



GANDHI SCHOOL OF ENGINEERING

Brahmapur, Odisha

Laboratory Manual

Engineering Physics Laboratory

Complete Laboratory Manual

B.Tech 1st Year · Semester 1 · Circuit Branch

Academic Year 2026-27



About this lab manual

This manual covers the **Engineering Physics Laboratory** (0-0-2) of the first semester. For every experiment it gives:

- **Aim, apparatus and a labelled diagram** of the set-up.
- **Theory with a full explanation** of the physics behind the experiment and the formula used, with the meaning and unit of every symbol.
- **Step-by-step procedure** exactly as it is done on the laboratory bench.
- **Observation tables with a complete set of sample readings**, the graph, and a **fully worked calculation**, so you can see how the result is obtained. Your own readings will differ slightly; use the same method.
- **Result, precautions, sources of error and viva-voce questions with answers.**

No.	Experiment	Main topic
1	Acceleration due to gravity and radius of gyration by a bar (compound) pendulum	Oscillations
2	Wavelength of sodium light by Newton's rings	Interference
3	Wavelength of mercury lines by a plane diffraction grating	Diffraction
4	V-I characteristics of a PN junction diode	Semiconductors
5	Verification of the laws of transverse vibration of strings (sonometer)	Waves
6	Surface tension of water by the capillary rise method	Properties of matter
7	Young's modulus by bending of a beam (non-uniform bending)	Elasticity
8	Planck's constant using light-emitting diodes	Quantum physics
9	Refractive index of the material of a prism (minimum deviation)	Optics
10	Energy band gap of a semiconductor	Semiconductors

How to write the lab record

- Write the **aim, apparatus, formula (with explanation of symbols), diagram, procedure** on the right-hand page and the **observation tables, calculation and graph** on the left-hand page.
- Record readings directly in ink in the observation table; never copy from a rough sheet.
- Every graph should have a title, labelled axes with units, a suitable scale and neatly plotted points with a best-fit line or smooth curve.
- Express the result with the correct unit and a sensible number of significant figures, and compare it with the standard value.



Least count of common instruments

Instrument	Least count	How it is found
Vernier callipers	0.01 cm	1 main-scale division (0.1 cm)/number of vernier divisions (10)
Screw gauge	0.001 cm	Pitch (0.1 cm)/number of head-scale divisions (100)
Travelling microscope	0.001 cm	Value of 1 main-scale division (0.05 cm)/vernier divisions (50)
Spectrometer	1' (one minute of arc)	Value of 1 main-scale division ($0.5^\circ = 30'$)/vernier divisions (30)
Stop-watch (digital)	0.01 s	—

Zero error: if the zero of the vernier or head scale does not coincide with the main-scale zero when the jaws are closed, the reading at that moment is the zero error; the **corrected reading = observed reading – zero error** (with sign).

Safety in the physics laboratory

- Do not look directly into the sodium or mercury lamp or into a laser beam.
- Switch on the lamps a few minutes before use and do not switch them on and off repeatedly.
- Keep glass capillaries, lenses and prisms by their edges; report breakages immediately.
- In electrical experiments check the polarity of meters and keep the current within the rated value of diodes and LEDs.



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Engineering Physics Laboratory

Ten experiments · Theory with explanation · Sample readings · Calculations · Graphs · Viva

Experiment 1: Bar (Compound) Pendulum

Aim

To determine the acceleration due to gravity (g) and the radius of gyration (K) of a bar pendulum about an axis through its centre of gravity.

Apparatus

Bar pendulum (a uniform steel bar about 100 cm long with holes at 5 cm intervals), knife-edge on a rigid support, stop-watch, metre scale, spirit level.

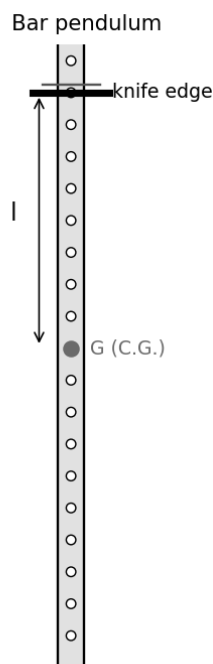


Figure 1.1: Bar pendulum suspended on a knife edge through a hole at distance l from the centre of gravity G .

Theory (with explanation)

A **compound pendulum** is a rigid body that can oscillate in a vertical plane about a horizontal axis passing through it. Unlike a simple pendulum, its mass is distributed along its length, so we must use rotational dynamics.

When the bar is displaced by a small angle θ , gravity acting at the centre of gravity G produces a **restoring torque** $\tau = -mgl \sin \theta \approx -mgl\theta$, where l is the distance of the point of suspension from G . By Newton's law for rotation, $\tau = I \, d^2\theta/dt^2$, where I is the moment of inertia about the axis of suspension. So

$$I \, d^2\theta/dt^2 = -mgl \, \theta \Rightarrow \text{simple harmonic motion with } T = 2\pi\sqrt{I/mgl}$$

By the **parallel axis theorem**, $I = I_G + ml^2 = m(K^2 + l^2)$, where K is the radius of gyration about a parallel axis through G . Substituting:

$$T = 2\pi\sqrt{[(K^2 + l^2)/(gl)]} = 2\pi\sqrt{L/g}, \text{ where } L = (K^2 + l^2)/l = l + K^2/l$$

Meaning: the bar oscillates like a simple pendulum of length L , called the **length of the equivalent simple pendulum**.

Why do we get four points for the same period? The equation $L = l + K^2/l$ can be rearranged as $l^2 - Ll + K^2 = 0$, a quadratic with two roots l_1 and l_2 for each value of L (on each side of G). Their sum and product are:

$$l_1 + l_2 = L \text{ and } l_1 l_2 = K^2$$

So if we draw a horizontal line $T = \text{constant}$ on the T - l graph, it cuts the curve at l_1 and l_2 ; then $g = 4\pi^2(l_1 + l_2)/T^2$ and $K = \sqrt{l_1 l_2}$.

Minimum period: T is minimum when $l = K$; then $L = 2K$ and $T_{\min} = 2\pi\sqrt{2K/g}$. The period becomes very large near G ($l \rightarrow 0$) because the restoring torque becomes very small.

Procedure

- Balance the bar on a knife edge to locate its centre of gravity G and mark it. Measure the distance of each hole from G .
- Suspend the bar through the hole nearest one end (side A) so that the knife edge rests horizontally in the hole (check with a spirit level).
- Displace the bar through a small angle (less than 5°) and release it without jerk. After a few oscillations, start the stop-watch and note the time for 20 oscillations. Repeat and take the mean.
- Repeat for successive holes on side A up to the hole nearest G , then turn the bar upside down and repeat for holes on side B.
- Find $T = t/20$ for each hole and plot T against l , taking distances on side A as negative and side B as positive. Two symmetric curves are obtained.
- Draw horizontal lines at chosen values of T , read l_1 and l_2 , and calculate g and K .

Observations and calculation (sample readings)

Length of bar = 100 cm; number of oscillations counted = 20; least count of stop-watch = 0.01 s.

Hole distance from C.G., l (cm)	Time for 20 osc. (side A) t (s)	Time for 20 osc. (side B) t (s)	Mean period $T = t/20$ (s)
5	52.8	52.9	2.642
10	38.6	38.8	1.935
15	33.8	33.7	1.688
20	31.5	31.5	1.575
25	30.6	30.6	1.530
30	30.5	30.4	1.522
35	30.6	30.8	1.535
40	31.3	31.3	1.565
45	31.9	32.0	1.597

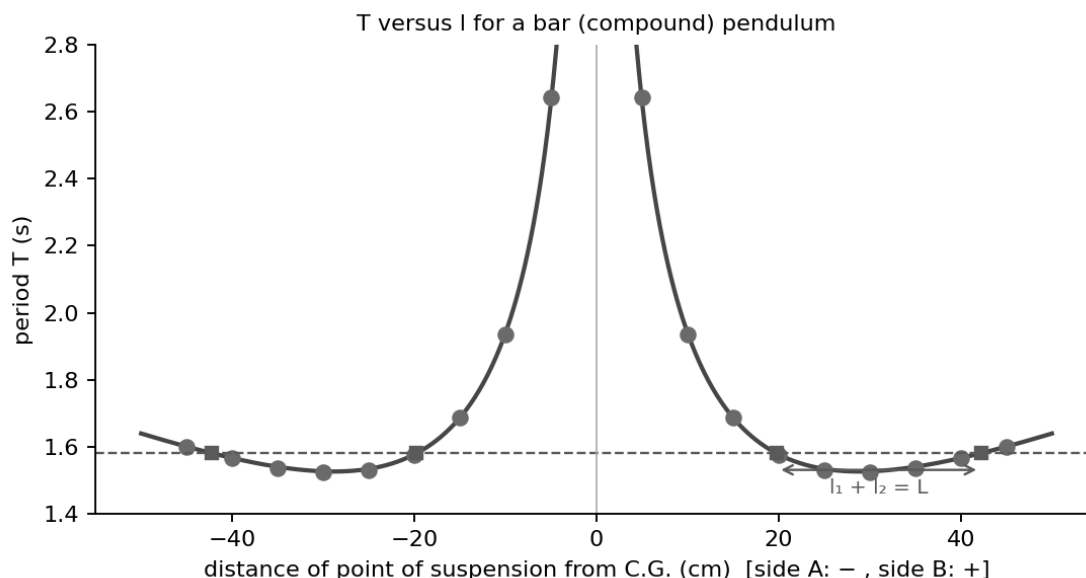


Figure 1.2: Period T against distance l on both sides of the centre of gravity. The horizontal line at $T = 1.58$ s cuts the curve at four points (two on each side of G).

Calculation (from the graph):

$$\text{Equivalent length } L = l_1 + l_2; g = 4\pi^2 L / T^2; K = \sqrt{l_1 l_2}$$

- The line $T = 1.58$ s cuts the curve at $l_1 = 19.7$ cm and $l_2 = 42.2$ cm on each side.
- $L = 19.7 + 42.2 = 62.0$ cm = 0.6197 m.
- $g = 4\pi^2 \times 0.6197 / 1.58^2 = 39.478 \times 0.6197 / 2.4964 = \mathbf{9.80 \text{ m/s}^2}$.
- Radius of gyration $K = \sqrt{l_1 l_2} = \sqrt{19.7 \times 42.2} = \mathbf{28.9 \text{ cm}}$ (theoretical $L_{\text{bar}} / \sqrt{12} = 100 / \sqrt{12} = 28.9$ cm for a 100 cm bar).
- Percentage error in $g = |9.80 - 9.81| / 9.81 \times 100 = 0.1\%$.

Result

Using the bar pendulum, $g = 9.80 \text{ m/s}^2$ and radius of gyration $K = 28.9$ cm.

Precautions and sources of error

- The amplitude must be small ($\theta < 5^\circ$) because the formula uses $\sin \theta \approx \theta$.
- The knife edge must be horizontal and sharp, and the bar must not touch the stand while oscillating.
- Start counting only after the oscillations become steady; count carefully to avoid missing one oscillation.
- Air resistance and friction at the knife edge cause small errors; there should be no wind.

Viva-voce questions

Q1. What is a compound pendulum? How does it differ from a simple pendulum?

A rigid body oscillating about a horizontal axis. In a simple pendulum the mass is concentrated at a point on a weightless string; in a compound pendulum the mass is distributed, so its moment of inertia must be considered.



Q2. What is the length of the equivalent simple pendulum?

$L = l + K^2/l$; a simple pendulum of this length has the same period as the compound pendulum.

Q3. What are the centre of suspension and the centre of oscillation?

The point of suspension and the point at distance L below it on the line through G . They are interchangeable: the period is the same about either (Kater's principle).

Q4. When is the period of a compound pendulum minimum?

When $l = K$; then $T_{\min} = 2\pi\sqrt{(2K/g)}$.

Q5. Why does the period become very large near the C.G.?

As $l \rightarrow 0$, the restoring torque $mg l \rightarrow 0$, so $T = 2\pi\sqrt{[(K^2 + l^2)/(gl)]} \rightarrow \infty$.

Q6. Define radius of gyration.

The distance from the axis at which the whole mass could be concentrated to give the same moment of inertia: $I = mK^2$.

Experiment 2: Newton's Rings

Aim

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

Apparatus

Plano-convex lens of large radius of curvature (about 100 cm), optically plane glass plate, glass plate inclined at 45° , sodium vapour lamp, convex lens, travelling microscope, spherometer (to find R).

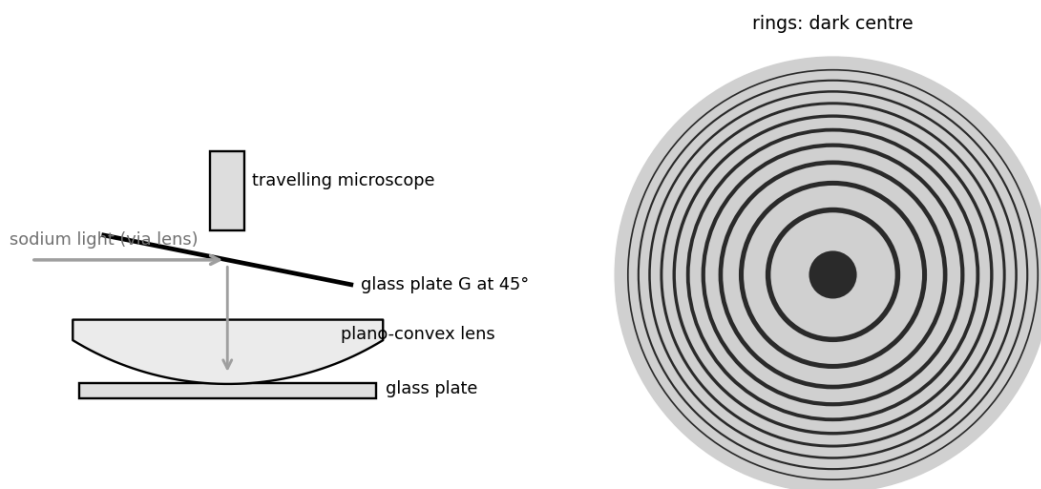


Figure 2.1: Set-up for Newton's rings (left) and the ring pattern seen in reflected light with a dark centre (right).

Theory (with explanation)

When a plano-convex lens rests on a flat glass plate, a thin **air film** is formed between them. Its thickness is zero at the point of contact and increases outwards, and it is the same at all points on a circle centred on the point of contact.

Light falling normally is partly reflected from the lower surface of the lens (glass $\rightarrow$ air) and partly from the upper surface of the plate (air $\rightarrow$ glass). These two reflected waves come from the same incident wave, so they are **coherent** and interfere (**division of amplitude**).

Path difference: for an air film of thickness t (refractive index $\mu = 1$) at normal incidence, the extra path is $2t$. The reflection at the air-glass surface (rarer to denser medium) adds a phase change of π , i.e. an extra path of $\lambda/2$. So the effective path difference is $2t + \lambda/2$.

- Dark ring: $2t + \lambda/2 = (2n + 1)\lambda/2 \Rightarrow 2t = n\lambda$
- Bright ring: $2t + \lambda/2 = n\lambda \Rightarrow 2t = (2n - 1)\lambda/2$

At the centre $t = 0$, so the path difference is $\lambda/2$ and the **centre is dark**.

Relation between thickness and radius of the ring: from the geometry of the sphere of radius R , $r^2 = (2R - t)t \approx 2Rt$ (since $t \ll R$), so $t = r^2/2R = D^2/8R$, where D is the diameter of the ring. For the n th dark ring, $2t = n\lambda$ gives

$$D_n^2 = 4n\lambda R$$

For two rings n and $n + p$, subtracting eliminates errors due to dust or imperfect contact at the centre:

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

The diameters grow as $\sqrt{n}$, so the rings get closer together as we move outwards.

Procedure

- Clean the lens and plate, place the lens on the plate and arrange the 45° glass plate so that light from the sodium lamp (made parallel by a convex lens) falls normally on the lens.
- Focus the travelling microscope to see sharp dark and bright rings with a dark centre.
- Move the microscope so that the cross-wire is tangential to, say, the 22nd dark ring on the left. Moving in one direction only (to avoid backlash), note readings for rings 22, 20, 18 ... 4 on the left, cross the centre and note the readings for rings 4, 6 ... 22 on the right.
- Find the diameter D of each ring (difference of the right and left readings) and D^2 .
- Find R of the lower surface of the lens with a spherometer: $R = l^2/6h + h/2$, where l is the mean distance between the legs and h the sagitta.
- Plot D^2 against n and calculate λ from the slope and from pairs of rings.

Observations and calculation (sample readings)

Microscope readings (least count 0.001 cm; $R = 100$ cm):

Ring no. n	Left reading (cm)	Right reading (cm)	Diameter $D = R - L$ (cm)	D^2 (cm ²)
4	1.3430	1.6570	0.3141	0.09865
6	1.3094	1.6906	0.3812	0.14534
8	1.2806	1.7194	0.4388	0.19259
10	1.2547	1.7453	0.4905	0.24063
12	1.2320	1.7680	0.5359	0.28721
14	1.2112	1.7888	0.5776	0.33366
16	1.1914	1.8086	0.6173	0.38102
18	1.1726	1.8274	0.6548	0.42872
20	1.1547	1.8453	0.6907	0.47704
22	1.1386	1.8614	0.7227	0.52235

Calculation of wavelength:

n	$n + p$ ($p = 10$)	$D_{n+p}^2 - D_n^2$ (cm ²)	$\lambda = (D_{n+p}^2 - D_n^2)/4pR$ (Å)
4	14	0.23503	5876
6	16	0.23562	5891
8	18	0.23622	5905
10	20	0.23624	5906
12	22	0.23514	5879

- Mean $\lambda = 5891 \text{ \AA} = 589.1 \text{ nm}$.

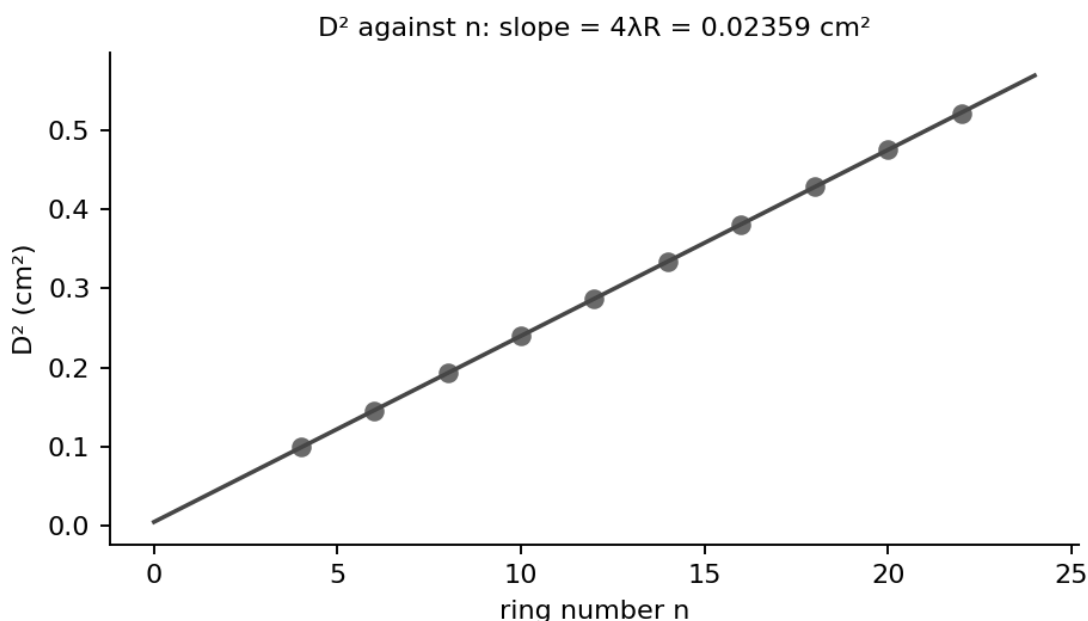


Figure 2.3: Graph of D^2 against n is a straight line; its slope equals $4\lambda R$.

- From the graph: slope = 0.02359 cm^2 , so $\lambda = \text{slope}/4R = 0.02359/400 = 5897 \text{ \AA}$.
- Standard value for sodium light: $5893 \text{ \AA}$. Percentage error = 0.0% .

Result

From Newton's rings, the wavelength of sodium light is $5891 \text{ \AA}$ (589.1 nm).

Precautions and sources of error

- The lens and plate must be clean; dust at the contact point makes the centre bright or irregular (the D^2 difference method removes this error).
- The microscope must move in one direction only to avoid backlash error.
- The cross-wire should be tangential to the ring, on the same side (inner or outer edge) throughout.
- Rings near the centre are broad; very far rings are crowded, so use rings between about 4 and 22.

Viva-voce questions

Q1. Why are the rings circular?

The air film has the same thickness along any circle centred on the point of contact, so points of equal thickness (and equal path difference) lie on circles; these are fringes of equal thickness.

Q2. Why is the centre dark in reflected light?

At the centre $t = 0$ and the reflection at the air-glass surface introduces a path difference of $\lambda/2$, giving destructive interference.

Q3. What happens if water is introduced between the lens and plate?



The path difference becomes $2\mu t$, so $D^2 = 4n\lambda R/\mu$; the rings shrink. This is used to find the refractive index of the liquid.

Q4. Why do the rings become closer as their order increases?

Because $D \propto \sqrt{n}$, so the difference between successive diameters decreases.

Q5. What is meant by division of amplitude?

Splitting one wave into two parts by partial reflection and refraction, so that the two parts are coherent (used in thin films and Newton's rings).

Q6. Why is a lens of large radius of curvature used?

To get a thin, slowly varying air film, so that the rings are broad and widely spaced enough to measure.

Experiment 3: Plane Diffraction Grating

Aim

To determine the wavelengths of the prominent lines of the mercury spectrum using a plane transmission diffraction grating and a spectrometer (normal incidence method).

Apparatus

Spectrometer, plane transmission grating (15000 lines per inch), mercury vapour lamp, spirit level, reading lens.

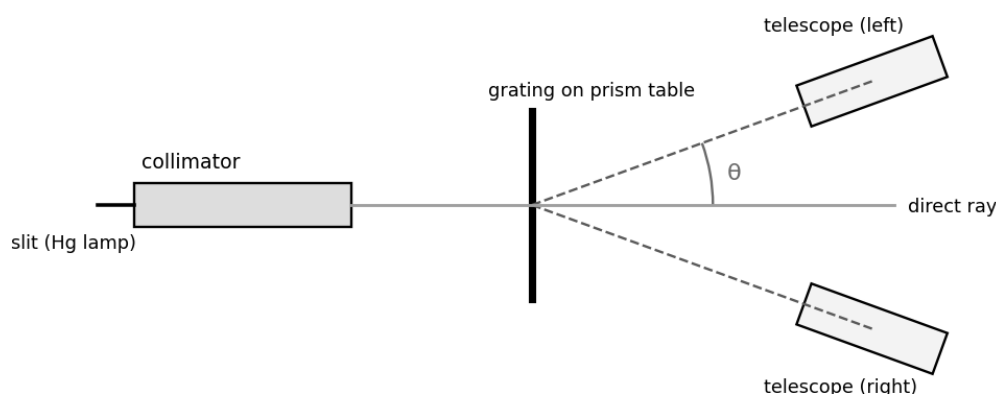


Figure 3.1: Grating on the prism table of a spectrometer; the first-order image is seen at angle θ on both sides of the direct ray.

Theory (with explanation)

A **plane transmission grating** is a glass plate with a very large number of equidistant parallel lines ruled on it. The ruled lines are opaque (width b) and the gaps are transparent (width a). The distance $(a + b)$ between corresponding points of adjacent slits is the **grating element**. If there are N lines per inch, $(a + b) = 2.54/N$ cm.

When parallel light falls normally on the grating, each slit acts as a source of secondary wavelets (Huygens' principle). In a direction θ , the path difference between waves from corresponding points of adjacent slits is $(a + b) \sin \theta$. When this is a whole number of wavelengths, all the waves arrive in phase and a bright **principal maximum** is formed:

$$(a + b) \sin \theta = n\lambda \quad (n = 0, 1, 2 \dots \text{is the order of the spectrum})$$

Because θ depends on λ , the different colours of the source are deviated through different angles, so the grating produces a **spectrum**: violet (shortest λ) is deviated least and red most — the opposite of a prism. Since there are thousands of slits, the maxima are extremely sharp and bright, so the spectral lines are well resolved.

Why readings are taken on both sides: the angle between the first-order images on the left and right is 2θ ; taking half of it cancels any small error in setting the grating exactly normal to the beam.

Procedure

- **Adjust the spectrometer:** level it with a spirit level; focus the eyepiece on the cross-wires; focus the telescope on a distant object (Schuster's method may also be used); illuminate the slit with the mercury lamp, make the slit narrow and vertical, and focus the collimator so that a sharp image of the slit is seen.
- **Set the grating for normal incidence:** bring the telescope in line with the collimator and note the direct reading; rotate the telescope by exactly 90° ; place the grating on the prism table and rotate the table until the reflected image of the slit falls on the cross-wire; then rotate the table back by 45° so the grating surface is normal to the incident light. Clamp the table.
- Turn the telescope to the left to see the first-order spectrum; set the cross-wire on each line (violet, blue, green, yellow) and note the vernier readings.
- Repeat on the right side for the same lines. Find 2θ , then θ , and calculate $\lambda = (a + b) \sin \theta$ for $n = 1$.

Observations and calculation (sample readings)

Grating element: $N = 15000$ lines per inch, so $(a + b) = 2.54/15000 = 1.6933 \times 10^{-4}$ cm.

Spectrometer readings (least count $1'$; normal incidence, first order, $n = 1$):

Spectral line	Left side (1st order)	Right side (1st order)	2θ	θ	$\lambda = (a + b) \sin \theta$ (Å)
Violet	$193^\circ 49'$	$166^\circ 11'$	27.633°	13.817°	4044
Blue	$194^\circ 56'$	$165^\circ 04'$	29.867°	14.933°	4364
Green	$198^\circ 48'$	$161^\circ 12'$	37.600°	18.800°	5457
Yellow	$199^\circ 57'$	$160^\circ 03'$	39.900°	19.950°	5778
Line	Calculated λ (Å)	Standard λ (Å)	Error (%)		
Violet	4044	4047	0.08		
Blue	4364	4358	0.13		
Green	5457	5461	0.07		
Yellow	5778	5780	0.04		

Result

Using a plane diffraction grating, the wavelengths of the prominent mercury lines are violet 4044 Å, blue 4364 Å, green 5457 Å, yellow 5778 Å.

Precautions and sources of error

- The grating must be exactly normal to the incident light; its ruled surface should face the telescope.
- Hold the grating by its edges; never touch the ruled surface.
- The slit should be narrow and vertical, and the telescope focused for parallel rays.
- Read both verniers where possible to avoid eccentricity error.

Viva-voce questions

Q1. What is a diffraction grating? What is the grating element?



A plate with a large number of equally spaced parallel slits. The grating element ($a + b$) is the distance between corresponding points of two adjacent slits.

Q2. How does a grating spectrum differ from a prism spectrum?

In a grating spectrum violet is deviated least and red most, the dispersion is nearly uniform, and several orders are formed. A prism deviates violet most and forms only one spectrum.

Q3. What is the maximum number of orders possible?

$n_{\max} = (a + b)/\lambda$, since $\sin \theta$ cannot exceed 1. For this grating and green light, $n_{\max} = 1.693 \times 10^{-4} / 5.461 \times 10^{-5} \approx 3$.

Q4. What is the difference between interference and diffraction?

Interference is the superposition of waves from two (or a few) coherent sources; diffraction is the bending of light round obstacles and the superposition of wavelets from different parts of the same wavefront.

Q5. Why is the zero-order image white?

At $\theta = 0$ the path difference is zero for all wavelengths, so all colours overlap.

Experiment 4: V-I Characteristics of a PN Junction Diode

Aim

To draw the forward and reverse bias characteristics of a silicon PN junction diode and to find its cut-in voltage and dynamic resistance.

Apparatus

Silicon diode (1N4007), DC regulated power supply (0–30 V), resistor 1 k Ω , milliammeter (0–25 mA), microammeter (0–50 μ A), voltmeters (0–1 V and 0–20 V), breadboard and connecting wires.

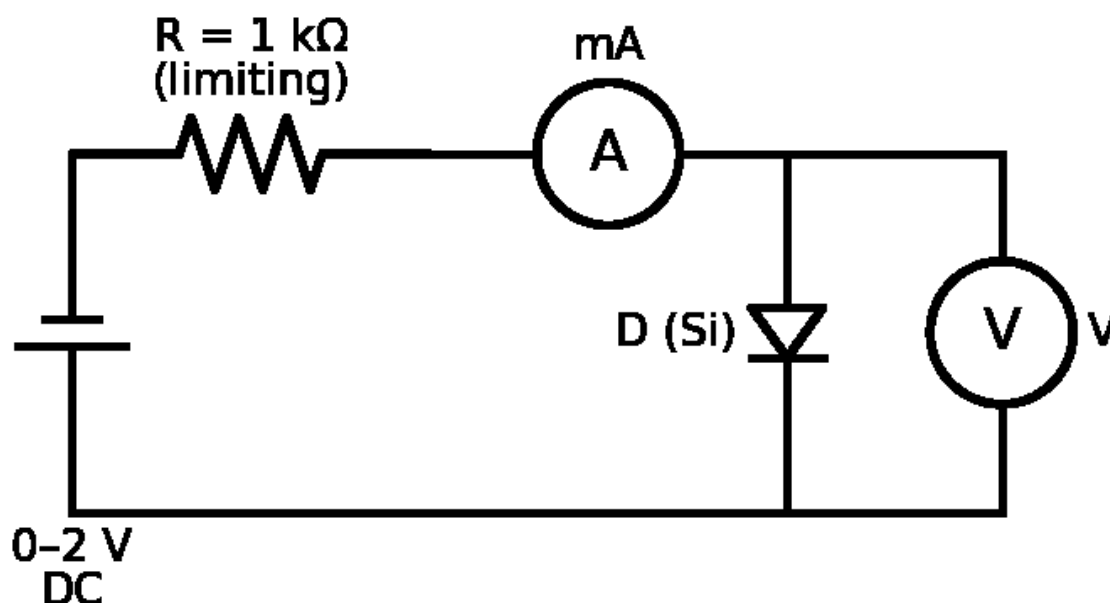


Figure 4.1: Circuit for the forward characteristic. For the reverse characteristic, reverse the diode (or supply), replace the milliammeter by a microammeter and use a 0–20 V voltmeter.

Theory (with explanation)

A **PN junction** is formed when a p-type region (majority carriers: holes) and an n-type region (majority carriers: electrons) are made in the same crystal. Near the junction, electrons diffuse into the p-side and holes into the n-side and recombine, leaving behind immobile ions. This thin region without free carriers is the **depletion layer**, and the ions create a **barrier potential** (about 0.7 V for silicon, 0.3 V for germanium) that opposes further diffusion.

Forward bias (p to +, n to –): the applied voltage opposes the barrier potential, so the depletion layer narrows. Very little current flows until the applied voltage approaches the barrier potential; after this **cut-in (knee) voltage** the current rises rapidly (exponentially). The current is due to majority carriers.

Reverse bias (p to –, n to +): the applied voltage adds to the barrier, widening the depletion layer. Only a tiny **reverse saturation current** (nA to μ A) flows, due to minority carriers generated by heat; it is almost independent of the voltage. At a very high reverse voltage the junction **breaks down** (avalanche or Zener breakdown) and the current rises sharply — this must be avoided for an ordinary diode.

The diode current follows the **Shockley equation**:

$$I = I_s (e^{V/\eta V_T} - 1), V_T = kT/e \approx 26 \text{ mV at room temperature, } \eta = 1 \text{ to } 2$$

Resistances of a diode: static (d.c.) resistance $R = V/I$ at a point; dynamic (a.c.) resistance $r_d = \Delta V/\Delta I$, the reciprocal of the slope of the characteristic. The diode has a low resistance in forward bias and a very high resistance in reverse bias — this one-way property makes it a **rectifier**.

Procedure

- Connect the circuit of Figure 4.1 for forward bias (anode to the positive terminal through the 1 kΩ current-limiting resistor).
- Increase the supply voltage slowly from zero; note the diode voltage V_F and current I_F in steps of 0.1 V (smaller steps of 0.02–0.05 V near the knee). Do not exceed 20 mA.
- For reverse bias, reverse the diode, connect the microammeter and the 0–20 V voltmeter, and note I_R for $V_R = 0, 2, 4 \dots 10 \text{ V}$.
- Plot I_F against V_F in the first quadrant and I_R against V_R in the third quadrant (with different scales). Find the cut-in voltage and the dynamic resistance.

Observations and calculation (sample readings)

Forward bias:

Forward voltage V_F (V)	Forward current I_F (mA)
0.00	0.000
0.10	0.000
0.20	0.001
0.30	0.004
0.40	0.03
0.50	0.21
0.55	0.54
0.60	1.43
0.65	3.75
0.70	9.87
0.72	14.53
0.74	21.39

Reverse bias:

Reverse voltage V_R (V)	Reverse current I_R (μA)
0	0.0
2	0.4
4	0.6
6	0.7
8	0.8
10	0.9

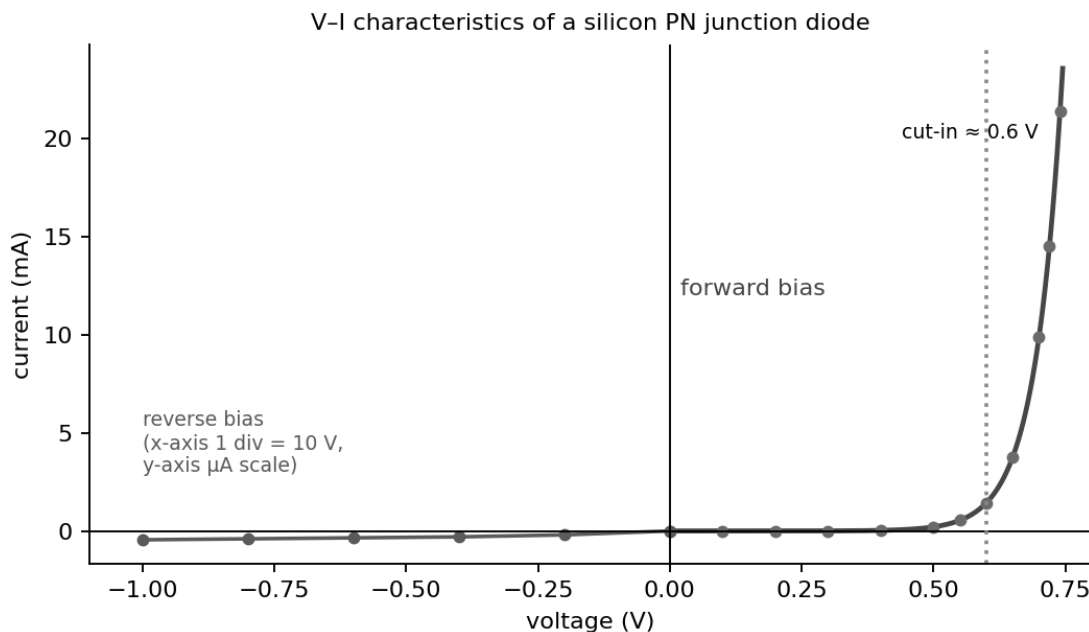


Figure 4.2: Forward and reverse characteristics. The current rises sharply after the cut-in (knee) voltage of about 0.6 V.

Calculation:

- Cut-in (knee) voltage from the graph ≈ 0.6 V.
- Dynamic (a.c.) forward resistance between 0.70 V and 0.72 V: $r_d = \Delta V / \Delta I = 0.02 \text{ V} / (4.66 \text{ mA}) = \mathbf{4.3 \Omega}$.
- Static resistance at 0.72 V: $R = V / I = 0.72 / (14.53 \times 10^{-3}) = 49.6 \Omega$.
- Reverse resistance at 10 V: $R_r = 10 / (0.9 \times 10^{-6}) \approx 11 \text{ M}\Omega$.

Result

From the V-I characteristics, the cut-in voltage of the silicon diode is about 0.6 V, its dynamic forward resistance near 0.71 V is about 4.3 Ω and its reverse resistance is of the order of 10 M Ω . The diode conducts well in forward bias and hardly at all in reverse bias.

Precautions and sources of error

- Always use a current-limiting resistor; never connect the diode directly across the supply.
- Do not exceed the maximum forward current or the peak inverse voltage of the diode.
- Use a microammeter for reverse current and connect meters with correct polarity.
- The diode warms up at high currents, which changes its characteristic; take readings quickly.

Viva-voce questions

Q1. What is the depletion layer?

A thin region on both sides of the junction that is depleted of free charge carriers and contains only immobile ions.

Q2. What is the cut-in voltage? Give values for Si and Ge.



The forward voltage beyond which the current increases rapidly: about 0.6–0.7 V for silicon and 0.2–0.3 V for germanium.

Q3. Why is the reverse current called the saturation current?

It is due to thermally generated minority carriers, whose number is fixed at a given temperature, so it hardly changes with the reverse voltage.

Q4. What is dynamic resistance?

The ratio of a small change in voltage to the corresponding change in current, $r_d = \Delta V / \Delta I$, at a point on the characteristic.

Q5. What is the effect of temperature on the diode?

The reverse saturation current roughly doubles for every 10 °C rise, and the forward voltage for a given current decreases by about 2 mV/°C.

Q6. Give two applications of a diode.

Rectifiers (AC to DC), clippers and clampers, protection against reverse polarity, and switching.

Experiment 5: Sonometer — Laws of Transverse Vibration of Strings

Aim

To verify the laws of transverse vibration of a stretched string using a sonometer and to determine the linear density (mass per unit length) of the wire.

Apparatus

Sonometer with a steel wire, two movable knife-edge bridges, set of tuning forks (256–512 Hz), rubber pad, weight hanger with slotted weights, paper rider, metre scale.

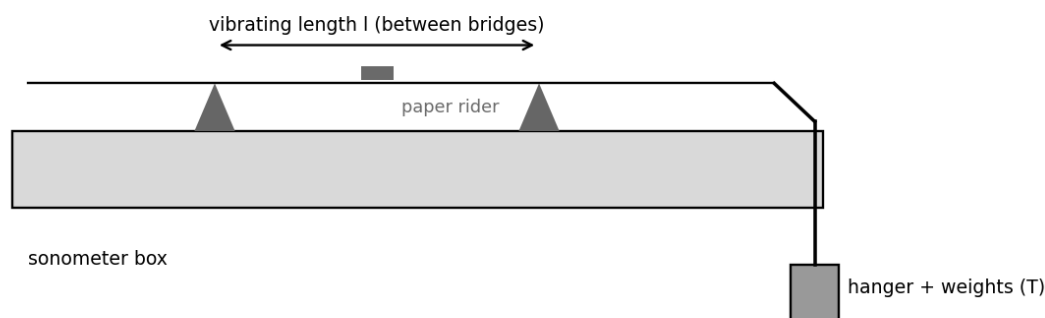


Figure 5.1: Sonometer. The vibrating length l between the two bridges is adjusted until it resonates with the tuning fork; the paper rider then flies off.

Theory (with explanation)

When a stretched string is plucked, **transverse waves** travel along it and are reflected at the fixed ends (bridges). The incident and reflected waves superpose to form a **stationary (standing) wave** with nodes at the bridges. In the fundamental mode there is one loop, so the vibrating length equals half a wavelength: $l = \lambda/2$.

The speed of a transverse wave on a string of tension T and linear density m (mass per unit length) is $v = \sqrt{T/m}$. Since $v = f\lambda = f \times 2l$:

$$f = (1/2l)\sqrt{T/m}$$

This single formula contains the three **laws of transverse vibration**:

- **Law of length:** $f \propto 1/l$ when T and m are constant, i.e. $f \times l = \text{constant}$.
- **Law of tension:** $f \propto \sqrt{T}$ when l and m are constant. Equivalently, for a fixed frequency (tuning fork), $l \propto \sqrt{T}$, i.e. $l/\sqrt{T} = \text{constant}$.
- **Law of mass:** $f \propto 1/\sqrt{m}$ when l and T are constant.

Resonance: when the natural frequency of the vibrating length equals the frequency of the tuning fork (whose stem is pressed on the sonometer box), the wire vibrates with maximum amplitude. A small paper rider placed at the middle of the wire is thrown off. This is how the exact resonating length is found.

Procedure

- **Law of length:** put a load of 2 kg on the hanger ($T = 19.6 \text{ N}$). Strike the 256 Hz tuning fork on the rubber pad and press its stem on the box. Place the paper rider at the middle of the wire and adjust the bridges (starting from a small length) until the rider flies off. Measure l .

- Repeat with the other tuning forks and find $f \times l$ for each.
- **Law of tension:** use the 256 Hz fork and find the resonating length for loads of 1.0, 1.5, 2.0, 2.5 and 3.0 kg. Calculate $l/\sqrt{T}$.
- Plot l against $1/f$ and l against $\sqrt{T}$; both should be straight lines through the origin.

Observations and calculation (sample readings)

Law of length (tension constant, $T = 2 \text{ kg-wt} = 19.6 \text{ N}$):

Frequency f (Hz)	Resonating length l (cm)	$f \times l$ (Hz·m)
256	50.1	128.3
288	44.5	128.2
320	40.0	128.0
384	33.4	128.3
426.7	29.5	125.9
480	26.8	128.6
512	24.8	127.0

Law of tension (frequency constant, $f = 256 \text{ Hz}$):

Load M (kg)	Tension $T = Mg$ (N)	Resonating length l (cm)	$l/\sqrt{T}$ (cm $\text{N}^{-1/2}$)
1.0	9.8	35.1	11.21
1.5	14.7	43.3	11.29
2.0	19.6	50.0	11.29
2.5	24.5	55.7	11.25
3.0	29.4	61.0	11.25

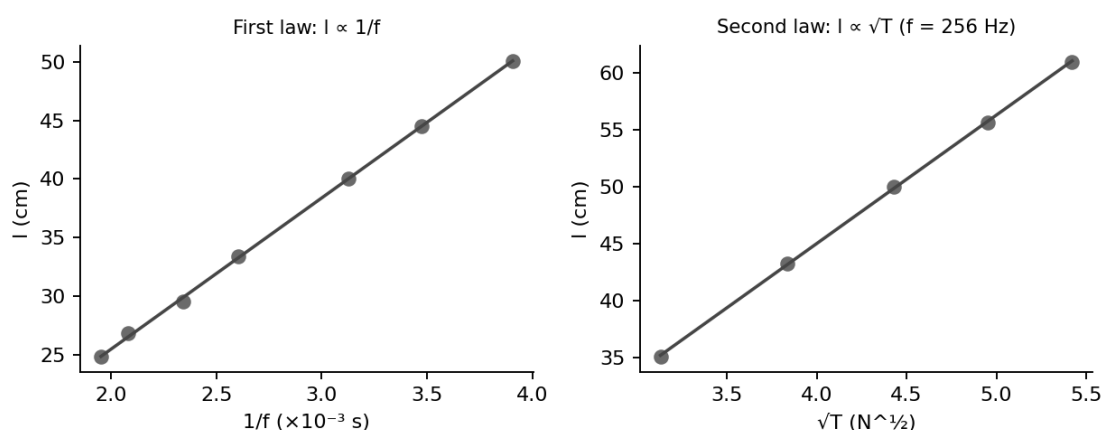


Figure 5.2: Both graphs are straight lines through (nearly) the origin, verifying the first two laws.

Calculation:

- $f \times l$ is nearly constant: mean = 127.7 Hz·m, so the first law ($f \propto 1/l$) is verified.
- $l/\sqrt{T}$ is nearly constant, so the second law ($f \propto \sqrt{T}$ at constant l , i.e. $l \propto \sqrt{T}$ at constant f) is verified.
- Linear density of the wire: $f = (1/2l)\sqrt{(T/m)} \Rightarrow m = T/(2fl)^2 = 19.6/(2 \times 127.7)^2 = \mathbf{3.00 \times 10^{-4} \text{ kg/m}}$.



- Unknown frequency (example): with $T = 19.6 \text{ N}$, a fork resonates at $l = 30.0 \text{ cm} \Rightarrow f = (f l)/l = 127.7/0.300 = 426 \text{ Hz}$.

Result

With the sonometer, $f \times l$ is constant ($\approx 127.7 \text{ Hz}\cdot\text{m}$) and $l/\sqrt{T}$ is constant, so the first two laws are verified; the linear density of the wire is $3.00 \times 10^{-4} \text{ kg/m}$.

Precautions and sources of error

- The wire should be uniform and free from kinks; the bridges should be sharp.
- Strike the tuning fork gently on a rubber pad (never on a hard surface) and do not touch the prongs.
- Approach the resonance length from a smaller length each time.
- The load should hang freely; friction at the pulley reduces the actual tension.

Viva-voce questions

Q1. What are stationary waves?

Waves formed by the superposition of two identical waves travelling in opposite directions; they have fixed nodes and antinodes and do not transport energy.

Q2. What is resonance?

The condition in which the natural frequency of a body equals the frequency of the applied periodic force, so it vibrates with maximum amplitude.

Q3. Why is the paper rider placed at the middle of the wire?

The middle is an antinode in the fundamental mode, where the amplitude is maximum.

Q4. What is the use of the sonometer box and its holes?

The hollow box resonates and amplifies the sound (forced vibration of the enclosed air); the holes connect the inside air with the outside air.

Q5. Why should the tuning fork not be struck on a hard surface?

It may produce overtones or change its frequency (and may damage it).

Experiment 6: Surface Tension by the Capillary Rise Method

Aim

To determine the surface tension of water by the capillary rise method.

Apparatus

Capillary tubes of different bores, beaker of clean water, stand with clamps, travelling microscope, pointer (pin), spirit level.

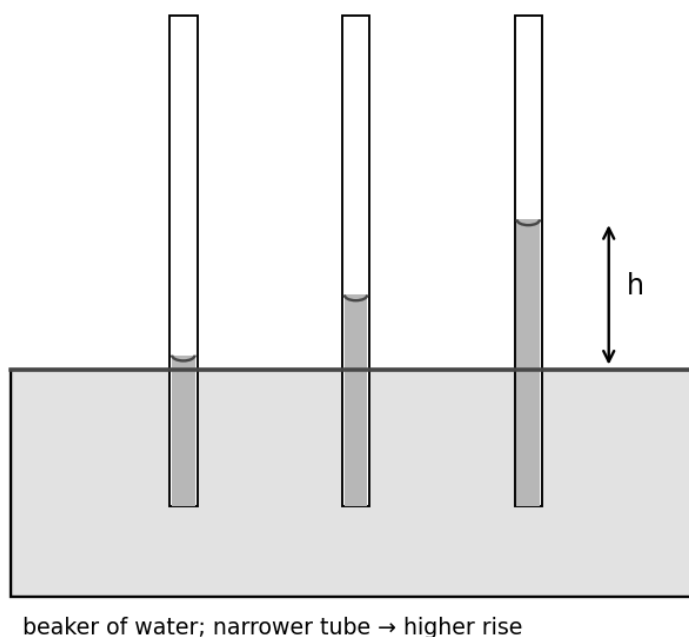


Figure 6.1: Water rises in capillary tubes; the narrower the tube, the higher the rise.

Theory (with explanation)

Surface tension (T) is the force per unit length acting along the surface of a liquid, perpendicular to an imaginary line drawn on the surface (unit N/m). It arises because molecules at the surface are pulled inwards by their neighbours, so the surface behaves like a stretched membrane.

When a clean glass capillary is dipped in water, water **wets** the glass (adhesion between water and glass is stronger than the cohesion of water), so the meniscus is concave with an angle of contact $\theta \approx 0^\circ$. The surface tension acts along the glass all round the circumference of the meniscus and pulls the water up.

Balance of forces: the upward force due to surface tension = $T \times 2\pi r \cos \theta$. The weight of the liquid column of height $h = \pi r^2 h \rho g$ (the small volume of the meniscus is neglected or added as $r/3$ to h). In equilibrium:

$$2\pi r T \cos \theta = \pi r^2 h \rho g \Rightarrow T = r h \rho g / (2 \cos \theta) = r h \rho g / 2 \quad (\theta \approx 0 \text{ for water and clean glass})$$

Here r is the radius of the capillary bore, h the height of the water column above the free surface, ρ the density of water and g the acceleration due to gravity. The relation also shows that $h \propto 1/r$ (Jurin's law): the product $r \times h$ is constant for a given liquid.

Procedure

- Clean the capillary tubes with dilute nitric acid, caustic soda and distilled water so that water wets them well.
- Clamp a capillary vertically with its lower end dipping in water in a beaker. Water rises to a height h .
- Focus the travelling microscope on the bottom of the meniscus in the capillary and note the vertical reading.
- Adjust a pointer so that its tip just touches the water surface in the beaker; remove the beaker and focus the microscope on the tip of the pointer; note the reading. The difference is h .
- Break the capillary at the meniscus mark and measure the internal diameter in two perpendicular directions with the microscope; find the mean radius r .
- Repeat for other capillaries and calculate T .

Observations and calculation (sample readings)

Density of water $\rho = 1000 \text{ kg/m}^3$; $g = 9.8 \text{ m/s}^2$; room temperature about 25°C .

Height of liquid column (travelling microscope, least count 0.001 cm):

Capillary	Microscope reading, meniscus (cm)	Reading, water surface in beaker (cm)	Height h (cm)	Radius r (cm)	$T = r h \rho g / 2$ (N/m)
A	16.933	12.000	4.933	0.0300	0.0725
B	17.961	12.000	5.961	0.0251	0.0735
C	19.404	12.000	7.404	0.0202	0.0734

Radius of the capillary bore (after breaking at the meniscus mark):

Capillary	Horizontal readings x_1, x_2 (cm)	Vertical readings y_1, y_2 (cm)	Mean diameter (cm)
A	2.412, 2.472	5.130, 5.190	0.060
B	2.412, 2.462	5.130, 5.180	0.050
C	2.412, 2.452	5.130, 5.170	0.040

Calculation (capillary A): $T = r h \rho g / 2$ with $\theta \approx 0$ for clean water and glass.

- Mean surface tension = $(0.0725 + 0.0735 + 0.0734)/3 = \mathbf{0.0731 \text{ N/m}}$ (standard value at 30°C : 0.0712 N/m ; at 20°C : 0.0728 N/m).
- A narrower tube gives a larger rise ($h \propto 1/r$), and $r \times h$ is almost the same for all three capillaries.

Result

By the capillary rise method, the surface tension of water at room temperature is 0.0731 N/m .

Precautions and sources of error

- The capillary and water must be perfectly clean; grease increases the angle of contact and reduces the rise.
- The capillary must be vertical, and the microscope must move only vertically.
- The bore should be uniform; measure the radius exactly at the meniscus.



- Temperature affects surface tension (it decreases as temperature rises); note the room temperature.

Viva-voce questions

Q1. Define surface tension and give its SI unit.

The force per unit length acting perpendicular to an imaginary line on the liquid surface, or the surface energy per unit area; unit N/m (J/m²).

Q2. What is the angle of contact?

The angle between the tangent to the liquid surface and the solid surface at the point of contact, measured inside the liquid. For water and clean glass it is nearly 0°; for mercury and glass about 140°.

Q3. Why does mercury fall in a capillary?

Its angle of contact with glass is obtuse ($\cos \theta$ negative), so the meniscus is convex and the level is depressed.

Q4. What happens to capillary rise if the tube is shorter than h?

The water rises to the top and the meniscus becomes flatter (larger radius of curvature); it does not overflow.

Q5. How does temperature affect surface tension?

Surface tension decreases as temperature increases and becomes zero at the critical temperature.

Q6. Give two examples of capillary action.

Rise of ink in a nib, oil in a lamp wick, water in soil and plants, absorption by blotting paper.

Experiment 7: Young's Modulus by Non-uniform Bending

Aim

To determine the Young's modulus of the material of a rectangular beam (wooden scale) by the method of non-uniform bending (central loading).

Apparatus

Rectangular beam (wooden metre scale), two knife edges, weight hanger with slotted weights (50 g each), travelling microscope, pin fixed vertically at the centre of the beam, vernier callipers, screw gauge, metre scale.

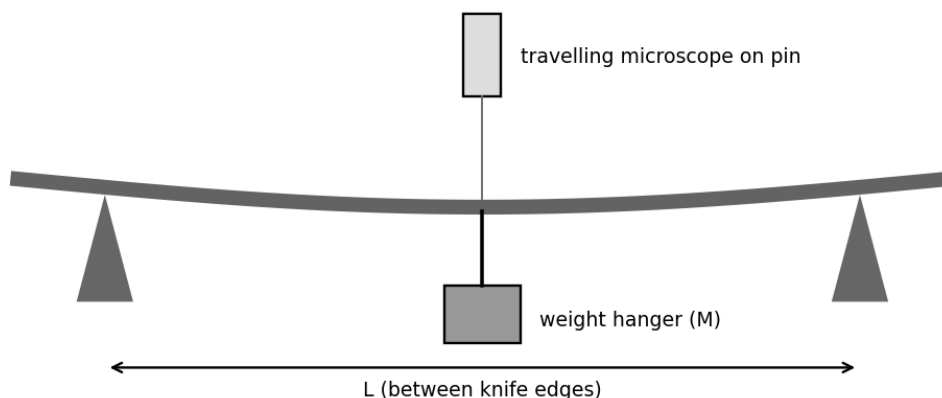


Figure 7.1: Beam supported on two knife edges and loaded at the centre. The depression of the centre is measured with a travelling microscope.

Theory (with explanation)

Young's modulus (Y) is the ratio of longitudinal (tensile or compressive) stress to longitudinal strain within the elastic limit: $Y = (F/A)/(\Delta L/L)$. It measures the stiffness of a material; its unit is N/m^2 (Pa).

When a beam supported at its ends is loaded at the centre, it bends. The upper layers (filaments) are compressed and the lower layers stretched; a middle layer, the **neutral surface**, is unchanged in length. The internal elastic stresses produce a **restoring couple** that balances the bending moment of the load. For a rectangular beam this internal couple is YI_g/R , where $I_g = bd^3/12$ is the geometrical moment of inertia of the section and R the radius of curvature.

Since the beam bends into a non-circular curve, this method is called **non-uniform bending**. Treating each half of the beam as a cantilever of length $L/2$ loaded with $Mg/2$ at its end, the depression of the centre is:

$$\delta = MgL^3/(48 Y I_g) = MgL^3/(4Ybd^3) \Rightarrow Y = MgL^3/(4bd^3\delta)$$

Here M is the load at the centre, L the distance between the knife edges, b the breadth and d the thickness of the beam. Because $\delta \propto d^{-3}$, the thickness must be measured most accurately (with a screw gauge). δ is proportional to M (Hooke's law), so readings for loading and unloading are averaged.

Procedure



- Place the beam symmetrically on the knife edges ($L = 50$ cm apart). Fix a pin vertically at the centre and suspend the weight hanger at the centre.
- Focus the travelling microscope on the tip of the pin and set the horizontal cross-wire on its image; note the reading with the dead load (hanger only).
- Add 50 g at a time up to 250 g, noting the microscope reading each time after the beam has settled. Then remove the loads one by one and note the readings again.
- Find the mean reading for each load and the depression δ for a load of 100 g (difference of readings two steps apart).
- Measure b with vernier callipers and d with a screw gauge at several places and take the mean. Calculate Y .

Observations and calculation (sample readings)

Dimensions of the beam: length between knife edges $L = 50.0$ cm; breadth $b = 2.50$ cm (vernier callipers); thickness $d = 0.60$ cm (screw gauge).

Microscope readings (least count 0.001 cm):

Load (g)	Reading, loading (cm)	Reading, unloading (cm)	Mean (cm)	Depression δ for 100 g (cm)
0	4.500	4.500	4.5000	—
50	4.470	4.468	4.4690	—
100	4.444	4.444	4.4440	0.0560
150	4.416	4.416	4.4160	0.0530
200	4.386	4.384	4.3850	0.0590
250	4.357	4.358	4.3575	0.0585

Calculation:

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

- Mean depression for $M = 100$ g: $\delta = 0.0566$ cm = 5.662×10^{-4} m.
- $Y = 0.100 \times 9.8 \times (0.50)^3 / (4 \times 0.025 \times (0.006)^3 \times 5.662 \times 10^{-4}) = 1.00 \times 10^{10}$ N/m² (a typical value for teak wood is about 1×10^{10} N/m²).

Result

By non-uniform bending, Young's modulus of the material of the beam (wood) is 1.00×10^{10} N/m².

Precautions and sources of error

- The beam must be placed symmetrically, and the load must hang exactly at the centre.
- The load should be well within the elastic limit so that the beam regains its original position.
- Wait for a few seconds after changing the load before taking a reading; avoid backlash in the microscope.
- Measure the thickness very carefully because it appears as d^3 in the formula.

Viva-voce questions

Q1. Define Young's modulus.



The ratio of longitudinal stress to longitudinal strain within the elastic limit; unit N/m^2 .

Q2. What is the neutral surface of a bent beam?

The layer whose length does not change during bending; layers above it are compressed and below it are extended.

Q3. Why is the method called non-uniform bending?

The bending moment varies along the beam, so the beam does not bend into an arc of a circle (in uniform bending, equal loads at both ends give a circular arc).

Q4. Why are girders made in the shape of an I-section?

Most of the bending stress is carried by the top and bottom flanges, far from the neutral axis; the I-section gives a large moment of inertia (stiffness) with less material.

Q5. Why are readings taken while loading and unloading?

To detect and average out any elastic lag or hysteresis and to check that the elastic limit is not exceeded.

Experiment 8: Planck's Constant using LEDs

Aim

To determine Planck's constant using light-emitting diodes (LEDs) of different colours.

Apparatus

Set of LEDs (red, orange, yellow, green, blue) of known wavelengths, DC power supply (0–5 V), rheostat or potentiometer, milliammeter, voltmeter (0–5 V), connecting wires.

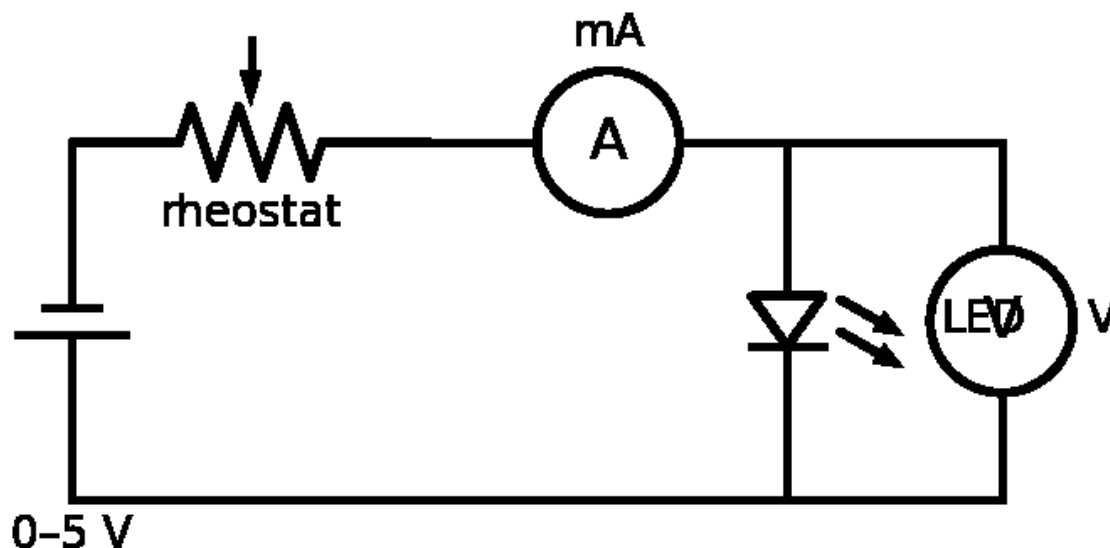


Figure 8.1: Circuit to find the threshold (knee) voltage of an LED.

Theory (with explanation)

An **LED** is a forward-biased PN junction made of a direct band-gap semiconductor (e.g. GaAsP, GaP, InGaN). When forward biased, electrons from the n-side cross the junction and **recombine** with holes. Each recombination releases energy approximately equal to the band gap E_g , emitted as a **photon** of energy $h\nu = hc/\lambda$. The colour of the LED depends on the band gap of its material.

The LED starts to conduct (and emit) when the energy gained by an electron from the applied voltage, eV , becomes equal to the photon energy. This **threshold (knee) voltage V** is found from the V - I characteristic by extending the straight rising part of the curve back to the voltage axis. Then:

$$eV = h\nu = hc/\lambda \Rightarrow V = (hc/e)(1/\lambda)$$

A graph of V against $1/\lambda$ is a straight line with slope hc/e , so

$$h = e \times \text{slope}/c \quad (e = 1.602 \times 10^{-19} \text{ C}, c = 3 \times 10^8 \text{ m/s})$$

Using several LEDs and a graph averages out the errors of individual readings.

Procedure

- Connect the red LED in forward bias as in Figure 8.1.
- Increase the voltage slowly in steps of 0.05 V and note the current. Note the voltage at which the LED just starts to glow and the current begins to rise.

- Draw the V-I curve, extend its linear part to meet the voltage axis and note the threshold voltage V.
- Repeat for all LEDs. Plot V against $1/\lambda$ and find the slope; calculate h.

Observations and calculation (sample readings)

LED colour	Wavelength λ (nm)	$1/\lambda$ ($\times 10^6 \text{ m}^{-1}$)	Knee (threshold) voltage V (V)
Red	630	1.587	1.94
Orange	610	1.639	2.03
Yellow	590	1.695	2.05
Green	565	1.770	2.16
Blue	470	2.128	2.63

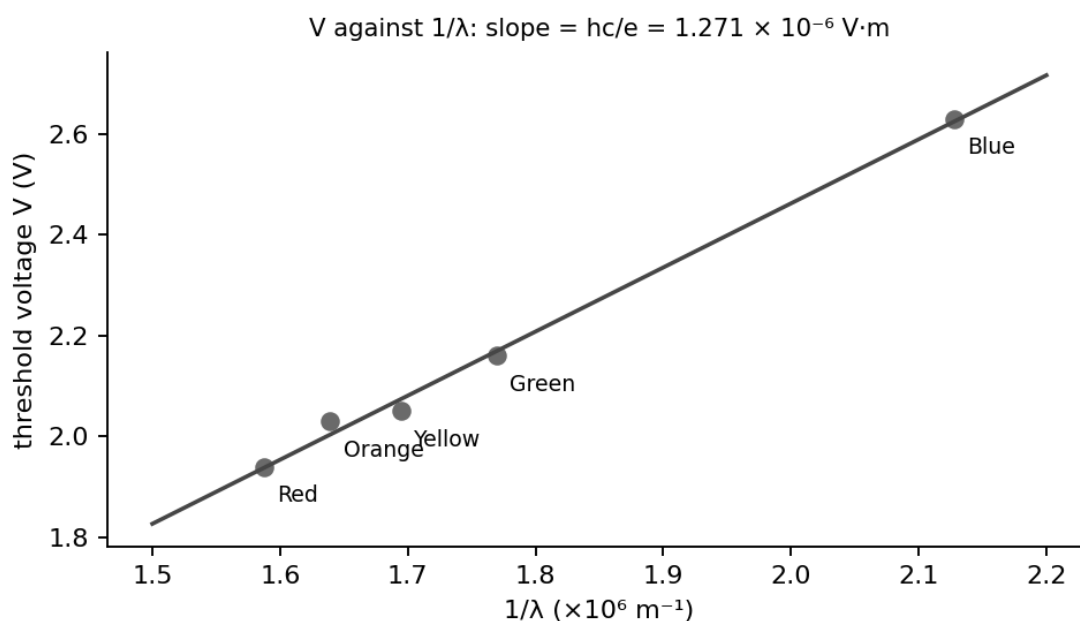


Figure 8.2: Threshold voltage against $1/\lambda$ is a straight line of slope hc/e .

Calculation:

$$eV = hc/\lambda \Rightarrow V = (hc/e)(1/\lambda); h = e \times \text{slope}/c$$

- Slope of the line = $1.271 \times 10^{-6} \text{ V}\cdot\text{m}$.
- $h = 1.602 \times 10^{-19} \times 1.271 \times 10^{-6}/(3 \times 10^8) = \mathbf{6.79 \times 10^{-34} \text{ J s}}$.
- Standard value $6.626 \times 10^{-34} \text{ J s}$; percentage error = 2.4%.

Result

Using LEDs, Planck's constant $h = 6.79 \times 10^{-34} \text{ J s}$.

Precautions and sources of error

- The current through an LED must not exceed about 20 mA; use a series resistance.
- Observe the onset of glow in a darkened room.
- The emitted light has a spread of wavelengths; use the peak wavelength given by the manufacturer.



- Voltage drops in the bulk resistance of the LED cause small errors; the intercept method reduces them.

Viva-voce questions

Q1. What is Planck's constant? Give its value.

The constant relating the energy of a photon to its frequency, $E = h\nu$; $h = 6.626 \times 10^{-34} \text{ J s}$.

Q2. Why do LEDs of different colours have different threshold voltages?

They are made of materials with different band gaps; a larger band gap gives a higher photon energy (shorter wavelength) and needs a higher voltage.

Q3. Why can silicon not be used to make LEDs?

Silicon has an indirect band gap; recombination releases energy mostly as heat (phonons), not light.

Q4. What is the relation between band gap (in eV) and wavelength (in nm)?

$\lambda \text{ (nm)} \approx 1240/E_g \text{ (eV)}$.

Q5. Give two advantages of LEDs.

Low power consumption, long life, small size, fast switching, and robustness.

Experiment 9: Refractive Index of a Prism by the Spectrometer

Aim

To determine the refractive index of the material of a prism using a spectrometer, by finding the angle of the prism and the angle of minimum deviation for sodium light.

Apparatus

Spectrometer, equilateral glass prism, sodium vapour lamp, spirit level, reading lens.

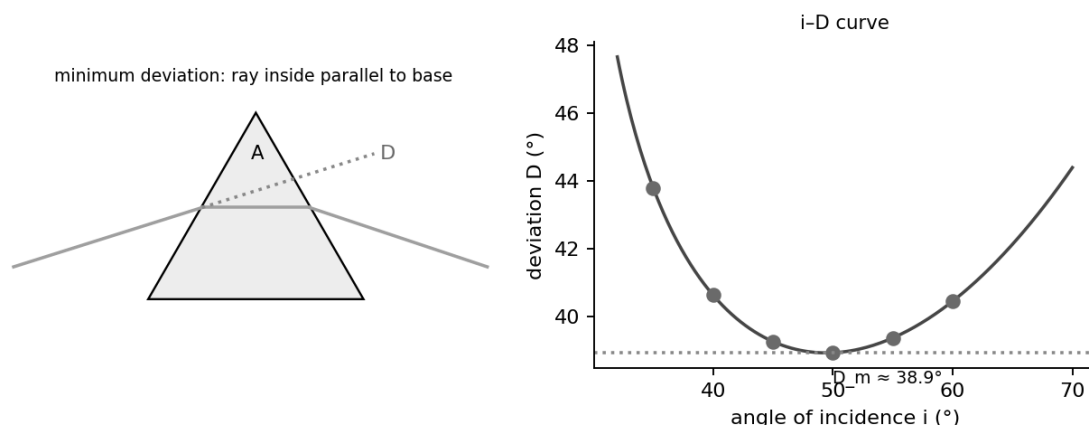


Figure 9.1: At minimum deviation the ray passes symmetrically through the prism (left); the i - D curve has a minimum at D_m (right).

Theory (with explanation)

When a ray passes through a prism of angle A , it is refracted at both faces and deviated from its original direction by an angle $D = i + e - A$, where i is the angle of incidence and e the angle of emergence. As i increases from a small value, D first decreases, reaches a **minimum value D_m** and then increases (i - D curve).

At minimum deviation, the ray passes **symmetrically**: $i = e$, and the angles of refraction inside are equal, $r_1 = r_2 = r$. Since $r_1 + r_2 = A$, $r = A/2$; and since $D_m = 2i - A$, $i = (A + D_m)/2$. By Snell's law, $\mu = \sin i / \sin r$:

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

Angle of the prism by reflection: when parallel light falls on the refracting edge, it is reflected from both faces. The angle between the two reflected beams is $2A$, so A = half the angle between the two telescope positions.

The refractive index depends on the wavelength (dispersion), so monochromatic sodium light (589.3 nm) is used.

Procedure

- Adjust the spectrometer (levelling, eyepiece, telescope and collimator focusing) as in Experiment 3.
- **Angle of prism:** place the prism with its refracting edge towards the collimator so that light falls on both faces. Find the reflected image with the telescope on one side and note the reading; find the other reflected image and note the reading. Half the difference is A .

- **Minimum deviation:** place the prism so that light enters one face; find the refracted image. Rotate the prism table slowly so that the image moves towards the direct ray; follow it with the telescope. At one position the image stops and turns back — this is the minimum deviation position. Set the cross-wire on it and note the reading.
- Remove the prism and note the reading of the direct ray. The difference is D_m .
- (Optional) Measure D for several angles of incidence and plot the i-D curve.

Observations and calculation (sample readings)

Least count of the spectrometer = $1'$.

(a) Angle of the prism (reflection method):

Telescope position	Reading
Reflected image from face 1	$180^\circ 01'$
Reflected image from face 2	$59^\circ 59'$
Difference = $2A$	120.033°
Angle of prism A	60.02°

(b) Angle of minimum deviation (sodium light):

Telescope position	Reading
Minimum deviation position	$288^\circ 58'$
Direct ray	$250^\circ 00'$
D_m = difference	38.97°

(c) i-D curve (for the graph):

Angle of incidence i	35°	40°	45°	50°	55°	60°
Deviation D	43.79°	40.63°	39.26°	38.93°	39.37°	40.45°

Calculation:

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

- $\mu = \sin[(60.02 + 38.97)/2] / \sin(60.02/2) = \sin(49.49^\circ) / \sin(30.01^\circ) = 0.7603 / 0.5001 = 1.520$.

Result

With the spectrometer, the angle of the prism is 60.02° , the angle of minimum deviation is 38.97° and the refractive index of the prism material for sodium light is 1.520.

Precautions and sources of error

- The prism must be placed at the centre of the prism table and should not be moved between readings of the same set.
- The position of minimum deviation must be found carefully by rotating the table slowly.
- The slit should be narrow; the telescope and collimator must be set for parallel rays.
- Read both verniers to eliminate eccentricity error.

Viva-voce questions



Q1. What is meant by minimum deviation?

The smallest angle through which a prism deviates a ray; it occurs when the ray passes symmetrically through the prism ($i = e$).

Q2. Does the refractive index depend on colour?

Yes; μ is greater for violet than for red (dispersion), so violet is deviated more.

Q3. What is dispersion?

The splitting of white light into its component colours because the refractive index varies with wavelength.

Q4. Why is the angle between the reflected rays equal to $2A$?

Each face turns its reflected ray through twice the angle it makes with the incident beam; the two faces are inclined at A , so the rays are separated by $2A$.

Q5. What are the functions of the collimator and the telescope?

The collimator produces a parallel beam from the slit; the telescope receives the parallel beam and forms a magnified image of the slit.

Experiment 10: Energy Band Gap of a Semiconductor

Aim

To determine the energy band gap of a semiconductor (germanium) from the variation of the reverse saturation current of a PN junction diode with temperature.

Apparatus

Germanium diode (e.g. OA79), DC supply (3 V), microammeter, oil bath with heater, thermometer (0–100 °C), stirrer.

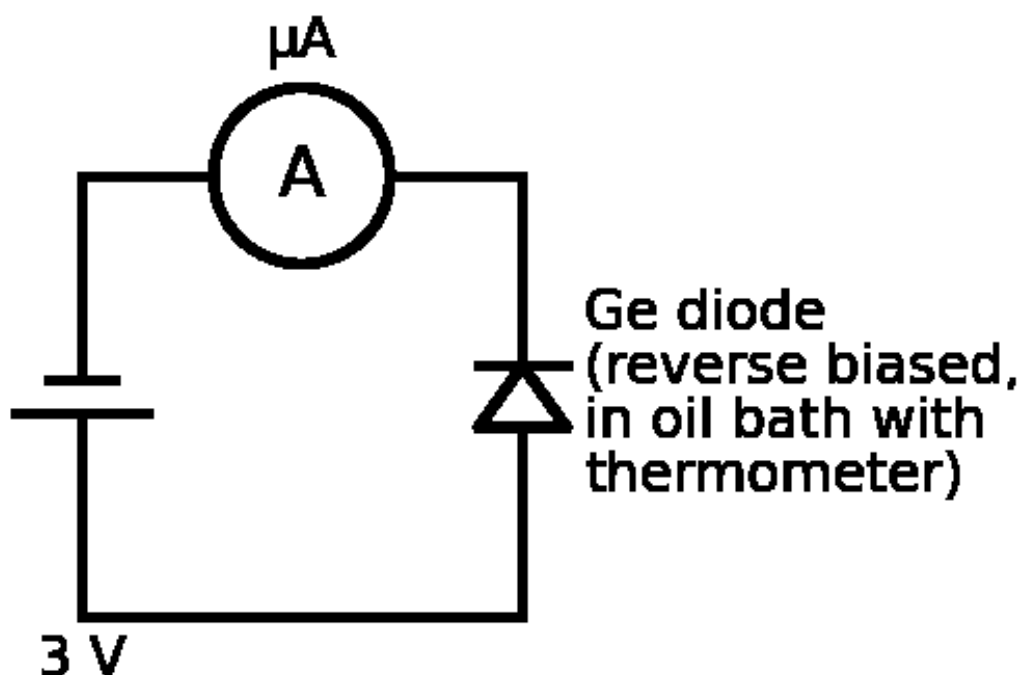


Figure 10.1: Circuit for measuring the reverse saturation current of a diode kept in a heated oil bath.

Theory (with explanation)

In a semiconductor the **valence band** is full and the **conduction band** is empty at absolute zero; they are separated by a forbidden **energy gap E_g** . At a temperature T , some electrons gain enough thermal energy to jump across the gap, creating electron-hole pairs. The number of these intrinsic carriers is

$$n_i^2 \propto T^3 e^{-E_g/kT}$$

In a reverse-biased PN junction the small reverse **saturation current** is carried by minority carriers, whose concentration is proportional to n_i^2 . So $I_s \propto T^3 e^{-E_g/kT}$. The exponential factor changes much faster than T^3 over a small temperature range, so approximately

$$I_s = C e^{-E_g/kT} \Rightarrow \log_{10} I_s = \log_{10} C - (E_g/2.303k)(1/T)$$

A graph of $\log_{10} I_s$ against $1/T$ (or $10^3/T$) is a straight line with negative slope. From its slope:

$$E_g = 2.303 k \times |\text{slope}| \quad (k = 8.617 \times 10^{-5} \text{ eV/K; slope in kelvin})$$

So the steeper the fall of current with cooling, the larger the band gap.

Procedure

- Connect the diode in reverse bias with a 3 V supply and a microammeter; place it in an oil bath with a thermometer close to it.
- Heat the oil to about 80 °C and switch off the heater. As the oil cools slowly (stir continuously), note the reverse current at every 10 °C (80, 70 ... 30 °C).
- Convert temperatures to kelvin and calculate $10^3/T$ and $\log_{10} I_s$.
- Plot $\log_{10} I_s$ against $10^3/T$, find the slope and calculate E_g .

Observations and calculation (sample readings)

Reverse bias kept constant at 3 V (germanium diode in an oil bath):

Temperature (°C)	T (K)	Reverse current I_s (μA)	$10^3/T$ (K ⁻¹)	$\log_{10} I_s$
30	303	2.02	3.300	0.306
40	313	4.20	3.195	0.624
50	323	9.66	3.096	0.985
60	333	20.63	3.003	1.314
70	343	40.02	2.915	1.602
80	353	81.95	2.833	1.914

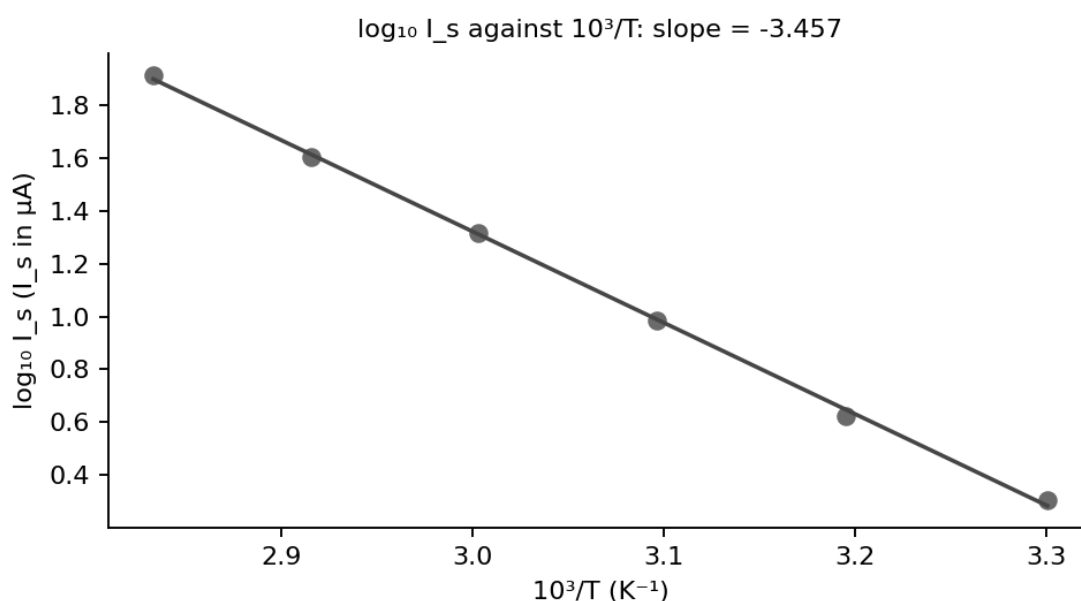


Figure 10.2: $\log_{10} I_s$ decreases linearly with $10^3/T$; the slope gives the band gap.

Calculation:

$$I_s \propto e^{-E_g/kT} \Rightarrow \log_{10} I_s = \text{constant} - E_g/(2.303 kT); E_g = 2.303 k \times |\text{slope}| \times 10^3$$

- Slope of the line = -3.457 (per $10^3/T$), i.e. -3457 K.
- $E_g = 2.303 \times 8.617 \times 10^{-5} \text{ eV/K} \times 3457 \text{ K} = \mathbf{0.69 \text{ eV}}$.
- Standard value for germanium at 300 K: 0.67 eV (silicon: 1.12 eV).

Result



From the temperature dependence of the reverse current, the energy band gap of the semiconductor (germanium) is 0.69 eV.

Precautions and sources of error

- Take readings while cooling slowly with constant stirring so that the diode and thermometer are at the same temperature.
- Keep the reverse voltage constant and well below breakdown.
- Do not heat above about 90 °C, which may damage the diode.
- Surface leakage current and the neglect of the T^3 factor cause small errors.

Viva-voce questions

Q1. What is the energy band gap?

The minimum energy needed to move an electron from the top of the valence band to the bottom of the conduction band; for Si 1.12 eV, for Ge 0.67 eV at room temperature.

Q2. How are materials classified by band gap?

Conductors: overlapping bands (no gap); semiconductors: small gap (about 0.2–3 eV); insulators: large gap (above about 3–5 eV, e.g. diamond 5.5 eV).

Q3. Why does the reverse current increase with temperature?

More electron-hole pairs are generated thermally, increasing the number of minority carriers.

Q4. Why is germanium preferred for this experiment in the laboratory?

Its smaller band gap gives a larger, easily measurable reverse current at moderate temperatures.

Q5. What is the Fermi level in an intrinsic semiconductor?

It lies approximately at the middle of the forbidden gap.



Appendix: Common Graphs and Model Viva Questions

Tips for plotting graphs

- Choose scales so that the graph occupies at least half the graph sheet; use simple scale values (1, 2 or 5 units per cm).
- Plot points with a sharp pencil as small circles or crosses; draw the best straight line with a transparent scale so that the points are evenly spread on both sides.
- To find a slope, choose two points on the line (not data points) far apart, and use slope $= (y_2 - y_1)/(x_2 - x_1)$ with units.

General viva questions

Q1. What is the difference between accuracy and precision?

Accuracy is closeness to the true value; precision is the closeness of repeated measurements to each other.

Q2. What is the least count of an instrument?

The smallest measurement that can be made accurately with the instrument.

Q3. What is backlash error?

The error due to the loose fit between a screw and its nut; the screw turns a little before the instrument moves. It is avoided by always turning the screw in one direction.

Q4. What are systematic and random errors?

Systematic errors always act in one direction (zero error, faulty calibration) and can be corrected; random errors vary unpredictably and are reduced by taking the mean of many readings.

Q5. What is monochromatic light? Give an example.

Light of a single wavelength, e.g. sodium light (589.0 and 589.6 nm doublet) or a He-Ne laser (632.8 nm).