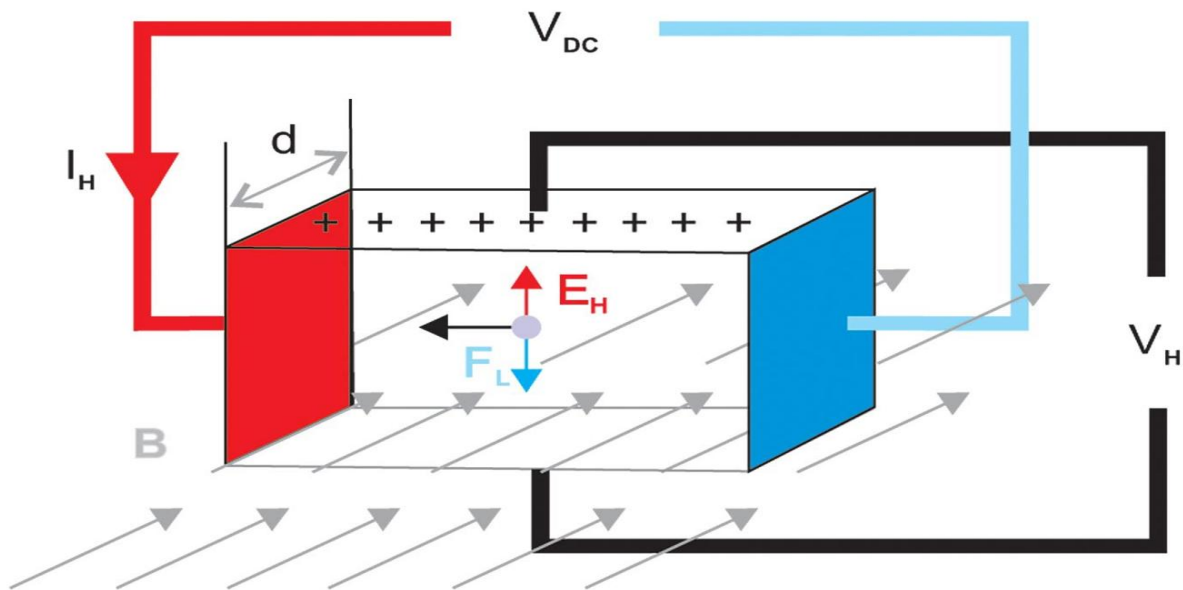
where $q = 1.6 \times 10^{-19} \text{C}$.

The sign of the Hall coefficient indicates the type of charge carrier:

- $R_H > 0$: **p-type semiconductor**

- $R_H < 0$: n-type semiconductor

4. Experimental Setup



6

The semiconductor specimen is placed between the pole pieces of an electromagnet. A constant current is passed through the specimen, while the magnetic field is applied perpendicular to the current. Hall voltage is measured across the transverse terminals.

5. Procedure

1. Check all electrical connections before switching on the power supply.
2. Place the Hall specimen properly between the pole pieces of the electromagnet.
3. Ensure that the magnetic field is perpendicular to the direction of current through the specimen.
4. Switch on the Hall-effect apparatus and allow the readings to stabilize.
5. Set the specimen current I to a suitable constant value.
6. With the magnetic field switched **OFF**, note the Hall voltage, if any. This is the **zero-offset voltage**.
7. Switch ON the electromagnet.
8. Set the magnetic field to a suitable value and note the corresponding Hall voltage.
9. Increase the magnetic field in suitable steps and record the Hall voltage for each value.
10. Repeat the observations for opposite directions of magnetic field, if the apparatus permits.
11. Calculate the corrected Hall voltage by eliminating the zero-offset/error.
12. Plot a graph of V_H versus B .

13. Determine the slope of the graph.
14. Calculate the Hall coefficient using the appropriate formula.
15. Calculate the carrier concentration using

$$n = qR_H I$$
16. Determine whether the semiconductor is **n-type** or **p-type** from the sign of R_H .

6. Observation Table

S. No.	Current I (mA)	Magnetic Field B (T)	Hall Voltage V_H (mV)
1			
2			
3			
4			
5			
6			

7. Calculations

From
 $V_H = R_H I B$
 we get
 $R_H = \frac{V_H}{I B}$

If the graph of V_H versus B is plotted,
 $\text{slope} = \frac{V_H}{B}$
 Therefore,
 $R_H = \frac{V_H}{I B} = \frac{\text{slope}}{I}$

Carrier concentration:
 $n = \frac{1}{e R_H}$
 where
 $e = 1.6 \times 10^{-19} \text{C}$.

8. Precautions

1. The Hall specimen should be correctly positioned between the magnet poles.
2. The magnetic field should be perpendicular to the current direction.
3. Keep the specimen current within the specified limit.
4. Do not change the current unnecessarily during observations.
5. Take readings only after the magnetic field and voltage have stabilized.
6. Check and remove the zero-offset voltage before taking final readings.

7. Avoid loose electrical connections.
8. Do not exceed the rated current of the Hall probe.
9. Take readings for both directions of magnetic field wherever possible to minimize errors.
10. Switch off the electromagnet and power supply after completing the experiment.

9. Sources of Error

- Zero-offset voltage
- Non-uniform magnetic field
- Error in measuring specimen thickness
- Fluctuation in current
- Instrumental error in measuring Hall voltage
- Improper alignment of the Hall specimen

10. Result

The **Hall coefficient R_H** of the given semiconductor is found to be:

$$R_H = \underline{\hspace{2cm}} \text{ m}^3/\text{C}$$

The carrier concentration is:

$$n = \underline{\hspace{2cm}} \text{ m}^{-3}$$

The given semiconductor is found to be **type (n-type/p-type)**.

Determination of the Velocity of Sound in Air Using a Tuning Fork

Aim

To determine the velocity of sound in air using a resonance tube and tuning fork.

Apparatus Required

Resonance tube apparatus, tuning fork of known frequency, rubber hammer, meter scale, water reservoir, and thermometer.

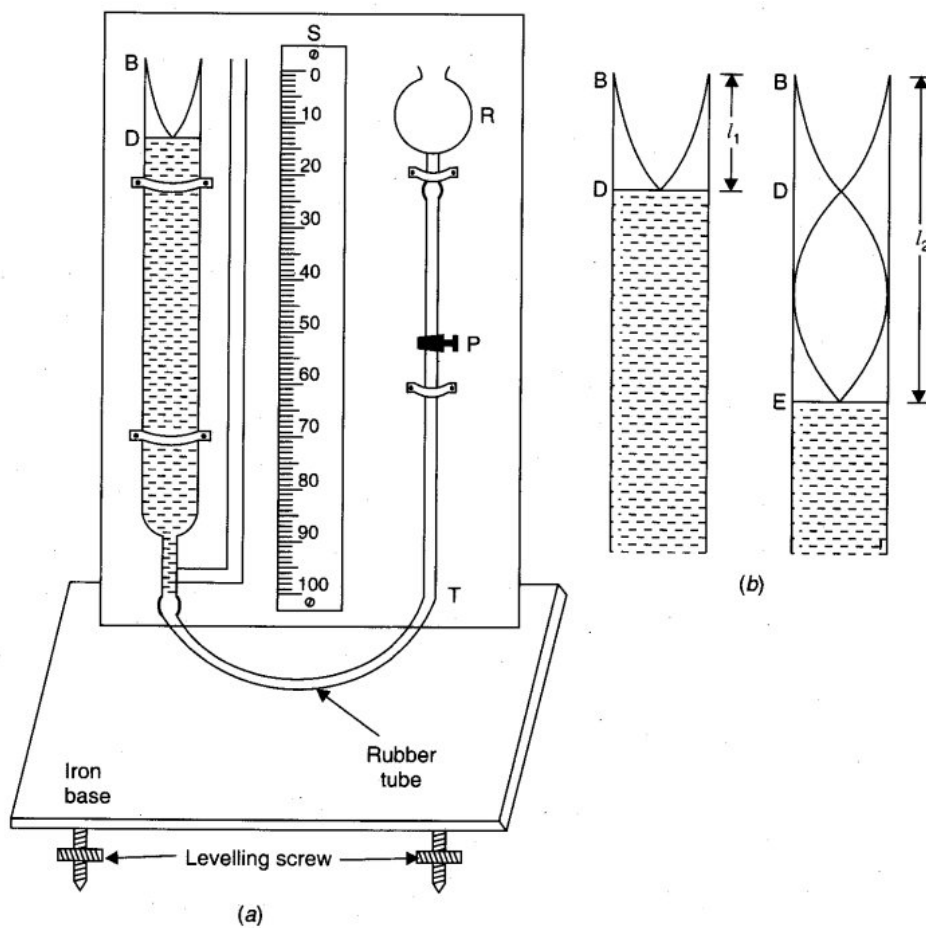


Fig. Resonance tube.

Theory

The velocity with which sound travels in any medium may be determined if the frequency and the wavelength are known. The relationship between these quantities is:

$$v = f\lambda \text{ where } v = \text{velocity of sound propagation}$$

$$f = \text{frequency}$$

$$\lambda = \text{wavelength}$$

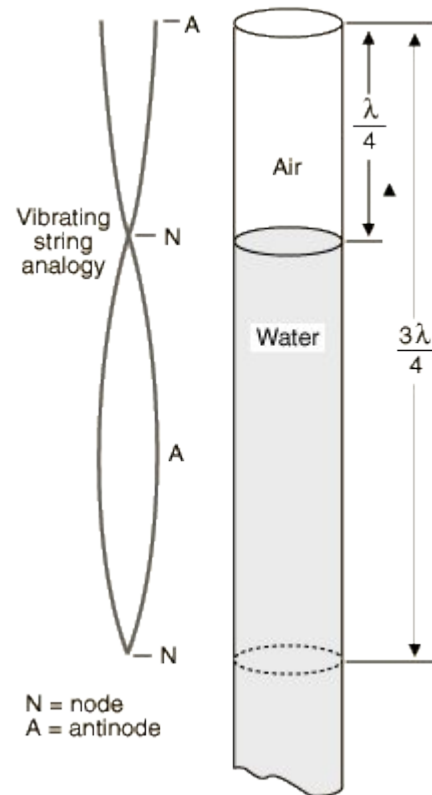
In this experiment the velocity of sound in air is to be found by using tuning forks of known frequency. The wavelength of the sound will be determined by making use of the resonance of an air column.

The apparatus for the experiment consists of a long cylindrical plastic tube attached to a water reservoir. The length of the water column may be changed by raising or lowering the water level while the tuning fork is held over the open end of the tube. Resonance is indicated by the sudden increase in the intensity of the sound when the column is adjusted to the proper length. The resonance is a standing wave phenomenon in the air column and occurs when the column length is:

$$\lambda/4, 3\lambda/4, 5\lambda/4$$

where λ is the sound wavelength.

The water surface constitutes a node of the standing wave since the air is not free to move longitudinally. The open end provides the conditions for an antinode, but the actual antinode has been found to occur outside the tube at a distance of about $0.6r$ from the end, where r is the tube radius. This end correction may be added to get a more accurate value if only one resonance can be measured, but it is usually more convenient to eliminate this "end effect" by subtracting the resonance length for $\lambda/4$ from those for $3\lambda/4$, $5\lambda/4$, etc.



Procedure

1. Fill the resonance tube apparatus with water.
2. Strike the tuning fork gently with a rubber hammer.
3. Hold the vibrating tuning fork above the mouth of the resonance tube.
4. Adjust the water level until the first loud resonance is heard and note the air column length L_1 .
5. Lower the water level further to obtain the second resonance and note L_2 .

6. Repeat the observations several times and record the readings.
7. Calculate the wavelength and then the velocity of sound.

Observation Table

Frequency (f) | First Resonance Length (L1) | Second Resonance Length (L2) | $\lambda = 2(L2 - L1)$
| $v = f\lambda$

Calculations

Mean resonance lengths are calculated from the observations.

Wavelength, $\lambda = 2(L2 - L1)$

Velocity of sound, $v = f\lambda$

Result

The velocity of sound in air at room temperature is determined to be _____ m/s.

Precautions

1. Strike the tuning fork gently.
2. Do not touch the prongs of the vibrating tuning fork.
3. Keep the tuning fork close to but not touching the tube.
4. Take resonance readings carefully to avoid parallax errors.
5. Perform the experiment in a quiet environment.

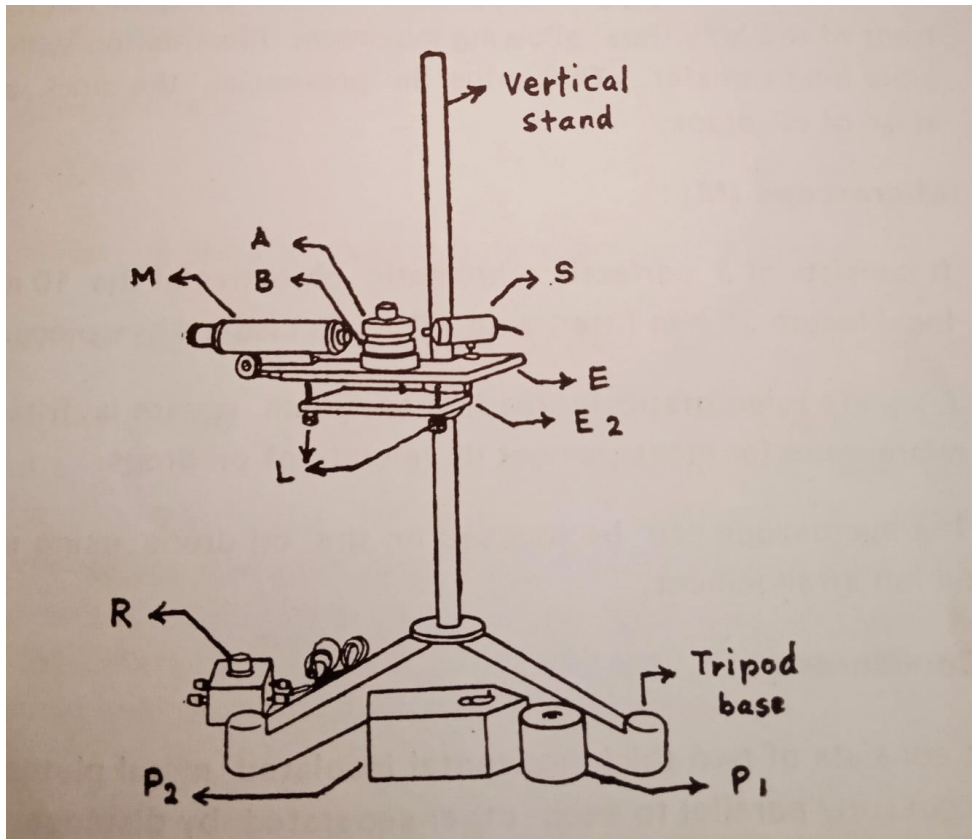
Determination of Electronic Charge (e) Using Millikan's Oil Drop Method

Aim

To determine the value of the electronic charge (e) using Millikan's oil drop apparatus.

Apparatus Required

Millikan oil drop apparatus, atomizer, microscope, illuminating system, regulated power supply, stopwatch, and thermometer.



S- Light source

M- Microscope

C-Condenser

E₂- Sub base

A,B- Metal Plates

E- Ebonite Plate

L-Screw

R -Reversing Switch

Theory

Millikan's oil drop experiment is used to determine the elementary electronic charge. Tiny charged oil droplets are introduced between two parallel plates. By balancing the electric force against gravity, the charge on an oil drop can be calculated. The measured charges are found to be integral multiples of the elementary charge e . The accepted value of e is approximately 1.602×10^{-19} C.

The oil drop experiment was performed by Robert A. Millikan and Harvey Fletcher in 1909 to measure the elementary electric charge (the charge of the electron). The experiment took place in the Ryerson Physical Laboratory at the University of Chicago. Millikan received the Nobel Prize in Physics in 1923

The experiment observed tiny electrically charged droplets of oil located between two parallel metal surfaces, forming the plates of a capacitor. The plates were oriented horizontally, with one plate above the other. A mist of atomized oil drops was introduced through a small hole in the top plate; some would be ionized naturally. First, with zero applied electric field, the velocity of a falling droplet was measured. At terminal velocity, the drag force equals the gravitational force. As both forces depend on the radius in different ways, the radius of the droplet, and therefore the mass and gravitational force, could be determined (using the known density of the oil). Next, a voltage inducing an electric field was applied between the plates and adjusted until the drops were suspended in mechanical equilibrium, indicating that the electrical force and the gravitational force were in balance. Using the known electric field, Millikan and Fletcher could determine the charge on the oil droplet. By repeating the experiment for many droplets, they confirmed that the charges were all small integer multiples of a certain base value, which was found to be 1.5924×10^{-19} C, about 0.6% difference from the currently accepted value of $1.602176634 \times 10^{-19}$ C. They proposed that this was the magnitude of the negative charge of a single electron.

Procedure

1. Switch on the illumination system and focus the microscope.
2. Spray fine oil droplets into the chamber.
3. Select a suitable oil drop and observe its motion without an electric field.
4. Measure the terminal velocity of the drop while falling.
5. Apply a known electric field and adjust the voltage so that the drop rises or remains suspended.
6. Record the required observations.
7. Calculate the charge on the oil drop using Millikan's formula.
8. Repeat for several oil drops and determine the elementary charge e .

Observation Table

Distance between marks: _____

Applied voltage: _____ V

Time of fall: _____ s

Time of rise: _____ s

Calculated charge on droplet: _____ C

Calculations

Calculate the radius of the oil drop, terminal velocity, and charge on each drop using the standard Millikan equations. Determine the greatest common factor of the measured charges to obtain the value of e .

Result

The value of the electronic charge is found to be $e =$ _____ C.

Sources of Error

1. Errors in timing measurements.
2. Variation in droplet size.
3. Temperature and viscosity changes.
4. Non-uniform electric field.

Precautions

1. Ensure proper focusing of the microscope.
2. Use stable voltage during observations.
3. Select isolated oil drops.
4. Avoid vibrations and air currents.
5. Record timings carefully.

STANDARD OPERATING PROCEDURE (SOP)

Experiment: To Find the Angle of a Prism Using a Spectrometer and Determine the Minimum Deviation

1. Aim

To determine the angle of the given prism using a spectrometer and to find the angle of minimum deviation produced by the prism.

2. Apparatus Required

- Spectrometer with collimator and telescope
- Glass prism
- Monochromatic light source (preferably sodium lamp)
- Spirit level

3. Principle / Theory

When a ray of light passes through a prism, it is deviated from its original direction. The angle through which the ray is deviated is called the angle of deviation (δ). As the prism is rotated, the deviation first decreases, reaches a minimum value, and then increases. The corresponding deviation is called the angle of minimum deviation (δ_m).

For a prism of angle A and refractive index μ : In a prism, the angle of deviation (δ) decreases with increase in the angle of incidence (i) up to a particular angle. This angle of incidence, where the angle of deviation in a prism is minimum, is called the minimum deviation position of the prism, and that very deviation angle is known as the minimum angle of deviation (denoted by $\delta_{\min}$, D_{λ} , or D_m).

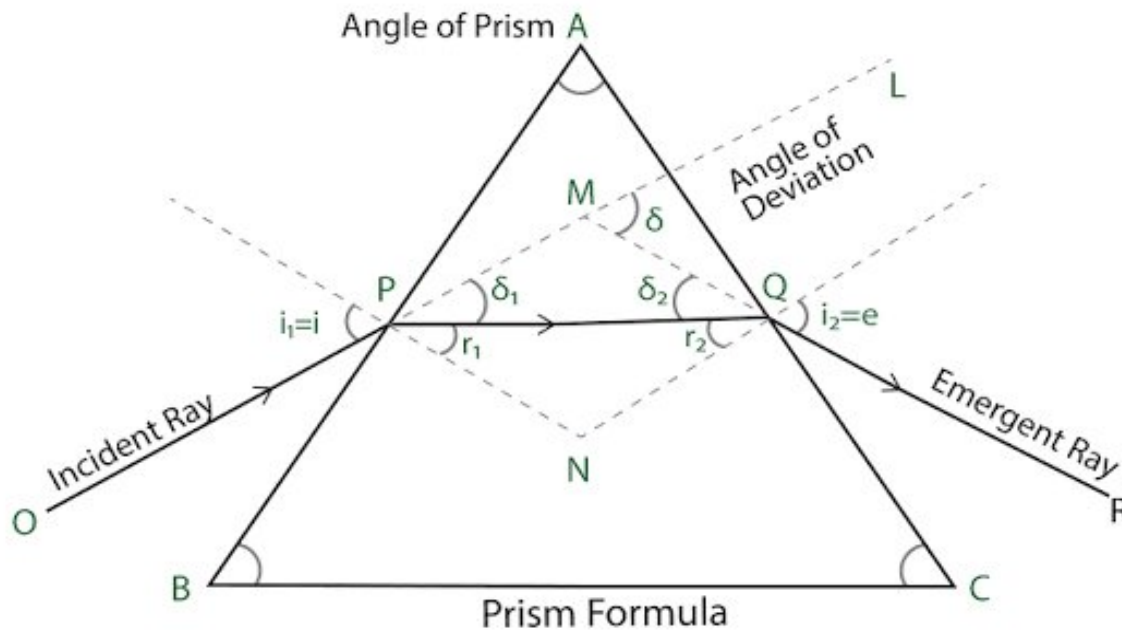
The angle of minimum deviation is related to the refractive index as:

$$\mu = \sin[(A + \delta_m)/2] / \sin(A/2)$$

$n = \frac{\sin(A + D_m)}{\sin(A/2)}$ This is useful to calculate the refractive index of a material. Rainbows and haloes occur at minimum deviation. Also, a thin prism is always set at minimum deviation.

In minimum deviation, the refracted ray in the prism is parallel to its base. In other words, the light ray is symmetrical about the axis of symmetry of the prism.^{[1][2][3]} Also, the angles of refractions are equal i.e. $r_1 = r_2$. The angle of incidence and angle of emergence equal each other ($i = e$). This is clearly visible in the graph below.

The formula for minimum deviation can be derived by exploiting the geometry in the prism. The approach involves replacing the variables in the Snell's law in terms of the Deviation and Prism Angles by making the use of the above properties.



$$\mu = \sin[(A + \delta_m)/2] / \sin(A/2)$$

4. Procedure

A. Preliminary adjustment of the spectrometer

- Place the spectrometer on a stable table and level it using the levelling screws.
- Focus the eyepiece on the cross-wires so that they appear sharp.
- Focus the telescope on a distant object or use the collimator to obtain a parallel beam.
- Adjust the collimator so that the slit is narrow, vertical, and clearly focused.

B. Measurement of the angle of the prism

- Place the prism on the prism table with its refracting edge approximately facing the collimator.
- Observe the reflected image of the slit from one face of the prism and bring it exactly on the vertical cross-wire by rotating the telescope.
- Note the telescope reading on both verniers.
- Repeat the observation for the reflected image from the other face of the prism.
- The difference between the two telescope positions gives $2A$; hence A is half of this difference.

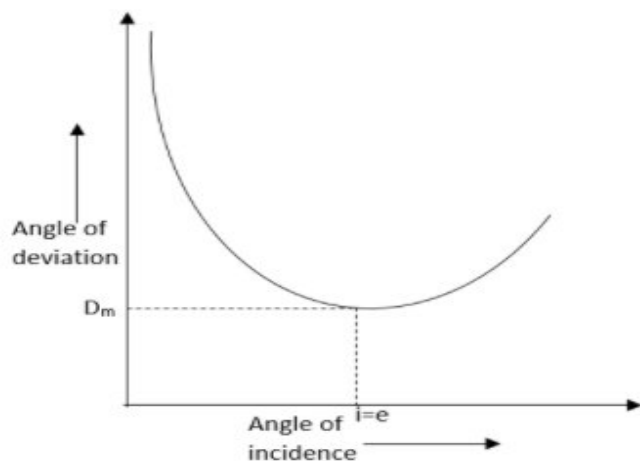
C. Determination of minimum deviation

- Place the prism in the position of minimum deviation and observe the refracted image through the telescope.
- Slowly rotate the prism table and follow the image with the telescope.
- The image will move in one direction, become momentarily stationary, and then move in the opposite direction. The stationary position corresponds to minimum deviation.
- Set the image exactly on the vertical cross-wire and note the telescope readings on both verniers.
- Remove the prism and observe the direct image of the slit. Note the corresponding telescope readings.
- The difference between the direct-ray and minimum-deviation positions gives the angle of minimum deviation, δ_m .

5. Observation Table

Observation	Vernier I (°)	Vernier II (°)	Mean (°)	Remarks
Reflected image from face I				
Reflected image from face II				
Direct image				
Minimum deviation image				

Plot



6. Calculations

Angle of prism:

$$A = \frac{1}{2} \times (\text{difference between the two reflected-image telescope positions})$$

Angle of minimum deviation:

δm = difference between the direct-image and minimum-deviation telescope positions

If required, refractive index of the prism can be calculated using:

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

7. Result

The angle of the given prism is $A = \underline{\hspace{2cm}}$ ° and the angle of minimum deviation is $\delta m = \underline{\hspace{2cm}}$ °.

8. Precautions

- The spectrometer should be properly levelled before taking observations.
- The slit should be narrow and vertical for accurate readings.
- The prism faces and optical surfaces should be clean.

- The telescope and collimator should be properly focused.
- Read both verniers to reduce observational error.
- For minimum deviation, the prism should be adjusted carefully so that the refracted image is at the turning point.
- Avoid parallax while aligning the cross-wire with the image.

9. Sources of Error

- Improper focusing or levelling of the spectrometer.
- Parallax while taking readings.
- Finite width of the slit and spectral image.
- Error in identifying the exact minimum-deviation position.
- Instrumental or vernier reading errors.

STANDARD OPERATING PROCEDURE (SOP)

Aim: To study the diode as a clipping and clamping element.

1. Objective

To study the operation of a PN junction diode as a clipper and a clamper circuit, and to observe the corresponding changes in the shape and DC level of an AC input waveform.

2. Apparatus and Materials

- PN junction diode(s)
- Resistors and capacitors of suitable values
- DC bias supply, where required
- Function generator/signal generator
- CRO or digital storage oscilloscope
- Breadboard or electronics experiment kit
- Connecting wires and probes

3 Theory

Clipping Circuits (Voltage Limiters)

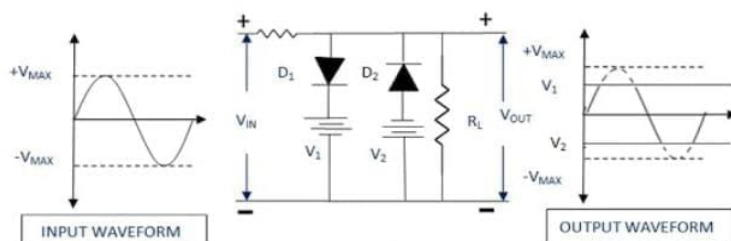
A clipper circuit removes or "clips" a specific portion of an input voltage waveform (above or below a set reference level) without distorting the remaining part of the signal.

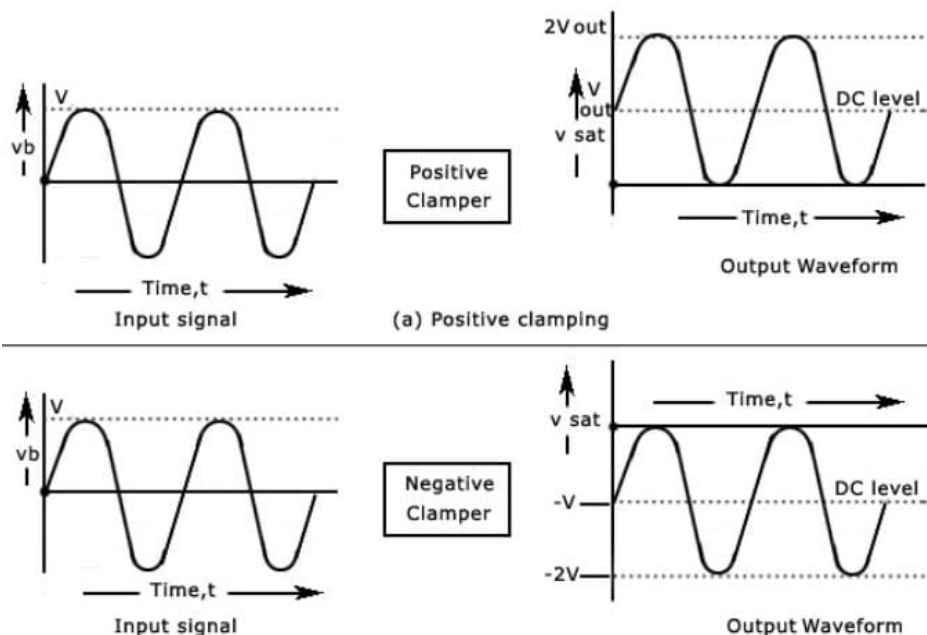
- **Series Clipper:** The diode is in series with the load resistor. The output is taken across the resistor or the diode depending on configuration.
- **Shunt/Parallel Clipper:** The diode is connected in parallel (shunt) with the output load.
- **Biased Clipper:** A DC battery is added in series with the diode to set a custom clipping threshold level For a visual walkthrough of testing positive and negative clippers:

Clamping Circuits (DC Level Shifters)

A clamper circuit shifts the entire AC input signal upward or downward to a new DC reference level without changing the peak-to-peak shape or size of the original waveform. It uses an energy storage capacitor in combination with a diode.

- **Positive Clamper:** Shifts the entire waveform toward the positive DC region so the negative peak aligns with 0V (or a chosen DC reference).
- **Negative Clamper:** Shifts the entire waveform toward the negative DC region so the positive peak aligns with 0V





Principle

A diode clipper is a wave-shaping circuit that removes or limits a selected portion of an input waveform without significantly affecting the remaining portion. Depending on the diode orientation and bias, positive, negative, or biased clipping can be obtained.

A diode clamper shifts the entire waveform to a different DC level while maintaining approximately the same peak-to-peak amplitude. A capacitor stores charge during one half-cycle and, together with the diode, produces the required DC level shift.

4. Procedure – Clipper Circuit

1. Assemble the required diode clipper circuit on the breadboard according to the laboratory circuit diagram.
 2. Connect the function generator to the input and set a suitable sinusoidal or square-wave signal.
 3. Connect the oscilloscope to display the input and output waveforms simultaneously.
 4. Adjust the input amplitude and frequency to the specified values.
 5. Observe the output waveform and record the clipping level and waveform shape.
 6. Reverse the diode orientation or change the bias arrangement to obtain the required positive/negative or biased clipping characteristic.
 7. Record the input and output waveforms for each configuration.
- Clamper Circuit**
8. Assemble the required diode clamper circuit using the specified diode and capacitor.
 9. Apply the AC input from the function generator while keeping the input amplitude and frequency within the recommended range.
 10. Connect the oscilloscope to observe the input and clamped output waveforms.
 11. Adjust the circuit as required to obtain positive or negative clamping.
 12. Observe the DC level shift of the output waveform and record the maximum and minimum output voltages.
 13. If a biased clamper is used, apply the specified DC bias and observe the resulting clamping level.

6. Observations – Clipper

S. No.	Input Vpp (V)	Input Frequency (Hz)	Output Vpp (V)	Clipping Level (V)

7. Observations – Clamper

S. No.	Input Vpp (V)	Frequency (Hz)	Vmax (V)	Vmin (V)	DC Level Shift (V)

8. Waveforms and Analysis

Use the oscilloscope to compare the input and output waveforms. For the clipper, identify the portion of the waveform that has been removed or limited. For the clamper, verify that the waveform is shifted upward or downward while its approximate peak-to-peak amplitude remains nearly unchanged.

9. Result

The PN junction diode is studied as a clipping and clamping element. The observed output waveforms show that the diode can selectively clip portions of an input waveform and can shift the DC level of an AC waveform.

Clipper configuration studied: _____

Clamping configuration studied: _____

10. Precautions

- Check the diode polarity and circuit connections before switching on the supply.
- Use voltage and frequency settings within the ratings of the diode, capacitor, and other components.
- Do not exceed the maximum input voltage of the oscilloscope.
- Use suitable probe grounding and avoid short circuits in the circuit.
- Allow the capacitor to charge sufficiently before taking clamper measurements.
- Keep the input amplitude and frequency constant while comparing different circuit configurations.

STANDARD OPERATING PROCEDURE (SOP)

Aim: To study the characteristics of GM counter and draw the plateau curve.

1. Objective

To study the characteristics of a Geiger-Müller (GM) counter and to draw the plateau curve by measuring the count rate at different applied voltages.

2. Apparatus and Materials

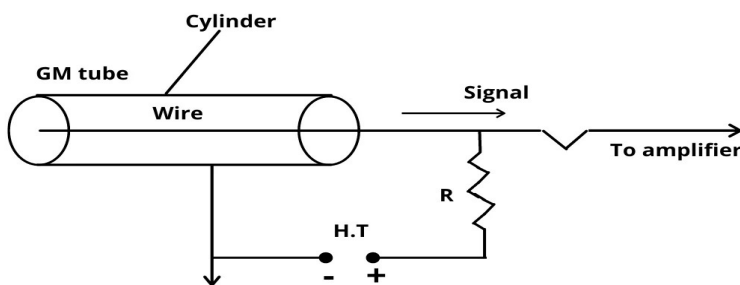
- GM counter with suitable housing
- High-voltage (HV) power supply (as specified for the instrument)
- Scaler/counter
- Connecting cables
- Radioactive source (as authorized for the laboratory)
- Laboratory notebook and pen.

3. Theory

A Geiger Muller counter consists of a fine wire (usually made of tungsten) mounted along the axis of a cylindrical cathode made of glass or metal with a metalized inner coating and filled with a suitable gas mixture.

The gas mixture usually consists of the organ (90%) at 10 cm of Hg and ethyl alcohol (10%) at 1 cm of Hg. The diameter of the cylindrical cathode or tube varies from 1cm to 5 cm and its length varies from 2cm to 100cm depending on the purpose for which it is to be used.

The circuit to which the Geiger Muller tube is connected to detect the radiation is shown in the figure. A high voltage is established across the cylinder and the wire.



Geiger muller counter diagram

When ionizing radiation passes through the gas in the Geiger Muller tube, the ionization of gas molecules takes place. The electrons produced in the process of ionization are attracted towards the central wire and counted as a single voltage pulse.

The wire (i.e anode) is surrounded by the slow-moving positive ions sheath which in turn reduces the electric field. As a result of this decreased electric field, the discharge stops. The discharge continues to cease till the positive ions around the wire move away from it. Since it is positive and takes enough time to move away from the anode, so during this period of time, the Geiger Muller counter remains **insensitive** or **dead**.

This time period is known as **dead time**. Thus, the **dead time of a Geiger Muller counter is the time during which the counter fails to record any other ionizing particle entering the counter.**

As the positive Ions move away from the anode (i.e. central wire) toward the cathode, the value of the electric field increases and another electric discharge takes place due to the production of electrons when positive ions strike the wall of the cathode. As a result of this, the continuous electric discharge takes place and the counter is not ready to receive another incident particle.

In order to record the chain of incident particles (i.e. ionizing particles), it is essential that the electric discharge caused by the first ionizing particle is completely **quenched** before the arrival of a new particle.

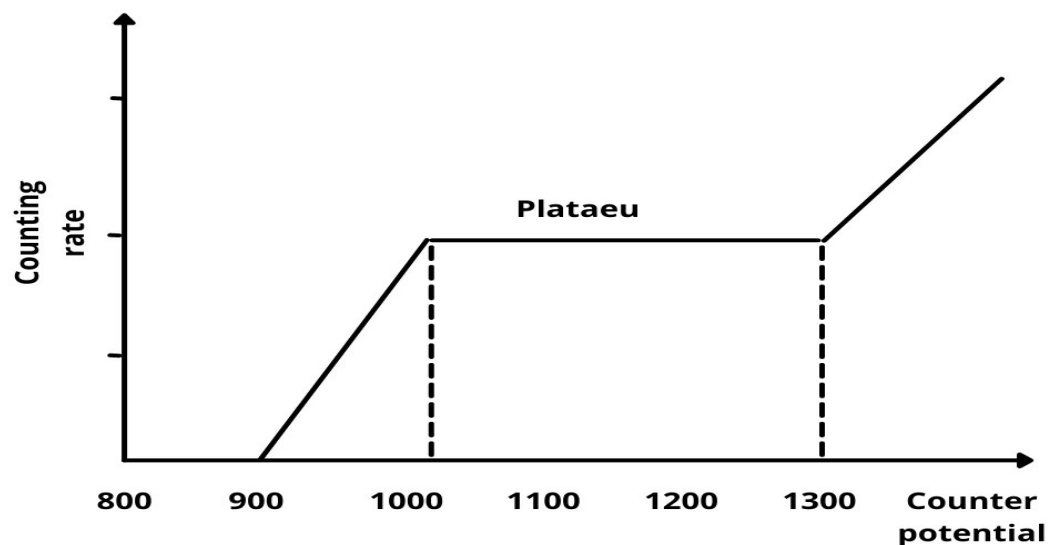
Though **quenching** depends upon a number of parameter like voltage, shape, and size of the counter it is the mixture of the gas which is of vital importance. Alcohol has a low ionization potential of 11.3 eV and Argon has an ionization potential of 15.7eV. Argon ion gets neutralized by acquiring an electron from the alcohol molecules.

This means that the ions reaching the cathode are particularly that of alcohol, where they get neutralized. The energy which these ions carry is absorbed in dissociating the alcohol molecule. The alcohol vapor also absorbs the ultraviolet photons emitted during the avalanche stage and prevent them from ejecting photoelectrons from the cathode.

This means that **ethyl alcohol has two specific functions**. First, it prevents the photoelectric effect of the quanta at the cathode. Second, it prevents the creation of secondary electrons, when the positive ions impinge on the cathode.

GM counter Working

The operation of a Geiger Muller counter is explained as follows: A radioactive source whose half-life period is very long compared with the duration of the experiment is taken and placed at a suitable distance from the counter. The applied voltage is gradually increased in steps keeping the source counter assembly undisturbed.



When the applied potential is low, the multiplication factor (m) shall below show the output pulse will not be strong enough even to operate the mechanical counter. The counting rate shall therefore be zero.

As the counter potential is raised, the multiplication factor increases, and more and more of the ionizing particles, starting with the ones which produce maximum ionization in the counter, start getting counted.

When the high voltage is reached, secondary ionization takes place and we find that there is a region where the number of impulses increases almost linearly with the applied voltage. This is known as the multiplication region where the total number of Ions produced is proportional to the number of original ions. This region is most suitable for proportional counters.

The counting rate rises and soon the Geiger region is reached when pulse due to all the ionizing particles become of the same size and are recorded, This operating potential is called Geiger threshold.

When the voltage is increased beyond the threshold, the counting rate remains the same for a large variation in counter potential though the pulse height rises. The pulse rate remains the same as all the particles are being counted.

This straight portion of the curve is called a Plateau. This plateau a continuous, till the excess potential over the threshold, called the overvoltage become so high that the counter breaks down into continuous discharge.

For a good Geiger Muller counter, the plateau region extends over 200 V. The operating point is so chosen that the value of overvoltage is not critical and small fluctuations in it do not affect the counting rate.

Recovery Time and Resolving time

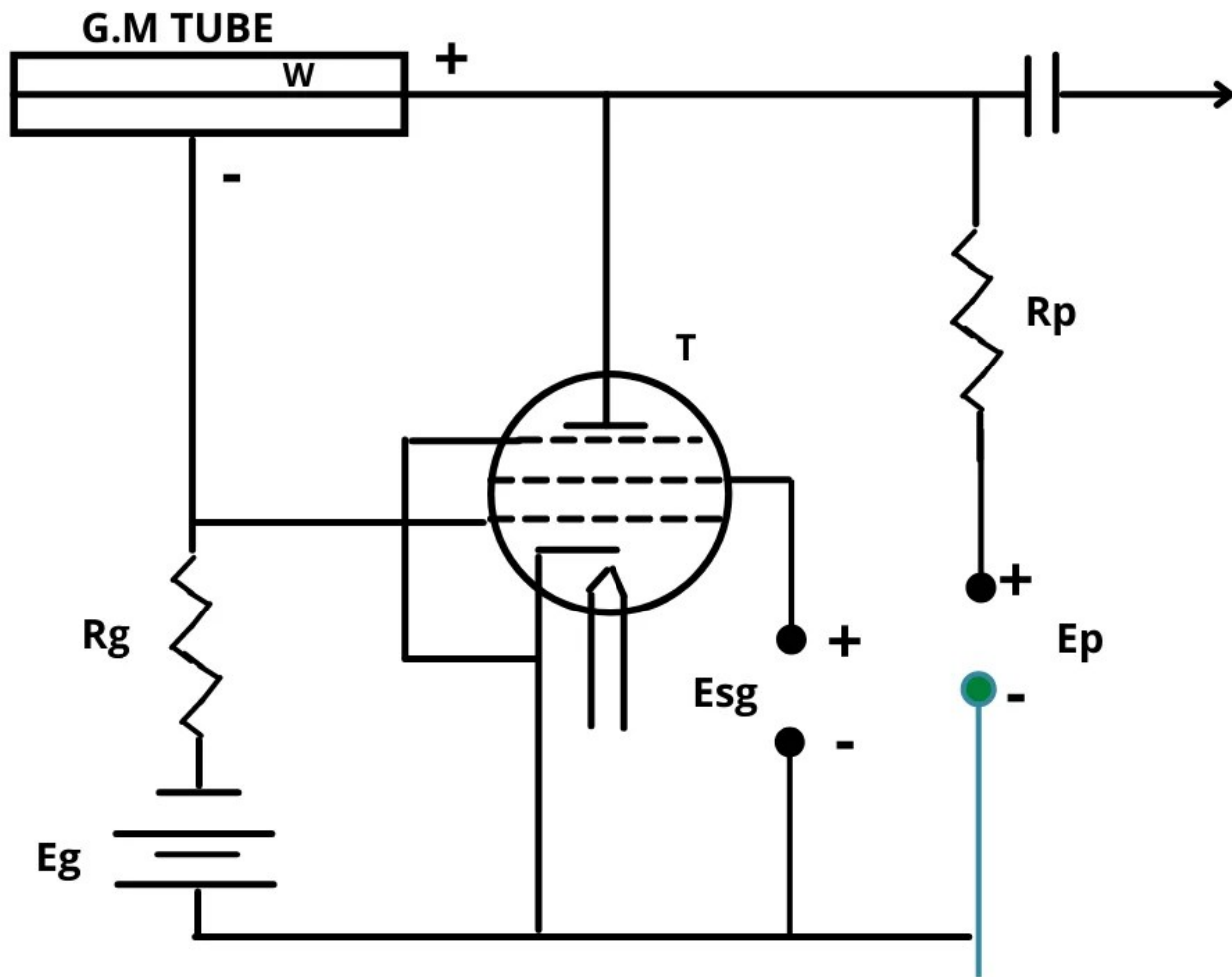
The counter remains dead or insensitive till the positive ions have moved sufficiently away from the avalanche sites to put the wire back at the Geiger threshold potential. The counter is insensitive to further ionization pulses as the ion sheath moves towards the small.

The time for which the counter is dead is called **dead time or resolving time**. The recovery time is the time after which the original pulse levels are restored. The usual resolving time of the order of 100 limits the counting rates of G.M. tubes to about 5000 pulses per second.

Electronic Circuit for External Quenching

Neher and Harper used the following circuit for external quenching where self-quenching is not possible. The wire W is connected to the plate of the pentode (T). The outer cylinder is connected to the control grid.

R_p is the plate load which is of the order of 2 Megohms, R_g ranges from 1 to 15 megohms. E_p is the plate voltage, whereas E_g is the grid bias. The grid bias is adjusted in such a way that no plate current flows before the arrival of the ionizing agent.



On the arrival of the ionizing particle, the gas gets ionized and the current flow in the plate circuit because the grid becomes less negative.

If the change in the [grid voltage](#) is sufficient, the voltage drop in R_p will result in the effective counter voltage dropping below the threshold value. Thus the counter discharge is extinguished and the circuit recovers to its original condition.

Efficiency of Geiger Muller Counter

The efficiency of the Geiger Muller counter is defined as the ratio of the number of particles of radiation detected to the number of particles of radiation emitted.

That is,

$$\eta = \frac{\text{Number of particles of radiation detected}}{\text{Number of particles of radiation emitted}}$$

if α -particles do not have very high energy, they are absorbed by the gas and enclosed in the cylinder. β -particles cause ionization of gas molecules in the Geiger Muller tube and hence Geiger Muller counter is most efficient for detecting β -particles.

γ -rays are detected when they scatter an electron in the Geiger Muller tube enclosing the gas. Thus, Geiger Muller counter detects all types of radiation: α , β , and γ but it is not most efficient for β -particles.

Advantages of Geiger Muller counter

Geiger Muller counter has the following advantages:

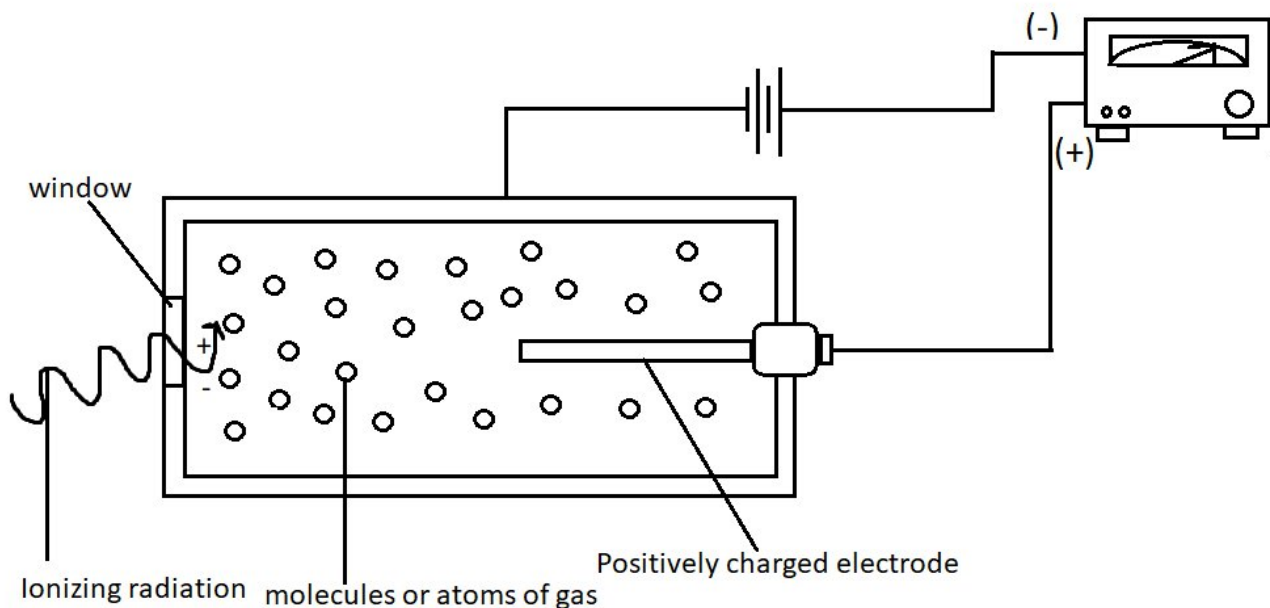
1. It is durable and easily portable.
2. It is a low-cost device.
3. It can detect all types of radiation. i.e α , β , and γ radiations.

Disadvantages of Geiger Muller counter

1. Its efficiency is low.
2. The output pulse from a Geiger Muller counter is always of the same magnitude irrespective of the energy of the incident radiation. Therefore, the Geiger Muller counter can detect all types of radiation but it cannot distinguish which type of radiation is detected.
3. It cannot determine the [energy](#) of the detected radiation.
4. During the dead time, it cannot detect any incident radiation. Therefore the measured count in the Geiger Muller counter is less than the actual count.

5. Principle

A GM counter operates in the Geiger region, where the count rate is nearly independent of the applied voltage. At low voltage, gas multiplication is incomplete and the count rate is low. As voltage increases, the count rate rises and then becomes nearly constant over a range of voltage called the plateau region. Beyond the plateau, continuous discharge can occur and the count rate may rise again.



4. Procedure

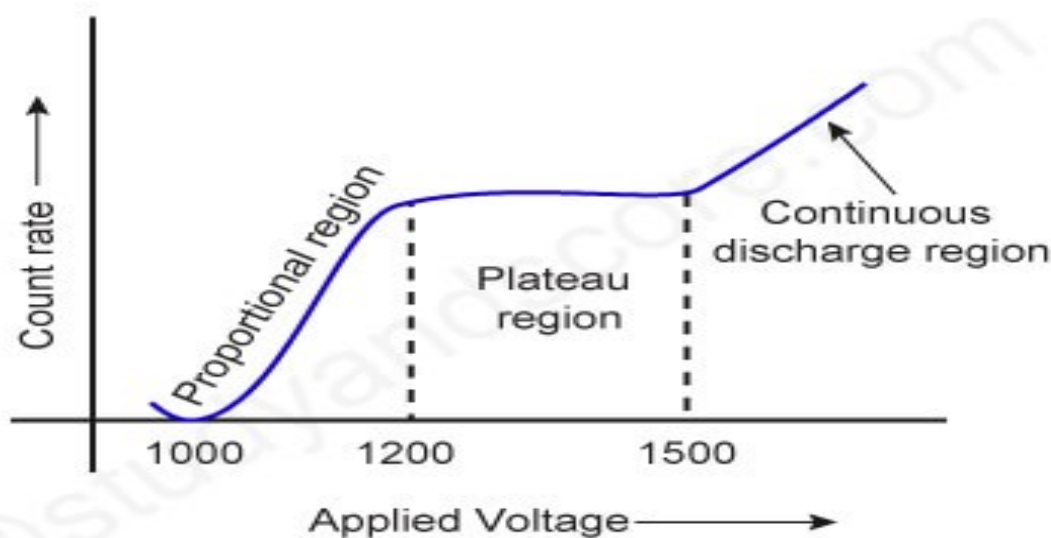
1. Set up the GM counter, HV supply, and scaler/counter according to the laboratory setup.
2. Place the radioactive source at a fixed position and distance from the GM detector.
3. Keep the source-to-detector geometry unchanged throughout the experiment.
4. Set the high voltage to the minimum recommended value for the GM tube.
5. Record the applied voltage and count for a fixed time interval (e.g., 60 s).
6. Increase the voltage in equal steps. At each voltage, record the count for the same time interval.
7. Continue until the count rate shows a nearly constant region followed by a rising trend.
8. Calculate count rate using: $\text{Count rate} = \text{Number of counts} / \text{Counting time}$.

5. Observations

S. No.	Applied Voltage (V)	Time (s)	Counts (N)	Count Rate (counts/s)

6. Plot

Plot Count Rate (counts/s) on the Y-axis against Applied Voltage (V) on the X-axis. The nearly horizontal portion of the graph represents the plateau region.



GEIGER-MULLER COUNTER: PLATEAU GRAPH

7. Result

The characteristics of the GM counter are studied and the plateau curve is obtained. The plateau region is identified as the voltage range over which the count rate remains nearly constant.

8. Precautions

- Keep the source at a fixed position and distance from the detector.
 - Use the same counting time at every voltage setting.
 - Do not exceed the maximum voltage specified for the GM tube.
 - Ensure proper earthing and secure electrical connections.
 - Handle and store the radioactive source only according to the laboratory's radiation-safety rules.
- .

STANDARD OPERATING PROCEDURE (SOP)

Investigation of Diamagnetism, Paramagnetism and Ferromagnetism

1. Aim

To investigate and distinguish the magnetic behaviour of diamagnetic, paramagnetic and ferromagnetic materials by observing their response to an applied magnetic field.

2. Apparatus Required

- Electromagnet / strong permanent magnet with pole pieces
- DC power supply
- Magnetic field control arrangement
- Samples of diamagnetic, paramagnetic and ferromagnetic materials
- Sample holder / balance arrangement as provided with the laboratory kit
- Gauss meter or magnetic field meter, if available
- Connecting wires and other accessories

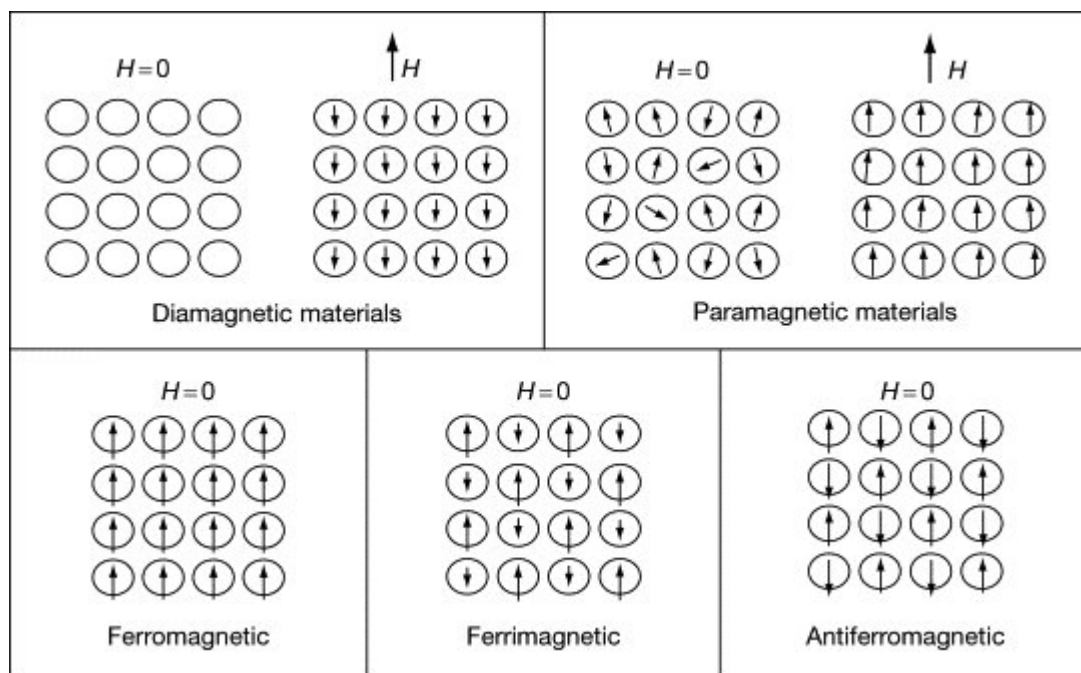
3. Principle / Theory

Magnetic materials are classified according to their response to an externally applied magnetic field. The magnetic susceptibility χ indicates the degree to which a material becomes magnetized in an applied field.

Diamagnetic materials have a weak, negative susceptibility to magnetic fields. Diamagnetic materials are slightly repelled by a magnetic field and do not retain the magnetic properties when the external field is removed. In diamagnetic materials all the electrons are paired so there is no permanent net magnetic moment per atom. Diamagnetic properties arise from the realignment of the electron paths under the influence of an external magnetic field. Most elements in the periodic table including copper, silver, and gold, are diamagnetic.

Paramagnetic materials have a small, positive susceptibility to magnetic fields. These materials are slightly attracted by a magnetic field and do not retain the magnetic properties when the external field is removed. Paramagnetic properties are due to the presence of some unpaired electrons, and from the realignment of the electron paths caused by the external magnetic field. Paramagnetic materials include magnesium, molybdenum, lithium, and tantalum.

Ferromagnetic materials have a large, positive susceptibility to an external magnetic field. They exhibit a strong attraction to magnetic fields and are able to retain their magnetic properties after the external field has been removed. Ferromagnetic materials have some unpaired electrons so their atoms have a net magnetic moment. They get their strong magnetic properties due to the presence of magnetic domains. In these domains, large numbers of atom's moments (10^{12} to 10^{15}) are aligned parallel so that the magnetic force within the domain is strong. When a ferromagnetic material is in the unmagnetized state, the domains are nearly randomly organized and the net magnetic field for the part as a whole is zero. When a magnetizing force is applied, the domains become aligned to produce a strong magnetic field within the part. Iron, nickel, and cobalt are examples of ferromagnetic materials. Components with these materials are commonly inspected using the magnetic particle method.



4. Comparison of Magnetic Materials

Property	Diamagnetic	Paramagnetic	Ferromagnetic	Magnetic susceptibility χ
Response to field	Weakly repelled	Weakly attracted	Strongly attracted	—
Susceptibility	Negative	Small positive	Large positive	—
Magnetic moments	No permanent net moments	Partially align with field	Strong domain alignment	—
Retains magnetization	No	No appreciable retention	Often yes	—

5. Experimental Setup

Place the magnetic sample near the pole pieces of the electromagnet or magnet without allowing unwanted contact. For a laboratory kit, mount the sample according to the manufacturer's arrangement. The applied magnetic field can be varied by changing the current through the electromagnet, if applicable.



S

6. Procedure

1. Identify and label the three samples as diamagnetic, paramagnetic and ferromagnetic (or use known reference samples).
2. Ensure that the electromagnet/pole pieces and measuring arrangement are properly aligned.
3. Keep the magnetic field switched off initially and record the zero/reference reading of the measuring arrangement.
4. Place the first sample in the prescribed position and apply a small magnetic field.
5. Observe the direction and magnitude of the sample's response to the applied field.
6. Increase the magnetic field gradually, if the apparatus permits, and record the corresponding observations.
7. Remove or reduce the magnetic field and observe whether the sample retains any appreciable magnetization.
8. Repeat the procedure for the other two samples under similar conditions.
9. Compare the observations and classify each material as diamagnetic, paramagnetic or ferromagnetic.
10. If magnetic field and magnetization measurements are available, calculate susceptibility using the appropriate relation for the given apparatus.

7. Observation Table

S. No.	Sample	Applied field	Observed response	Attraction/Repulsion	Nature
1					
2					

3					
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8. Calculations

If the experiment provides magnetization M and applied magnetic field H , magnetic susceptibility may be obtained from:

$$\chi = M / H$$

Use the exact field, magnetization and instrument relation specified for the particular laboratory apparatus. For a purely qualitative investigation, classification is made from the observed attraction/repulsion and strength of response.

9. Expected Observations / Result

Diamagnetic material: weak repulsion from the stronger magnetic-field region and negative magnetic susceptibility.

Paramagnetic material: weak attraction toward the stronger magnetic-field region and small positive magnetic susceptibility.

Ferromagnetic material: strong attraction toward the magnetic field and large positive magnetic susceptibility, with possible retention of magnetization.

10. Precautions

- Keep the apparatus on a stable and vibration-free surface.
- Do not place magnetic samples too close to sensitive electronic instruments unless specified by the apparatus instructions.
- Increase or decrease the electromagnet current gradually.
- Avoid heating the sample or electromagnet during prolonged operation.
- Keep the sample position and orientation the same for comparable observations.
- Do not allow strong ferromagnetic samples to snap onto the magnet or pole pieces.
- Keep watches, mobile phones, magnetic cards and other sensitive magnetic objects away from a strong magnetic field.

11. Sources of Error

- Non-uniformity of the applied magnetic field.
- Incorrect positioning or orientation of the sample.
- Instrument zero error or calibration error.
- Variation in electromagnet current.
- External magnetic fields and nearby ferromagnetic objects.
- Temperature changes affecting the magnetic properties of the sample.

12. Viva-Voce Questions

What is diamagnetism? It is the weak magnetic response in which a material is magnetized opposite to the applied magnetic field and is weakly repelled.

What is paramagnetism? It is the weak attraction of a material toward an applied magnetic field due to partial alignment of magnetic moments.

What is ferromagnetism? It is strong magnetism caused by cooperative alignment of magnetic moments in domains.

What is magnetic susceptibility? It is a measure of the magnetization produced in a material by an applied magnetic field; in SI form $\chi = M/H$.

Which materials have negative susceptibility? Diamagnetic materials.

Which material can retain magnetization? Ferromagnetic material can retain appreciable magnetization after the external field is removed.

Give examples of the three types. Diamagnetic: bismuth or copper; paramagnetic: aluminium or platinum; ferromagnetic: iron, cobalt or nickel.

13. Conclusion

The magnetic behaviour of the given samples is investigated by observing their response to an applied magnetic field. The samples can be distinguished as diamagnetic, paramagnetic or ferromagnetic based on the direction and strength of their magnetic response and, where measured, their magnetic susceptibility.

STANDARD OPERATING PROCEDURE (SOP)

Aim: To find the ionisation potential of mercury using the Franck–Hertz experiment.

1. Objective

To study the interaction of electrons with mercury atoms and determine the characteristic energy required for excitation/ionisation of mercury using the Franck–Hertz apparatus.

2. Apparatus and Materials

- Franck–Hertz apparatus with mercury-filled tube
- Heater/temperature control unit
- Accelerating-voltage supply
- Retarding-voltage supply
- Collector/current measuring unit or microammeter
- Connecting leads
- Graph paper or computer for plotting the characteristic curve

3. Principle/Theory

The Franck–Hertz experiment demonstrates the quantised interaction between electrons and atoms. Electrons emitted by a heated cathode are accelerated through mercury vapour. As the accelerating voltage is increased, the collector current varies periodically because electrons undergo inelastic collisions with mercury atoms at specific electron energies.

The positions of successive minima or maxima in the collector-current versus accelerating-voltage curve give the characteristic excitation energy of mercury. The corresponding excitation potential is obtained from the separation between successive features of the curve. If the laboratory manual specifically defines the requested value as the ionisation potential, use the prescribed analysis and reference value for mercury; the Franck–Hertz experiment directly measures the first excitation energy.

The standard ionization potential of mercury is 10.39 volts (V), which corresponds to an ionization energy of about 10.39 electron-volts (eV).

Ionization Potential

- Definition: The minimum potential difference needed to accelerate an electron so it gains enough energy to knock a loose electron completely out of a neutral mercury atom.
- How it works: In physics lab experiments using a mercury-vapor diode or thyratron tube, raising the plate voltage increases the current slowly. At 10.39 V, electrons gain sufficient energy for inelastic collisions, creating positive ions and causing a sharp, sudden rise in the measured current

Difference from Excitation Potential

- Excitation Potential: The lower energy (about 4.9 V in mercury) required only to bump an electron to a higher orbit, not remove it.
- Ionization Potential: The higher energy required to free the electron from the atom
-

4. Procedure

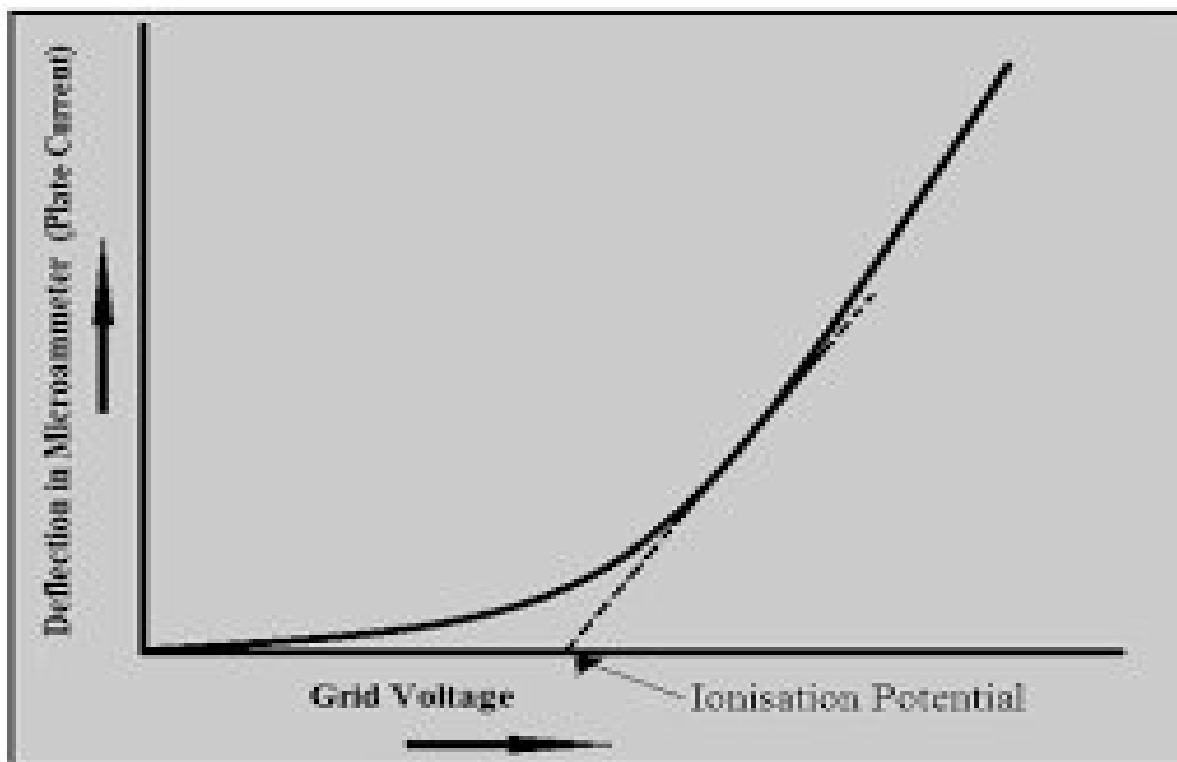
1. Set up the Franck–Hertz apparatus according to the manufacturer's/laboratory manual instructions.

2. Switch on the apparatus and allow the mercury tube and control electronics to reach the specified operating condition.
3. Set the retarding voltage to the value recommended for the apparatus.
4. Set the accelerating voltage to its initial value and record the collector current.
5. Increase the accelerating voltage gradually in equal steps and record the corresponding collector current.
6. Continue the measurements over the voltage range required to obtain several successive maxima and minima in the collector current.
7. Plot collector current on the Y-axis against accelerating voltage on the X-axis.
8. Determine the voltage separation between successive corresponding maxima or minima.
9. Use the appropriate relation given in the laboratory manual to determine the characteristic potential/energy of mercury.
10. Compare the experimental value with the accepted/reference value and calculate the percentage error, if required.

5. Observations

S. No.	Accelerating Voltage (V)	Collector Current (μA)	Remarks

Plot



6. Calculations

1. Identify the successive maxima or minima of the Franck–Hertz curve.
2. Calculate the voltage difference ΔV between successive corresponding maxima/minima.
3. Determine the characteristic excitation potential from the average value of ΔV , after applying any correction specified in the laboratory manual.
4. For an energy value, use $E = eV$, where e is the elementary charge and V is the corresponding potential.
5. If the experiment manual requires an ionisation-potential calculation, follow its stated relation and use the measured characteristic voltage accordingly.

7. Result

The Franck–Hertz characteristic curve for mercury is obtained, and the characteristic potential of mercury is determined from the separation of successive current maxima/minima.

Experimental characteristic potential = _____ V

Experimental value requested by the laboratory manual = _____

8. Precautions

- Allow the apparatus to reach the specified operating temperature before taking observations.
- Keep the retarding voltage and other control settings constant while recording a voltage scan.
- Increase the accelerating voltage gradually and avoid exceeding the apparatus limits.
- Take readings only after the collector current has stabilised sufficiently.
- Do not touch the heated tube or other hot parts of the apparatus.
- Follow the manufacturer's safety instructions for electrical connections and the mercury-filled tube.

STANDARD OPERATING PROCEDURE (SOP)

Aim: To find the value of Planck's constant using a photocell.

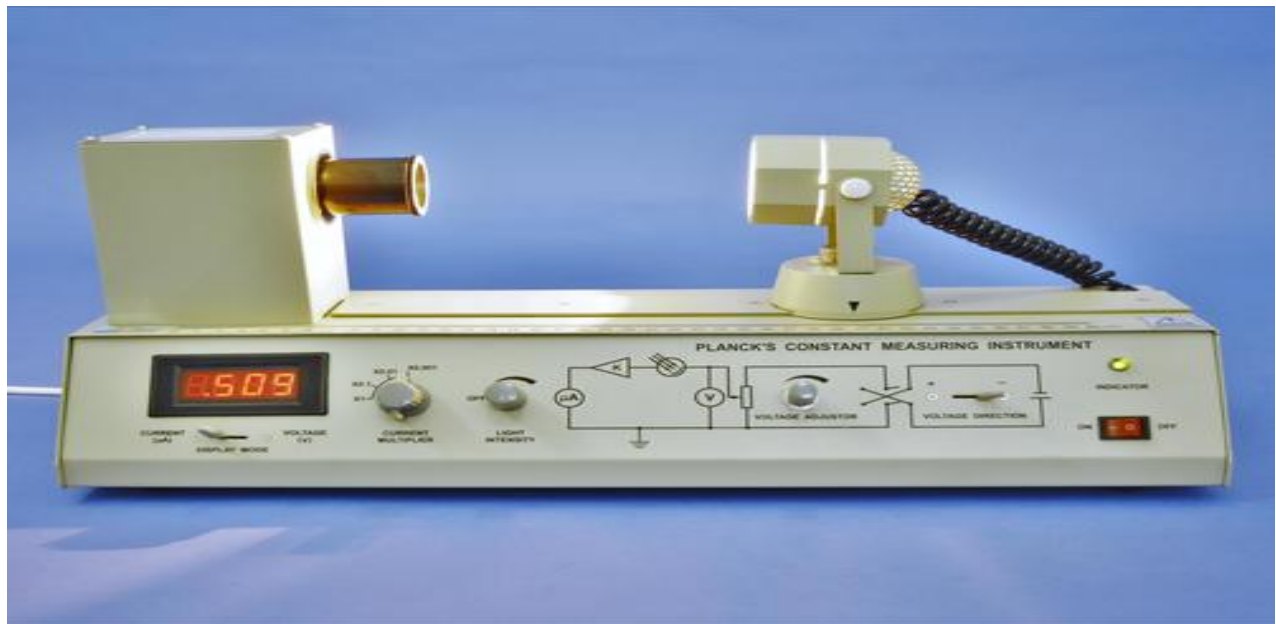
1. Objective

To determine Planck's constant (h) by studying the photoelectric effect using a photocell, different wavelengths of monochromatic light, and the corresponding stopping potentials.

2. Apparatus and Materials

- Photocell/photoelectric cell
- Light source with suitable monochromatic filters or LEDs of different wavelengths
- Variable DC power supply/potentiometer
- Microammeter or sensitive current meter
- Voltmeter/digital voltmeter
- Connecting wires and switch
- Optical bench or suitable mounting arrangement
- Filters of known wavelengths

Diagram



3. Principle/Theory

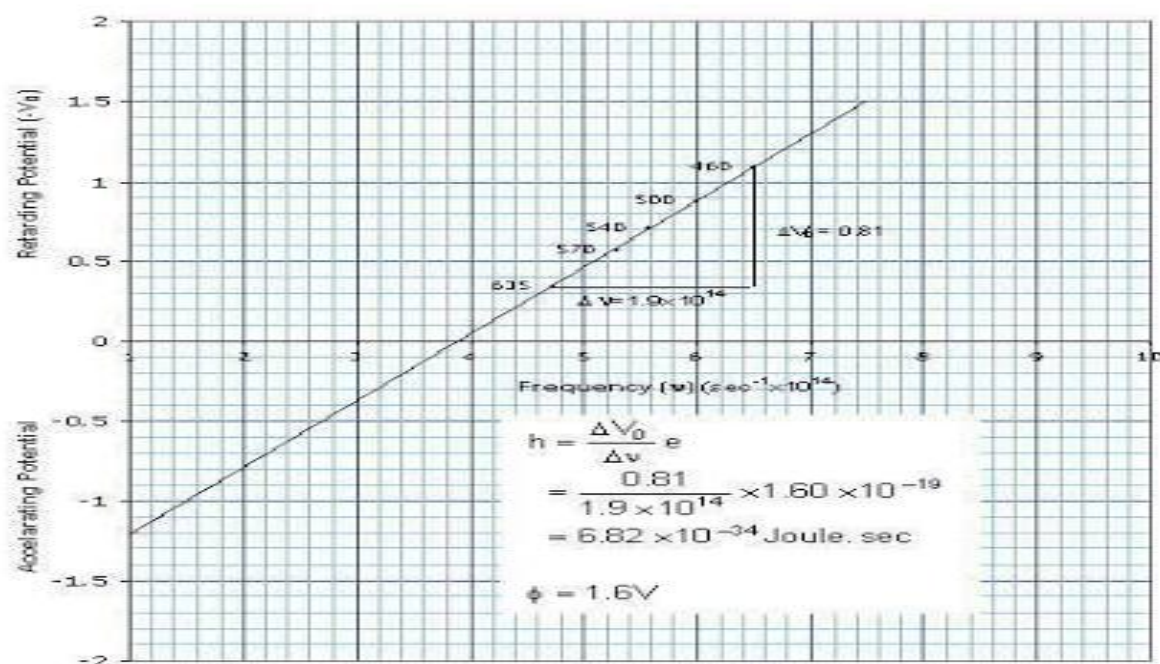
Photo electric effect is the liberation of electrons from the surface of a material by absorption of energy from incident light. For each metal, there exists a minimum binding energy for electron, which is a characteristic of the element, called the work function. When a photon strikes a bound electron, it transfers its energy to the electron. If this energy is less than the metal's work function, the photon is remitted and no electrons are liberated. If this energy is greater than an electron's binding energy, the electron escapes from the metal with a kinetic energy equal to the difference between the photon's original energy and the electron's binding energy.

The stopping potential is measured by varying the anode voltage until the current drops to zero. The slope of a plot of stopping potential versus frequency is the value of the ratio, h/e . Hence the value of Planck's constant (h) and work function of the material can be determined. This instrument also imparts students, fundamental understanding of the quantum nature of light.

According to Einstein's photoelectric equation, the energy of an incident photon is used partly to overcome the work function of the photocathode and the remainder appears as the maximum kinetic energy of the emitted photoelectrons.

$$h\nu = \phi + K_{\max} = \phi + eV_0$$

Therefore, $V_0 = (h/e)\nu - \phi/e$. A plot of stopping potential V_0 against frequency ν is a straight line. The slope of this graph is h/e , so Planck's constant is obtained from $h = e \times \text{slope}$.



4. Procedure

1. Connect the photocell, voltmeter, microammeter, and power supply according to the laboratory circuit diagram.
2. Illuminate the photocathode with the first monochromatic light source/filter and keep the geometry fixed.
3. Adjust the applied potential in the retarding direction and observe the photocurrent.
4. Increase the retarding potential until the photocurrent becomes zero or reaches the specified cut-off level. Record this stopping potential V_0 .
5. Repeat the measurement for each available wavelength, keeping the experimental arrangement unchanged.
6. Convert each wavelength λ into frequency using $\nu = c/\lambda$.
7. Prepare a table containing wavelength, frequency, and stopping potential.
8. Plot stopping potential V_0 on the Y-axis against frequency ν on the X-axis.
9. Determine the slope of the straight-line graph.
10. Calculate Planck's constant using $h = e \times \text{slope}$ and compare the experimental value with the accepted value.

5. Observations

S. No.	Wavelength λ (nm)	Frequency ν (Hz)	Stopping Potential V_0 (V)	Remarks

Plot

6. Calculations

1. Calculate the frequency of each light source using $\nu = c/\lambda$.
2. Plot V_0 versus ν and determine the slope of the best-fit straight line.
3. Since slope = h/e , calculate Planck's constant from $h = e \times \text{slope}$.
4. If required, calculate percentage error using the accepted value of Planck's constant.

Experimental Planck's constant, $h =$ _____ J·s

7. Result

The value of Planck's constant is determined from the photoelectric effect using a photocell and the measured stopping potentials for different frequencies of incident light.

$h =$ _____ J·s

8. Precautions

- Use monochromatic light of known wavelength and keep the light intensity arrangement fixed as far as possible.
- Keep the photocell and light source properly aligned throughout the experiment.
- Measure the stopping potential carefully near the zero-current condition.
- Avoid stray light falling on the photocell.
- Check the polarity and electrical connections before taking readings.
- Do not exceed the voltage/current limits of the apparatus.
- Take repeated readings where possible and use a best-fit straight line for determining the slope.

STANDARD OPERATING PROCEDURE (SOP)

Aim: To draw the forward and reverse bias characteristics of a PN junction diode.

1. Objective

To study the current-voltage (I-V) characteristics of a PN junction diode under forward and reverse bias conditions and to determine important parameters such as cut-in voltage and reverse saturation current.

2. Apparatus and Materials

- PN junction diode
- DC power supply
- Milliammeter for forward-bias current measurement
- Microammeter for reverse-bias current measurement
- Voltmeter
- Series resistance/rheostat
- Connecting wires
- Switch/key
- Breadboard or diode characteristic experiment kit

3. Principle/Theory

PN Junction Diode

A PN-junction diode is formed when a p-type semiconductor is fused to an n-type semiconductor creating a potential barrier voltage across the diode junction

The PN junction diode consists of a p-region and n-region separated by a depletion region where charge is stored. The effect described in the previous tutorial is achieved without any external voltage being applied to the actual PN junction resulting in the junction being in a state of equilibrium.

However, if we were to make electrical connections at the ends of both the N-type and the P-type materials and then connect them to a battery source, an additional energy source now exists to overcome the potential barrier.

The effect of adding this additional energy source results in the free electrons being able to cross the depletion region from one side to the other. The behaviour of the PN junction with regards to the potential barrier's width produces an asymmetrical conducting two terminal device, better known as the PN Junction Diode.

A PN Junction Diode is one of the simplest semiconductor devices around, and which has the electrical characteristic of passing current through itself in one direction only. However, unlike a resistor, a diode does not behave linearly with respect to the applied voltage. Instead it has an exponential current-voltage (I-V) relationship and therefore we can not described its operation by simply using an equation such as Ohm's law.

If a suitable positive voltage (forward bias) is applied between the two ends of the PN junction, it can supply free electrons and holes with the extra energy they require to cross the junction as the width of the depletion layer around the PN junction is decreased.

Forward Bias

- Connect the P-type (anode) of the diode to the positive terminal of the DC power supply and the N-type (cathode) to the negative terminal.
- Place a voltmeter in parallel across the diode and a milliammeter in series.
- Measurement: Slowly increase the forward voltage in steps (e.g., 0.1V) using the potentiometer/rheostat.
- Note the corresponding forward current

- Notice that current rises sharply after reaching the knee voltage (~0.7V for Silicon, ~0.2V for Germanium).

By applying a negative voltage (reverse bias) results in the free charges being pulled away from the junction resulting in the depletion layer width being increased. This has the effect of increasing or decreasing the effective resistance of the junction itself allowing or blocking the flow of current through the diodes pn-junction.

Reverse Bias

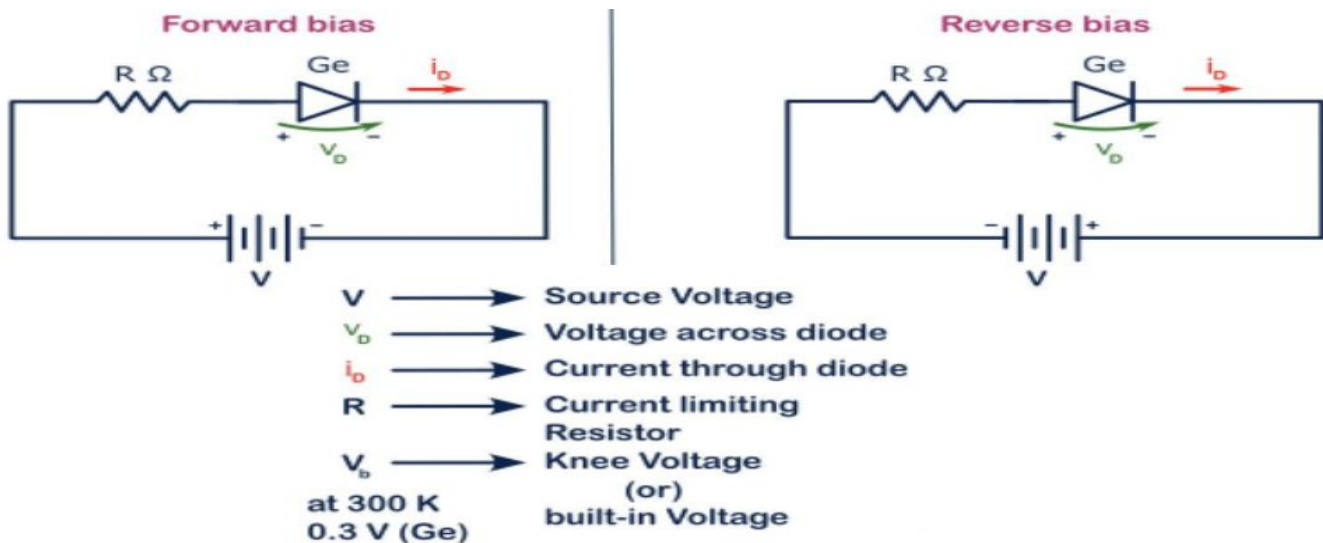
- Connect the P-type (anode) to the negative terminal of the power supply and the N-type (cathode) to the positive terminal.
- Place a voltmeter in parallel and a micro ammeter in series with the circuit.
- Measurement: Increase the reverse voltage in steps (e.g., 1V or 2V) up to high values like 20V–25V.
- Record the tiny reverse saturation current which stays nearly constant until the breakdown voltage is reached

Then the depletion layer widens with an increase in the application of a reverse voltage and narrows with an increase in the application of a forward voltage. This is due to the differences in the electrical properties on the two sides of the PN junction resulting in physical changes taking place. One of the results produces rectification as seen in the PN junction diodes static I-V (current-voltage) characteristics. Rectification is shown by an asymmetrical current flow when the polarity of bias voltage is altered as shown below.

A PN junction diode conducts current readily when it is forward biased and offers very high resistance when it is reverse biased. In forward bias, the applied voltage reduces the depletion-region barrier and the current increases rapidly after the cut-in (knee) voltage. In reverse bias, only a small reverse saturation current flows until breakdown is approached.

$$I = I_0 [e^{(V/\eta V_t)} - 1]$$

The forward and reverse current-voltage readings are used to plot the diode characteristic curve. For a silicon diode, the cut-in voltage is typically around 0.6–0.7 V, while for a germanium diode it is typically around 0.2–0.3 V; the actual value should be obtained experimentally.



4. Procedure

1. Connect the PN junction diode in forward-bias configuration with a suitable series resistance, ammeter, and voltmeter.
2. Check the polarity and electrical connections before switching on the supply.
3. Set the supply voltage to a low value and record the diode voltage and corresponding forward current.
4. Increase the forward voltage gradually in small steps and record the current at each voltage.
5. Continue until sufficient readings are obtained without exceeding the rated current of the diode.
6. Switch off the supply and reconnect the diode in reverse-bias configuration using the appropriate high-resistance/current-measuring arrangement.
7. Increase the reverse voltage gradually and record the small reverse current at each voltage.
8. Do not approach or exceed the diode's breakdown voltage unless the apparatus is specifically designed for a controlled breakdown experiment.
9. Plot forward current versus forward voltage and reverse current versus reverse voltage on the appropriate graph.

5. Forward-Bias Observations

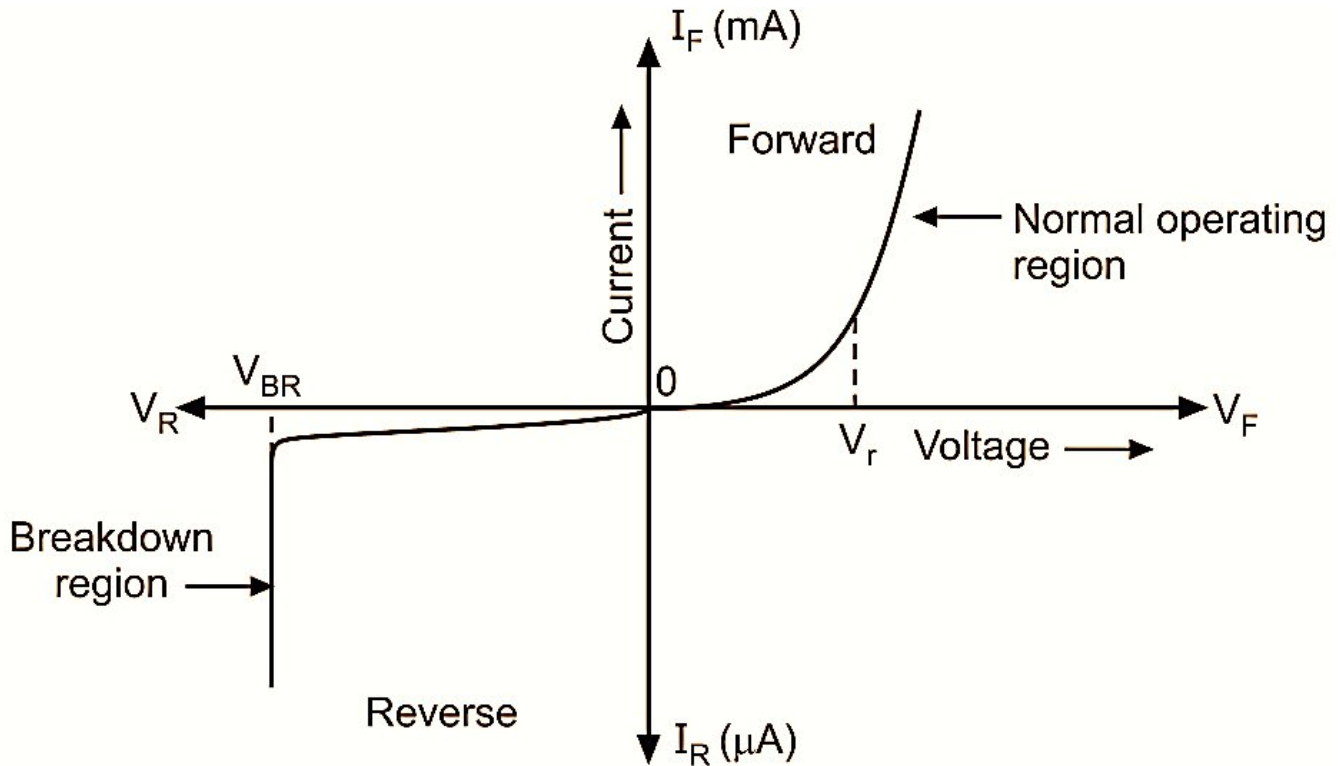
S. No.	Forward Voltage V_F (V)	Forward Current I_F (mA)	Remarks

6. Reverse-Bias Observations

S. No.	Reverse Voltage V_R (V)	Reverse Current I_R (μ A)	Remarks

7. Graph

Plot forward current I_F on the Y-axis against forward voltage V_F on the X-axis. Plot reverse current I_R on the Y-axis against reverse voltage V_R on the X-axis. The forward curve should show a sharp rise after the cut-in voltage, while the reverse curve should show a small nearly constant current in the normal reverse-bias region.



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8. Calculations

1. Identify the cut-in (knee) voltage from the forward characteristic curve.
2. Determine the reverse saturation current from the reverse characteristic, if required.
3. If required by the laboratory manual, calculate the DC or AC (dynamic) resistance from the I-V data.

9. Result

The forward and reverse bias characteristics of the PN junction diode are drawn successfully. The cut-in voltage and reverse current are obtained from the experimental curves.

Cut-in voltage, $V_{\gamma} = \underline{\hspace{2cm}} \text{ V}$

Reverse saturation current, $I_o = \underline{\hspace{2cm}} \mu\text{A}$

10. Precautions

- Check the diode polarity before connecting the circuit.
- Use a suitable series resistance to limit the forward current.
- Increase the voltage gradually and take readings only within the rated limits of the diode and meters.
- Use a sensitive microammeter for measuring the small reverse current.
- Do not exceed the reverse breakdown voltage unless a controlled breakdown experiment is specifically intended.
- Ensure all electrical connections are tight and correct before switching on the supply.

STANDARD OPERATING PROCEDURE (SOP)

Determination of Rydberg Constant Using a Diffraction Grating and Hydrogen Discharge Tube

1. Aim

To determine the value of the Rydberg constant (R) with the help of a diffraction grating and a hydrogen discharge tube by measuring the wavelengths of the visible spectral lines of hydrogen.

2. Apparatus Required

- Spectrometer with collimator and telescope
- Plane transmission diffraction grating of known number of lines per unit length
- Hydrogen discharge tube (H-tube) with suitable power supply
- Spirit level
- Reading lens
- Magnifying glass (if required)
- Blackened screen or suitable dark background

3. Principle / Theory

The history of the study of the distinct colors emitted from excited gases, called spectral lines, dates back to the late 19th century, where we meet a high school mathematics teacher from Basel, Switzerland, named Johann Balmer. Balmer created an equation describing the wavelengths of the visible hydrogen emission lines. However, he did not support his equation with a physical explanation. In a paper written in 1885, Balmer proposed that his equation could be used to predict the entire spectrum of hydrogen, including the ultraviolet and infrared spectral lines. To find the n th wavelength, λ_n , he said to use this formula, the Balmer formula:

$$\lambda_n = B \left(\frac{n^2}{n^2 - 4} \right)$$

where n is an integer greater than 2 (e.g. 3, 4, 5, etc.), and B is Balmer's constant, a number found to make the equation fit the observed spectrum. When one solves the equation, the calculated wavelengths are very close to the four emission lines in the visible light range for a hydrogen gas discharge tube. Balmer apparently derived his equation by trial and error. Sadly, he would not live to see Niels Bohr and Johannes Rydberg prove the validity of his equation. Johannes Rydberg was a mathematics teacher like Balmer (he also taught a bit of physics). In 1890, Rydberg's research of spectroscopy (inspired, it is said, by the work of Dmitri Mendeleev) led to his discovery that Balmer's equation was a specific case of a more general principle that worked for many elements, not just hydrogen. Rydberg substituted the wavenumber, $1/\text{wavelength}$, for wavelength and, by applying appropriate constants, developed a variation of Balmer's equation. The Rydberg equation is given as

$$1/\lambda = R(1/n_f^2 - 1/n_i^2)$$

Here, n_i and n_f are again integers. R is the Rydberg constant. Relating it to the Balmer equation, $RH = 4/B$. For the hydrogen atom, $n_f = 2$, as 2 <http://hyperphysics.phy-astr.gsu.edu/hbase/hyde.html#c4> 160 Last updated June 17, 2014 10.5. In today's lab shown in the first equation. The term $1/\lambda$ is the wavenumber, as expressed by Rydberg in his version of the Balmer equation. Niels Bohr used this equation to show that each line in the hydrogen spectrum corresponded to the release of energy by an electron as it passed from a higher to a lower energy level.

Hydrogen gives a line spectrum consisting of discrete wavelengths. The visible lines belong mainly to the Balmer series, in which the electron falls from a higher energy level n to the level $m = 2$.

The wavelength of a hydrogen spectral line is related to the Rydberg constant by the Rydberg formula:

$$1/\lambda = R(1/2^2 - 1/n^2), \quad n = 3, 4, 5, \dots$$

For a diffraction grating, the condition for principal maxima is:

$$d \sin \theta = n_g \lambda$$

where d is the grating element (distance between corresponding points of adjacent lines), θ is the diffraction angle, n_g is the diffraction order, and λ is the wavelength.

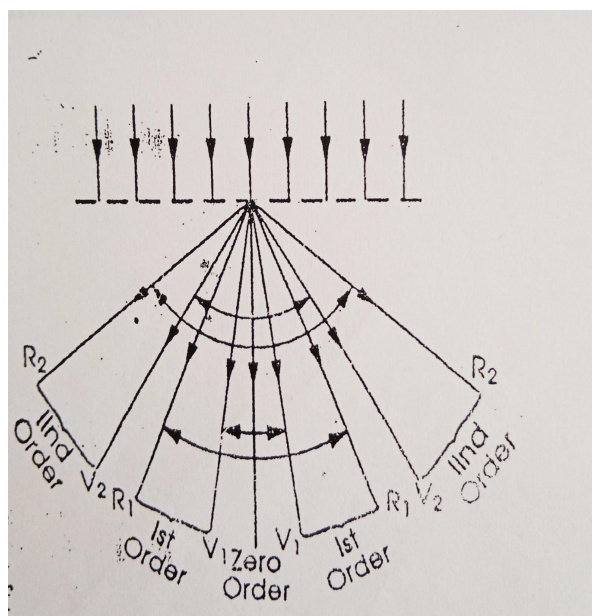
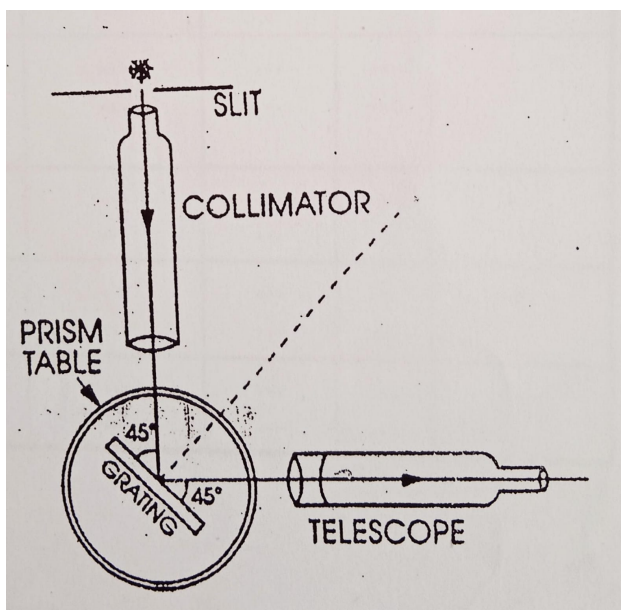
If the grating has N lines per unit length, then $d = 1/N$. The wavelength of each observed hydrogen line is first calculated from the grating equation. The corresponding value of R is then obtained from the Rydberg formula.

4. Identification of Hydrogen Lines

The prominent Balmer lines normally observed are approximately: $H\alpha$ (red), $H\beta$ (blue-green), $H\gamma$ (violet), and $H\delta$ (violet). Their transitions are respectively $3 \rightarrow 2$, $4 \rightarrow 2$, $5 \rightarrow 2$, and $6 \rightarrow 2$. The approximate wavelengths are 656.3 nm, 486.1 nm, 434.0 nm, and 410.2 nm, respectively. These values are used only for identification; experimental wavelengths should be calculated from the measured diffraction angles.

5. Experimental Setup

The hydrogen discharge tube is placed in front of the spectrometer so that its light enters the collimator. A transmission diffraction grating is mounted vertically on the grating table. The telescope is used to observe the diffracted spectral lines on both sides of the central image.



6. Procedure

1. Level the spectrometer and adjust the collimator and telescope for parallel rays and sharp cross-wires.
2. Place the diffraction grating vertically on the grating table with its ruled surface suitably oriented for normal incidence, following the laboratory spectrometer setup.
3. Switch on the hydrogen discharge tube and allow the spectrum to become steady.
4. Observe the undeviated central image and then locate the first-order hydrogen spectral lines on the right and left sides.
5. For each clearly visible Balmer line, bring the vertical cross-wire exactly onto the line and record the telescope reading.
6. Record readings for the same spectral line in the first order on both sides of the central image. Repeat for the second order if the lines are sufficiently distinct.
7. Calculate the diffraction angle θ for each line using the mean of the left- and right-side readings. Use the appropriate angular difference from the central direction.
8. Calculate the wavelength λ using $d \sin \theta = n_g \lambda$, where $d = 1/N$.
9. Identify the transition corresponding to each line: $H\alpha$ ($3 \rightarrow 2$), $H\beta$ ($4 \rightarrow 2$), $H\gamma$ ($5 \rightarrow 2$), $H\delta$ ($6 \rightarrow 2$).
10. For each line, calculate R from $R = [1/\lambda] / [1/2^2 - 1/n^2]$.
11. Take the mean of the R values obtained from the observed lines to obtain the experimental Rydberg constant.
12. Compare the experimental value with the accepted value, approximately $1.097 \times 10^7 \text{ m}^{-1}$, and calculate the percentage error.

7. Observation Table

Line	Transition ($n \rightarrow 2$)	Order n_g	Left reading	Right reading	θ	λ (m)	R (m^{-1})	Mean R
$H\alpha$	$3 \rightarrow 2$							
$H\beta$	$4 \rightarrow 2$							
$H\gamma$	$5 \rightarrow 2$							
$H\delta$	$6 \rightarrow 2$							

8. Calculations

1. Grating element: $d = 1/N$
2. Wavelength: $\lambda = (d \sin \theta)/n_g$
3. Rydberg constant for a line: $R = [1/\lambda] / [1/4 - 1/n^2]$
4. Mean experimental value: $\bar{R} = (R_1 + R_2 + \dots + R_k)/k$
5. Percentage error = $|\bar{R} - R_0|/R_0 \times 100$, where $R_0 \approx 1.097 \times 10^7 \text{ m}^{-1}$.

9. Result

The Rydberg constant for hydrogen is determined experimentally using the diffraction grating and hydrogen discharge tube. The experimental value is:

$$R = \underline{\hspace{2cm}} \times 10^7 \text{ m}^{-1}$$

10. Precautions

- The spectrometer should be properly levelled and the telescope and collimator should be correctly adjusted.
- The grating must be mounted vertically and securely.
- Do not touch the ruled surface of the diffraction grating.
- The hydrogen tube should be operated only with the specified power supply and handled carefully.
- Take readings only after obtaining sharp and well-defined spectral lines.
- Always take readings on both sides of the central image and use their mean to reduce instrumental error.
- Avoid parallax while aligning the cross-wire with a spectral line.
- Use the same diffraction order consistently for calculations.
- Keep the room sufficiently dark to distinguish the weaker violet lines.
- Switch off the discharge-tube supply after completing the experiment.

11. Sources of Error

- Error in spectrometer angle readings.
- Uncertainty in locating the exact centre of a spectral line.
- Imperfect adjustment or alignment of the diffraction grating.
- Limited visibility of higher-order or violet spectral lines.
- Error in the stated number of grating lines per unit length.

STANDARD OPERATING PROCEDURE (SOP)

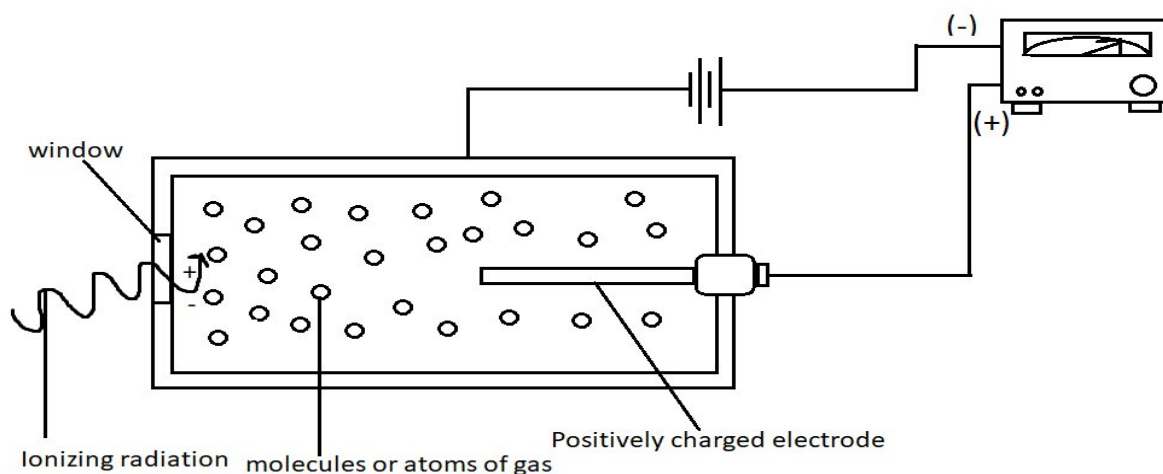
Aim: To study the statistical fluctuation of a GM counter and find the standard deviation (SD) of the observed counts.

1. Objective

To study the random statistical fluctuations in the counting rate of a Geiger-Müller (GM) counter under constant experimental conditions and determine the standard deviation of repeated count measurements.

2. Apparatus and Materials

- GM counter with suitable detector tube and housing
- High-voltage (HV) power supply, as specified for the instrument
- Scaler/counter or digital counting unit
- Connecting cables
- Radioactive source, as authorized for the laboratory
- Stopwatch or timer
- Laboratory notebook and pen



3. Principle/Theory

Geiger-Müller (GM) counters were invented by H. Geiger and E.W. Müller in 1928, and are used to detect radioactive particles. A typical GM Counter consists of a GM tube having a thin end window (e.g. made of mica), a high voltage supply for the tube, a scalar to record the number of particles detected by the tube, and a timer which will stop the action of the scalar at the end of a preset interval. The sensitivity of the GM tube is such that any particle capable of ionizing a single atom of the filling gas of the tube will initiate an avalanche of electrons and ions in the tube. The collection of the charge thus produced results in the formation of a pulse of voltage at the output of the tube. The amplitude of this pulse, on the order of a volt or so, is sufficient to operate the scalar circuit with little or no further amplification. The pulse amplitude is largely independent of the properties of the particle detected, and gives therefore little information as to the nature of the particle. Even so, the GM Counter is a versatile device which may be used for counting alpha particles, beta particles, and gamma rays, albeit with varying degrees of efficiency

All nuclear radiations, whether they are charged particles or gamma rays, it will ionize atoms/molecules while passing through a gaseous medium. This ionizing property of a nuclear radiation is utilized for its detection.

Geiger-Muller counter, commonly called as GM counter or simply as Geiger tube is one of the oldest and widely used radiation detectors. It consists of a metallic tube with a thin wire mounted along its axis. The wire is insulated from the tube using a ceramic feed-through (Fig. 1). The central wire (anode) is kept at a positive potential of a few hundreds of volt or more with respect to the metallic tube, which is grounded. The tube is filled with argon gas mixed with 5-10% of ethyl alcohol or halogens (chlorine or bromine).

When an ionizing radiation enters the Geiger tube some of the energy of the radiation may get transferred to a gas molecule within the tube. This absorption of energy results in ionization, producing an electron-ion pair (primary ions). The liberated electrons move towards the central wire and positive ions towards the negatively charged cylinder. The electrons now cause further ionization by virtue of the acceleration due to the intense electric field. These secondary ions may produce other ions and these in turn still other ions before reaching the electrodes. This cascading effect produces an avalanche of ions. In an avalanche created by a single original electron many excited gas molecules are formed by electron collisions in addition to secondary ions. In a very short time of few nanoseconds these excited molecules return to ground state through emission of photons in the visible or ultraviolet region. These photons are the key element in the propagation of the chain reaction that makes up the Geiger discharge. If one of these photons interacts by photoelectric absorption in some other region of the tube a new electron is liberated creating an avalanche at a different location in the tube. The arrival of these avalanches at the anode causes a drop in the potential between the central wire and the cylinder. This process gives rise to a very large pulse with an amplitude independent of the type and energy of the incident radiation. The pulse is communicated to the amplifier through an appropriate RC circuit, and then to a counter which is called as scaler. Suitable arrangements are made to measure the counts for a preset time interval.

Dead Time In nearly all detector systems, there will be a minimum amount of time that separates two events in order that they may be recorded as two separate pulses. In some cases the limiting time may be set by processes in the detector itself, while in other cases the limit may arise due to the GM Tube Insulator C Amplifier Scaler R WIRE Ar Gas Source * HV Supply delays associated with the electronics. This minimum time separation is usually called the dead time of the counting system. Because of the random nature of radioactive decay, there is always some probability that a true event will be lost because it occurs too quickly following a preceding event. Two models of dead time are in common use, categorized on the basis of paralyzable and nonparalyzable response of the detector.

Radioactive decay is a random process, so the number of pulses recorded by a GM counter during equal time intervals fluctuates about an average value. These fluctuations are called statistical fluctuations. For repeated measurements made under identical conditions, the spread of the observed counts can be quantified by the standard deviation.

For N repeated observations $N_1, N_2, \dots, N_n$, the mean count is:

$$\bar{N} = (N_1 + N_2 + \dots + N_n) / n$$

$$SD = \sqrt{[\sum(N_i - \bar{N})^2 / n]}$$

Here, $\bar{N}$ is the mean count, N_i is an individual count, and n is the number of observations. If your laboratory manual specifies the sample standard deviation, use $n - 1$ in the denominator instead.

4. Procedure

1. Set up the GM counter, HV supply, and scaler/counter according to the laboratory setup.
2. Place the radioactive source at a fixed position and distance from the GM detector.

3. Set the GM counter to a suitable operating voltage, preferably within the plateau region determined previously.
4. Keep the source position, detector geometry, applied voltage, and counting time constant throughout the experiment.
5. Record the number of counts during a fixed time interval, such as 60 s.
6. Repeat the counting measurement for a sufficient number of trials (e.g., 10–20 observations) without changing the experimental conditions.
7. Record every observed count in the observation table.
8. Calculate the mean count, the deviation of each observation from the mean, the squared deviations, and the standard deviation.
9. Compare the observed spread of counts with the expected statistical fluctuation and state the result.

7. Observations

S. No.	Counting Time (s)	Observed Counts (N_i)	$N_i - \bar{N}$	$(N_i - \bar{N})^2$

8. Calculations

1. Calculate the mean count, $\bar{N}$, from all repeated observations.
2. Calculate the deviation ($N_i - \bar{N}$) for each observation.
3. Square each deviation and find $\Sigma(N_i - \bar{N})^2$.
4. Calculate the standard deviation using the formula given in the Principle section.
5. If required, calculate the standard deviation of the count rate by dividing the count SD by the counting time.

7. Result

The statistical fluctuation of the GM counter counts is studied by taking repeated measurements under constant conditions. The mean count and standard deviation are determined from the observations.

Mean count, $\bar{N}$ = _____ counts

Standard deviation, SD = _____ counts

8. Precautions

- Keep the source-to-detector distance and geometry fixed for all observations.
- Use the same counting time for every measurement.
- Keep the GM operating voltage constant during the experiment.

- Do not exceed the maximum voltage specified for the GM tube.
- Ensure proper earthing and secure electrical connections.
- Handle and store the radioactive source only according to the laboratory's radiation-safety procedures.

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