

EXPERIMENT 14

A_{IM}

To determine refractive index of a glass slab using a travelling microscope.

A_{PPARATUS AND MATERIAL REQUIRED}

A travelling microscope, a glass slab, lycopodium powder/chalk dust and a paper.

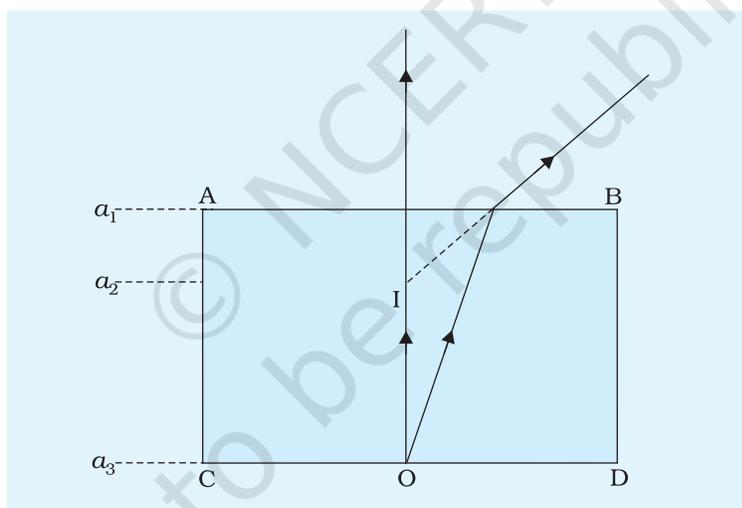


Fig. E 14.1 Formation of image I of a point O in a glass slab

P_{RINCIPLE}

If a glass slab is placed in air on a horizontal surface and its bottom surface is viewed from top, it appears to be elevated due to the phenomenon of refraction. The distance between this apparent bottom and the top surface of the slab gives the apparent thickness of the slab. In case of normal observation, it can be shown that the refractive index of glass with respect to the medium, air is,

$$n_{ga} = \frac{\text{real thickness of the slab}}{\text{apparent thickness of the slab}}$$

PROCEDURE

1. Find the least count of the microscope scale, being used.
2. Put a mark on a sheet of paper.
3. Place the paper on the horizontal platform of the microscope. Adjust the microscope in such a way that its lens system is vertically above the mark.
4. Focus the microscope on the mark and record the reading a_1 using Main Scale Reading (MSR) and Vernier Scale Reading (VSR) of its coinciding division as shown in the Table E 14.1.
5. Next, place the glass slab over the mark on the sheet of paper.
6. Move the microscope upward until mark on the paper, seen through the slab is sharp and clear. Take the reading a_2 with the main scale and coinciding division of the vernier scale.
7. Spread a little lycopodium powder/chalk dust over the top surface of the glass slab.
8. Raise the lens system of the microscope and focus the microscope to see some of their particles clearly and record reading a_3 .
9. Invert the slab and repeat steps 3 to 8.

OBSERVATIONS

Least Count (LC) of the travelling microscope:

20 Main Scale Divisions (MSD) = 1 cm (say)

$$\therefore 1 \text{ MSD} = \frac{1}{20} \text{ cm}$$

50 Vernier Scale Divisions (VSD) = 49 MSD (say)

$$\therefore 1 \text{ VSD} = \frac{49}{50} \text{ MSD} = \frac{49}{50} \times \frac{1}{20} \text{ cm}$$

Least Count of the microscope = (1 MSD – 1 VSD)

$$= \frac{1}{20} - \frac{49}{50} \times \frac{1}{20} = \frac{1}{20} \left(1 - \frac{49}{50} \right) \text{ cm}$$

$$\text{LC} = 0.001 \text{ cm}$$

Table E 14.1: Refractive index of glass slab

Reading of the microscope when focused on									
Sl. no.	Mark made on paper			Mark on paper through the slab			Particles on top of the glass surface		
	M.S.R. M (cm)	V.S.R. N (cm)	$a_1 = M + N \times \text{L.C.}$ (cm)	M.S.R. M (cm)	V.S.R. N (cm)	$a_2 = M + N \times \text{L.C.}$ (cm)	M.S.R. M (cm)	V.S.R. N (cm)	$a_3 = M + N \times \text{L.C.}$ (cm)
1									
2									
3									

CALCULATIONS

The refractive index n_{ga} is given by

$$n_{ga} = \frac{\text{real thickness of the slab}}{\text{apparent thickness of the slab}} = \frac{a_1 - a_3}{a_1 - a_2} = \frac{b}{c} \text{ (say)}$$

Find n_{ga} for the two sets of observations and then the mean value of n_{ga} .

Error

The estimated uncertainty in the measurement of n_{ga} is

$$\frac{\Delta n_{ga}}{n_{ga}} = \frac{\Delta b}{b} + \frac{\Delta c}{c} \quad \text{(E 14.1)}$$

where
$$\frac{\Delta b}{b} = \left(\frac{\Delta a_1}{a_1} + \frac{\Delta a_3}{a_3} \right) \quad \text{(E 14.2)}$$

and
$$\frac{\Delta c}{c} = \left[\frac{\Delta a_1}{a_1} + \frac{\Delta a_2}{a_2} \right] \quad \text{(E 14.3)}$$

From Eq. (E14.1)

$$\frac{\Delta n_{ga}}{n_{ga}} = \left(\frac{2\Delta a}{b} + \frac{2\Delta a}{c} \right)$$

or
$$\Delta n_{ga} = 2n_{ga} \left[\frac{\Delta a}{b} + \frac{\Delta a}{c} \right]$$

Δa = least count of microscope and hence uncertainty in a_1 , a_2 , and a_3 measurements.

Maximum value of Δn_{ga} as obtained from the two sets of observations should be reported with the result as experimental error.

RESULT

The refractive index of glass of the slab was found to be $n_{ga} \pm \Delta n_{ga} = \dots \pm \dots$

n_{ga} is mean value of refractive index of glass with respect to the medium air.

PRECAUTIONS

1. The screws used in focussing the microscope should be moved in only one direction to avoid *back-lash error*.
2. Once the microscope is focused for the first reading i.e., a_1 , the focusing arrangement in the lens system should not be changed/alterd for subsequent readings namely for a_2 and a_3 .
3. The glass slab should be placed on a horizontal surface.
4. Use hand lens/magnifying glass to read the vernier scale to avoid error in finding vernier coinciding division.

SOURCES OF ERROR

1. Position of the microscope may not be normal to the surface of the glass slab.
2. If the layer of lycopodium powder/chalk dust spread on the glass slab is thick, it will not actually represent the top of the glass slab and thus produce error in the result.

DISCUSSION

1. You will get a feel of the apparent and real depths if you try to lift a coin in a bucket filled with water.
2. Consider the situation in which rays coming from an object strike on the glass slab obliquely. Can you obtain a mathematical expression for n_{ga} ?

SELF ASSESSMENT

1. Will a colourless slab be visible if immersed in a transparent liquid of the same refractive index as that of the slab? State the reason for it.

2. You have three slabs of same dimensions – the first one being hollow and completely filled with water, the second one is made of crown glass and the third flint glass. If each of them has a coloured mark at the bottom, in which case will it appear to have risen the most?

Given its $n_{\text{flint}} > n_{\text{crown}} > n_{\text{water}}$

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

Use the method mentioned above to find the refractive indices of commonly available transparent liquids. You may use a thin glass beaker for this experiment.

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EXPERIMENT 15

AIM

To determine the refractive index of a liquid (water) using (i) concave mirror, (ii) convex lens and a plane mirror.

(i) Refractive index of water using concave mirror

APPARATUS AND MATERIAL REQUIRED

Concave mirror of small aperture and large focal length, water, a laboratory stand with rigid base and clamp arrangement (height of the stand must be more than double the focal length of the given concave mirror), a pin, a metre scale, a spirit level, a plumb line, and some small cork pieces.

PRINCIPLE

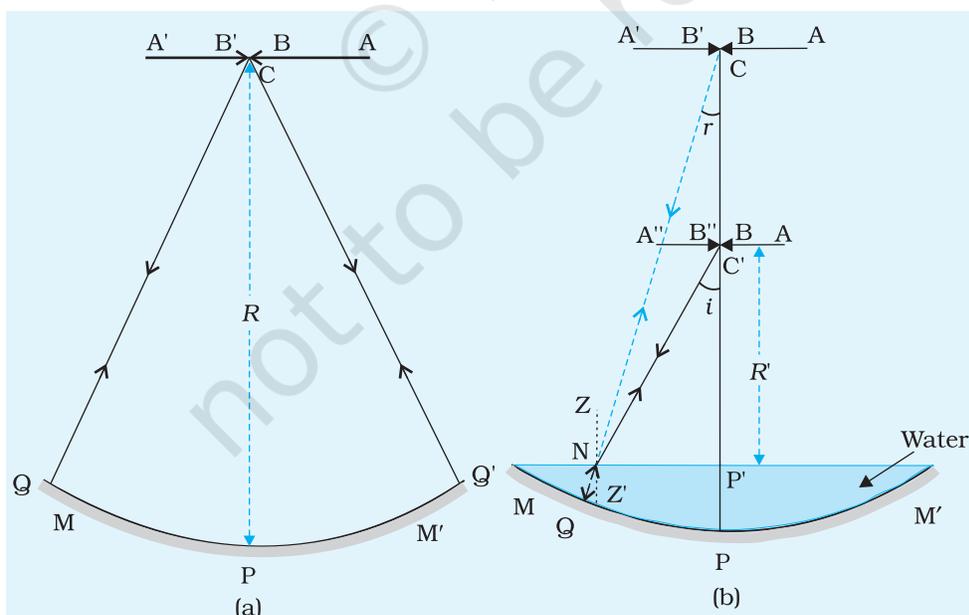


Fig. E 15.1 Formation of image $A'B'$ of an object AB by a concave mirror MM' placed at its centre of curvature. (a) Mirror without water and (b) Mirror with some water

When an object is placed in front of the reflecting surface of a concave mirror MM' at a distance equal to its radius of curvature R , a real and inverted image is formed at the centre of curvature, i.e., $u = v = R =$ distance PC ; P being the pole of the mirror [Fig. E15.1 (a)]. Thus the centre of curvature C of a concave mirror can be located by the method of parallax between

a sharp-edged pin and its real and inverted image formed by a concave mirror.

Fig. E 15.1(b) shows the location of centre of curvature C' when the mirror is partially filled with some transparent liquid (say water). In this case the parallax between the object pin and image of the pin would be removed at a shorter distance from the pole P of the mirror. The incident ray $C'N$ is refracted at the water-air boundary along the path NM such that it falls normally on the curved reflecting surface at point M . The reflected ray retraces back on the same path along MN in water and meets the axis at C along NC , when produced. In air, actually the reflected ray travels along NC' . Thus the real and inverted image is formed at C' . Therefore the distance PC' would be the apparent radius of curvature R' of the water-filled concave mirror.

Fig. E 15.1(b) shows the refraction of incident ray $C'N$ in water. Let ZZ' be the normal at the water surface. $\angle ZNC'$ and $\angle ZNC$ are the angles of incidence i and refraction r , respectively. From geometrical arguments, it is clear that $\angle i = \angle NC'P$ and $\angle r = \angle NCP$. Thus, the refractive index of water with respect to air n_{wa} can be given as:

$$n_{wa} = \frac{\sin i}{\sin r} = \frac{NP'/NC'}{NP'/NC} = \frac{NC}{NC'}$$

For a mirror having very small aperture and large radius of curvature, distances NC and NC' can be approximated as distances PC and $P'C'$, respectively. Further, if only a little quantity of water is taken in the mirror, then distance PP' can be neglected in comparison to PC or PC' . Thus

$$n_{wa} = \frac{PC}{P'C'} = \frac{R}{R'}$$

Thus, using this method the refractive index of any transparent liquid can be determined.

PROCEDURE

1. Obtain approximate value of focal length of the concave mirror by focussing the image of a distant object. It can be found by obtaining a sharp image of the Sun or a tree on a plane wall or on a sheet of paper, and measuring the distance between the mirror and image with a scale. This distance is an approximate value of the focal length f , of the concave mirror. Twice of this focal length is an approximate value of the radius of curvature of the mirror.

Note: Do not look at the Sun's image in a concave mirror as it may hurt your eyes.

2. Place the given concave mirror on the base of a firm and stable laboratory stand keeping its reflecting surface upwards. Use a spirit level to ensure that the plane on which the mirror rests is horizontal. It makes the principal axis of the mirror vertical. Some pieces of paper, plasticine or cork may be used to keep the position of mirror stable on the stand.
3. Fix a sharp edged bright pin in the clamp and place it horizontally just above the mirror. Adjust the position of the pin such that its tip B lies just above the pole P of the mirror or lies on the principal axis of the mirror.
4. Shift the clamped pin to a distance roughly equal to twice the rough focal length of the concave mirror (obtained in step 1) from the pole P of the mirror placed on the laboratory stand. Once again verify that the tip of the pin and pole P lie along the same vertical line (principal axis of the mirror).
5. Adjust the position of the pin till the parallax between the tip of the pin and its inverted image is removed.
6. Measure the vertical distance between the tip of the pin and the mirror using a plumb line and metre scale. This distance would be the real radius of curvature of the mirror.
7. Pour some water on the curved surface of the mirror.
8. Lower the pin slowly, till once again the parallax between the tip of the pin and its inverted image formed by the water-filled mirror is removed.
9. Remove water from the mirror and measure the vertical distance between the tip of the pin and the mirror. This distance would be the apparent radius of curvature of the water-filled mirror.
10. Repeat the experiment (steps 2 to 9) atleast two more times.

OBSERVATIONS

1. Approximate value of the focal length of the concave mirror, $f = \dots$ cm.
2. Approximate value of the radius of curvature, $R = 2f = \dots$ cm.

Table E 15.1: Observations for R , R' and n_{wa}

Sl. No.	Position of pin with respect to pole P		$n_{wa} = \frac{R}{R'}$	Δn_{wa}
	For empty concave mirror, distance PC R (cm)	For water - filled mirror, distance PC' R' (cm)		
1				
2				
3				
	Mean			

CALCULATIONS

Calculate n_{wa} and its mean value.

Error

$$\frac{\Delta n_{wa}}{n_{wa}} = \frac{\Delta R}{R} + \frac{\Delta R'}{R'}$$

$$\therefore \Delta n_{wa} = \left(\frac{\Delta R}{R} + \frac{\Delta R'}{R'} \right) n_{wa}$$

RESULT

The refractive index of water with respect to air is $n_{wa} \pm \Delta n_{wa} = \dots \pm \dots$

n_{wa} is mean value and Δn_{wa} is the maximum of the three values of error.

PRECAUTIONS

1. Pin should be kept horizontal and above the curved reflecting surface of the horizontally placed concave mirror such that the tip of the pin lies above the pole of the mirror on its vertical principal axis.
2. Aperture of mirror should be small.
3. The mirror should be very thin otherwise multiple reflections will form an unclear image.
4. The quantity of water taken in the mirror should be sufficient so that the water surface remains horizontal, or else the surface may not remain horizontal because of surface tension.
5. Eye should be kept at a distance of more than 25 cm from the pin.

SOURCES OF ERROR

The line joining PC may not be vertical.

DISCUSSION

1. If the refractive index of water is determined using concave mirrors of different radii of curvature, how will this affect the values of the refractive index?
2. A plumb line may be used to find the accurate value of PC and PC'. How can plumb line ensure correct measurement?

SELF ASSESSMENT

1. Find the refractive index of water from this experiment considering that a concave mirror filled with water behaves as a combination of concave mirror and a plano-convex lens.
2. If you gradually increase the quantity of water in the mirror, starting with a few drops, do you expect any change in the position or brightness of the image?
3. If colours are added to water keeping its transparency, would this alter the value of refractive index and intensity of the image?
4. If a small quantity of some transparent liquid (like kerosene) lighter than water is added such that it forms a thin film on the water surface; can the experiment still be performed? If so, would the value of refractive index change?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Determine the refractive indices of different liquids (white vinegar, kerosene, glycerine, cooking oil).
2. Take a table lamp. Covering it with cellophane paper of various colours, determine the refractive index of a liquid (say, water) using a concave mirror. Do you observe any change in the value of refractive index of the liquid?
3. Study the variation in the refractive index of salt/sugar solution by changing its concentration.

(ii) Refractive index of water using convex lens and a plane mirror

APPARATUS AND MATERIAL REQUIRED

Double convex lens (focal length nearly 20 cm), plane mirror (bigger in size than the aperture of the lens), laboratory stand fixed with a pin in clamp, metre scale, plumb line, water dropper.

PRINCIPLE

In this method, a real and inverted image coincides with the object placed on the principal focus point of a convex lens. The rays from a pin AB placed on the principal focus F of a convex lens emerge out parallel to its axis. When these rays fall normally on a plane mirror placed horizontally below the convex lens, they retrace their path and form a real and inverted image $A'B'$ at the principal focal plane of the lens [Fig. E 15.2(a)]. The size of image $A'B'$ is equal to the size of object pin AB and the tip of the pin gives the position of the second principal focus. Then $f(OF)$ is the focal length of the convex lens (for a thin lens) where O is the optical centre of the lens.

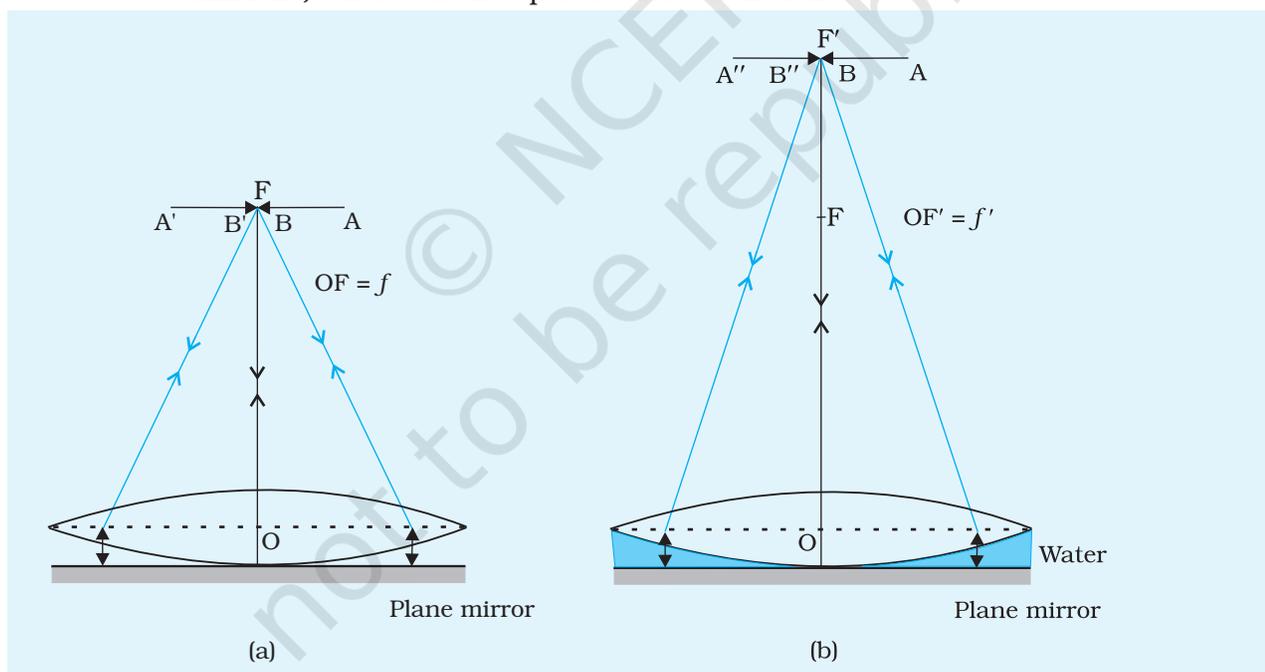


Fig. E 15.2 Image formed by a equiconvex lens backed by a plane mirror coinciding with the object AB . (a) $A'B'$ when there is air in between the lens and the mirror; and (b) $A''B''$ when there is water in between the lens and mirror

Now, if the space between the lens and the plane mirror is filled with a transparent liquid (say water) having refractive index n_{wa} , and the above procedure is repeated to find the position of the principal focus F in the new situation then the distance between the optical centre O

of the lens and point F' , OF' (say f') would be the focal length of the combination of the two lenses. The combination consists of a glass convex lens (radius of curvature of both the curved surfaces are same, R) and a water plano-concave lens of same radius of curvature, R . The focal length f_w of water lens can be determined from the relation between the three focal lengths. viz. f' , f , and f_w , i.e.,

$$(E\ 15.1) \quad \frac{1}{f'} = \frac{1}{f} + \frac{1}{f_w}$$

$$(E\ 15.2) \quad \frac{1}{f_w} = \frac{f - f'}{f f'}$$

But with sign convention : $f = +ve$, $f' = +ve$ one finds $f_w = -ve$

$$f_w = \frac{f f'}{f - f'}$$

Also, from the lens maker's formula for a plano-concave lens

$$(E\ 15.3) \quad \frac{1}{f_w} = (n_{wa} - 1) \frac{1}{R}$$

$$\text{Thus, } R = (n_{wa} - 1) \frac{f f'}{f - f'}$$

Hence,

$$(E\ 15.4) \quad n_{wa} = \left(1 + \frac{R}{f f'} \right)$$

Following the procedure given in the *Laboratory Manual of Physics Class XI, (NCERT) Experiment-3*, the radius of curvature R of the spherical surfaces of the convex lens (using a spherometer) can be determined, and Eq. 15.4 can be utilised for calculating n_{wa} .

Therefore, by using this method, the refractive index of a transparent liquid can be determined.

PROCEDURE

1. Place the plane mirror on the base of a rigid laboratory stand keeping its reflecting surface upwards.
2. Place the convex lens on the plane mirror.
3. Fix a sharp-edged bright pin in the clamp and place it horizontally and above the lens. Adjust the position of the pin such that its tip B lies vertically above the optical centre of the convex lens. A plumb line and a spirit level may be used to achieve this.

4. Shift the clamped pin gradually upward looking at the image and bring it to a height such that the tip B of the pin exactly coincides with the tip of its image B'. Ensure that there is no parallax between the object pin and its image. Measure the distance OF [Fig. E 15.2(a)]. For this, observe the distances of the pin from the upper and lower surfaces of the lens and take $OF = f$ as the average of these two distances.
5. With the help of a dropper, put a few drops of water under the lens so that the space between mirror and lens is filled with water.
6. Move the object pin upward and remove the parallax between the tip of the object pin and its image formed by the lens mirror system. Measure the distance OF' [Fig. E 15.2(b)]. Here again, as before, measure the distances of the pin from the two surfaces of the lens and take $OF' = f'$ as their average.
7. Repeat the experiment and record your observations in Table 15.2.

OBSERVATIONS

1. Mean value of distance between the two legs of the spherometer $l = \dots \text{cm}$
2. Mean value of sagitta (bulge of the lens) $h = \dots \text{cm}$
3. Mean value of the radius of curvature of the lens $R = \dots \text{cm}$

Table 15.2 : Focal length of convex lens, OF (= f) and water plano-convex lens OF' (= f')

Sl. No.	Position of pin with respect to optical centre O						$f_w = \frac{f f'}{f - f'}$	Δf_w	n_{wa}	Δn_{wa}	
	Without water (OF = f)			With water (OF' = f')							
	Upper surface of the lens	Plane mirror	$\frac{d_1 + d_2}{2}$	Upper surface of the lens	Plane mirror	$\frac{d_3 + d_4}{2}$					
	d_1 (cm)	d_2 (cm)	f (cm)	d_3 (cm)	d_4 (cm)	f' (cm)					
1											
2											
3											
	Mean										

CALCULATIONS

$$n_{wa} = 1 + \frac{R}{f_w}$$

Error

$$\frac{\Delta n_{wa}}{n_{wa}} = \frac{\Delta R}{R} + \frac{\Delta f_w}{f_w}$$

$$\text{or } \Delta n_{wa} = n_{wa} \left[\frac{\Delta R}{R} + \frac{\Delta f_w}{f_w} \right]$$

$$\text{where } \Delta R = R \left[\frac{2\Delta l}{l} + \frac{2\Delta h}{h} \right]^*$$

We use Eq. 15.1 for finding the value of Δf_w .

$$\frac{\Delta f_w}{f_w} = \frac{\Delta f}{f^2} + \frac{\Delta f'}{f'^2}$$

$$\text{or, } \Delta f_w = f_w^2 \left[\frac{\Delta f}{f^2} + \frac{\Delta f'}{f'^2} \right]$$

Note that Δl , Δh , Δf and $\Delta f'$ represent least count of the measuring scale.

RESULT

The refractive index of a given liquid (say water) with respect to air is $n_{wa} \pm \Delta n_{wa} = \dots \pm \dots$

Here, n_{wa} is mean value and Δn_{wa} is the maximum of three values of error.

PRECAUTIONS

1. Pin should be kept horizontal and its tip should be above the optical centre of the lens on its vertical principal axis otherwise it will be difficult to remove the parallax.
2. The thin lens should be used so that the distance measured from its surface is nearly equal to the distance measured from the

optical centre. Still it is better to measure distance from both the surfaces and take the average for f or f' .

- Water should be gently put between the mirror and the lens surface with the help of a dropper so that it may fill up the air space between them without disturbing the position of the lens.

SOURCES OF ERROR

- Two surfaces of the convex lens may not have the same radius of curvature.
- The plane mirror may not be horizontal.

DISCUSSION

- Convex lens used should be thin. How will the result change if a thick lens is used?
- How is a plumb line effective in ensuring that the rays retrace their path after refraction through the lens and reflection from the mirror? Draw suitable diagram with principal axis at an angle to the vertical, showing the plane mirror at an angle to the horizontal.

SELF ASSESSMENT

- What will happen if you are given a convex lens of small focal length?
- What are the basic assumptions you have made in performing this experiment?
- Why do we have to raise the object pin upward after filling water between the lens and the mirror?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

- Find out refractive index of any other transparent liquid using this method.
- Study the effect of change in concentration of a solution taken in between the lens and mirror on the refractive index of the solution.
- Measure the focal length of the given convex lens using a plane mirror. Now replace the plane mirror with a convex mirror of the same curvature, and repeat the experiment to find the focal length of the lens. Draw a suitable ray diagram.

EXPERIMENT 16

AIM

To draw the $I - V$ characteristic curves of a p-n junction in forward bias and reverse bias.

APPARATUS AND MATERIAL REQUIRED

A p-n junction diode (OA-79 or 1N4007), a resistor of value (3Ω , $1/2W$), one variable voltage power supply (0-12V), voltmeter (0-12V), milliammeter (0-200 mA), a plug key, connecting wires, sand paper and a microammeter (0-200 μA).

TERMS AND DEFINITIONS

1. *Forward bias*: When an external voltage is applied to a p-n junction diode in such a way that the p-side is at a higher potential with respect to the n-side, it is said to be forward biased.
2. *Threshold voltage or "Cut-in" voltage*: When the p-side is connected to the positive terminal of the battery and the voltage is increased, initially a negligible current flows till the applied voltage crosses a certain value. After, a characteristic voltage, the diode current increases significantly (exponentially), even for a very small increase in the diode bias voltage. This voltage is called the threshold voltage or cut-in-voltage of the diode.
3. *Reverse bias*: When the n-region of a p-n junction diode is at a higher potential with respect to the p-region, it is said to be reverse biased. In reverse bias, the p-side of the p-n junction diode is connected to the negative of the battery.
4. *Reverse saturation current*: As the applied voltage is increased in the reverse biased condition, starting from zero value, the current increases, but soon becomes constant. This current is very small (a few microamperes). It is called the reverse saturation current.

PROCEDURE

1. Note the range and least count of the given voltmeter (V), milliammeter (mA) and the microammeter (μA).
2. Remove the insulating layers from the connecting wires and leads of diode using a sand paper.
3. Connect the variable voltage power supply, p-n junction diode, voltmeter, milliammeter, resistor and a plug key in a circuit as shown in Fig. E 16.1.
4. Initially when the key is open, you would note at this stage, that no current is flowing through the circuit. Now close the key.

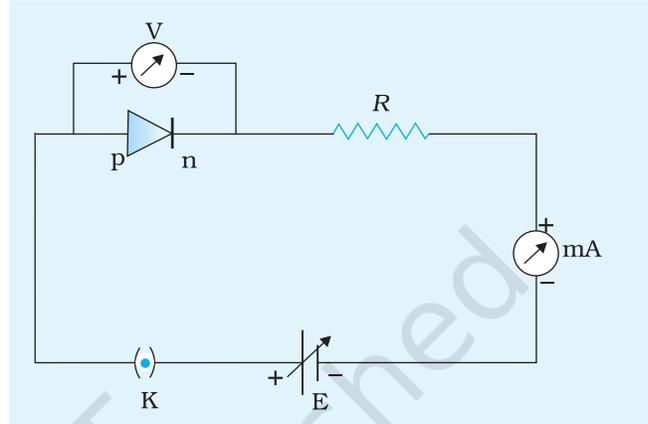


Fig. E 16.1 Forward biasing for a p-n junction diode

5. Give a small voltage to the circuit by slight and gentle turning of the power supply knob. Note the voltmeter reading across the diode and the corresponding milliammeter reading to find the current I flowing through the diode.
6. Gradually, increase the applied voltage (in steps) in the circuit and note the corresponding voltmeter and milliammeter readings in Table E 16.1.

The value of current flowing through the diode would be negligibly small till the voltage across the diode exceeds the value of its *cut in or threshold voltage*. After the *cut-in voltage*, the variation in current will be rapid.

7. Once the threshold voltage is reached, vary the diode voltage very slowly (preferably in steps of 0.1V) noting the corresponding current I flowing through the diode. Continue increasing voltage till the current reaches the limit of the milliammeter.
8. Now disconnect the circuit and make the connections as shown in Fig. E 16.2 for the reverse bias characteristics. Connect p-side of p-n junction diode to the

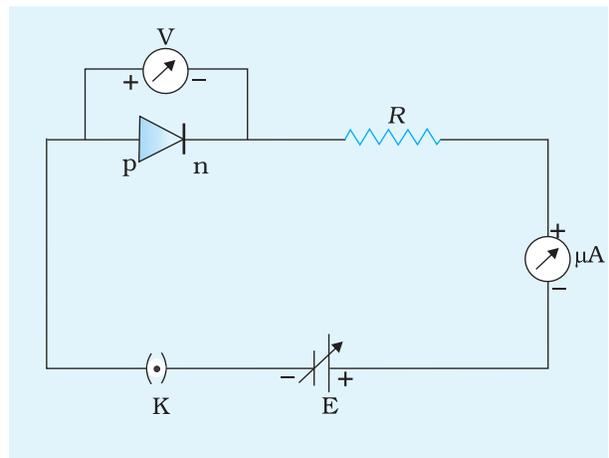


Fig. E 16.2 Reverse biasing for a p-n junction diode

negative terminal of the power supply and replace milliammeter with a microammeter. Gradually, increase the applied voltage (in steps) in the circuit and note the corresponding voltmeter and microammeter readings in Table E 16.2. In this part of experiment, with the given supply voltage you will get only flat portion of the reverse bias characteristic curve.

CAUTION

Never increase the value of the voltage too much across the diode. Excessive current flow may damage the diode if it exceeds its limit. Maximum permissible current that can pass through the diode can be known from the technical data as specified by the manufacturer.

OBSERVATIONS

1. p-n junction diode used (diode no.) = ...
2. For forward biasing
 - (i) Range of the voltmeter = ... V to ... V
 - (ii) Least count of the voltmeter scale = ... V
 - (iii) Range of the milliammeter = ... mA to ... mA
 - (iv) Least count of the milliammeter scale = ... mA
3. For reverse biasing
 - (i) Range of the voltmeter = ... V to ... V
 - (ii) Least count of the voltmeter scale = ... V
 - (iii) Range of the microammeter = ... μ A to ... μ A
 - (iv) Least count the microammeter = ... μ A

Table E 16.1: Variation of forward current with voltage across the diode (forward bias)

Sl.No.	Forward voltage V_f (V)	Forward current I_f (mA)
1		
2		
3		
-		
20		

Table E 16.2: Variation of reverse current with voltage across the diode (reverse bias)

Sl.No.	Reverse voltage V_r (V)	Reverse current I_r (μ A)
1		
2		
...		
20		

PLOTTING GRAPH

1. Plot a graph between forward voltage across the diode (V_f) along the positive x-axis and current flowing through the diode (I) along the positive y-axis. The graph as shown in Fig. E 16.3 represents a typical I - V characteristic of a silicon diode used. Locate the knee and determine the cut-in voltage.
2. Now plot the reverse voltage (V_r) along the negative x-axis and the corresponding current (in μ A) along the negative y-axis as shown in Fig. E 16.3. Determine the reverse saturation current.

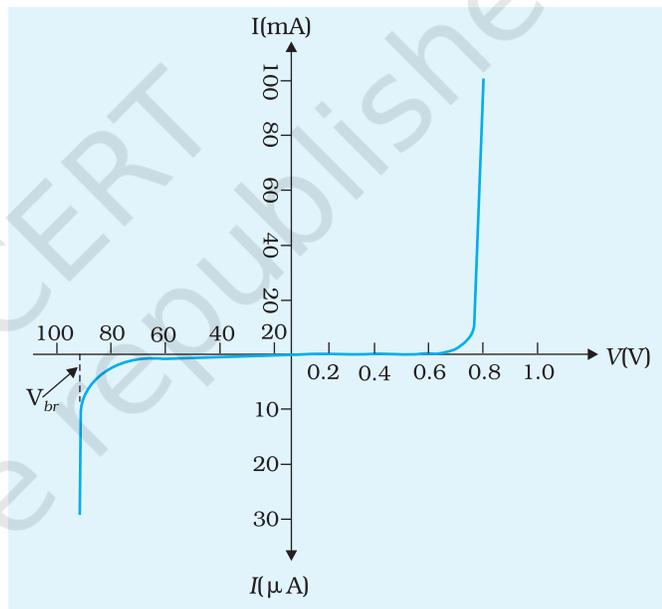


Fig. E 16.3 Typical I - V characteristics of a silicon diode in forward biasing and reverse biasing

RESULT

- A. The value of cut-in voltage for the given diode is ... V.
- B. The reverse saturation current for the given diode is... μ A.

PRECAUTIONS

1. Find out manufacturer's specification for maximum permissible

current through the given diode in forward bias. Take care not to exceed this limit.

2. Find out manufacturers specification for maximum reverse voltage to be applied to the diode. Take care not to exceed this limit.
3. It is important to take care that the potential difference across the diode is increased gradually, in small steps. Keep your eyes on the ammeter and let the current not exceed the specified limit.

DISCUSSION

If we use different diodes (Ge or Si), what change do you observe in the $I - V$ characteristics? Does the threshold voltage / cut-in voltage of the diode depend on the material of the diode?

SELF ASSESSMENT

1. How can you operate diode as a switch or as a rectifier?
2. What is the difference between a diode and a resistor?
3. If a resistor of higher value (greater than the resistor connected in the circuit) is connected in series with diode, then comment on the slope of linear region of $I - V$ characteristics.

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Perform the same experiment with a different value of R connected in series with the diode. What changes will be observed in
 - (a) cut - in voltage?
 - (b) actual value of current for same voltage for different values of R ?
 - (c) shape of $I - V$ characteristics?
2. Perform the same experiment with a light emitting diode (LED) in place of a diode and plot the $I - V$ characteristics. What change do you observe in the threshold voltage when you use different coloured LEDs?

EXPERIMENT 17

AIM

To draw the characteristic curve of a Zener diode and to determine its reverse breakdown voltage.

APPARATUS AND MATERIAL REQUIRED

A p-n junction Zener diode (IN 758), a variable dc power supply (0-15 V) with least count 0.1 V, a microammeter (0-100 μ A), a voltmeter (0-15 V), a resistance of 125 Ω , a high resistance rheostat and connecting wires.

PRINCIPLE

Zener diodes are essentially p-n junction diodes (both p and n regions are more heavily doped as compared to rectifying p-n junction diode) operated in the breakdown region of the reverse voltage characteristic. These diodes are designated with sufficient power dissipation capacities to work in the breakdown region. The following two mechanisms can cause breakdown in a junction diode:

(i) Avalanche breakdown

With increasing reverse bias voltage, the electric field across the junction of p-n diode increases. At a certain reverse bias, the electric field imparts a sufficiently high energy to a thermally generated carrier crossing the junction. This carrier, on colliding with a crystal ion on its way, disrupts a covalent bond and produces an electron-hole pair. These carriers on gaining sufficient energy from the applied field collide with other crystal ions and generate further electron-hole pairs. This process is cumulative and produces an avalanche of carriers in a very short time. This mechanism is known as avalanche multiplication, causes large reverse current and the diode is said to work in the region of avalanche breakdown.

(ii) Zener breakdown

In a Zener diode, both the p and n-sides are heavily doped. Due to the high dopant densities, the depletion layer junction width is small. Since the junction width is small i.e. less than 10^{-7} m, even a small

voltage across it may create a very high field. This high junction field may strip an electron from the valence band which can tunnel to the n-side through the thin depletion layer. Such a mechanism of emission of electrons after applying certain electric field ($\sim 10^6$ V/m) or voltage

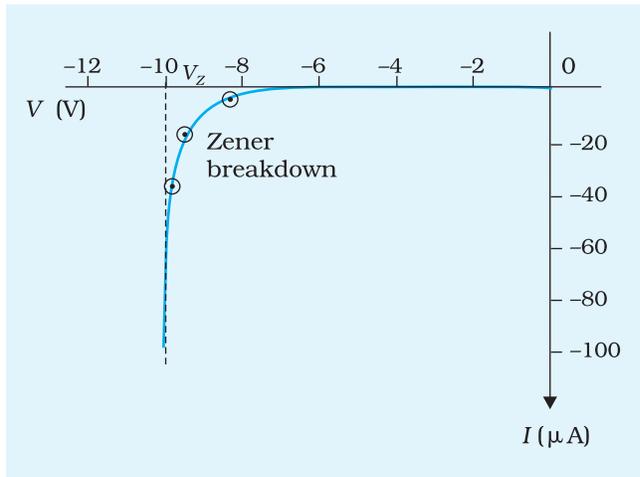


Fig. E 17.1 Zener diode characteristics curve

V_z is termed as internal field emission which gives rise to a high reverse current or breakdown voltage. This breakdown is termed as *Zener breakdown* and the voltage at which it occurs is called *Zener voltage*. The reverse current at Zener voltage is called *Zener current*.

The very nature of breakdown suggests that the ideal V versus I characteristics (schematically as shown in Fig. E 17.1) of a Zener diode after breakdown will be running parallel to the current axis implying thereby, that a small change in voltage leads to almost infinite or very large change in current. You will appreciate that this is what we have called “breakdown” earlier. However, there is a danger of such a large current flow through the diode that it can result in its excessive heating. To protect the diode from such a damage, normally in practical circuits, we connect a resistance termed as protective resistance (R_p) with the Zener diode which limits the maximum current which can ever pass through the diode.

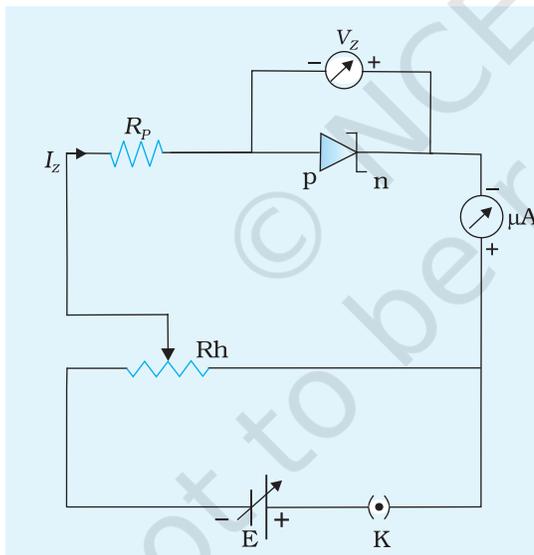


Fig. E 17.2 Circuit for Zener diode characteristic curve

A simple method of determining the approximate value of protective resistance in practical circuits is discussed below:

Suppose we are given a Zener diode IN 758 with $V_z = 10$ V. This diode can withstand a maximum power dissipation of 0.4 W (as per the ratings given by the manufacturer). We can find a simple relation between protective resistance R_p and Zener breakdown voltage.

A Zener diode having zener voltage V_z and power dissipation rating P_z is connected across a potential divider arrangement with maximum potential V_z across it (Fig. E 17.2). If the potential drop across the Zener diode is V_z and the rest drops across the protective resistance then we get

$$V = V_z + I_z R_p$$

Since
$$I_z = \frac{P_z}{V_z} \quad \text{(E 17.1)}$$

$$V = V_z + \frac{P_z}{V_z} R_p$$

and
$$R_p = \frac{(V - V_z)V_z}{P_z} \quad \text{(E 17.2)}$$

Therefore a resistance of value $R_p = \frac{(15 - 10)10}{0.4} = 125 \Omega$ should be connected in series with the Zener diode IN 758 to protect it from damage.

PROCEDURE

1. Note the least count of the given voltmeter and microammeter.
2. The voltmeter and microammeter should read zero with zero applied voltage. If not, then correct the initial reading of the meter suitably.
3. Clean the ends of the connecting wires with the help of sand paper and connect various components by the connecting wires as per the circuit arrangement (Fig. E 17.2). Take care that Zener diode is in reverse bias mode and the terminal of the microammeter and voltmeter marked positive are connected to the higher potential side of the power supply.
4. Ensure that the microammeter is connected in series with the Zener diode having a series protective resistance R_p and voltmeter in parallel to the Zener diode.
5. Switch on the power supply.
6. Move the contact point of the potential divider to apply some reverse bias voltage (V_r). For low reverse bias, the current is negligibly small i.e., of the order of 10^{-8} A to 10^{-10} A and hence with milliammeter or microammeter, you will observe zero reading.
7. Slowly increase the voltage across the Zener diode in steps and record the value of reverse bias voltage V_r and also record the corresponding reverse current I_r from the reading of the microammeter. Take care that the reverse voltage V_r is increased in steps of 0.1 V.

OBSERVATIONS

1. Range of the voltmeter = ... V to ...V
2. Least count of the voltmeter = ...V
3. Range of the microammeter = ... μ A to ... μ A
4. Least count of the microammeter = ... μ A
5. Specification of Zener diode used (code no.) =...
6. To calculate the value of protective resistance R_p , following data is required.

Maximum permissible power (power rating) of the Zener diode specified by the manufacturer, $P_z = \dots$ W

Maximum permissible voltage (voltage rating) of the Zener diode as specified by the manufacturer, $V_z = \dots$ V

Value of the protective resistor to be used in series with the Zener diode, $R_p = \dots$ V (from E 17.2)

7. Note down the reading of the voltmeter and microammeter in Table E 17.1.

Table E 17.1: Variation of reverse current I_r with reverse voltage, V_r across the Zener diode

Sl.No.	For Zener diode	
	Voltmeter reading V_r (V)	Microammeter I_r (μ A)
1		
2		
...		
10		

PLOTting GRAPH

- (i) Plot a graph between reverse voltage, V_r and reverse current, I_r taking V_r along x-axis and I_r along y-axis by using the readings from Table E 17.1.
- (ii) Discuss the nature of $V_r - I_r$ graph and interpret it.
- (iii) Note the value of the breakdown voltage from the $V_r - I_r$ graph.

RESULT

The breakdown voltage of the Zener diode obtained from the graph is

$$V_z = \dots \text{ V.}$$

PRECAUTIONS

1. Ends of the connecting wires should be cleaned properly with sand paper.
2. Zero reading of voltmeter and microammeter should be checked properly.

DISCUSSION

1. Ideally after breakdown, the current I_r should become infinitely large. Is it so in your case? In case it is not and you find that the current does increase rapidly but not infinitely, then think of the reason. Does the protective resistance or any other contact resistance in the circuit has any role to play in this case?
2. From the manual of electric components, note down the breakdown voltages of the Zener diodes which can be used in any circuit for different voltages.
3. Discuss the role of Zener diode in voltage regulation.

SELF ASSESSMENT

1. What is the principle of Zener diode?
2. How is reverse current obtained?
3. What happens at Zener breakdown?
4. What is meant by internal field emission?
5. How can you use a Zener diode as a voltage regulator?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

Repeat the experiment using Zener diodes of different code numbers. Do you observe any variation in their reverse breakdown voltages?

EXPERIMENT 18

AIM

To study the characteristics of a common emitter n-p-n (or p-n-p) transistor and to find out the values of current and voltage gains.

APPARATUS AND MATERIAL REQUIRED

A transistor (BC 147 or BC 177 or AC 128), a microammeter (0-100 μ A), a milliammeter (0-20 mA), two high resistance rheostats, a 100k Ω carbon resistance, two dc power supplies to provide voltage both for input (0-3V) and output (0-15V), two one way keys and connecting wires.

PRINCIPLE

An n-p-n transistor is made up of a semiconductor such as Ge or Si in which there is a thin p-type layer between two n-type layers. A p-n-p transistor has a thin n-type layer between two p-type layers. The schematic diagram of n-p-n and p-n-p transistors along with their circuit symbols are shown in Fig. E 18.1(a) and E 18.1(b) respectively.

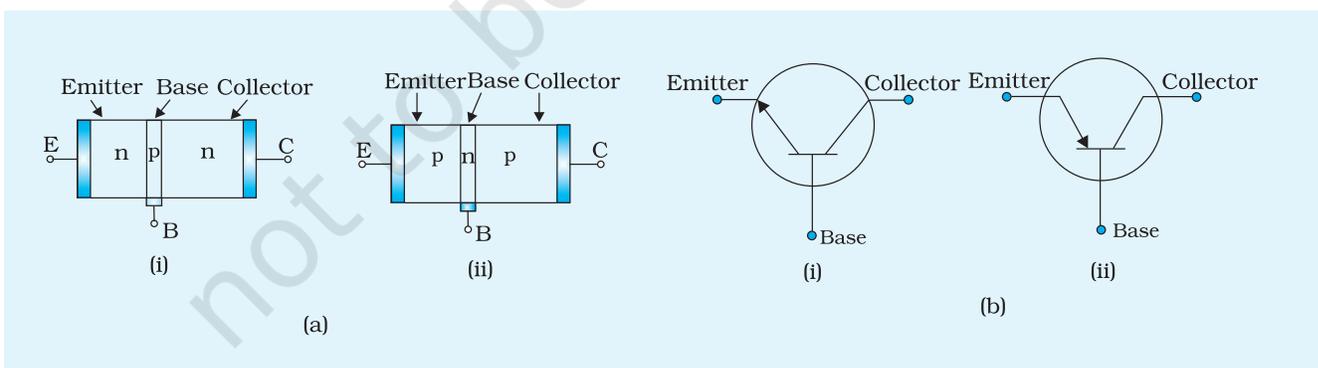


Fig. E 18.1 (a) Schematic representations of n-p-n and p-n-p transistors along with their (b) circuit symbols

The middle portion of the transistor is called base. It is very thin and lightly doped. Emitter is of moderate size and heavily doped. The collector is moderately doped and larger in size as compared with

emitter. When a transistor is to be connected in a circuit, one of the terminals has to be common between the input and output. Thus, three circuit configurations are possible.

- (i) common emitter (CE) configuration
- (ii) common base (CB) configuration
- (iii) common collector (CC) configuration.

CE configuration

When a transistor is used in CE configuration, the input is fed between the base-emitter terminals and the output is derived between the collector-emitter terminals as shown in Fig. E 18.2 (a) and (b).

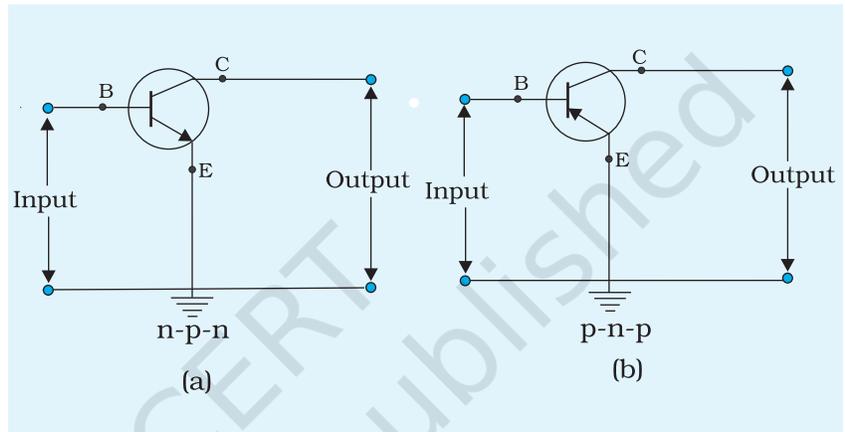
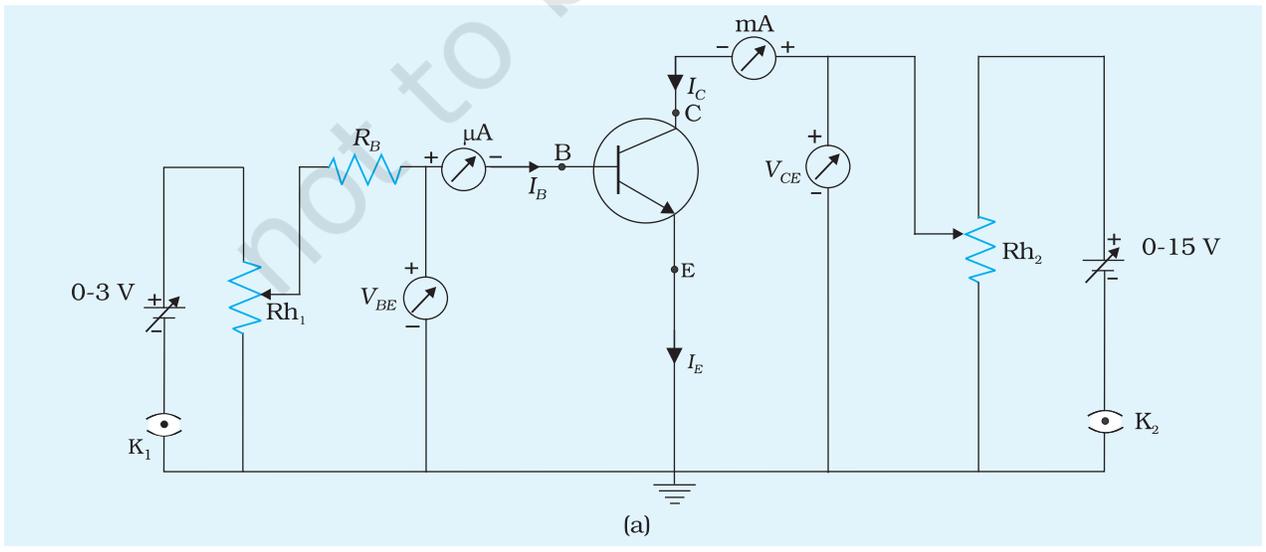


Fig. E 18.2 Input is fed between the base and emitter terminals and the output part is obtained between the collector and emitter terminals in CE configuration in (a) n-p-n transistor (b) p-n-p transistor

The characteristics of a transistor when the emitter is kept as a common terminal and grounded, the base as input terminal and the collector as output terminals, are called common emitter characteristics. Fig.E 18.3 (a) and (b) show the



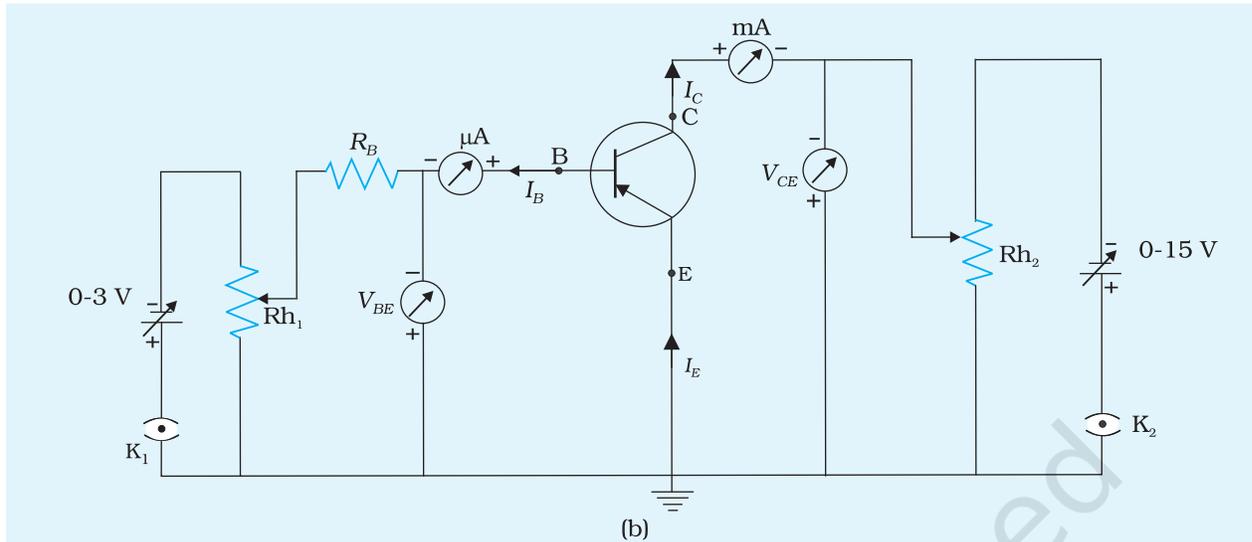


Fig. E 18.3 Circuit diagram for studying the characteristics of (a) n-p-n transistor (b) p-n-p transistor, in CE configuration

circuit diagram for studying the common emitter characteristics of n-p-n and p-n-p transistors respectively. The CE characteristics are of three types:

(I) Input characteristics

The variation of the input current I_B with input voltage V_{BE} keeping output voltage V_{CE} constant is known as input characteristics. As long as the input voltage V_{BE} is less than the knee voltage, current is small and beyond that the current I_B rises [Fig. E 18.4(a)].

Thus, the input resistance r_i is defined as the ratio of change in base - emitter voltage (ΔV_{BE}) to the resulting change in base current (ΔI_B) at constant collector-emitter voltage (V_{CE}). Also, it is defined as the reciprocal of slope at a fixed point on the input characteristics curve i.e.,

$$r_i = \frac{\Delta V_{BE}}{\Delta I_B} \quad V_{CE} = \text{const.} \tag{E 18.1}$$

The value of r_i is of the order of a few hundred ohms.

(II) Output characteristics

The variation in output collector current I_C with output voltage V_{CE} for different values of input current I_B is known as the output

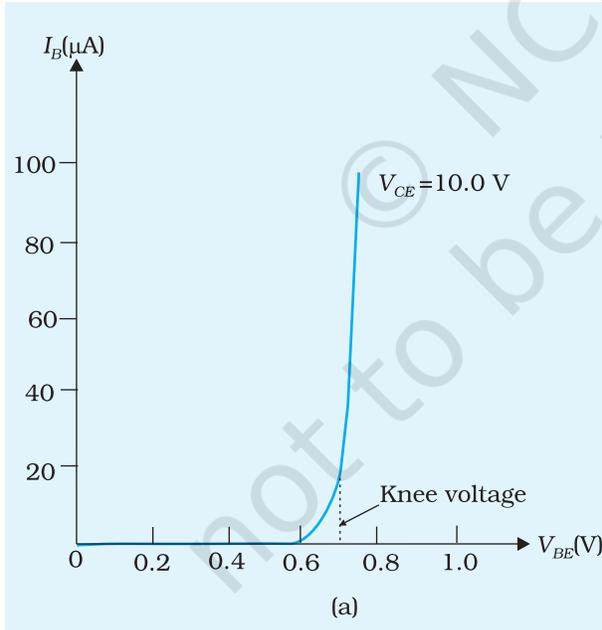


Fig. E 18.4 (a) Typical input characteristics of a transistor in CE configuration

characteristics (Fig. E 18.4 (b)). Greater is the value of input current I_B greater is the output current I_C for a given output voltage V_{CE} .

The output resistance r_o is defined as the ratio of change in collector-emitter voltage (ΔV_{CE}) to the change in collector current (ΔI_C) at constant base current I_B . Further it is also defined as the reciprocal of slope at a fixed point on the output characteristics curve i.e.,

(E 18.2)
$$r_o = \frac{\Delta V_{CE}}{\Delta I_C} \quad I_B = \text{const.}$$

The values of r_o are of the order of 50 to 100 k Ω .

(III) Transfer characteristics

The variation in output collector current I_C with input base current I_B at constant output voltage V_{CE} is known as the transfer characteristics [Fig. E 18.4(c)]. The *current gain* β is defined as

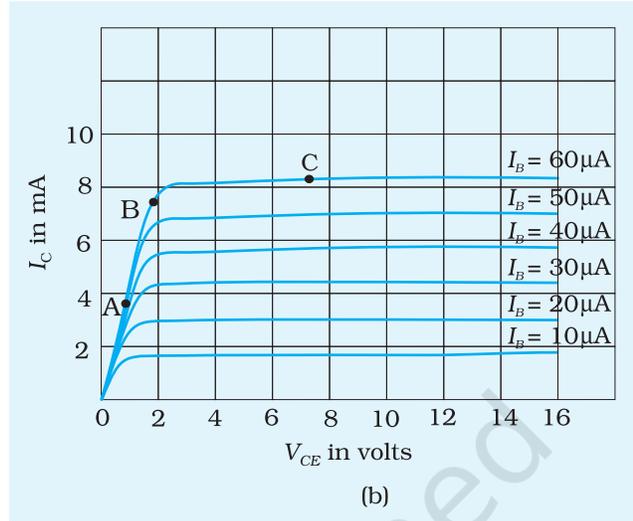


Fig. E 18.4 (b) Typical output characteristics of a transistor in CE configuration

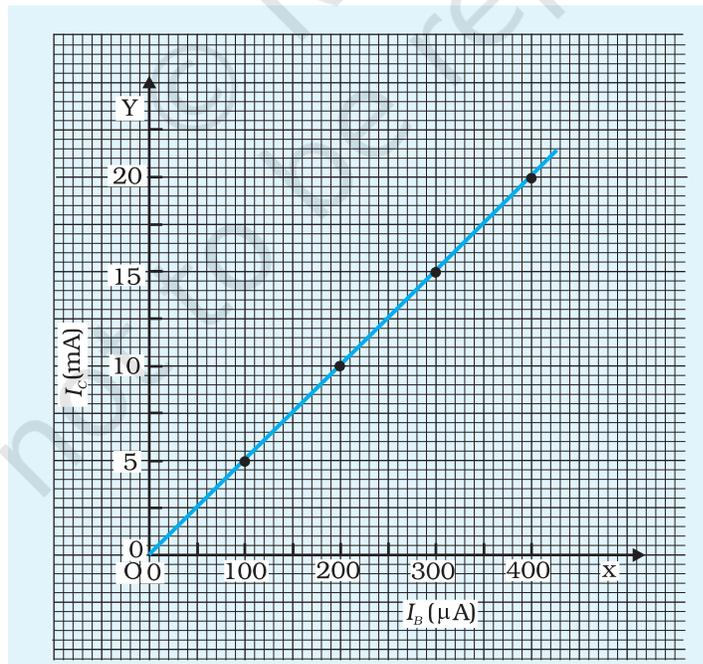


Fig. E 18.4 (c) Typical transfer characteristics of a transistor in CE configuration

the ratio of the change in collector current (ΔI_C) to the change in base current (ΔI_B) when the collector to emitter voltage V_{CE} is fixed i.e.,

$$(E\ 18.3) \quad \beta = \left(\frac{\Delta I_C}{\Delta I_B} \right)_{V_{CE}=\text{const.}}$$

It is also called forward current gain.

Voltage Gain: If ΔV_o is change in the output voltage at the collector for a small voltage change ΔV_i in the emitter base,

voltage gain

$$(E\ 18.4) \quad A_v = \frac{\Delta V_o}{\Delta V_i} = \frac{\Delta I_C}{\Delta I_B} \frac{r_o}{r_i}; \quad A_v = \beta \frac{r_o}{r_i}$$

PROCEDURE

1. First check whether the given transistor is n-p-n or p-n-p.
2. Connect the circuit as shown in Fig. E 18.3. (Note that the base-emitter junction is forward biased and the collector-base junction is reverse biased. For example, in an n-p-n transistor; base is given a + ve voltage w.r.t. emitter. Also collector is given a high + ve voltage w.r.t. emitter.)
3. To obtain the input characteristics of the transistor, keep the value of the collector-emitter voltage V_{CE} fixed. First adjust $V_{CE} = 0$ V and then vary the base-emitter voltage V_{BE} in steps of 0.1 V and for each value of V_{BE} note the base current I_B .
4. Repeat step 3 by keeping V_{CE} fixed at three different values. You will observe that I_B will continue to be zero for a number of observations i.e., till $V_{BE} = 0.6$ to 0.7 V for silicon transistor and 0.2 to 0.3 V for germanium transistor. Thereafter, it will increase slowly and then rapidly, till I_B is nearly 90per cent of maximum range of the microammeter.
5. To obtain the output characteristics of transistor, keep the base current I_B at 10 μ A (say). Note the value of collector current I_C keeping $V_{CE} = 0$ V.

Now increase the value of V_{CE} very carefully in small steps. Note the corresponding values of I_C . (At first the value of I_C will increase very rapidly and then increase slowly to almost a constant value [Fig. E 18.4 (b)]. I_B should be retained constant as noted earlier.

- Repeat step 5 for three different values of I_B i.e., say $20\ \mu\text{A}$, $30\ \mu\text{A}$, $40\ \mu\text{A}$. You will observe that when I_B increases I_C also increases.

OBSERVATIONS

- Range of the voltmeter used in the input circuit = ... V to ...V
- Least count of the voltmeter used in the input circuit = ... V
- Range of the voltmeter used in the output circuit = ...V to ...V
- Least count of the voltmeter used in the output circuit = ... V
- Range of the microammeter used in the input circuit = ... μA to ... μA
- Least count of the microammeter used in the input circuit = ... μA
- Range of the milliammeter used in the output circuit = ... mA to ...mA
- Least count of the milliammeter used in the output circuit = ... mA
- Specification of the transistor used =...

Table E 18.1: Variation in input current I_B with input voltage V_{BE} for fixed value of V_{CE}

Sl. No.	Input voltage $V_{BE} = \dots\ \text{V}$	Input current, I_B (μA) at			
		$V_{CE} = \dots\ \text{V}$	$V_{CE} = \dots\ \text{V}$	$V_{CE} = \dots\ \text{V}$	$V_{CE} = \dots\ \text{V}$
1					
2					
--					
5					

Table E 18.2: Variation in output current I_C with output voltage V_{CE} for fixed value of I_B

Sl. No.	Output voltage V_{CE} $V_{CE} = \dots\ \text{V}$	Output current I_C (mA) at			
		$I_B = \dots\ \mu\text{A}$	$I_B = \dots\ \mu\text{A}$	$I_B = \dots\ \mu\text{A}$	$I_B = \dots\ \mu\text{A}$
1					
2					
--					
5					

For transfer characteristics, using Table E 18.2 note the values of I_C corresponding to different values of I_B for a fixed value of V_{CE} .

Table E 18.3: Variation in output current I_C with input current I_B for fixed value of V_{CE}

Sl. No.	Input current $I_B = \dots \mu\text{A}$	Output current, I_C (mA) at			
		$V_{CE} = \dots \text{V}$	$V_{CE} = \dots \text{V}$	$V_{CE} = \dots \text{V}$	$V_{CE} = \dots \text{V}$
1					
2					
--					
5					

PLOTTING GRAPH

- (i) For input characteristics, plot the graph between input voltage V_{BE} and input current I_B for fixed value of V_{CE} , taking V_{BE} along x-axis and I_B along y-axis, using the readings from Table E 18.1.
- (ii) Discuss the nature of V_{BE} versus I_B graph and interpret it.
- (iii) For output characteristics, plot the graph between output voltage V_{CE} and output current I_C for fixed value of I_B , taking V_{CE} along x-axis and I_C along y-axis, using the readings from Table E 18.2.
- (iv) Discuss the nature of V_{CE} versus I_C graph and interpret it.
- (v) For transfer characteristics, plot the graph between input current I_B and output current I_C for fixed value of V_{CE} , taking I_B along x-axis and I_C along y-axis, using the readings from Table E 18.3.
- (vi) Discuss the nature of I_B versus I_C graph and interpret it.

CALCULATIONS

- (i) Draw a tangent on the input characteristics curve at a point on the rapid rising portion [Fig. E 18.4(a)], and from it, determine the reciprocal of slope of the curve at that point. This gives the dynamic input resistance, of the transistor

$$r_i = \frac{\Delta V_{BE}}{\Delta I_B} \quad V_{CE} = \text{const.}$$

- (ii) Draw tangents on the output characteristics curve (at linearly rising part A, at turning point B and nearly horizontal part C)

[Fig. E 18.4(b)]. Measure the reciprocal of slopes which will give the dynamic output resistances,

$$r_o = \frac{\Delta V_{CE}}{\Delta I_C} \quad I_B = \text{const.}$$

at operating points A, B and C [Fig. E18.4(b)]. Note that the dynamic output resistance depends on the operating point.

- (iii) Find the slope on the transfer characteristics of the transistor to obtain current gain β of the transistor as

$$\beta = \frac{\Delta I_C}{\Delta I_B} \quad V_{CE} = \text{const.}$$

- (iv) Take the values of input resistance r_i , output resistance r_o and current gain β and calculate the value of voltage gain A_v of the transistor by using the relation

$$A_v = \beta \frac{r_o}{r_i}$$

RESULT

For the given transistor (...) in the common emitter (CE) configuration

1. The characteristics of the transistor are shown in the graphs drawn.
2. At $V_{CE} = \dots V$ input resistance = $\dots \Omega$
3. At $V_{BE} = \dots V$ output resistance = $\dots \Omega$
4. Current gain, $\beta = \dots$
5. Voltage gain, $A_v = \dots$

PRECAUTIONS

- (i) Biasing of the transistor should be done considering whether the transistor is n-p-n or p-n-p.
- (ii) Key should be plugged out to break the circuit when circuit is not in use.

DISCUSSION

1. Is there any change in characteristic curves if we use a p-n-p transistor instead of n-p-n transistor?
2. Why is the input circuit forward biased and output circuit reverse biased?
3. You notice the dynamic output resistance r_o is different for different regions of the output characteristic curve. What do you infer from this?
4. If you use some input resistance say $200\ \Omega$ at the input then the characteristic curves are called dynamic input characteristics of a CE transistor. The resistors used in the circuit are basically to control the current so as to avoid the burning out or any damage to the transistor. If no resistor is used in the circuit and the experiment is performed, then the characteristics curves are known as the static input characteristics and static output characteristics. While obtaining the static characteristics, extra care has to be taken to avoid any damage to the transistor due to large flow of current beyond the permissible limits.

SELF ASSESSMENT

1. What do you mean by dynamic input resistance and why is it called dynamic?
2. For CE configuration, I_C is not cut-off even for $I_B = 0$. For determination of the cut-off voltage in CE mode, how will you reduce I_C to zero?
3. Is I_C almost independent of V_{CE} for $V_{CE} > V_{BE}$ in CE configuration?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

Connect the n-p-n transistor in common base configuration. Draw the characteristic curves. Compare input and output characteristic curves of CB and CE configurations. Also find r_i and r_o .