02 Errors in Measurements and Instruments and Semiconductor

ERRORS IN MEASUREMENTS AND INSTRUMENTS

Error & Its Types

Whenever an experiment is performed, two kinds of errors can appear in the measured quantity:

(1) Random and

(2) Systematic errors

1. **Random errors** appear randomly because of operator, fluctuations in external conditions and variability of measuring instruments. The effect of random error can be some what reduced by taking the average of measured values. Random errors havse no fixed sign or size.

2. **Systematic errors** occur due to error in the procedure, or miscalibration of the instrument etc. Such errors have same size and sign for all the measurements. Such errors can be determined.

A measurement with relatively small random error is said to have high precision. A measurement with small random error and small systematic error is said to have high accuracy.

The experimental error [uncertainty] can be expressed in several standard ways.

Error limits $Q \pm \Delta Q$ is the measured quantity and ΔQ is the magnitude of its limit of error. This expresses the experimenter's judgment that the 'true' value of Q lies between $Q - \Delta Q$ and $Q + \Delta Q$. This entire interval within which the measurement lies is called the range of error. Random errors are expressed in this form.

Absolute Error

Error may be expressed as absolute measures, giving the size of the error in a quantity in the same units as the quantity itself.

Least Count Error: If the instrument has known least count, the absolute error is taken to be equal to the least count unless otherwise stated.

Relative (or Fractional) Error

Error may be expressed as relative measures, giving the ratio of the quantity's error to the quantity itself.

In general,

$$\text{Relative error} = \frac{\text{Absolute error in a measurement}}{\text{Size of the measurement}}$$

We should know the error in the measurement because these errors propagate through the calculations to produce errors in results.

A. Systematic errors:

They have a known sign. The systematic error is removed before beginning calculations. Bench error and zero error are examples of systematic error.

B. Random error:

They have unknown sign. Thus, they are represented in the form $A \pm a$.

Here we are only concerned with limits of error. We must assume a "worst-case" combination. In the case of subtraction, $A - B$, the worst-case deviation of the answer occurs when the errors are either $+ a$ and $- b$ or $- a$ and $+ b$. In either case, the maximum error will be $(a + b)$.

For example, in the experiment on finding the focal length of a convex lens, the object distance (u) is found by subtracting the positions of the object needle and the lens. If the optical bench has a least count of 1 mm, the error in each position will be 0.5 mm. So, the error in the value of u will be 1 mm.

Calculation of error in mathematical functions:

Addition and subtraction rule:

The absolute random errors add.

Thus, if $R = A + B$, $r = a + b$ and if $R = A - B$, $r = a + b$

Calculation of error in complex mathematical functions

Product and quotient rule: The relative random errors add.

Thus if $R = AB$, $\frac{r}{R} = \frac{a}{A} + \frac{b}{B}$ and if $R = \frac{A}{B}$, then also $\frac{r}{R} = \frac{a}{A} + \frac{b}{B}$

1. **Power rule:** When a quantity Q is raised to a power P, the relative error in the result is P times the relative error in Q. This also holds for negative powers. If $R = Q^P$, $\frac{r}{R} = P \times \frac{q}{Q}$

2. The quotient rule is not applicable if the numerator and denominator are dependent on each other.

e.g if $R = \frac{XY}{X+Y}$. We cannot apply quotient rule to find the error in R. Instead we write the equation as follows $\frac{1}{R} = \frac{1}{X} + \frac{1}{Y}$. Differentiating both the sides, we get $-\frac{dR}{R^2} = -\frac{dX}{X^2} - \frac{dY}{Y^2}$.

Thus $\frac{r}{R^2} = \frac{x}{X^2} + \frac{y}{Y^2}$

Illustration 1:

A student finds the constant acceleration of a slowly moving object with a stopwatch. The equation used is $S = (1/2)AT^2$. The time is measured with a stopwatch, the distance, S with a meter stick. What is the acceleration and its estimated error?

$S = 2 \pm 0.005$ meter

$T = 4.2 \pm 0.2$ second

Solution:

We use capital letters for quantities, lower case for errors. Solve the equation for the result, a. $A = 2S/T^2$.

Its random error equation is $\frac{a}{A} = 2\frac{t}{T} + \frac{s}{S}$. Thus $A = 0.23 \pm 0.02$ m/s^2.

Significant digits & rounding off

Significant digits

The reported result of measurement is a number that includes all digits in the number that are known reliably plus the first digit that is uncertain. The reliable digits plus the first uncertain digit are known as significant digits or significant figures.

Rules for significant figures in Computed value

The proper number of significant figures that a computed value should have is decided by a set of conventional rules. However, before we get to those rules for computed values we have to consider how to determine how many significant digits are indicated in the numbers being used in the math computation.

A. Rules for determining the number of significant digits in number with indicated decimals.

1. All nonzero digits (1-9) are to be counted as significant.
2. Zeros that have any nonzero digits anywhere to the LEFT of them are considered significant zeros.
3. All other zeros not covered in rule (2) above are NOT be considered significant digits.

For example: 0.0040000

The 4 is obviously to be counted significant (Rule-1), but what about the zeros? The first three zeros would not be considered significant since they have no nonzero digits anywhere to their left (Rule-3). The last four zeros would all be considered significant since each of them has the nonzero digit 4 to their left (Rule-2). Therefore, the number has a total of five significant digits.

Here is another example: 120.00420

The digit 1, 2, 4 and 2 are all considered significant (Rule-1). All zeros are considered significant since they have non-zero digits somewhere to their left (Rule-2). So, there are a total of eight significant digits. If in the question, we are given a number like 100, we will treat that the number has only one significant digit by convention.

B. Determining the number of significant digits if number is not having an indicated decimal.

The decimal indicated in a number tells us to what position of estimation the number has been indicated. But what about 1,000,000?

Notice that there is no decimal indicated in the number. In other words, there is an ambiguity concerning the estimated position. This ambiguity can only be clarified by placing the number in exponential notation.

For example:

If we write the number above in this manner.

1.00×10^6

We have indicated that the number has been recorded with three significant digits. On the other hand, if we write the same number as:

1.0000×10^6

We have identified the number to have 5 significant digits. Once the number has been expressed in exponential notation form then the digits that appear before the power of ten will all be considered significant. So, for example: 2.0040×10^4 will have five significant digits. This means that unit conversion will not change the number of significant digits.

Thus 0.000010 km = 1.0 cm = 0.010 m = 1.0×10^{-2} m = 1.0×10^{-5} km

Rule for expressing proper number of significant digits in an answer from multiplication or division

For multiplication AND division there is the following rule for expressing a computed product or quotient with the proper number of significant digits.

The product or quotient will be reported as having as many significant digits as the number involved in the operation with the least number of significant digits.

For example: $0.000170 \times 100.40 = 0.017068$

The product could be expressed with no more that three significant digits since 0.000170 has only three significant digits, and 100.40 has five. So according to the rule the product answer could only be expressed with three significant digits. Thus, the answer should be 0.0171 (after rounding off)

Another example: $2.000 \times 10^4 / 6.0 \times 10^{-3} = 0.33 \times 10^7$

The answer could be expressed with no more that two significant digits since the least digit number involved in the operation has two significant digits.

Sometimes this would required expressing the answer in exponential notation.

For example: $3.0 \times 800.0 = 2.4 \times 10^3$

The number 3.0 has two significant digits and then number 800.0 has four. The rule states that the answer can have no more than two digits expressed. However, the answer as we can all see would be 2400. How do we express the answer 2400 while obeying the rules? The only way is to express the answer in exponential notation so 2400 could be expressed as: 2.4×10^3.

Rule for expressing the correct number of significant digits in an addition or substraction:

The rule for expressing a sum or difference is considerably different than the one for multiplication of division. The sum or difference can be no more precise than the least precise number involved in the mathematical operation. Precision has to do with the number of positions to the RIGHT of the decimal. The more position to the right of the decimal, the more precise the number. So, a sum or difference can have no more indicated positions to the right of the decimal as the number involved in the operation with the LEAST indicated positions to the right of its decimal.

For example: 160.45 + 6.732 = 167.18 (after rounding off)

The answer could be expressed only to two positions to the right of the decimal, since 160.45 is the least precise.

Another example: 45.621 + 4.3 – 6.41 = 43.5 (after rounding off)

The answer could be expressed only to one position to the right of the decimal, since the number 4.3 is the least precise number (i.e. having only one position to the right of its decimal). Notice we aren't really determining the total number of significant digits in the answer with this rule.

Rules for rounding off digits:

There are a set of conventional rules for rounding off.

1. Determine according to the rule what the last reported digit should be.

2. Consider the digit to the right of the last reported digit.

3. If the digit to the right of the last reported digit is less than 5 round it and all digits to its right off.

4. If the digit to the right of the last reported digit is greater than 5 round it and all digits to its right off and increased the last reported digit by one.

5. If the digit to the right of the last reported digit is a 5 followed by either no other digits or all zeros, round it and all digits to its right off and if the last reported digit is odd round up to the next even digit. If the last reported digit is even then leave it as is.

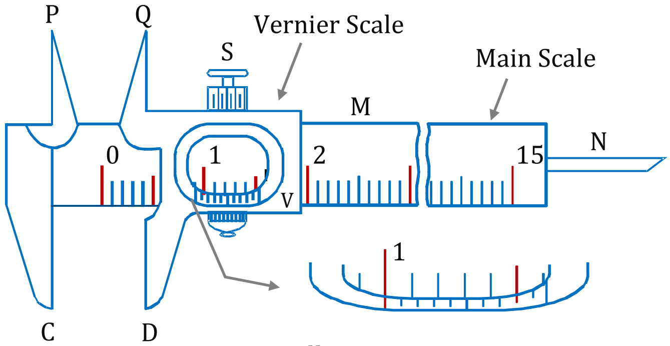
For example, if we wish to round off the following number to 3 significant digits: 18.3682.

The last reported digits would be the 3. The digit to its right is a 6 which is greater than 5. According to the Rule-4 above, the digit 3 is increased by one and the answer is: 18.4.

Another example: Round off 4.565 to three significant digits.

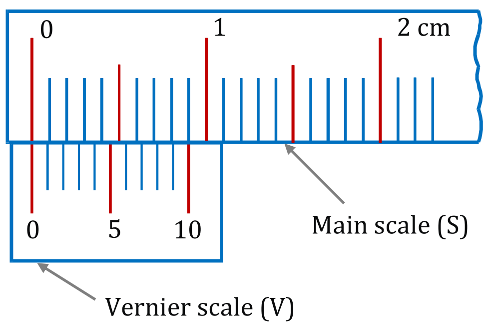
The last reported digit would be the 6. The digit to the right is a 5 followed by nothing. Therefore, according to Rule-5 above since the 6 is even it remains so and the answer would be 4.56.

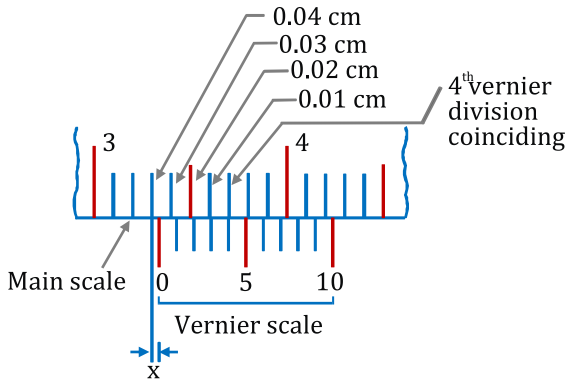
Vernier Callipers:



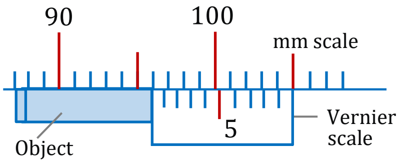
Vernier Callipers

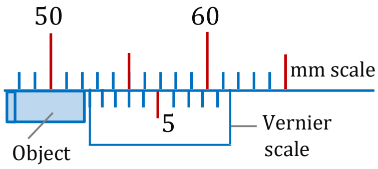
Principle of Vernier





Reading a vernier with 4th division coinciding





It consists of a main scale graduated in *cm/mm* over which an auxiliary scale (or Vernier scale) can slide along the length. The division of the Vernier scale being shorter than the divisions of the main scale.

Least count of Vernier Callipers

The least count or Vernier constant (v. c) is the minimum value of correct estimation of length without eye estimation. If N division of vernier coincides with (N-1) division of main scale, then

$$N\,(VS) = (N-1)\,ms \;\Rightarrow\; 1VS = \frac{N-1}{N}\,ms$$

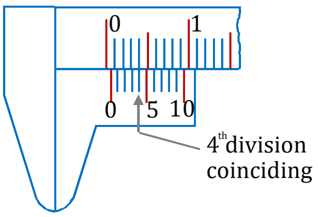
Vernier constant = 1 ms – 1 vs = $\left(1-\frac{N-1}{N}\right) ms = \frac{1ms}{N}$, which is equal to the value of the smallest division on the main scale divided by total number of divisions on the vernier scale.

Length as measured by Vernier Callipers

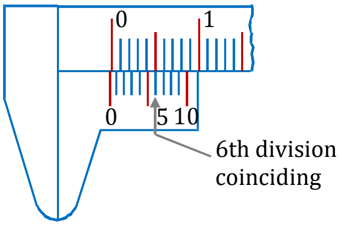
The formula for measuring the length is L = main scale reading + least count of vernier scale × Vernier scale division coinciding with a main scale division

Main scale reading is given by the zeroth division of the vernier scale as shown in the figure.

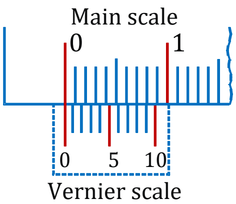
Zero error:



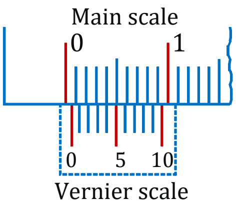
Positive zero error (+0.04 cm)
and its correction



Negative zero error= (–0.04 cm)
and its correction

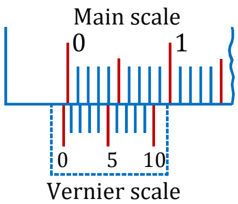


without zero error



with positive zero error

(i)



with negative zero error

(ii)

If the zero marking of main scale and vernier callipers do not coincide, necessary correction has to be made for this error which is known as zero error of the instrument.

Positive zero error:

If the zero of the vernier scale is to the right of the zero of the main scale the zero error is said to be positive and the correction will be negative.

The zero error is always subtracted from the reading to get the corrected value.

Negative zero error:

If the zero of the vernier scale is to the left of the zero of the main scale the zero error is said to be negative and the correction will be positive.

If the zero error is positive, its value is calculated as we take any normal reading. If the zero-error negative (The zero of vernier scale lies to the left of the zero of main scale),

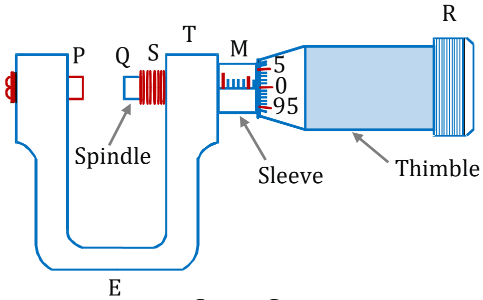
Negative zero error = – [Total number of *vsd* – *vsd* coinciding] × L.C.

Do not try to read the main scale at the point where the lines match best. This has no meaning. Read from the vernier scale instead. Sometimes it is difficult to tell whether the best match of lines is for vernier marks 9, 0, or 1. Make your best estimate, but realize that the final result including the vernier must round off to the result you would choose if there was no vernier. If the mark is close to 3.20 on the main scale, but the vernier reading is 9, the length is 3.19 *cm*. If the mark is close to 3.2 on the main scale and the vernier is 1, the length is 3.21 *cm*.

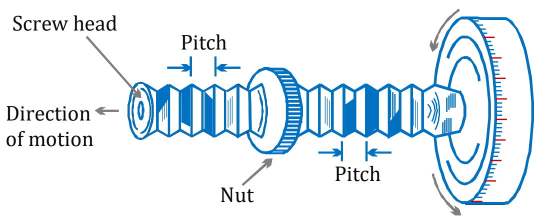
SCREW GAUGE

Screw Gauge (Micrometer Screw)

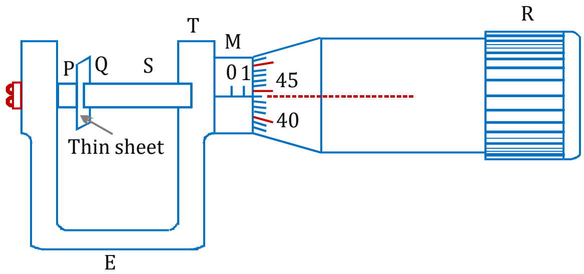
In general vernier callipers can measure accurately upto 0.01 *cm* and for greater accuracy micrometer screw devices e.g. screw gauge, spherometer are used. These consist of accurately cut screw which can be moved in a closely fitting fixed nut by turning it axially. The instrument is provided with two scales:

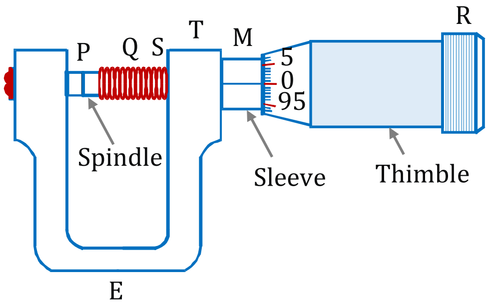


Screw Gauge

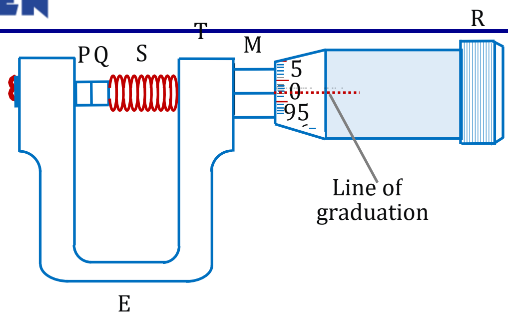


Principle of a micrometer

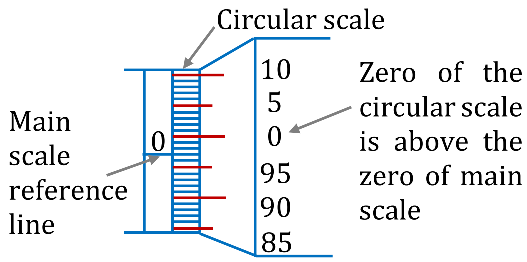


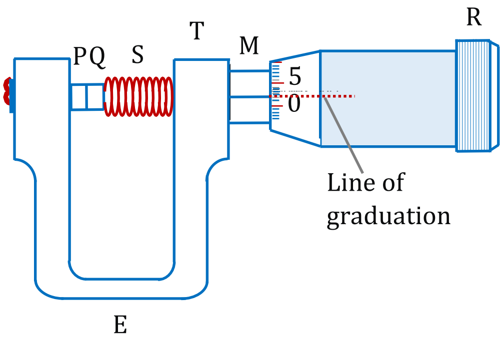


Screw gauge with no zero error

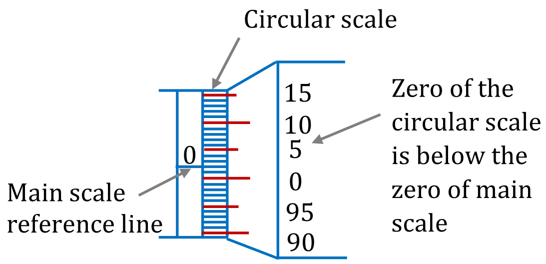


Negative zero error
(3 division error) i.e., - 0.003 cm





Negative zero error
(2 division error) i.e., + 0.002 cm



(i) The main scale or pitch scale M graduated along the axis of the screw.

(ii) The cap-scale or head scale H round the edge of the screw head.

Constants of the Screw Gauge

(a) Pitch: The translational motion of the screw is directly proportional to the total rotation of the head. The pitch of the instrument is the distance between two consecutive threads of the screw which is equal to the distance moved by the screw due to one complete rotation of the cap. Thus for 10 rotation of cap = 5 *mm*, then pitch = 0.5 *mm.*

(b) Least count: In this case also, the minimum (or least) measurement (or count) of length is equal to one division on the head scale which is equal to pitch divided by the total cap divisions. Thus in the aforesaid illustration, if the total cap division is 100, then least count = 0.5*mm*/100 = 0.005 *mm.*

(c) Measurement of length by screw gauge:

$L = n \times \text{pitch} + f \times \text{least count}$, where n = main scale reading and f = caps scale reading

Zero Error:

In a perfect instrument the zero of the head scales coincides with the line of graduation along the screw axis with no zero-error, otherwise the instrument is said to have zero-error which is equal to the cap reading with the gap closed. This error is positive when zero line or reference line of the cap lies **below** the line of graduation and versa. The corresponding corrections will be just opposite.

Searle's Experiment

EXPERIMENT

Objective: Determine Young's modulus of elasticity of the material of a given wire by using Searle's apparatus.

Apparatus required: - Searle's apparatus, a metre scale, a screw gauge, slotted weights, hanger etc.

Theory: Suppose a wire of length L and cross-section A is stretched by an amount ℓ by a force F acting along its length, then

$$\text{Stress} = \frac{F}{A} \text{ and strain} = \frac{\ell}{L}$$

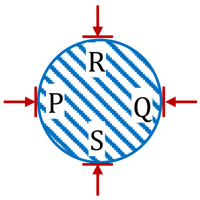
$\therefore$ Young's modulus $Y = \frac{F}{A} \times \frac{L}{\ell}$

Here $F = Mg$ and $A = \pi r^2$ $\Rightarrow$ $\boxed{Y = \frac{MgL}{\pi r^2 \ell}}$

Procedure:

1. Attach weights to the hooks of both the frames so that the wires A and B become free from kinks and stretched. Then prepare it for the experimental load and unload one-kilogram weight on the hanger of the experimental wire B to remove its fatigue and attached only a constant weight W on the hook H_1 to keep the reference wire A taut.

2. Measure the length of the experimental wire from the point where it leaves the fixed support to the point where it is fixed in the frame. Find the pitch and least count of the screw gauge and determine the diameter of the wire at about ten different places and at each place in two mutually perpendicular directions. Determine the mean diameter and radius.



3. Consult the table of constants and find the breaking stress for the steel wire used. The maximum load should not exceed one-third of the breaking stress. Find the pitch and the least count of the micrometer attached to the frame and adjust it such that the bubble in the spirit level is exactly in the centre. Take the reading of the micrometer.

4. Now, increase gradually the load on the hanger of the experimental wire B in steps of 0.5 kg. Observe the reading on the micrometer at each stage, after levelling the instrument with the spirit level till the maximum permissible load is reached. In these cases, the adjusting screw has to be moved upwards to bring the bubble in the Centre. To avoid back lash error, all the final adjustments should be made by moving the screw in the upward direction only. If at any time the screw is raised too much, lower it below the central position and then raise it slowly to the proper position.

5. Unload the wire by removing the weights in the same order and take the reading on the micrometer screw each time. In this case the screw has to be moved downwards but again, to avoid the back-lash error, move the screw in the same direction only. These readings taken for a particular load while loading the wire or unloading the wire, should agree closely.

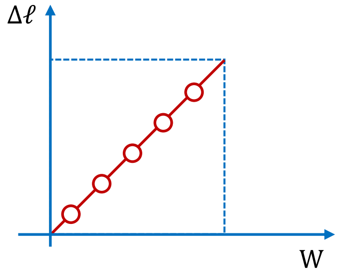
From the data obtained, a graph showing extension (Δl) against the load (W) is plotted which is obtained as a straight line passing through the origin.

The slope of the line gives $\tan\theta = \frac{l}{W} = \frac{l}{Mg}$

Now, stress = $\frac{Mg}{\pi r^2}$ and strain = $\frac{l}{L}$

Y = Stress/ strain = $\frac{MgL}{\pi r^2 l}$ = $\frac{L}{\pi r^2 \tan\theta}$

With known values of initial length L, radius r of the experimental wire and $\tan\theta$, Young's modulus Y can be calculated.



Precautions:

1. Both the wires should be supported from same rigid support.

2. Kinks should be removed from experimental wire before starting the experiment.

3. Diameter of wire should be measured at different places and along two mutually perpendicular directions at every place.

4. Slotted weights should be added and removed gently.

5. We should wait for taking observations after adding or removing weight.

6. Load should be increased or decreased in regular steps.

7. Do not load the wire beyond one-third of the breaking stress.

8. To avoid backlash error, the screw should always be turned in the same direction.

Sources of Error:

1. Experimental wire may not have uniform cross-section through-out.

2. The slotted weights may not have standard weight.

3. The screw gauge may have friction or backlash error.

Resonance column experiment

Golden Key Points:

1. Speed of sound in solids is given by, $v = \sqrt{\frac{Y}{\rho}}$ where Y - Young's modulus of elasticity p - density

2. Speed of sound in fluids is given by

$$v = \sqrt{\frac{B}{\rho}}$$

where B : Bulk modulus of elasticity of fluid

ρ : density of fluid

3. Newton's formula for speed of sound

$$v = \sqrt{\frac{P}{\rho}}$$ here, $B = P$ (assuming isothermal conditions)

4. Laplace formula for speed of sound

$$v = \sqrt{\frac{\gamma P}{\rho}}$$ here $B = \gamma P$ assuming adiabatic conditions.

5. At constant temperature, speed of sound is independent of pressure and density.

6. Effect of temperature on speed of sound

$$v \propto \sqrt{T} \quad \text{or} \quad \boxed{v_t = v_0 + 0.61t}$$

Resonance Tube:

It has a 100 *cm* long glass or brass tube *AB* of about 2.5 *cm* internal diameter. The tube is fixed on a vertical board along the side of a metre scale marked in millimeters. The zero of the scale coincides with the upper end of the tube. The lower end of the glass tube is drawn out and is connected to a reservoir of water with the help of rubber tubing. A pinch cock is attached with the rubber tubing. The water level in the resonance tube *AB*, can be adjusted by manipulating the adjustable screw attached with the reservoir for clamping. To find adjustments of the water level in the tube *AB*, the pinch-cock is used. The tube *AB* can be made vertical with the help of the levelling screws *SS* provided at the heavy base of the frame.

End correction:

It is found that antinode occurs slightly above the open end of the resonance tube. So, a small correction has to be applied to the observed resonant length of the air column. This correction is called end correction. Theoretically, it was found by lord Rayleigh and it is $0.3D$ or $0.6\ R$, where D is diameter and R is radius of the tube.

Experiment:

Objective: To find the speed of sound in air at room temperature using a resonance tube by two resonance positions.

Apparatus required: Resonance tube apparatus, tuning forks of different frequencies, a rubber pad, a thermometer, a set square, a spirit level etc.

Concept / Theory:

If ℓ_1 and ℓ_2 are the lengths of the air columns for the first and the second positions of resonance respectively,

$\ell_1 + x = \ell/4$ ...(i)

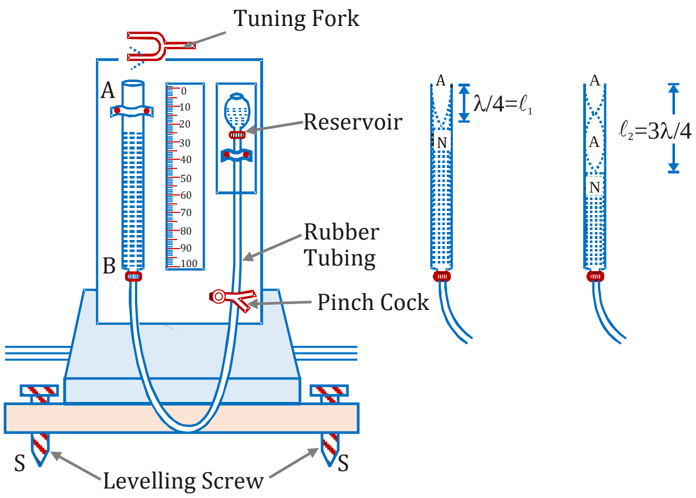
and $\ell_2 + x = 3\ell/4$ ...(ii)

x = end correction

ℓ = wavelength of the sound wave

So, $$\ell_2 - \ell_1 = \frac{\lambda}{2}$$

or $\ell = 2\,(\ell_2 - \ell_1)$ $\Rightarrow \because v = n\ell$



where v and n are the velocity and frequency of the sound wave respectively.

So, $v = 2n\,(\ell_2 - \ell_1)$

The velocity at 0°C is given by,

$v_0 = (v_t - 0.61 \times t)$ in ms^{-1}

where v_t is velocity at room temperature t°C.

Also, by eliminating ℓ from equations (i) and (ii), the end correction.

Procedure:

1. With the help of the plumb line and the levelling screws at the base set the resonance tube *AB* vertical. Fill water in the reservoir *R* and some portion of the resonance tube.
   Suspend the thermometer by the side of the resonance tube to note the room temperature.
2. Release the pinch-cock and adjust the level of water in the resonance tube near the end *A* by adjusting the position of the reservoir *R* and then, after closing the pinch-cock lower down the position of the reservoir *R*.
3. Strike the tuning fork gently on the rubber pad and place it just above the upper end *A* of the resonance tube so that the prongs of the vibrating tuning fork are in vertical plane. Now open then pinch-cock and let the water level fall in the resonance tube slowly. At some position of the water level, you will listen sound of increasing loudness.
4. Repeat above steps to get the exact position of water level in the resonance tube for which the sound is of maximum intensity. Note the position of the water level with the help of a set square keeping one of its perpendicular edges tangential to meniscus of water and other edge parallel to line of graduations on the metre scale. Note the length ℓ_1 of the resonance column as shown in figure. This position corresponds to the first resonance position. Confirm the resonance positions by taking four readings, two when the level of water is falling and the other two when the water level is rising. Note down these lengths of the air column as ℓ_1.
5. Lower the position of water level so that it is increased about three times the length ℓ_1. Repeat above steps to get the second position of resonance with the same tuning fork. Note this length ℓ_2 of air column.

Errors:

The major systematic errors introduced are due to end effects in (end correction) and also due to excessive humidity.

Random errors are given by $\frac{\delta C}{C} = \frac{\delta(l_2 - l_1)}{l_2 - l_1} = \frac{\delta l_2 + \delta l_1}{l_2 - l_1}$.

Precautions:

1. The resonance tube should be set vertical using leveling screw.
2. Tuning fork should be vibrated gently by a rubber pad.
3. Prongs should be vibrated in a vertical plane just above the mouth (end) of the resonance tube.
4. Readings should be taken for water level rising as well as water level falling in the tube.
5. While measuring air temperature, thermometer bulb should not touch water or sides of resonance tube.

Sources of error:

1. Frequency of the tuning fork may differ than prescribed.
2. Resonance tube may not be vertical.
3. Thermometer may have faulty calibration.
4. There may be humidity in air column which can affect sound's velocity.
5. Meter scale attached with the resonance tube may have faulty calibrations.

OHM'S LAW EXPERIMENT

Ohm's law:

According to this law the ratio of the potential difference across any conductor to the electric current flowing through it is constant, under constant physical conditions i.e. temperature, pressure etc. If V is the potential difference between the two points along a conductor and I is current flowing through it, then $V = IR$. Where R is constant. This constant is known as resistance of the conductor.

Resistance:

Obstruction in the flow of charge through a conductor is called a resistance. Its S.I. unit is Ohm (Ω).

Conductance:

The inverse of resistance is known as conductance. Its S.I. unit is $(\text{ohm})^{-1}$ or mho or siemen.

Specific resistance or resistivity:

For conductors of given material at given temperature, the resistance is directly proportional to the length ℓ and inversely proportional to the area of cross-section A, i.e.,

$$R \propto \frac{\ell}{A} \Rightarrow R = \frac{\rho\ell}{A}$$

where ρ is a constant which depends upon the nature of the material and is called resistivity or specific resistance of the conductor. For unit length and unit area of cross-section, $\rho = R$; so specific resistance is the resistance of a conductor of unit length and of unit area of cross-section. Its S.I. unit is ohm-metre.

Temperature dependence of resistivity:

When temperature of a conductor increases, ρ increases as; $\rho_\theta = \rho_0 (1 + \alpha\,\theta)$. Resistance of metals increase with rise in temperature. $R_\theta = R_0 (1 + \alpha\,\theta)$, where α is coefficient of resistance given as

$$\alpha = \frac{R_\theta - R_0}{R_0.\theta} (°C)^{-1}$$

Electrical conductivity:

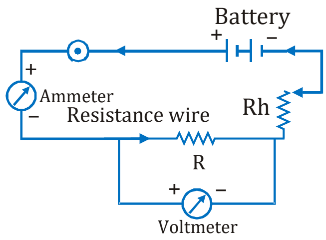
Electrical conductivity is the inverse of term resistivity and is denoted by sigma (σ) given, as,

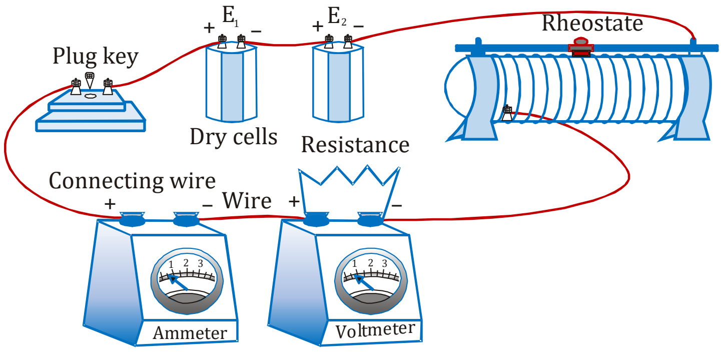
$$\sigma = \frac{1}{\rho} = \frac{\ell}{RA} \quad \text{(S.I. unit of } \sigma \text{ is } ohm^{-1}m^{-1})$$

Experiment:

Objective: To determine the resistance of a given wire by plotting a graph of potential difference versus current.

Apparatus required: A given resistance wire in the form of a coil, a battery eliminator or an accumulator or two dry cells, a *dc* voltmeter, a *dc* ammeter, a rheostat, one plug key, thick connecting wire, sand paper etc.





Circuit Diagram:

Procedure:

1. Draw the circuit diagram as shown in figure.

2. Note the range, the least count, and the zero error of voltmeter as well as that of the ammeter.

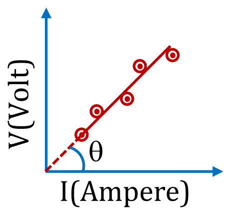
3. Insert the plug-in key *K*. Slide the rheostat contact to the extreme right figure. So that the current passing through the resistance wire is minimum.

4. Adjust the rheostat and record the readings of the ammeter and the voltmeter. Then shift the rheostat contact to increase the current and note readings again. Take similarly ten observations.

5. Cut the resistance wire at the ends just coming out of voltmeter and measure its length 'ℓ', using meter scale.

Graph:

Using the readings of voltmeter (V) and ammeter (I) draw a graph as straight line best fitting all the points.



Calculation:

Slope of $V-I$ curve = $\dfrac{\Delta V}{\Delta I} = \tan\theta = R$

Error analysis:

The error in computing the ratio $R = \dfrac{V}{i}$ is given by $\left|\dfrac{\delta R}{R}\right| = \left|\dfrac{\delta V}{V}\right| + \left|\dfrac{\delta i}{i}\right|$

where δV and δi are of the order of the least counts of the instruments used.

Precautions:

1. Connections should be neat, clean and tight.

2. Connecting wires should be of thick copper wires.

3. Voltmeter and ammeter should be of proper range.

4. The key/plug should be inserted only while taking observations, otherwise current gives unnecessary heating of wires.

5. The unknown resistance should not be too low (than internal resistance of battery).

Sources of error:

1. Connections may be loose.

2. Rheostat may have very high resistance.

3. The unknown resistance may be too low.

4. Thick connecting wires may not be available.

Meter bridge experiment:

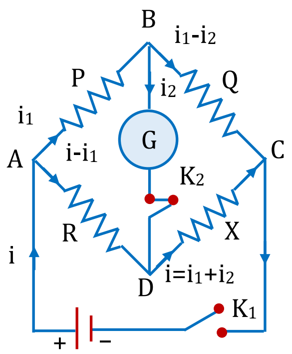
Wheatstone Bridge:

Wheatstone bridge is a special electric network in which four resistors *P, Q, R* and *X* are connected to form the four arms of a quadrilateral *ABCD*. A cell with key K_1 is connected across the diagonal *AC* and a galvanometer with key K_2 across another diagonal *BD*. The arrangement may be used to measure resistance of a conductor accurately.

The resistances *P* and *Q* are kept in a fixed ratio and hence they are said to form the ratio arms of the bridge. Unknown resistance is placed for resistance *X* and *R* is a resistance box to provide variable known resistance in steps.

After closing keys K_1 and K_2 resistance in resistance box *R* may be adjusted to obtain null deflection in galvanometer. In this situation bridge is said to be balanced. When bridge is balanced, *B* and *D* must be at same potential.

$V_B = V_D$



No current flows through the galvanometer i.e., $i_2 = 0$

$\therefore \quad V_A - V_B = V_A - V_D$ and $V_B - V_C = V_D - V_C$

$\Rightarrow \quad Pi_1 = R(i - i_1) \quad$ ...(i)

and $\quad Q(i_1 - i_2) = X(i - i_1 + i_2) \quad$ ...(ii)

$Qi_1 = X(i - i_1) \quad$ ...(iii)

Dividing (i) and (iii), we get $\frac{P}{Q} = \frac{R}{X}$

This, is the condition of balanced bridge. [Wheatstone bridge]

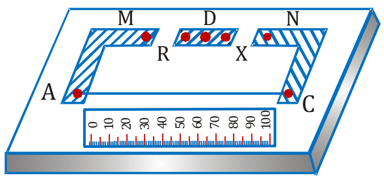
In balancing condition of the bridge, unknown resistance can be calculated.

Two practical versions of Wheatstone bridge are:

(a) Post office box, and

(b) Meter bridge or slide wire bridge.

Meter Bridge:

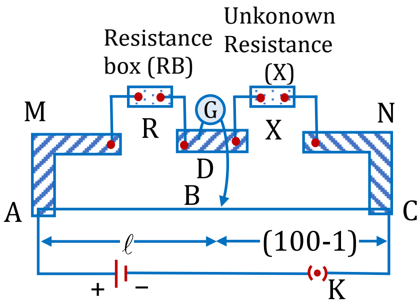


A meter bridge consists of a one-meter long wire *AC*, made of a homogeneous material constantan or eureka alloy and having a uniform cross-section. The wire is stretched on a wooden board. A meter scale is fixed on the board parallel to the wire.

The ends *A* and *C* of the wire are fixed to two thick copper strips *M* and *N* respectively. Another strip *D* is fixed between strips *M* and *N* to form two gaps for introducing resistances *R* and *X*. Connecting terminals are attached at the ends of the copper strips and also in the middle of strip *D* for making connections.

Experiment:

Objective: To find resistance of a given wire using a meter bridge and hence determine the specific resistance of its material.



Apparatus required: A resistance box, a wire about 1 meter long (of the material whose specific resistance is to be determined), a meter bridge, a jockey, one- way key, a galvanometer, a battery eliminator or a cell, thick connecting wires, sand paper, screw gauge etc.

Required formula: Unknown resistance $X = R\left(\frac{100-\ell}{\ell}\right)$ and specific resistance of the material of the given wire, $\rho = \frac{XA}{L} = \frac{X(\pi r^2)}{L}$, where r and L are the radius and length of the given wire respectively.

Procedure:

1. Arrange the meter bridge and the various component as shown in figure and make tight connections.
Putting RB in right gap and X in left gap.

2. Take out the plug from RB to introduce a suitable resistance say, $R = 2\Omega$ and close the key K.

3. Now, touch the jockey on meter-bridge wire at different places to obtain such a position, where there is no deflection in the galvanometer. At this condition

$AB = \ell$ and $BC = (100 - \ell)$

Putting RB in left gap and X in right gap.

4. Repeat step 2 and 3. But in this balancing condition, $BC = \ell$ and $AB = (100 - \ell)$.

5. Now disconnect the unknown resistance wire from the circuit. Straighten it by stretching and remove any kinks and measure its length with the help of a meter scale.

6. Measure the diameter of the wire with the help of a screw gauge.

Errors:

The major systematic errors in this experiment are due to the heating effect, end corrections introduced due to shift of the zero of the scale at A and B, and stray resistances in P and Q, and errors due to non-uniformity of the meter bridge wire.

Error analysis:

End corrections can be estimated by including known resistances P_1 and Q_1 in the two ends and finding the null point:

$$\frac{P_1}{Q_1} = \frac{l_1 + \alpha}{100 - l_1 + \beta} \qquad ...(1)$$

where α and β are the end corrections.

When the resistance Q_1 is placed in the left gap and P_1 in the right gap,

$$\frac{Q_1}{P_1} = \frac{l_2 + \alpha}{100 - l_2 + \beta} \qquad ...(2)$$

which give two linear equation for finding α and β.

In order that α and β be measured accurately, P_1 and Q_1 should be as different from each other as possible.

For the actual balance point, $\frac{P}{Q}=\frac{l+\alpha}{100-l+\beta}=\frac{l'_1}{l'_2}$

Errors due to non-uniformity of the meter bridge wire can be minimized by interchanging the resistances in the gaps P and Q.

$$\therefore \qquad \frac{\delta P}{P}=\left|\frac{\delta l'_1}{l'_1}\right|+\left|\frac{\delta l'_2}{l'_2}\right|$$

where, $\delta l'_1$ and $\delta l'_2$ are of the order of the least count of the scale.

The error is, therefore, minimum if $l'_1 = l'_2$ i.e. when the balance point is in the middle of the bridge. The error in ρ is $\frac{\delta\rho}{\rho}=\frac{2\delta r}{r}+\frac{\delta L}{L}+\frac{\delta P}{P}$.

Precautions:

1. The connections should be neat, clean and tight.

2. All the plugs in the resistance box should be tight.

3. While moving the jockey to locate the balance point, the jockey should be lifted again and again and should not be pressed and slided on the wire throughout.

4. The plug-in key K should be inserted only when the observations are to be taken.

5. The balance point should always be obtained near the midpoint or in between from 30 *cm* to 70 *cm*.

6. Diameter of wire should be measured in two mutually perpendicular direction at one place.

Source and of error:

1. The plugs may not be clean.

2. The meter bridge wire may not have uniform cross-section.

3. Connections may loose.

4. The screw gauge may have faulty calibration or backlash error.

Potentiometer experiment:

Potentiometer:

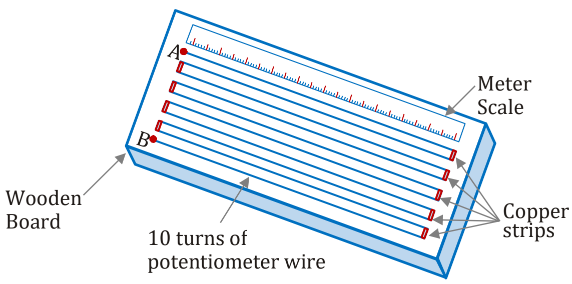
1. It is a device used to measure potential difference between two point in an electric circuit or emf of a cell with greater accuracy.

2. It behaves like an ideal voltmeter means its effective resistance is infinity.

3. It uses the concept of zero deflection during measurement.

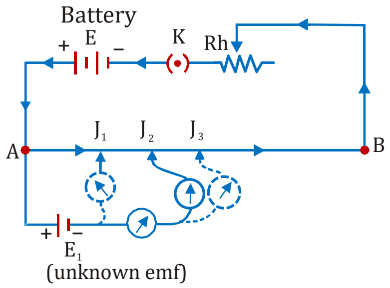
Construction:

A thin, long, straight and uniform wire AB of constantan or manganin, which has a low temperature coefficient of resistance and high resistivity, is stretched on a wooden board along a meter-scale. The longer wire (taken long to increase accuracy) is arranged in the form of parallel wires and its ends are connected by thick strips of copper, so that the current flows through the wires in series.



Principle:

When a steady current flow through the potentiometer wire from the end A to B, as shown in figure, by a battery E then an electric potential fall uniformly along the whole length of the wire. This fall in potential per unit length of the wire, is known s "potential gradient".



Due to the constant current through potentiometer wire potential difference between any two points on the wire is directly proportional to the distance between the points, means

$$V \propto \ell$$

$\Rightarrow$ $V = x\ell$ or $\dfrac{V}{\ell} = x$ = potential gradient

By comparing the unknown emf, say as E_1 in the figure, with the help of a galvanometer to the uniformly distributed potential over the wire, we can find the value of unknown. So, now suppose the jockey is made to touch a point J_1 on the wire such that the potential difference between A and J_1 is lower than the emf of E_1, then a resultant current flow through the secondary circuit or galvanometer and the needle of the galvanometer deflects in one direction.

On the other hand, if the jockey is made to touch a point J_2 on the wire such that the potential difference between A and J_2 is higher than the emf of the cell E_1, then a resultant current flow in opposite direction than previous one in the galvanometer and its needle deflects in the opposite side.

It is evident that in between J_1 and J_2, there will be a point J such that when the jockey is made to touch on J, there will be no deflection in the galvanometer. This point J is called **balancing null point** and the distance AJ is called **balancing length.** At this situation.

p.d. between A and J = emf of the cell

$\Rightarrow$ $x\,\ell = E_1$ $\Rightarrow$ $E_1 = x\ell$

where x - potential gradient ; ℓ - balancing length ; E_1 - unknown emf

Sensitivity of Potentiometer:

If on displacing the jockey slightly from the null point position, the galvanometer shows a large deflection, then the potentiometer is said to be sensitive. The sensitivity of the potentiometer depends upon the potential **gradient as:**

$$\text{Sensitivity of potentiometer} \propto \frac{1}{\text{Potential gradient}}$$

The potential gradient can be reduced by employing a long wire in the potentiometer.

Experiment

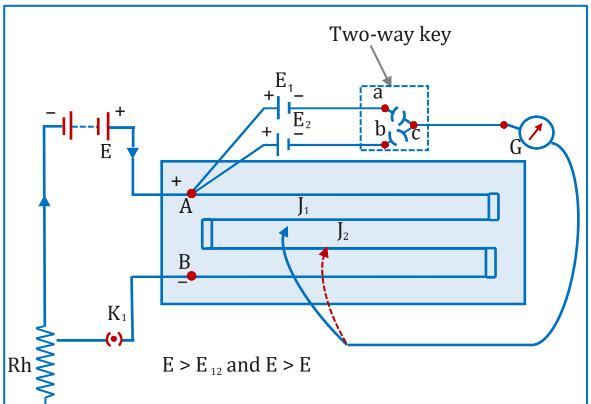
Objective: To compare the emf of two given primary cells (Daniel and Lechlanche Cell) using a potentiometer.

Apparatus required: A battery eliminator, a low resistance box about 20Ω, a one-way key, two primary cells (Daniel and Lechlanche), one two-way key, a resistance box plug type, a galvanometer, a potentiometer with a sliding jockey, connecting wires etc.

Formula required:

where E_1 and E_2 are the emf's of the given primary cells and ℓ_1 and ℓ_2 are their respective balancing lengths on potentiometer wire.

Circuit diagram:



[Circuit diagram]

Procedure:

1. Arrange the circuit as shown in figure and plug key K_1.
2. In this circuit, by inserting the plug in the gap ac, cell E_1 comes in the secondary circuit. Introduce minimum resistance by Rh (rheostate) and then press the jockey at one end of the wire and note the direction of deflection in the galvanometer. Now repeat the same process with the jockey pressed near the other end of the wire and note the direction of deflection. The connections are correct if two deflections are in opposite directions.
3. If deflections are obtained in same direction, check connections and assure that $E > E_1$ and $E > E_2$.
4. After this, touch the jockey at different places on the wire and obtain a balance point, where on pressing the jockey, there is no deflection in the galvanometer note the length AJ_1 as ℓ_1.
5. Introduce E_2 in the S circuit by transferring the plug ac to bc. Obtain the balancing point J_2 and note the length AJ_2 as ℓ_2.
6. Repeat the experiment by shifting the contact point of rheostate.

Precautions:

1. The plugs should be introduced in the keys only when the observations are to be taken.
2. The positive poles of the battery and cells E_1 and E_2 should all be connected to the terminal at zero of the wires.
3. The emf of the battery should be greater than the emfs of either of the two cells.
4. The jockey should not be rubbed along the wire. It should touch the wire gently.
5. The current should not be passed for a long time so as to avoid any heating of the wires resulting into change of resistance.
6. The balancing point should always be obtained at large distance and if possible, it should be obtained at the last wire.

Source of error:

1. The battery (E) may not be fully charged.

2. By rubbing the jockey on the wire, it may not have uniform cross-section throughout its length.

3. The resistance of copper strips may not be zero.

4. Due to the current passed through the wire for a long time, its resistance may change.

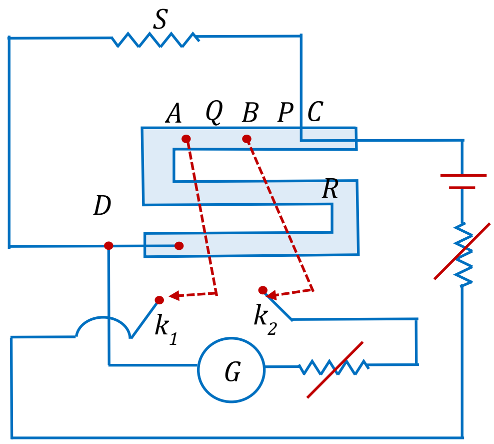
Post office box experiment

Measurement of unknown resistance using a P.O. Box

A P.O. Box can also be used to measure an unknown resistance. It is a Wheatstone Bridge with three arms P, Q and R; while the fourth arm(s) is the unknown resistance. P and Q are known as the ratio arms while R is known at the rheostat arm. At balance, the unknown resistance

$$S = \left(\frac{P}{Q}\right) R \qquad \text{...(1)}$$

The ratio arms are first adjusted so that they carry 100 Ω each. The resistance in the rheostat arm is now adjusted so that the galvanometer deflection is in one direction, if $R = R_0$ (Ohm) and in the opposite direction when $R = R_0 + 1$ (ohm).



This implies that the unknown resistance, S lies between R_0 and $R_0 + 1$ (ohm). Now, the resistance in P and Q are made 100 Ω and 1000 Ω respectively, and the process is repeated.

Equation (1) is used to compute S.

The ratio P/Q is progressively made 1 : 10, and then 1 : 100. The resistance S can be accurately measured.

Errors:

The major sources of error are the connecting wires, unclear resistance plugs, change in resistance due to Joule heating, and the insensitivity of the Wheatstone bridge.

These may be removed by using thick connecting wires, clean plugs, keeping the circuit on for very brief periods (to avoid Joule heating) and calculating the sensitivity.

In order that the sensitivity is maximum, the resistance in the arm P is close to the value of the resistance S.

Half deflection method

Galvanometer:

- It is a device which is used to detect the presence of current or to measure weak current in the circuit.
- It is based on the principle that a current carrying coil placed in a uniform magnetic field experiences a torque.
- Basically, galvanometers are of two types:

  (i) Moving coil type (ii) Moving Magnet type (Tangent Galvanometer)

Principle of a moving coil galvanometer

When a current I is flowing through a coil in a uniform magnetic field, the coil experiences first deflecting torque $\tau = NAIB$ and then restoring torque $\tau = C\theta$. Because both the torque opposes each other, therefore in equilibrium.

$$\tau_{\text{deflecting}} = \tau_{\text{restoring}}$$

$$NIAB = c\theta$$

$$\Rightarrow \quad I = \left(\frac{C}{BAN}\right)\theta = k\theta$$

$\Rightarrow \quad I \propto \theta$ or Current $\propto$ deflection where $k = \dfrac{C}{BAN}$ (Galvanometer's constant)

i.e. deflection of the needle in the galvanometer is directly proportional to the current flowing through it.

(i) Figure of Merit: Current required to produce a deflection of one division is called figure of merit of galvanometer.

$$F = \frac{I}{\theta} = k$$

(ii) Current Sensitivity: Deflection per unit current is called current sensitivity of galvanometer.

$$S_C = \frac{\theta}{I} = \frac{1}{k} = \frac{1}{F} = \text{reciprocal of figure of merit}$$

(iii) Voltage sensitivity: Deflection per unit voltage i.e.

$$S_V = \frac{\theta}{V} = \frac{\theta}{IR} = \frac{S_C}{R}$$

Special Note:

Suspension type moving coil galvanometers are used in advanced laboratories in colleges and universities for very accurate measurements whereas in school laboratories pivoted type (weston) galvanometers are used.

Experiment

Objective:

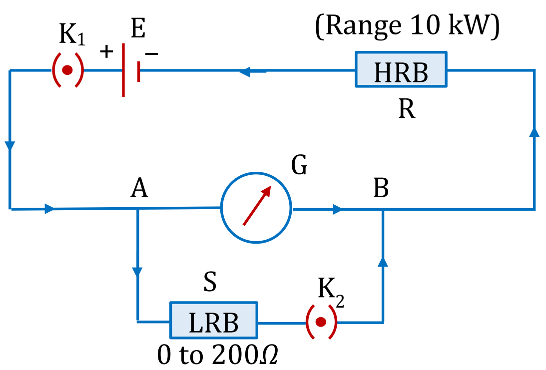
(a) To determine the resistance of a galvanometer by half deflection method and

(b) To find its figure of merit.

Apparatus required:

A galvanometer, a battery or accumulator, a low resistance box (LRB), a high resistance box (HRB), two one-way keys, connecting wires etc.

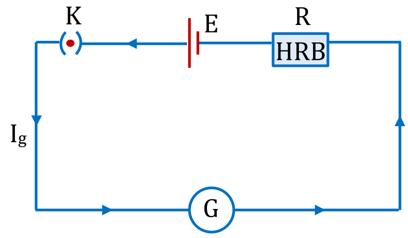
Circuit diagram:



Theory:

(a) **Resistance of galvanometer by half deflection method:** When a high resistance R is applied in the circuit with K_1 closed and K_2 open, the galvanometer draws a current I_g and shows a deflection θ such that

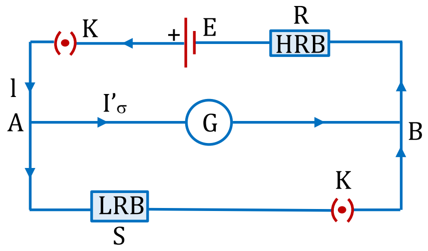
$$I_g = \frac{E}{R+G} \quad \text{...(i)}$$



where E, is emf of the battery and G is resistance of the galvanometer.

Now K_2 is closed. Adjust the resistance in LRB such that galvanometer deflection becomes equal to. $\frac{\theta}{2}$ Now the galvanometer draw the current.

$$I'_g = \frac{IS}{G+S} = \frac{ES}{R(G+S)+GS} \quad \left(\text{where } I = \frac{E}{R+\frac{GS}{G+S}}\right)$$



Also $I'_g = \frac{1}{2} I_g$

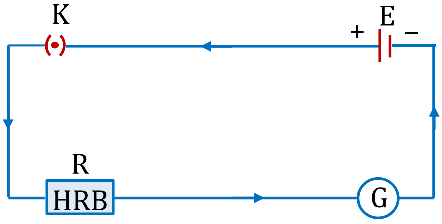
$$\therefore \quad \frac{ES}{R(G+S)+GS} = \frac{1}{2} \cdot \frac{E}{R+G}$$

Gives $G = \frac{RS}{R-S}$

Knowing R and S, G can be calculated.

Also, if $R >> S$, S can be dropped in comparison to R and then $\boxed{G \simeq S}$.

(b) **Figure of merit of galvanometer** is defined as the current required per division of deflection in galvanometer. It is denoted by k. Figure merit $k = \frac{I}{\theta}$



The circuit diagram for determination of figure of merit (k) of a galvanometer is shown in the figure.

When a high resistance R is introduced in the circuit through HRB, a small current I_g is drawn by it and it shows a deflection θ such that

$$I_g = k\theta = \frac{E}{R+G}$$

$$\Rightarrow \quad \text{Figure of merit} \quad k = \frac{1}{\theta}\left(\frac{E}{R+G}\right) \quad \text{...(ii)}$$

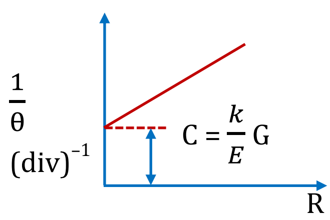
Maximum current measured by galvanometer or full-scale deflection current for galvanometer

I_g = Number of division on one side of galvanometer scale × figure of merit

From equation (ii)

$$\frac{1}{\theta} = \frac{k}{E}R + \frac{k}{E}G \quad \text{...(iii)}$$

$\therefore$ Graph between $\frac{1}{\theta}$ and R is as shown.



(Graph between (1/θ) and R)

Procedure:

1. In the circuit, introduce a high resistance R in HRB and then insert the plug in the key K_1. Adjust the value of R to get deflection θ in even number of divisions.

2. Now close the key K_2 also and adjust the shunt resistance S from low resistance box (LRB) to get a deflection exactly half of θ in galvanometer.

3. Repeat experiment for different values of R and θ.

Precautions:

1. All connections in the circuit should be neat, clean and tight.

2. All the plugs in HRB and LRB should be tight.

3. A very high resistance R from HRB should be introduced first and then key K_1 should be closed to avoid any over current damage in galvanometer.

4. The emf of the cell or battery should be constant.

5. The deflection in the galvanometer should be as large as possible and should be even number of divisions.

Sources of error

1. The plugs of HRB and LRB may not be clean.

2. The emf of the battery may not be constant.

3. The galvanometer divisions may not be uniform.

U-V Method:

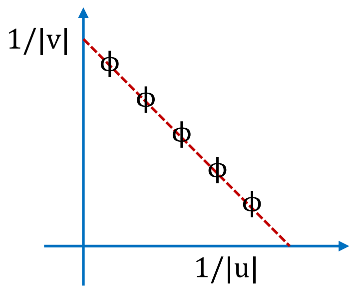
Focal length of a concave mirror and a convex lens using the *u-v* method.

In this method one uses an optical bench and the convex lens (or the concave mirror) is placed on the holder.

The position of the lens is noted by reading the scale at the bottom of the holder. A bright object (a filament lamp or some similar object) is placed at a fixed distance (u) in front of the lens (mirror).

The position of the image (v) is determined by moving a white screen behind the lens until a sharp image is obtained (for real images).

For the concave mirror, the position of the image is determined by placing a sharp object (a pin) on the optical bench such that the parallax between the object pin and the image is nil.



A plot of $|u|$ versus $|v|$ gives a rectangular hyperbola. A plot of $\frac{1}{|v|}$ vs $\frac{1}{|u|}$ gives a straight line. The intercepts are equal to $\frac{1}{|f|}$, where f is the focal length.

Error:

The systematic error in this experiment is mostly due to improper position of the object on the holder. This error maybe eliminated by reversing the holder (rotating the holder by 180° about the vertical) and then taking the readings again. Averages are then taken.

The equation for random errors gives:

$$\frac{\delta f}{f^2} = \frac{\delta u}{u^2} + \frac{\delta v}{v^2}$$

The errors δu, δv correspond to the error in the measurement of u and v. Actually, we know the errors in the object position, lens position & image position. So, the errors in u & v are too be estimated as described before.

Index Error or Bench Error and its correction:

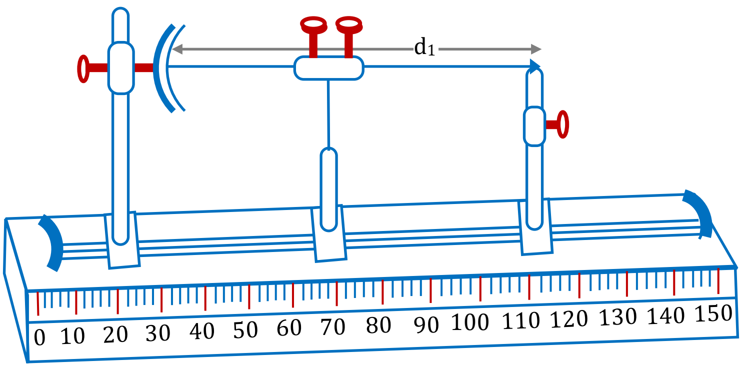
In an experiment using an optical bench we are required to measure the object and image distances from the pole or vertex on the mirror. The distance between the tip of the needles and the pole of the mirror is the actual distance. But we practically measure distances between the indices with the help of the scale engraved on the bench. These distances are called the observed distances. The actual distances may not be equal to the observed distances and due to this reason an error creeps in the measurement of the distances. This error is called the index or the bench error. This error is estimated with the help of a needle of known length placed horizontally between the tip of the needle and the pole.

Index Error = Observed distance – Actual distance and

Index Correction = Actual – Observed distance

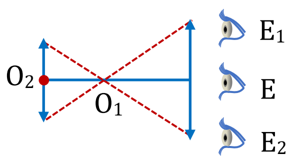
Note:

Index correction whether positive or negative, is always added algebraically to the observed distance to get the corrected distance.



Parallax :

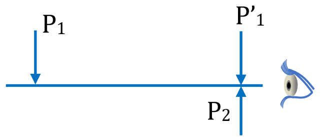
When two objects O_1 and O_2 are placed in such a way that both of them lie in the same line of sight as shown in figure, then the object nearer to the eye covers the object farther from it. Their images on the retina are superimposed and therefore, it is impossible to decide which is the nearer object. To identify this fact, the observer displaces his eye to a position E_1 or E_2 until he is able to see two distinct objects.



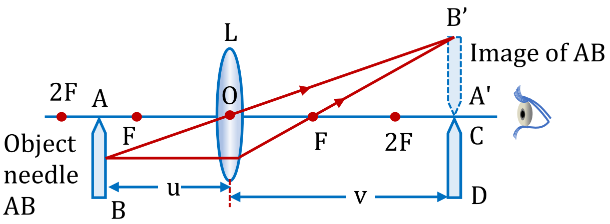
The more distant object O_2 apparently moves in the direction opposite to the displacement of the observer's eye with respect to the nearer object O_1. This relative shift in the position of two objects due to the shift in the position of the observer's eye is called parallax.

Parallax between the two objects disappear if they are at the same position.

The figure shows the tips of two pins P_1 and P_2 kept in the upright positions. The parallax between P_1 and P_2 is removed by shifting the position of observer's eye sideways. As the farther pin P_1 is displaced towards the pin P_2 the relative shift (parallax) between their positions decreases as the position of eye is displaced sideways. The relative shift vanishes when the pin P_1 occupies the position P'_1, that is, when the tips of the two are just coincident. At this position there is no parallax between the tips of the two pins.



Experiment



Ray Diagram

Objective: To find the values of v for different values of u in case of a convex lens and to find its focal length.

Apparatus required: An optical bench with three uprights, one lens holder, two needles, given convex lens etc.

Formula required: Focal length of a lens from lens formula

Procedure:

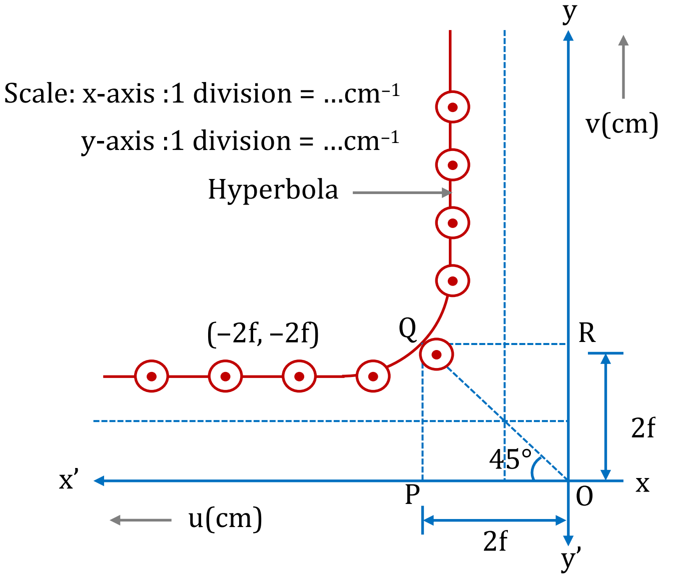
1. Roughly find the focal length of convex lens by focusing a sharp, clear and inverted image of a distant object on a white paper and measuring this distance between the lens and the white paper with a meter scale.
2. Level the optical bench. Mount the convex lens on the central upright of the optical bench. On the remaining two uprights mount the two needles. Arrange the tips of the needle at the same vertical height as the centre of the lens.
3. One needle AB is object needle and the other one CD is image needle and to make difference between them tip of one of the needles with a piece of chalk or putting a paper flag on it.
4. Shift the position of the object needle AB to a distance greater than $2f$ from the lens. Look from the other side of the lens along its principal axis near the end of the bench. If the setting is correct, an inverted, real image $A'B'$ is seen. Now adjust the position of the second needle CD such that parallax between the image of the object needle and the image needle is removed.

5. Note the positions of the lense, the object needle and the image needle on the bench scale and thus find the observed values of *u* and *v*.

6. Repeat the above steps for 5 different positions of the object by placing it beyond 2 *F* and between *F* and 2*F*.

Calculation from graph:

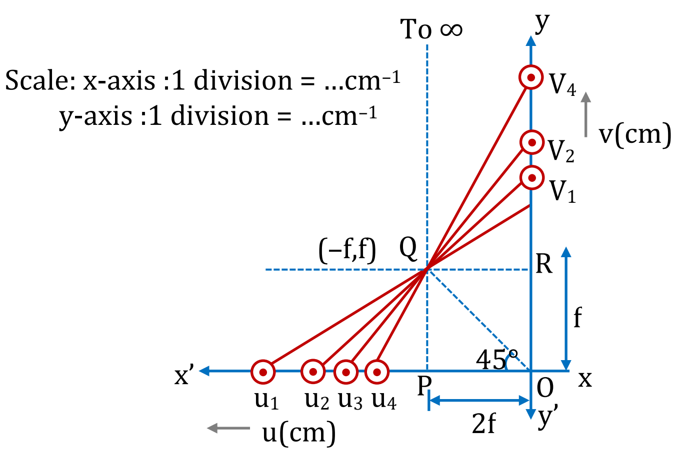
Method-I



In this graph

Focal length $f = \frac{QP}{2}$ or $\frac{QP}{2}$

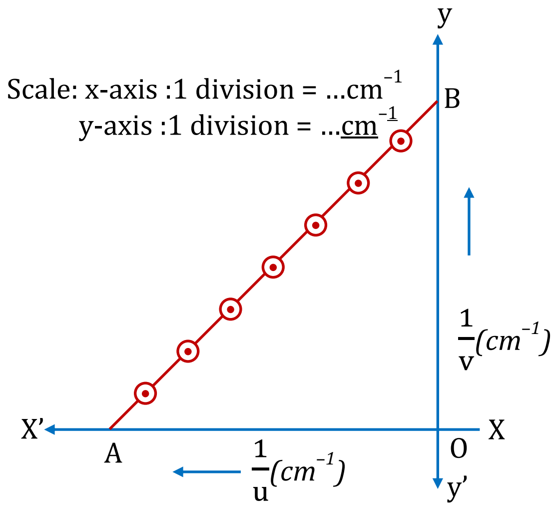
Method-II



In this graph,

Focal length $f = -QP = QR$

Method-III



In this graph,

Focal length $f = \frac{1}{OA} = \frac{1}{OB}$

Precautions:

1. All the uprights should be vertical.
2. The tip of the needles and centre of lens should be at same height.
3. Principle axis of the lens should be horizontal and parallel to the central line of the optical bench.
4. Parallax of the image and object needles should be removed tip to tip.
5. The object needle should be placed at such a distance that only real, inverted image of it will formed.

Sources of Error:

1. The uprights may not be vertical.
2. Parallax removal may not be perfect.

Refractive index using travelling microscope:

Travelling Microscope:

It is a compound microscope fitted vertically on a vertical scale. It can be moved up and down. It consists of a vernier scale moving along the main scale.

The reading is taken by combining the main scale and vernier scale reading.

Experiment:

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

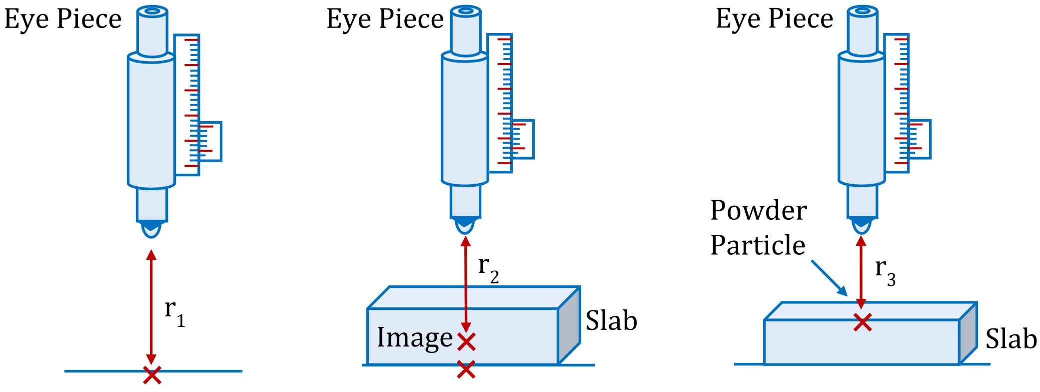
Apparatus: A marker, glass slab, travelling microscope, lycopodium powder, etc.

Concept: As, Refractive index,

$$\mu = \frac{\text{Real depth}}{\text{Apparent depth}}$$

To measure real and apparent depth a travelling microscope is used.

If the reading microscope when focussed on ink mark on white paper r_1, reading when the slab is kept over the ink mark is r_2 and the reading of image of lycopodium powder then real depth = $r_3 - r_1$ and apparent depth = $r_3 - r_2$. Therefore, refractive index of the material of slog is $\boxed{\mu = \frac{r_3 - r_1}{r_3 - r_2}}$.



(a) (b) (c)

Procedure:

1. Note the number of divisions of vernier which coincide with number of main scale divisions. Find the value of each main division and hence least count of the microscope scale as (1 M.S.D.– V.S.D.).

2. Set the microscope in its stand such that it is capable of sliding vertically up and down as the screw attached to rack and pinion is turned.

3. Mark a cross on a sheet of paper and place it below the objective of the microscope. Move the microscope very gently. Using the screw, focus the eye piece on cross mark and bring the cross in focus such that the cross of cross wires, coincides with the marked cross on the paper. Note the reading of the microscope as r_1.

4. Place the given glass slab on the cross mark. The cross mark appears to be raised.

5. Move the microscope gradually and gently upward to bring the cross mark in focus and on cross of cross wires. Record the reading as r_2.

6. Sprinkle some fine powder on the glass slab and move the microscope upward till the powder particles come into focus. Record the reading on the scale as r_3.

7. $r_3 - r_1$ = real depth and $r_3 - r_2$ = apparent depth.

Precautions:

1. Microscope should focus properly and reading should be taken carefully.

2. Extremely small amount of powder should be used.

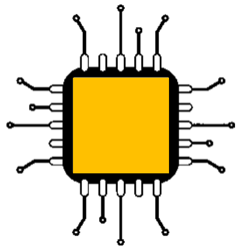
Source of error:

1. Microscope may not be focused well.

2. It may have faulty calibration.

SEMICONDUCTOR

We are surrounded by semiconductor devices and our day-to-day life depends on them.



Example: Mobile phone, Laptop, T.V., MRI Machine etc.

Material are majorly classified into three categories:

Classification of Solids

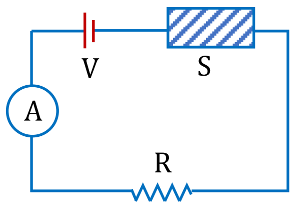
Conductors	Insulators	Semiconductors
• Abundance of free e^-	• Very few free e^-	• Few free e^-
• Low resistivity	• High resistivity	• Intermediate resistivity
• High conductivity	• Low conductivity	• Intermediate conductivity
• $\alpha =$ +ve	• $\alpha = -$ ve	• $\alpha = -$ve

Illustration 2:
A Platinum rod and a Silicon rod are heated, what happens to their resistances ?

Solution:

As temperature increases, resistance of platinum increases whereas that of silicon decreases.

Illustration 3:
In the diagram 'S' is a semiconductor strip. Comment on the reading of the ammeter if temperature of strip is reduced.



Solution:

As temperature of strip decreases, resistance increases and hence current in circuit decreases so reading of ammeter decreases.

Energy Bands in Solids:
Based on Pauli's exclusion principle:
In an isolated atom electron present in energy level that is according to Quantum Mechanical Laws, the energies of electrons in a free atom can not have arbitrary values but only some definite (quantized) values but in solid, atoms are not isolated, there is interaction among each other, due to this energy level split into different energy levels.

- This modification is not appreciable in the case of energy levels of electrons in the inner shells (completely filled).
- But in the outermost shells, modification is appreciable because the electrons are shared by many neighboring atoms.
- So, what used to be the discrete energy levels, now split-up or spread out to form energy bands.

Quantity of these different energy levels depends on the quantity of interacting atoms. Splitting of sharp and closely compact energy levels result into energy band. This is discrete in nature. Order of energy levels in a band is 10^{23} and their energy difference = 10^{-23} eV.

Energy band:

Range of energy possessed by electron in a solid is known as energy band.

Valence band (VB):

Range of energies possessed by valence electron is known as valence band.

(a) Have bonded electron.

(b) No flow of current due to such electron.

(c) Always fulfill by electron.

(d) This band is either partially or completely filled with electrons but never empty.

Conduction band (CB):

Range of energies/ possessed by free electron is known as conduction band.

(a) It has conducting electrons.

(b) Current flows due to such electrons.

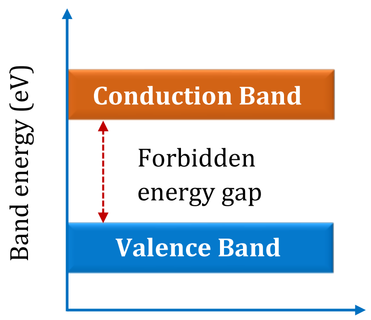
(c) If conduction band is fully empty then current conduction is not possible.

(d) Electrons may exist or not in it.

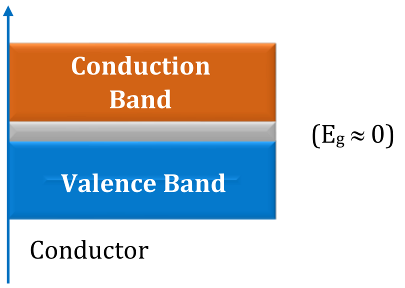
Forbidden Energy Gap (FEG) (ΔEg):

$$\Delta E_g = (C\,B)_{min} - (V\,B)_{max}$$

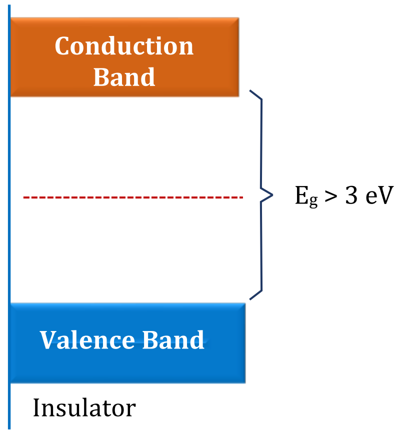
Energy gap between conduction band and valence band, where no free electron can exist.



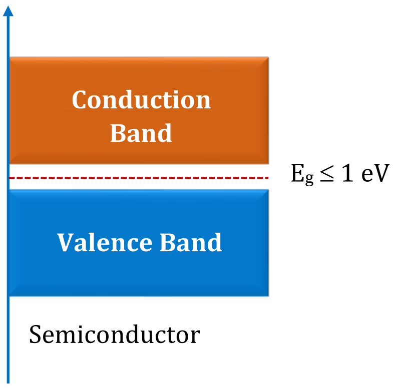
- Width of forbidden energy gap depends upon the nature of substance.
- Width is more, then valence electrons are strongly attached with nucleus.
- Width of forbidden energy gap is represented in eV.
- As temperature increases forbidden energy gap decreases (very slightly).



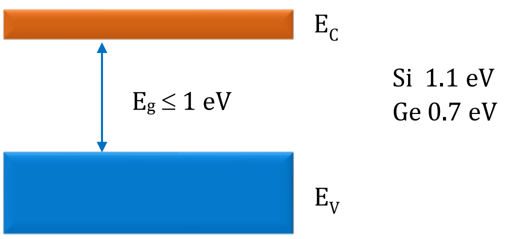
In conductors, there is no band gap since the valence band overlaps the conduction band.



The large energy gap between the valence and conduction bands in an insulator says that at ordinary temperatures, no electrons can reach the conduction band.



In semiconductors, the band gap is small enough that thermal energy can bridge the gap for a small fraction of the electrons.



- At absolute zero temperature, no electron has energy to jump from valence band to conduction band and hence the crystal is an insulator.
- At room temperature, some valence electrons gain energy more than the energy gap and move to conduction band and can conduct under the influence of weak electric field.

Classification of Conductors, Insulators and Semiconductor:

On the basis of the relative values of electrical conductivity and energy bands the solids are broadly classified into three categories

(i) Conductor

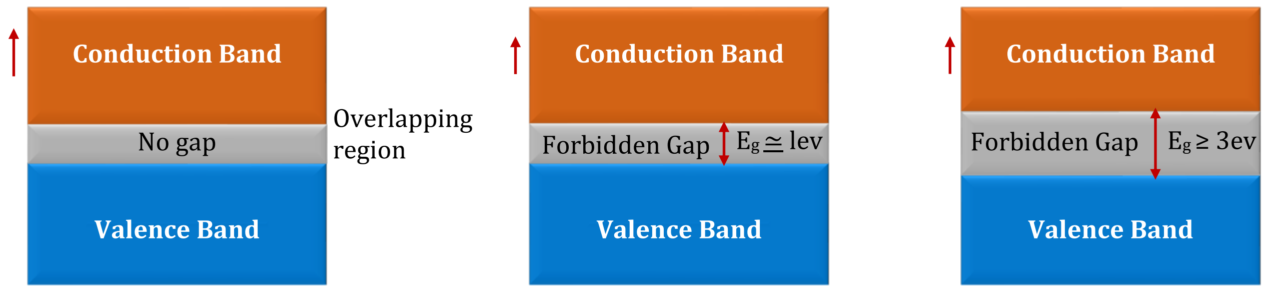
(ii) Semiconductor

(iii) Insulator

Comparison between conductor, semiconductor and insulator:

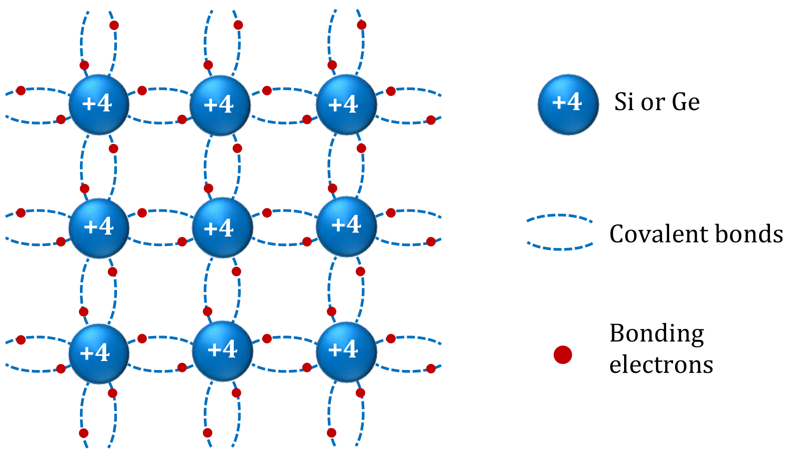
Properties	Conductor	Semiconductor	Insulator
Resistivity	$10^{-2} - 10^{-8}\ \Omega m$	$10^{-5} - 10^{6}\ \Omega m$	$10^{11} - 10^{19}\ \Omega m$
Conductivity	$10^{2} - 10^{8}\ mho/m$	$10^{5} - 10^{-6}\ mho/m$	$10^{-11}–10^{-19}\ mho/m$
Temp. Coefficient of resistance (α)	Positive	Negative	Negative
Current	Due to free electrons	Due to electrons and holes	No current
Forbidden energy gap	$\cong 0eV$	$\cong 1eV$	$\geq 3eV$

Energy band diagram

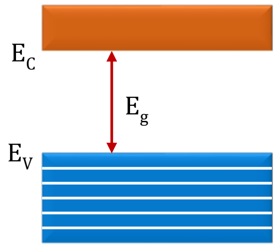


Conductor | Semi-Conductor | Insulator

Example : Pt, Al, Cu, Ag, GaF_2 | Ge, Si, GaAs, Diamond, | Wood, plastic, Mica



Semiconductors in their purest form. Free from any type of impurity.

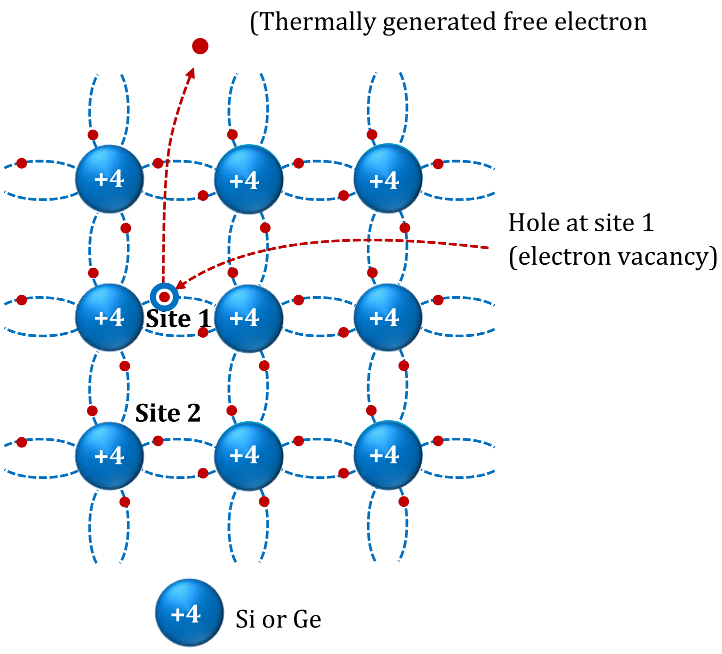


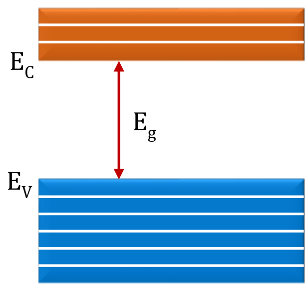
At Absolute Zero (0 *K*):

- All the covalent bonds are complete, no free electrons.
- Valence bands are completely filled.
- Conduction bands are completely empty.
- It behaves as perfect insulator.

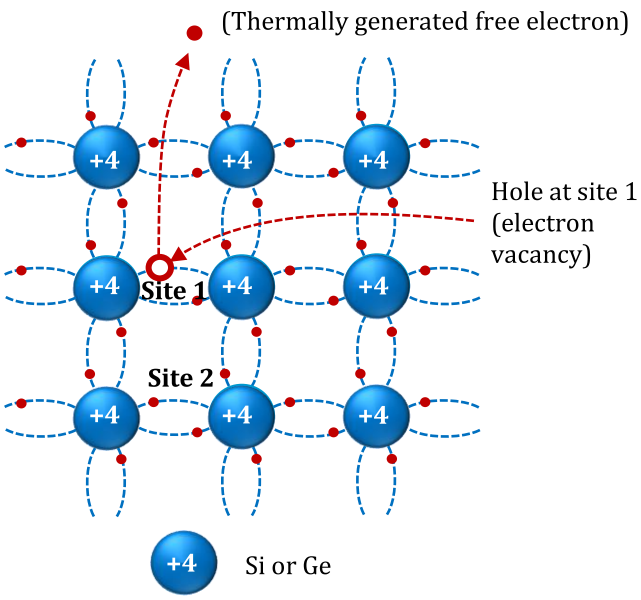
At Room Temperature (300 K):

- Some of the covalent bonds are broken due to thermal energy.
- Very few free electrons.
- Valence bands are partially empty.
- Conduction bands are partially filled.

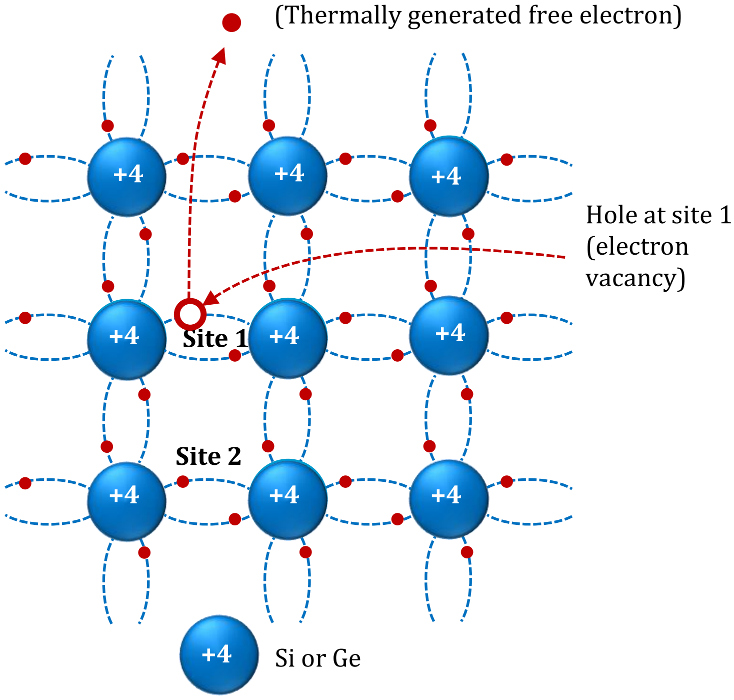




Electron-Hole Pair (EHP):



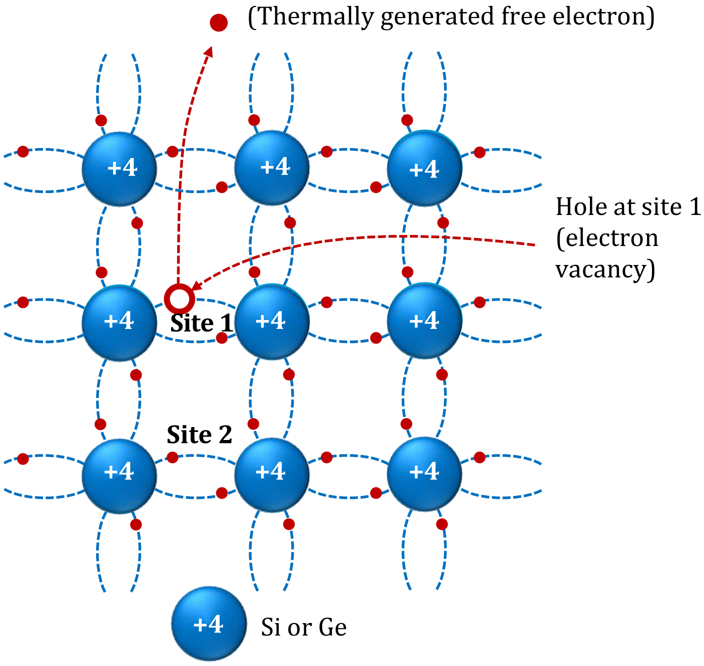
- On receiving an additional energy, one of the electrons from a covalent band breaks and is free to move in the crystal lattice.
- While coming out of the covalent bond, it leaves behind a vacancy named 'hole'. This process is called electron-hole pair generation.



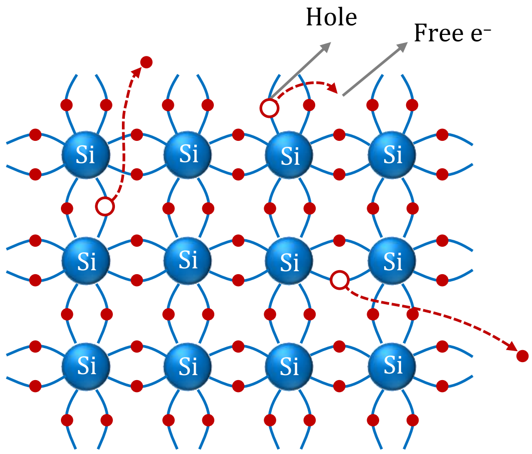
The holes move randomly in a crystal lattice. A free electron or electron from the neighboring atom can fill this vacancy and thus completing the covalent bond. This is referred to as 'electron – hole recombination'.

Concept of "Holes" In Semiconductors:

Due to external energy (temp. or radiation) when electron goes from valence band to conduction band (i.e. bounded electrons becomes free) a vacancy of free e^- creates in valence band, which has same charge as electron but positive. This positively charged vacancy is termed as hole and shown in figure.



- These are imaginary charge carriers.
- It is deficiency of electron in VB.
- It acts as positive charge carrier.
- These are absence of e^- and hence there charge can be assumed to be e^+.
- Movement of holes is due to breaking and making of covalent bonds.
- It's effective mass is more than electron.
- It's mobility is less than electron.



Note:

Hole acts as virtual charge carrier, although it has no physical significance.

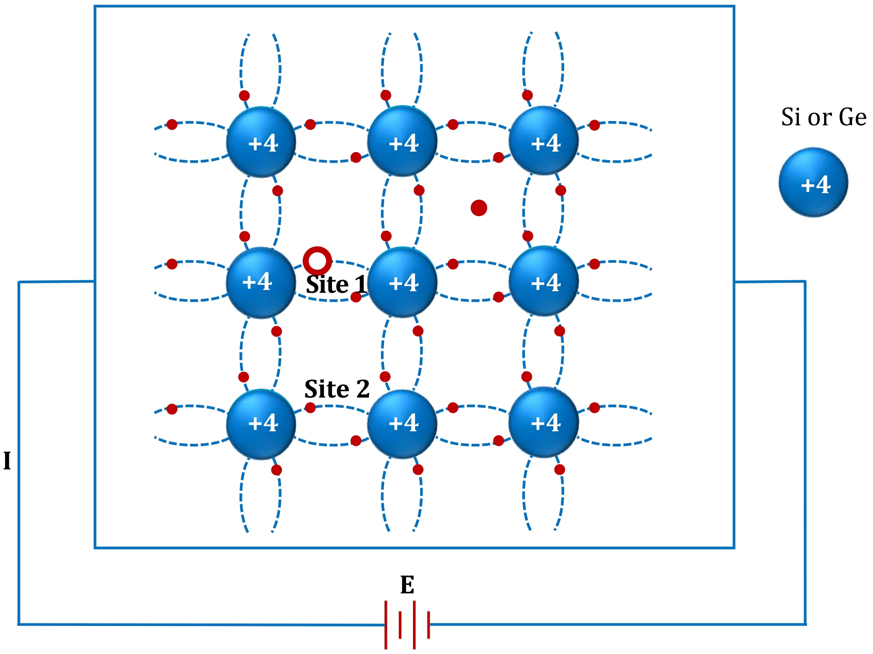
In intrinsic semiconductor, the number of thermally generated electrons always equals the number of holes.

n_e = free electron concentration

n_h = hole concentration

n_e or n_h is referred to as the 'intrinsic carrier concentration' n_i.

$n_e = n_h = n_i$



- When an intrinsic semiconductor is placed in external electric field, the charge carriers starts moving. Hence generating an electric current.

  Valence Band Current I_h

  Conduction Band Current I_e

Total Current = $I_h + I_e$

$I \;=\; I_e + I_h$

$I_e \;=\; n_e e A v_e$

$I_h \;=\; n_h e A v_h$

So, $\quad I \;=\; n_e e A v_e \;+\; n_h e A v_h$

Mobility

It is ease with which charge carrier drift in electrical field. Numerical value is the drift velocity per unit electric field.

$$\mu = \frac{v_d}{E}$$

1. The electron mobility is higher than the hole mobility.

2. The resistivity / conductivity depends not only on the electron and hole densities but also on their mobilities.

3. The mobility depends relatively weakly on temperature.

$$I = \frac{V}{R} = \; n_e e A v_e + n_h e A v_h = \; eA\,(n_e v_e \;+\; n_h v_h)$$

$$\frac{VA}{\rho l} = eA\,(n_e v_e + n_h v_h)$$

$$\sigma E \;=\; e\,(n_e v_e + n_h v_h)$$

$$\sigma E \;=\; e\,(n_e \mu_e + n_h \mu_h)E$$

$$\sigma \;=\; e\,(n_e \mu_e + n_h \mu_h)$$

Conductivity

$$\sigma \;=\; e\,(n_e \mu_e \;+\; n_h \mu_h)$$

$$\sigma \;= \sigma_e \;+ \sigma_h$$

Where, $\sigma_e = \mu_e n_e e$

$\sigma_h = \mu_h n_h e$

- Number of electrons reaching from VB to CB at temperature T kelvin

$$\boxed{n = AT^{3/2} e^{-\frac{E_g}{2kT}} = AT^{3/2}\exp\left[-\frac{E}{2kT}\right]}$$

where

k = Boltzmann constant = 1.38 × 10^{-23} J/K $\qquad$ T = absolute temperature

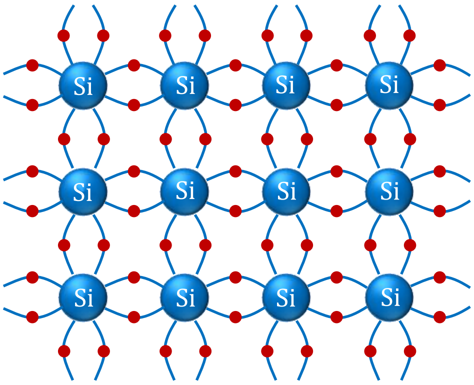
A = constant $\qquad$ E_g = energy gap between CB and VB

- In silicon at room temperature out of 10^{12} Si atoms only one electron goes from VB to CB.
- In germanium at room temperature out of 10^{9} Ge atoms only one electron goes from VB to CB.

Effect of Temperature on Semiconductor:

At absolute zero kelvin temperature:

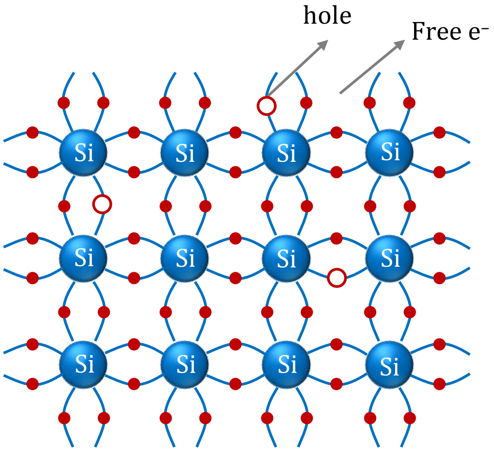
At this temperature covalent bonds are very strong and there are no free electrons and semiconductor behaves as perfect insulator.



At 0 K
Valence band full filled
Conduction band fully empty

Above, absolute temperature:

With increase in temperature few valence electrons jump into conduction band and hence it behaves as poor conductor.



At high temperature
Valence band partially empty
Conduction band partially filled

Effect of Impurity in Semiconductor

Doping is a method of addition of "desirable" impurity atoms to pure semiconductor to increase conductivity of semiconductor.

or

Doping is a process of deliberate addition of a desirable impurity atom to a pure semiconductor to modify its properties in controlled manner.

Added impurity atoms are called dopants.

The impurity added may be ≈ 1 part per million (ppm).

- The dopant atom should take the position of semiconductor atom in the lattice.
- The presence of the dopant atom should not distort the crystal lattice.
- The size of the dopant atom should be almost the same as that of the crystal atom.
- The concentration of dopant atoms should not be large (not more than 1% of the crystal atom).
  It is to be noted that the doping of a semiconductor increases its electrical conductivity to a great extent.
- The concentration of dopant atoms be very low, doping ratio is vary from
  Impure : pure :: $1 : 10^6$ to $1 : 10^{10}$ In general it is $1 : 10^8$
- There are two main method of doping.
  (i) Alloy method (ii) Diffusion method (The best)
- The size of dopant atom (impurity) should be almost the same as that of crystal atom. So that crystalline structure of solid remain unchanged.

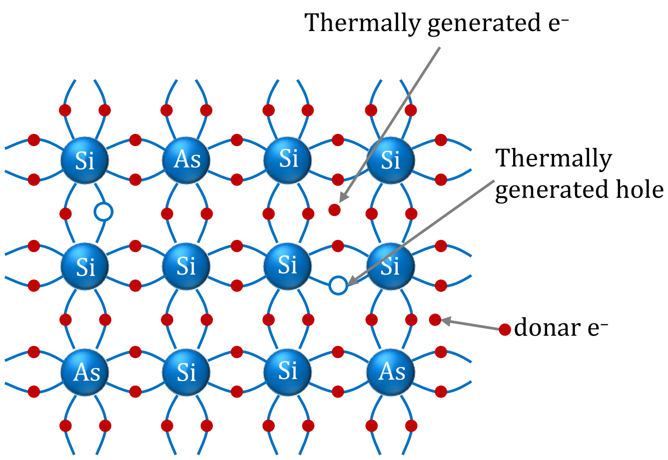
Classification of Semiconductor:

SEMICONDUCTOR

- Intrinsic semiconductor
  - (pure form of Ge, Si)
  - $n_e = n_h = n_i$
- Extrinsic semiconductor (doped semiconductor)
  - N-type
    - pentavalent impurity
    - (P, As, Sb etc.)
    - Donor impurity (N_D)
    - $n_e >> n_h$
  - P-type
    - trivalent impurity
    - (Ga, B, In, Al)
    - acceptor impurity (N_A)
    - $n_h >> n_e$

N type semiconductor

When a pure semiconductor (Si or Ge) is doped by pentavalent impurity (*P, As, Sb, Bi*) then four electrons out of the five valence electrons of impurity take part, in covalent bonding, with four silicon atoms surrounding it and the fifth electron is set free. These impurity atoms which donate free e^- for conduction are called as Donor impurity (N_D). Due to donor impurity free e^- increases very much so it is called as "*N*" type semiconductor. By donating e^- impurity atoms get positive charge and hence known as "Immobile Donor positive Ion". In *N*-type semiconductor free e^- are called as "majority" charge carriers and "holes" are called as "minority" charge carriers.

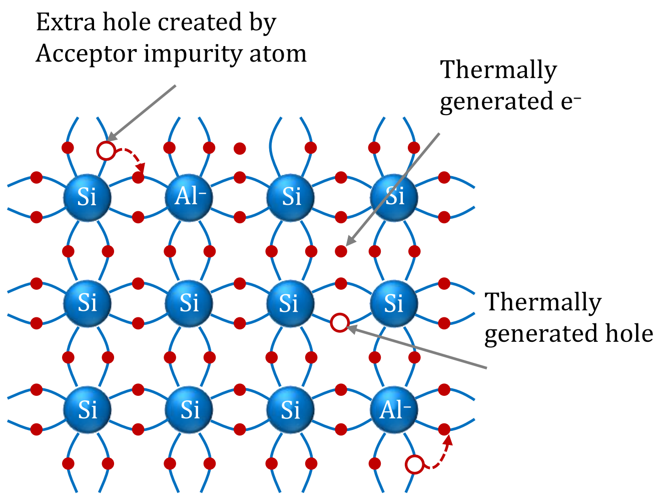


N-type semiconducting crystal

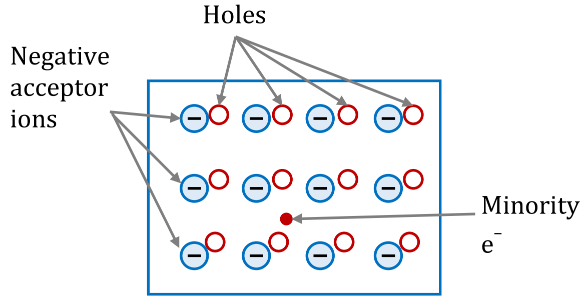
P type semiconductor

When a pure semiconductor (*Si* or *Ge*) is doped by trivalent impurity (*B, Al, In, Ga*) then outer most three electrons of the valence band of impurity take part, in covalent bonding with four silicon atoms surrounding it and except one electron from semiconductor and make hole in semiconductor. These impurity atoms which accept bonded e^- from valance band are called as Acceptor impurity (N_A). Here holes increase very much so it is called as "*P*" type semiconductor and impurity ions known as "Immobile

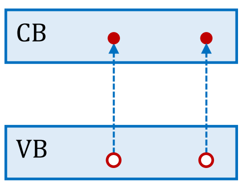
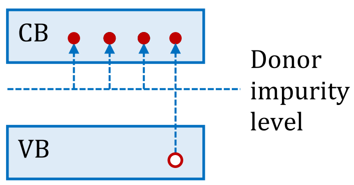
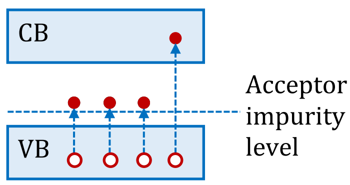
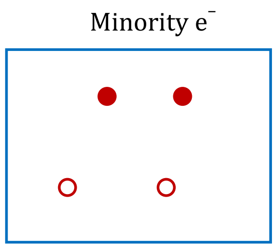
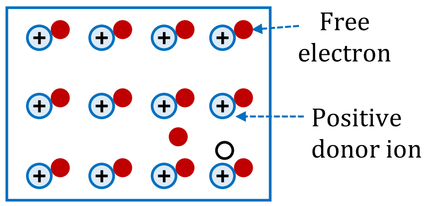
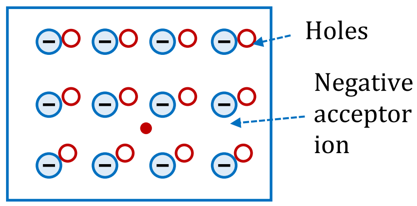
Acceptor negative Ion". In *P*-type semiconductor free e⁻ are called as minority charge carries and holes are called as majority charge carriers.



P-type semiconducting crystal



P-type semiconductor

	Intrinsic Semiconductor	N-type (Pentavalent impurity)	P-type (Trivalent impurity)
1.			
2.			
3.	Current due to	Mainly due to electrons electron and hole	Mainly due to holes
4.	$n_e = n_h = n_i$	$n_h << n_e$ $(N_D \simeq n_e)$	$n_h >> n_e$ $(N_A \simeq n_h)$
5.	$I = I_e + I_h$	$I \simeq I_e$	$I \simeq Ih$
6.	Entirely neutral	Entirely neutral	Entirely neutral
7.	Quantity of electrons and holes are equal	Majority - Electrons Minority - Holes	Majority – Holes Minority - Electrons

Mass action Law

In semiconductors due to thermal effect, generation of free e^- and hole takes place.

Apart from the process of generation, recombination also occurs simultaneously, in which free e^- further recombine with hole.

At equilibrium rate of generation of charge carries is equal to rate of recombination of charge carrier.

The recombination occurs due to e^- colliding with a hole, larger value of n_e or n_h, higher is the probability of their recombination.

Hence for a given semiconductor rate of recombination $\propto n_e \times n_h$

So, Rate of recombination = $R\, n_e \times n_h$

R = Recombination coefficient

The value of R remains constant for a solid, according to the law of thermodynamics until crystalline lattice structure remains same.

For intrinsic semiconductor $n_e = n_h = n_i$

So, Rate of recombination = $R\, n_i^2$

$R\, n_e \times n_h = R\, n_i^2$

$\Rightarrow$ $n_i^2 = n_e \times n_h$

Under thermal equilibrium, the product of the concentration $'n_e'$ of free electrons and the concentration n_h of holes is a constant and it is independent of the amount of doping by acceptor and donor impurities.

Thus, from mass action law $\boxed{n_e \times n_b = n_1^2}$

Electron-hole Recombination

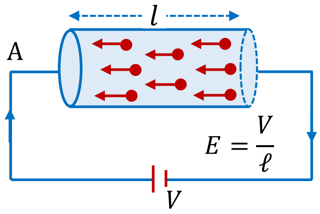
It is necessary to complete a band that electron is shared from neighboring atoms or it may also be received from conduction band. In the second case electron recombines with the hole of valance band. This process is known as electron-hole recombination.

The breaking of bands or generation of electron-hole pairs, and completion of bands due to recombination is taking place continuously.

At equilibrium, the rate of generation becomes equal to the rate of recombination, giving a fixed number of free electrons and holes.

Resistivity and Conductivity of Semiconductor

Conduction in conductor



Relation between current (I) and drift velocity (v_d)

$I = neAv_d$ n = Number of electron in unit volume

A = Cross sectional area

Current density $J = \dfrac{I}{A}\, amp/m^2 = ne\, v_d$ Drift velocity of electron $v_d = \mu E$

$J = ne\,\mu E$ $J = \sigma E$

Conductivity $\sigma = ne\mu = 1/\rho$ ρ = Resistivity

Mobility $\mu = \dfrac{v_d}{E}$

Conduction in Semiconductor

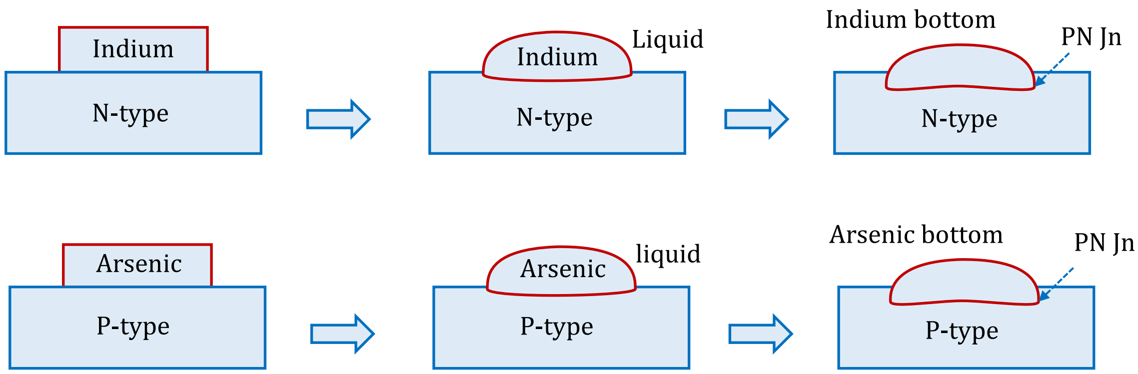
Intrinsic semiconductor	**P - type**	**N - type**
$n_e = n_h \quad n_h >> n_e$	$n_e >> n_h$	
$J = ne\,[\,v_e + v_h]$	$J \cong e\,n_h\,v_h$	$J \cong e\,n_e\,v_e$
$\sigma = \frac{1}{\rho} = en[\mu_e + \mu_h]$	$\sigma = \frac{1}{\rho} \cong en_h\mu_h$	$\sigma = \frac{1}{\rho} \cong en_e\mu_e$

P-N JUNCTION

Techniques for making P-N junction:

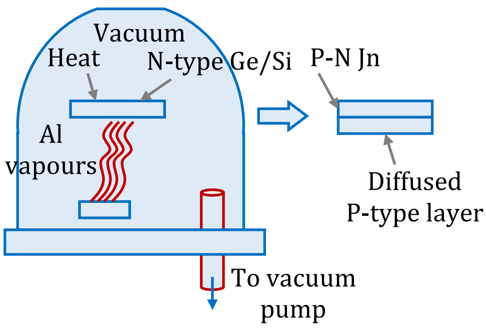
(i) Alloy Method or Alloy Junction:

Here a small piece of III group impurity like indium is placed over n–Ge or n–Si and melted as shown in figure ultimately $P - N$ junction form.



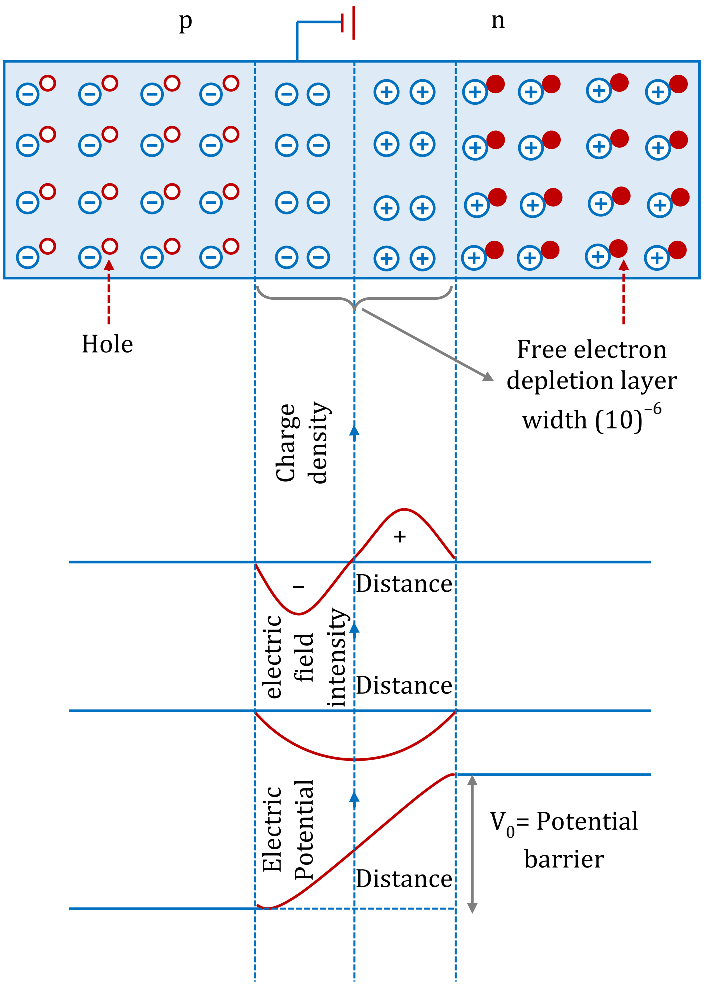
(ii) Diffusion Junction:

A heated P–type semiconductor is kept in pentavalent impurity vapors which diffuse into P–type semiconductor as shown and make P–N junction.



(iii) Vapor deposited junction or epitaxial junction:

If we want to grow a layer of n–Si or p–Si then p–Si wafer is kept in an atmosphere of Silane (a silicon compound which dissociates into Si at high temperatures) plus phosphorous vapors. On cracking of silane at high temperature a fresh layer on n–Si grows on p–Si giving the "P–N junction". Since this junction growth is layer by so it is also referred as layer growth or epitaxial junction formation of P–N junction.



Description of P-N Junction without applied voltage or bias

Given diagram shows a P–N junction immediately after it is formed.

P region has mobile majority holes and immobile negatively charged impurity ions.

N region has mobile majority free electrons and immobile positively charged impurity ions.

Due to concentration difference diffusion of holes starts from P to N side and diffusion of e^{-} s starts N to P side.

Due to this a layer of only positive (in N side) and negative (in P–side) started to form which generate an electric field (N to P side) which oppose diffusion process, during diffusion magnitude of electric field increases due to this diffusion it gradually decreased and ultimately stope.

The layer of immobile positive and negative ions, which have no free electrons and holes called as **depletion layer** as shown in diagram.

- **Width of depletion layer $\cong 10^{-6}$ m**

  (a) As doping increases depletion layer decreases

  (b) As temperature is increased depletion layer also increases.

  (c) P-N junction $\rightarrow$ nonohmic, due to nonlinear relation between I and V.

- **Potential Barrier or contact potential**

  $Ge \longrightarrow 0.3\ V$ $\qquad$ $Si \longrightarrow 0.7\ V$

- Electric field, produce due to potential barrier $E = \dfrac{V}{d} = \dfrac{0.5}{10^{-6}} \Rightarrow E \cong 10^5\ V/m$

  This field prevents the respective majority carrier from crossing barrier region

Diffusion and Drift Current

(1) Diffusion current – P to N side

(2) Drift current – N to P side

If there is no biasing diffusion current = drift current

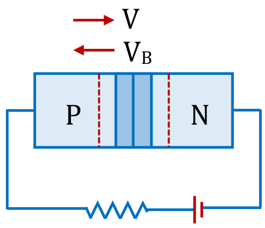
So total current is zero.

Behaviour of P–N Junction with An External Voltage Applied or Bias

Forward Bias

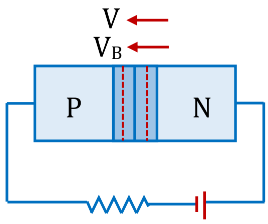
If we apply a voltage "V" such that P–side is positive and N–side is negative as shown in diagram.

The applied voltage is opposite to the junction barrier potential. Due to this effective potential barrier decreases, junction width also decreases, so more majority carriers will be allowed to flow across junction. It means the current flow in principally due to majority charge carriers and it is in the order of mA called as forward Bias.



Reverse Bias

If we apply a voltage "V" such that P–side is negative and N–side is positive as shown in diagram. The applied voltage is in same direction as the junction barrier potential. Due to this effective potential barrier increase junction, width also increases, so no majority carriers will be allowed to flow across junction.



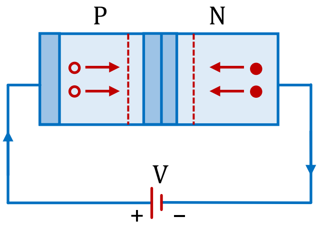
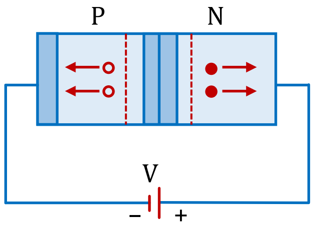
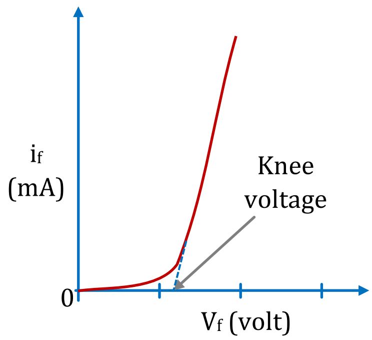
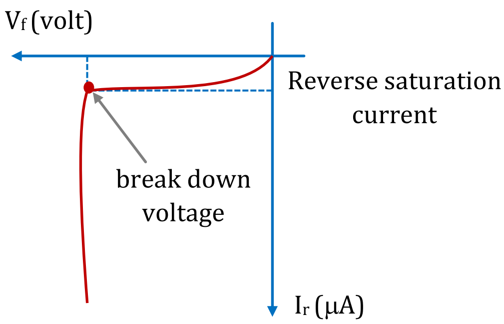
Only minority carriers will be drifted. It means the current flow in principally due to minority charge carriers and is very small (in the order of μA). This bias is called as reversed Bias.

- In reverse bias, the current is very small and nearly constant with bias (termed as reverse saturation current). However interesting behavior results in some special cases if the reverse bias is increased further beyond a certain limit, above particular high voltage breakdown of depletion layer started.
- Breakdown of a diode is of following two types:

  (i) Zener breakdown

  (ii) Avalanche breakdown

Comparison between Forward Bias and Reverse Bias

Forward Bias	Reverse Bias
P → positive N → negative	P → negative N → positive
	
1. Potential Barrier reduces	**1.** Potential Barrier increases.
2. Width of depletion layer decreases	**2.** Width of depletion layer increases.
3. *P-N* jn. provide very small resistance	**3.** *P-N* jn. provide high resistance
4 Forward current flows in the circuit	**4.** Very small current flows.
5. Order of forward current is milli ampere.	**5.** Order of current is micro ampere for Ge or Nano ampere for Si.
6. Current flows mainly due to majority carriers.	**6.** Current flows mainly due to minority carriers.
7. Forward characteristic curves.	**7.** Reverse characteristic curve
	
8. Forward resistance $R_f = \dfrac{\Delta V_f}{\Delta I_f} \cong 100\Omega$	**8.** Reverse resistance $R_r = \dfrac{\Delta V_r}{\Delta I_r} \cong 10^6\,\Omega$
9. Order of knee or cut in voltage *Ge* → 0.3 *V* *Si* → 0.7 *V*	**9.** Breakdown voltage *Ge* → 25 *V* *Si* → 35 *V*
Special point: Generally, $\dfrac{R_r}{R_f} = 10^3 : 1$ for Ge	$\dfrac{R_r}{R_f} = 10^4 : 1$ for Si

Light Emitting Diode (LED):

A light emitting diode is simply a forward biased *p-n* junction which emits spontaneous light radiation. When forward bias is applied, the electron and holes at the junction recombine and energy released is emitted in the form of light. for visible radiation phosphorus doped GaAs is commonly used. The advantages of LEDs are:

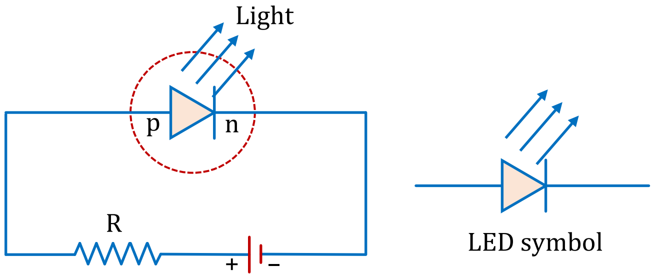
(i) Low operational voltage and less power.

(ii) Fast action with no warm up time.

(iii) Emitted light is nearly monochromatic.

(iv) They have long life.

I-V characteristics of LED are similar to that of Si junction diode but the threshold voltages are much higher and slightly different for each color. The reverse breakdown voltages of LED's are very low, about 5 V.

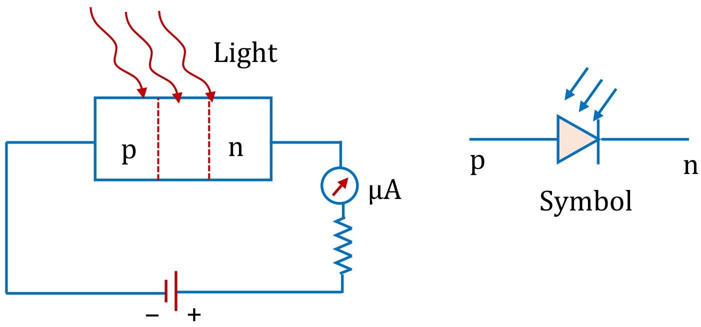


Photodiode:

It is a reversed-biased p-n junction, illuminated by radiation. When p-n junction is reversed biased with no current, a very small reverse saturated current flows across the junction called the dark current. When the junction is illuminated with light, electron-hole pairs are created at the junction, due to which additional current begins to flow across the junction; the current is solely due to minority charge carriers.

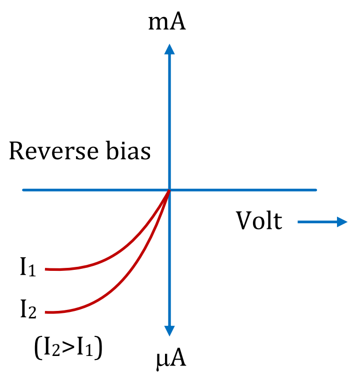
(1) A photodiode is used in reverse bias, although in forward bias current is more than current in reverse bias because in reverse bias it is easier to observe change in current with change in light intensity.

(2) Photodiode is used to measure light intensity because reverse current increases with increase of intensity of light.



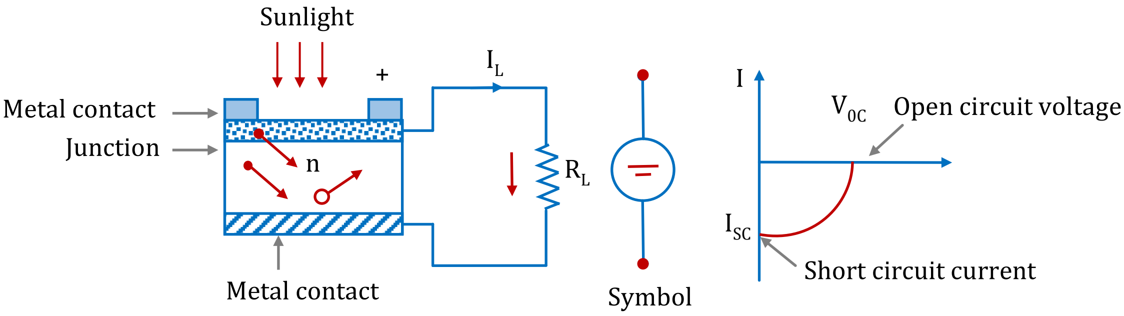
(a) **(b)**

The characteristic curves of a photodiode for two different illumination I_1 and I_2 ($I_2 > I_1$) are shown in figure.



Solar Cell

A solar cell is a junction diode which converts light energy 'into electrical energy. A p-n junction solar cell consists of a large junction with no external biasing.



Construction and working

(a) (b)

The surface layer of p-region is made very thin so that the incident photons may easily penetrate to reach the junction which is the active region. In an operation in the photovoltaic mode (i.e., generation of voltage due to bombardment of optical photons); the materials suitable for photocells are silicon (Si), gallium arsenide (GaAs), cadmium sulphide (CdS) and cadmium selenide (CdSe).

Working:

When photons of energy greater than band gap energy $(hv > E_g)$ are made incident on the junction, electron-hole pairs are created which move in opposite directions due to junction field. These are collected at two sides of junction, thus producing photo-voltage; this gives rise to photocurrent. The characteristic curve of solar cell is shown in fig. Solar cells are used in satellites to recharge their batteries.

Reverse breakdown:

If the reverse bias voltage is made too high, the current through the PN junction increases rapidly at Y_z. The voltage at which this happens is called **breakdown voltage** or **Zener voltage.**

There two mechanism which causes this breakdown. One is called avalanche breakdown and other is called **Zener breakdown.**

Zener breakdown:

When reverse bias is increased the electric field at the junction also increases. At some stage the electric field becomes so high that it breaks the covalent bonds creating electron, hole pairs, thus a large number of carriers are generated. This causes a large current to flow. This mechanism is known as Zener breakdown.

Avalanche breakdown:

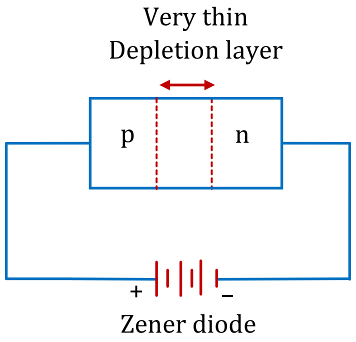
At high reverse voltage, due to high electric field, the minority charge carriers, while crossing the junction acquires very high velocities. These by collision breaks down the covalent bonds, generating more carriers. A chain reaction is established, giving rise to high current. This mechanism is called **avalanche breakdown.**

Zener Diode:

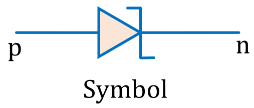
A Zener diode is a specially designed heavily doped p-n junction, having a very thin depletion layer and having a very sharp breakdown voltage. It is always operated in breakdown region. Its breakdown voltage V_z is less than $6V$.

Zener Diode as a Voltage Regulator:

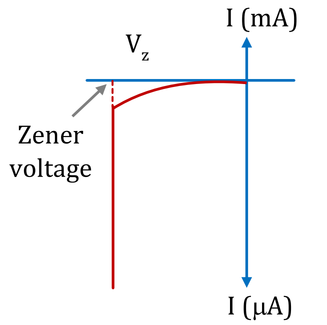
Zener diode may be used as a voltage regulator. The circuit of Zener-diode is shown in figure.



(a)



(b)

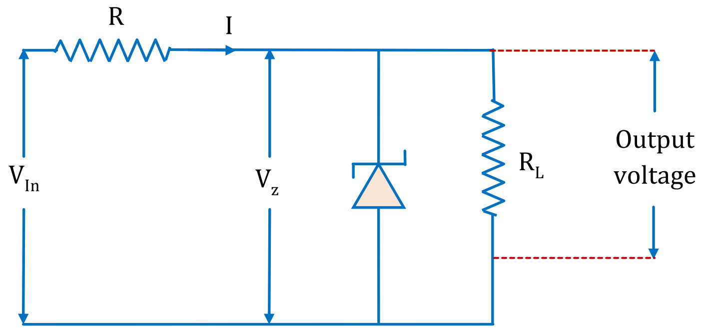


(c) Characteristics

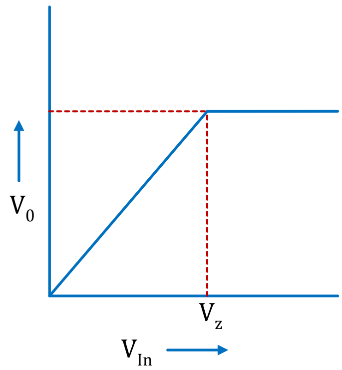
In breakdown region the equation:

$$V_0 = V_z = V_{in} - RI$$

Clearly, when the input voltage exceeds Zener voltage to keep the voltage regularity, the extra input voltage appears across series resistance R. The voltage regulation curve is shown in figure.



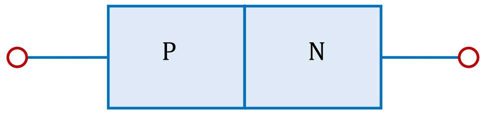
(d)

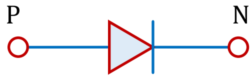


(e)

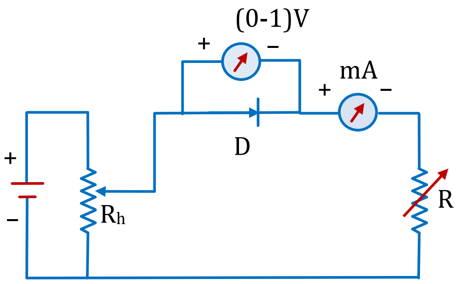
Zener Break down	**Avalanche Break down**
Where covalent bonds of depletion layer, its self-break, due to high electric field of very high Reverse bias voltage. This phenomenon predominant (i) At lower voltage after "break down" (ii) In P – N having "High doping" (iii) P – N Jn. having thin depletion layer Here P – N not damage permanently "In D.C voltage stabilizer Zener phenomenon is used".	Here covalent bonds of depletion layers are broken by collision of "Minorities" which acquire high kinetic energy from high electric field of very-very high reverse bias voltage. This phenomenon predominant (i) At high voltage after breakdown (ii) In P – N having "Low doping" (iii) P – N Jn. having thick depletion layer Here P – N damage permanently due to "Heating effect" due to abruptly increment of minorities during repetitive collisions.

Characteristic Curve Of P-N Junction Diode

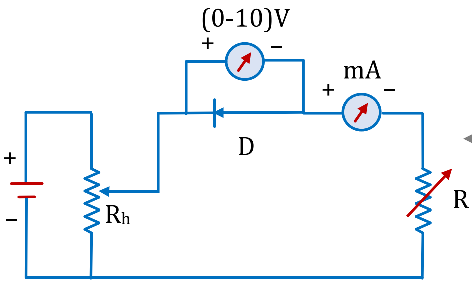




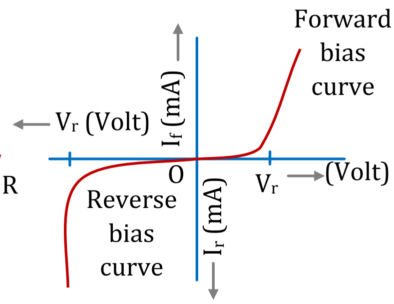
Symbol



Forward bias



Reverse bias



In forward bias when voltage is increased from $0V$ is steps and corresponding value of current is measured, the curve comes as OB of figure. We may note that current increase very sharply after a certain voltage knee voltage. At this voltage, barrier potential is completely eliminated and diode offers a low resistance. In reverse bias a microammeter has been used as current is very small. When reverse voltage is increased from $0V$ and corresponding values of current measured the plot comes as OCD. We may note that reverse current is almost constant hence called reverse saturation current. It implies that diode resistance is very high. As reverse voltage reaches value V_B, called breakdown voltage, current increases very sharply.

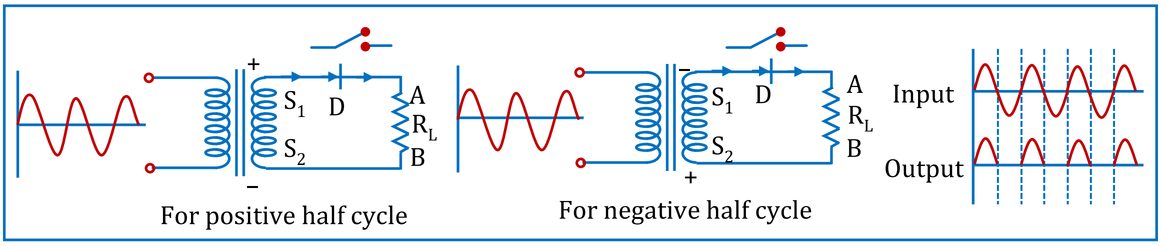
For Ideal Diode

In forward bias	In reverse bias
$R_f = 0$	 $R_f = \infty$
'ON' switch	'OFF' switch

Rectifier

It is device which is used for converting alternating current into direct current.

Half Wave Rectifier



During the first half (positive) of the input signal, let S_1 is at positive and S_2 is at negative potential. So, the PN junction diode D is forward biased. The current flows through the load resistance R_L and output voltage is obtained.

During the second half (negative) of the input signal, S_1 and S_2 would be negative and positive respectively. The PN junction diode will be reversed biased. In this case, practically no current would flow through the load resistance. So, there will be no output voltage.

Thus, corresponding to an alternating input signal, we get a unidirectional pulsating output as shown.

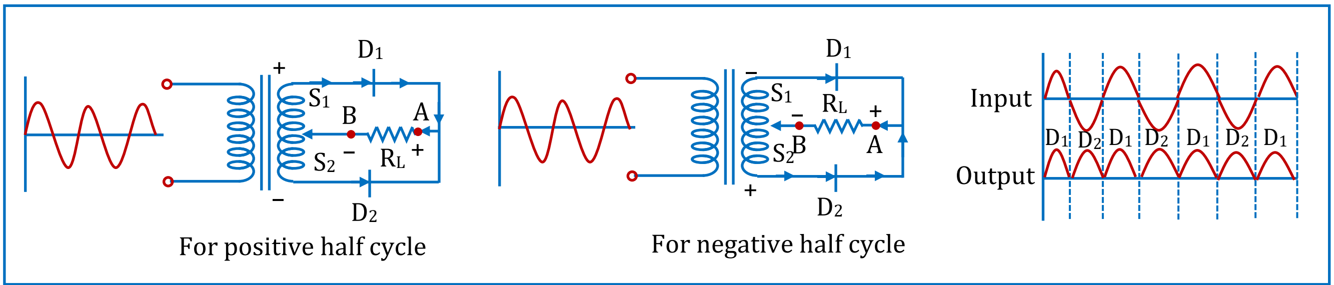
Peak Inverse Voltage (PIV)

In half wave rectifier PIV = maximum voltage across secondary coil of transformer (V_s)

= Peak value of output (V_m)

Full Wave Rectifier

When the diode rectifies the whole of the AC wave, it is called full wave rectifier. Figure shows the experimental arrangement for using diode as full wave rectifier. The alternating signal is fed to the primary a transformer. The output signal appears across the load resistance R_L.



During the positive half of the input signal:

Let S_1 positive and S_2 negative.

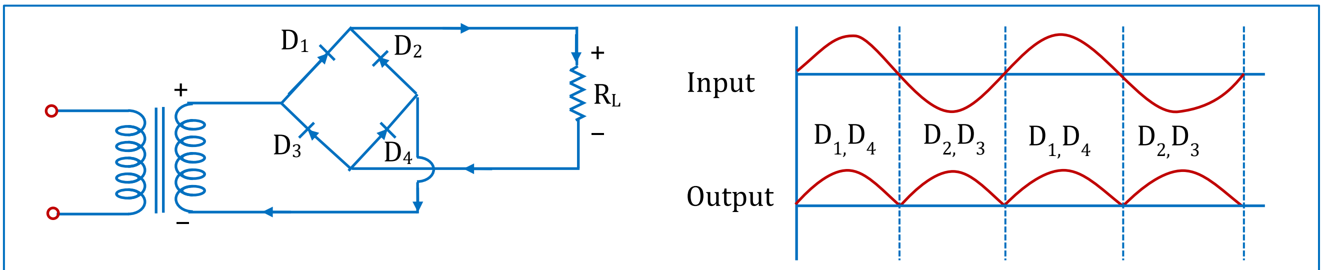
In this case diode D_1 is forward biased and D_2 is reverse biased. So only D_1 conducts and hence the flow of current in the load resistance R_L is from A to B.

During the negative half of the input signal:

Now S_1 is negative and S_2 is positive. So D_1 is reverse-biased and D_2 is forward biased. So only D_2 conducts and hence the current flows through the load resistance R_L from A to B.

It is clear that whether the input signal is positive or negative, the current always flows through the load resistance in the same direction and full wave rectification is obtained.

Bridge Rectifier



During positive half cycle

D_1 and D_4 are forward biased $\rightarrow$ on switch

D_2 and D_3 are reverse biased $\rightarrow$ off switch

In bridge rectifier peak inverse voltage $PIV = V_s = V_m$

During negative half cycle

D_2 and D_3 are forward biased $\rightarrow$ on switch

D_1 and D_4 are reverse biased $\rightarrow$ off switch

Form Factor

$$F = \frac{I_{rms}}{I_{dc}} \text{ or } \frac{E_{rms}}{E_{dc}}$$

For full wave rectifier $F = \dfrac{\pi}{2\sqrt{2}}$

For half wave rectifier $F = \dfrac{\pi}{2}$

Ripple and Ripple Factor

In the output of rectifier some A.C. components are present. They are called ripple & their measurement is given by a factor known as ripple factor. For a good rectifier ripple factor must be very low.

Total output current

$I_{rms} = \sqrt{I^2_{ac} + I^2_{dc}}$ Where I_{ac} = *rms* value of AC component present in output

Ripple factor, $r = \dfrac{I_{ac}}{I_{dc}} \Rightarrow r = \sqrt{\dfrac{I^2_{rms}}{I^2_{dc}} - 1} = \sqrt{F^2 - 1}$

Rectifier efficiency $\eta = \dfrac{P_{dc}}{P_{ac}} = \dfrac{I^2_{dc}\ R_L}{I^2_{rms}\ (R_F + R_L)}$

Half wave rectifier

$$\eta = \frac{0.406}{1 + \dfrac{R_f}{R_L}}$$

If $\dfrac{R_f}{R_L} << 1$, then $\eta = 40.6\%$

Special Note If $R_f = R_L$

$\eta = 20.3\%$

Full wave rectifier or bridge wave rectifier

$$\eta = \frac{0.812}{1 + \dfrac{R_f}{R_L}}$$

If $\dfrac{R_f}{R_L} << 1$, then $\eta = 81.2\%$

Special Note If $R_f = R_L$

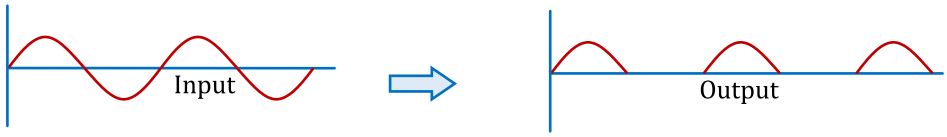
$\eta = 40.6\%$

Note:

In bridge full wave rectifier R_f is two times of resistance of P-N jn. diode in *FB*.

Ripple Frequency

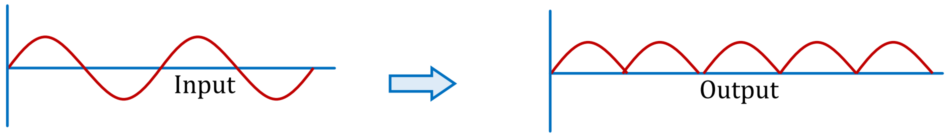
(i) For half wave rectifier



Input frequency = 50 Hz

Ripple frequency = 50 Hz

(ii) For full wave rectifier

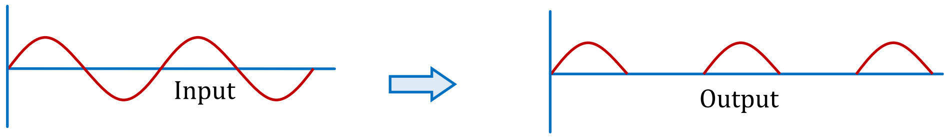


Input frequency = 50 Hz

Ripple frequency = 100 Hz

Pulse

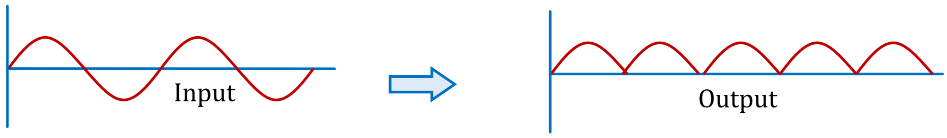
(i) For half wave rectifier



Number of pulse = $100s^{-1}$

Number of pulse = $50s^{-1}$

(ii) For full wave rectifier



Number of pulse = $100s^{-1}$

Number of pulse = $100s^{-1}$

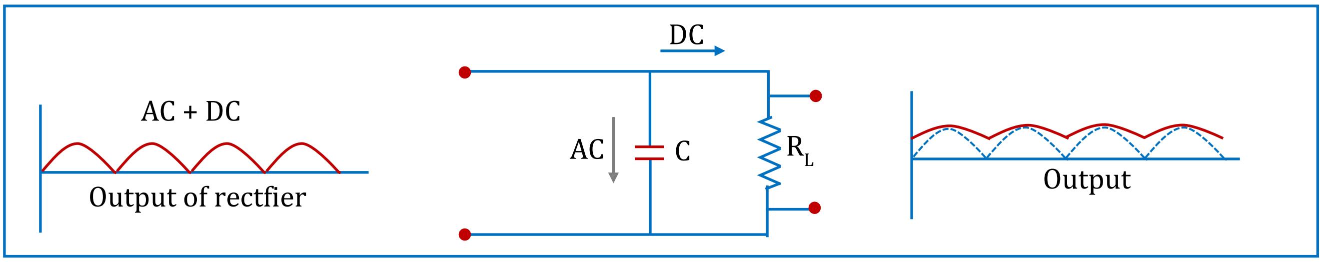
Comparison Between Average Rectifiers			
	Half-wave	**Centre-tap**	**Full-wave Bridge**
Number of Diodes	1	2	4
Transformer necessary	No	Yes	No
Peak secondary voltage	V_s	V_s	V_s
Peak Inverse Voltage (when peak of output = V_m)	$V_s = V_m$	$V_s = 2V_m$	$V_s = V_m$

Comparison Between Average Rectifiers			
	Half-wave	**Centre-tap**	**Full-wave Bridge**
Peak load Current, I_m	$\frac{V_{in}}{r_d + R_L}$	$\frac{V_{in}}{r_d + R_L}$	$\frac{V_{in}}{2r_d + R_L}$
RMS Current, I_{rms}	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
DC current, I_{dc}	$\frac{I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$
Ripple factor, r	1.21	0.482	0.482
Rectification efficiency (max)	40.6%	81.2%	81.2%
Ripple frequency (when input = 50 Hz)	50 Hz	100 Hz	100 Hz

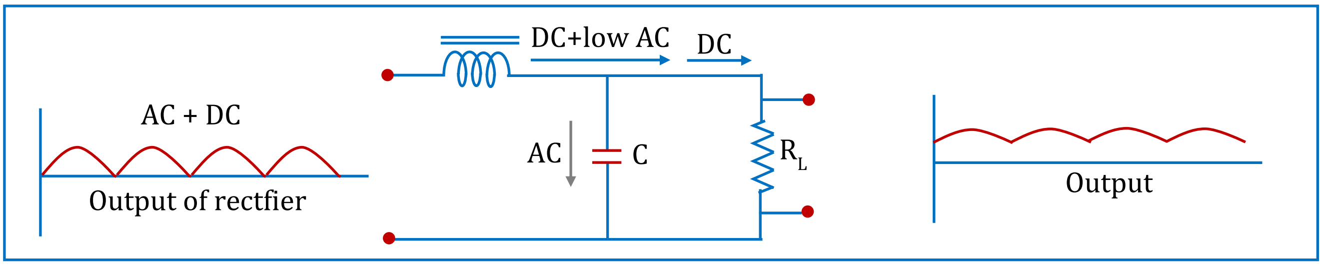
Filter Circuit

To reduce A.C. Components

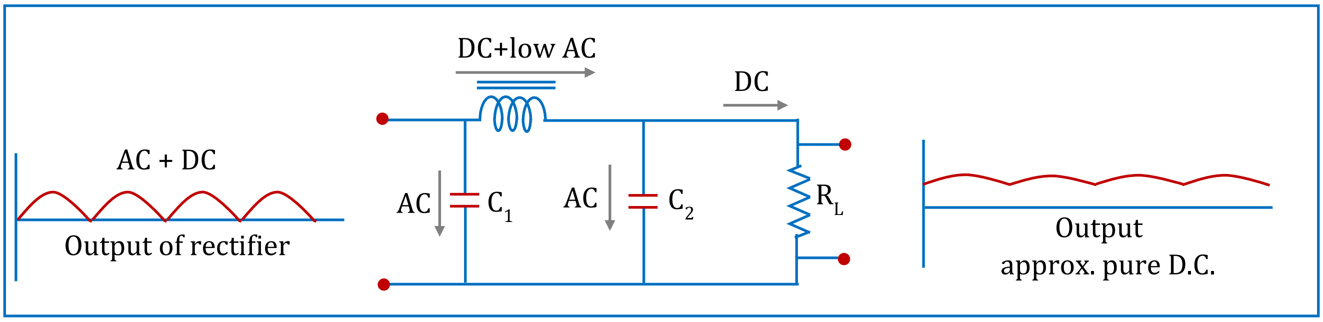
Capacitor Filter



L – C Filter



π - Filter (Best Filter)



Variable capacitor (Varactor)

P – N junction diode can be used as a "Capacitor" here depletion layer acts as "dielectric material" and remaining "P" and "N" part acts as metallic plates.

its symbol 

Diode laser

It is interesting form of LED in which special construction helps to produce stimulated radiation as in laser.

LOGIC GATES

Introduction:

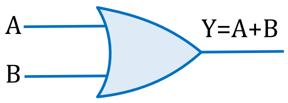
- A logic gate is a digital circuit which is based on certain logical relationship between the input and the output voltages of the circuit.
- The logic gates are built using the semiconductor diodes and transistors.
- Each logic gate is represented by its characteristic symbol.
- The operation of a logic gate is indicated in a table, known as truth table. This table contains all possible combinations of inputs and the corresponding outputs.
- A logic gate is also represented by a Boolean algebraic expression. Boolean algebra is a method of writing logical equations showing how an output depends upon the combination of inputs. Boolean algebra was invented by George Boole.

Basic Logic Gates

There are three basic logic gates. They are (1) OR gate (2) AND gate, and (3) NOT gate.

- **The OR gate:** The output of an OR gate attains the state 1 if one or more inputs attain the state 1.

  Logic symbol of OR gate

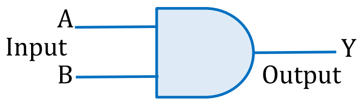
  The Boolean expression of OR gate is $Y = A + B$, read as Y equals A 'OR' B.

  Truth table of a two-input OR gate

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

- **The AND gate :-** The output of an AND gate attains the state 1 if and only if all the inputs are in state 1.

  Logic symbol of AND gate

The Boolean expression of AND gate is $Y = A.B$

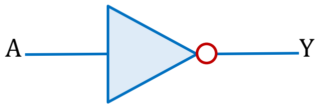
It is read as Y equals A 'AND' B

Truth table of a two-input AND gate

A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

- **The NOT gate:** The output of a NOT gate attains the state 1 if and only if the input does not attain the state 1.

  Logic symbol of NOT gate



  The Boolean expression is $Y = \bar{A}$, read as Y equals NOT A.

  Truth table of NOT gate

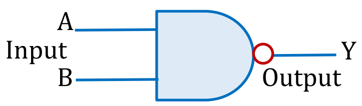
A	Y
0	1
1	0

Combination of gates:

The three basis gates (OR, AND and NOT) when connected in various combinations give us logic gates such as NAND, NOR gates, which are the universal building blocks of digital circuits.

- **The NAND gate:**

  Logic symbol of NAND gate

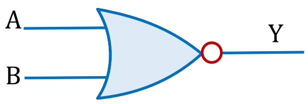


  The Boolean expression of NAND gate is $Y = \overline{A.B}$

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

- **The NOR gate:**

  Logic symbol of NOR gate



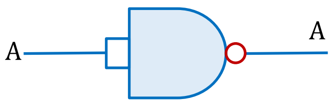
The Boolean expression of NOR gate is $Y = \overline{A + B}$

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

Universal gates:

The NAND or NOR gate is the universal building block of all digital circuits. Repeated use of NAND gates (or NOR gates) gives other gates. Therefore, any digital system can be achieved entirely from NAND or NOR gates. We shall show how the repeated use of NAND (and NOR) gates will gives us different gates.

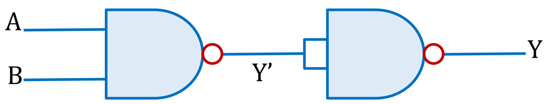
- **The NOT gate from a NAND gate: -** When all the inputs of a NAND gate are connected together, as shown in the figure, we obtain a NOT gate



Truth table of a single input NAND gate

A	B=(A)	Y
0	0	1
1	1	0

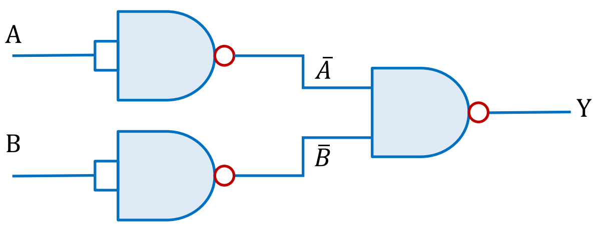
- **The AND gate from a NAND gates:-** If a NAND gate is followed by a NOT gate (i.e., a single input NAND gate), the resulting circuit is an AND gate as shown in figure and truth table given show how an AND gate has been obtained from NAND gates.



Truth table

A	B	Y'	Y
0	0	1	0
0	1	1	0
1	0	1	0
1	1	0	1

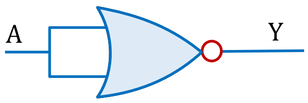
- **The OR gate from NAND gates: -** If we invert the inputs A and B and then apply them to the NAND gate, the resulting circuit is an OR gate.



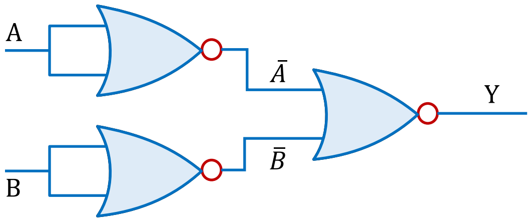
Truth table

A	B	$\bar{A}$	$\bar{B}$	Y
0	0	1	1	0
0	1	1	0	1
1	0	0	1	1
1	1	0	0	1

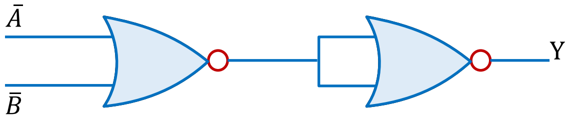
- **The NOT gate from NOR gates:-** When all the inputs of a NOR gate are connected together as shown in the figure, we obtain a NOT gate



- **The AND gate from NOR gates:-** If we invert the inputs *A* and *B* and then apply them to the NOR gate, the resulting circuit is an AND gate.



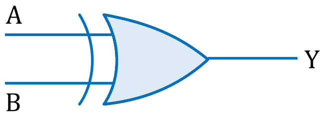
- **The OR gate from NOR gate:-** If a NOR gate is followed by a single input NOR gate (NOT gate), the resulting circuit is an OR gate.



XOR and XNOR gates:

- **The Exclusive - OR gate (XOR gate): -** The output of a two-input XOR gate attains the state 1 if one and only one input attains the state 1.

  Logic symbol of XOR gate



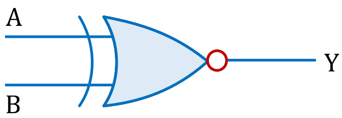
The Boolean expression of XOR gate is or $Y = A \oplus B$

Truth table of a XOR gate

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

- **Exclusive - NOR gate (XNOR gate): -** The output is in state 1 when it's both inputs are the same that is, both 0 or both 1.

  Logic symbol of XNOR gate

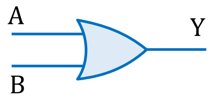
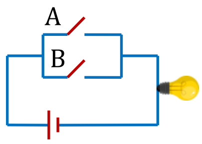
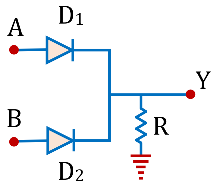
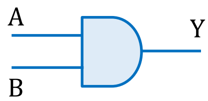
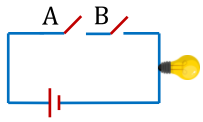
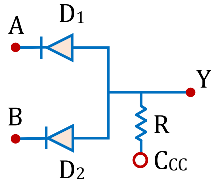
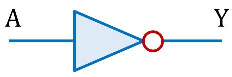
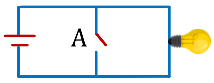
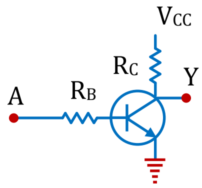
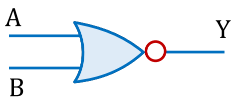
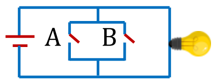
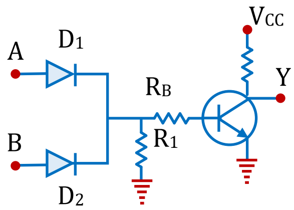
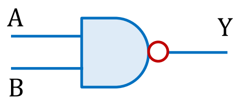
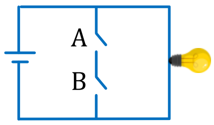
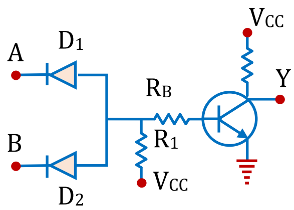
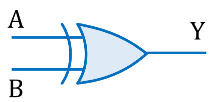
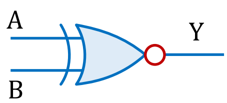


The Boolean expression of XNOR gate is or $A \odot B$

Truth table of a XNOR gate

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1

Summary of Logic Gates

Names	Symbol	Boolean Expression	Truth Table	Electrical Analogue	Circuit Diagram (Practical Realization)
OR		$Y = A + B$	A B Y 0 0 0 0 1 1 1 0 1 1 1 1		
AND		$Y = A.B$	A B Y 0 0 0 0 1 0 1 0 0 1 1 1		
NOT or Inverter		$Y = \overline{A}$	A Y 0 1 1 0		
NOR (OR+NOT)		$Y=\overline{A+B}$	A B Y 0 0 1 0 1 0 1 0 0 1 1 0		
NAND (AND+ NOT)		$Y=\overline{A.B}$	A B Y 0 0 1 0 1 1 1 0 1 1 1 0		
XOR (Exclusive OR)		$Y=A \oplus B$ or $Y=\bar{A}.B +$ $A.\bar{B}$	A B Y 0 0 0 0 1 1 1 0 1 1 1 0		
XNOR (Exclusive NOR)		$Y=A \odot B$ or $Y=A.B +$ $\bar{A}.\bar{B}$ or $Y=\overline{A \oplus B}$	A B Y 0 0 1 0 1 0 1 0 0 1 1 1		

CHARACTERISTIC CURVES OF A P-N JUNCTION

EXPERIMENT # 1

Aim

To study the static and dynamic curves of a p-n junction diode in forward bias and to determine its static and dynamic resistances.

Requirements

A p-n junction diode, a three-volt battery, a high resistance rheostat, 0-3-volt voltmeter, one milliammeter, one-way key and connecting wires.

Theory

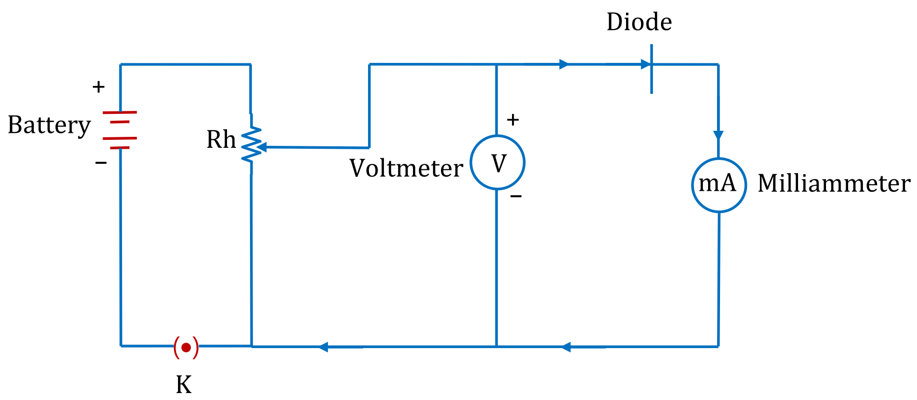
When a junction diode is forward biased, a forward current is produced which increases with increase in bias voltage. This increase is not proportional.

The ratio of forward bias voltage (V) and forward current (I) is called the static resistance of semiconductor diode, i.e., $R = \dfrac{V_F}{I_F}$.

In case of a varying bias voltage and varying forward current, the ratio of change in forward bias voltage (ΔV) and corresponding change in forward current (ΔI) is called the dynamic resistance $\left(r = \dfrac{\Delta V_F}{\Delta I_F}\right)$.

To find the static and dynamic resistance of semiconductor diode, a graph has to be plotted between forward bias voltage (V) and forward bias current (I). This graph is called the characteristic curve of semiconductor diode.

Procedure



(a) Make the connections as shown in above figure.

(b) Keep the moving contact of the rheostat to the minimum and insert the key K. Voltmeter and milliammeter will show a zero reading.

(c) Move the contact towards the positive to apply the forward bias voltage V = 0.1 V. The current remains zero.

(d) Increase the forward bias voltage to 0.3 *V* in steps. The current will still be zero. (This is due to the junction potential barrier of 0.3 *V*).

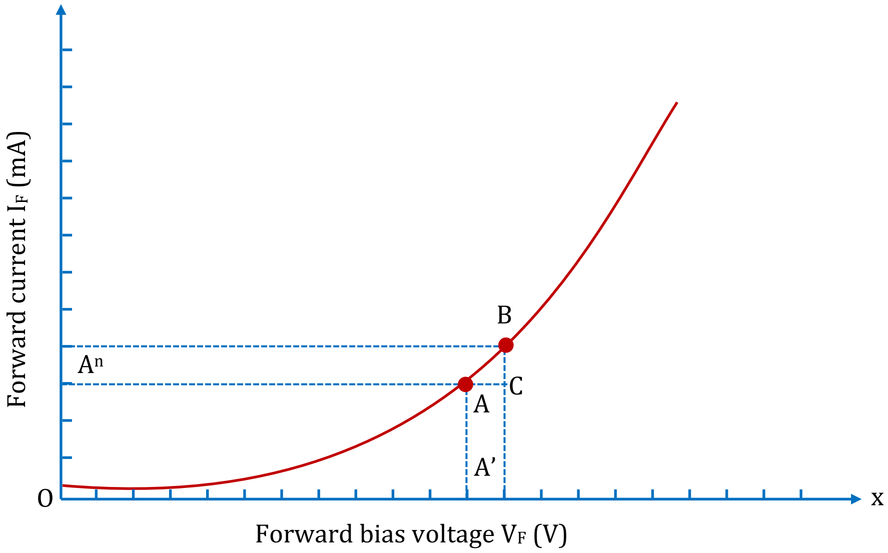
(e) Increase *V* to 0.4 *V*. Record the current.

(f) Increase *V* in step of 0.2 and note the corresponding current.

(g) At *V* = 2.4 *V*. The current increases suddenly. This represents the forward breakdown stage.

(h) Draw a graph of *I* on *y*-axis and *V* on *x*-axis. The graph will be as shown in figure.

Graph



Calculations

(i) For static resistance (*R*) $R = \dfrac{V_F}{I_F}$

From the graph $R = \dfrac{OA'}{OA}$ = ..., *ohm*

Diode used......(specify the code)

(ii) For dynamic resistance (*r*) $r = \dfrac{\Delta V_F}{\Delta I_F}$

∴ From the graph $r = \dfrac{AC}{BC}$ *ohms*

Precautions

(i) Make all connections neat, clean and tight.

(ii) Key should be used in circuit and opened when the circuit is not in use.

(iii) Avoid applying forward bias voltage beyond breakdown.

Possible Sources of Errors

(i) The connection may not be tight.

(ii) The junction diode may be faulty.

CHARACTERISTIC CURVES OF A ZENER DIODE

EXPERIMENT # 2

Aim

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

Apparatus

A Zener diode (with reverse breakdown voltage of 6 *V*), a ten-volt battery, a rheostat, two voltmeters (range 0, 10 *V*), one milliammeter, one 20Ω resistance, one-way key, connecting wires.

Theory

Zener diode is a semiconductor diode in which the *n*-type sections are heavily doped, this heavy doping results in a low value of reverse breakdown voltage.

The reverse breakdown voltage of Zener diode is called Zener voltage (V_Z). The reverse current that results after the breakdown, is called Zener current (I_z).

The circuit diagram is given in figure

V_i = Input voltage

V_0 = Output voltage

R_i = Input resistance

I_i = Input current

I_Z = Zener diode current

I_L = Load current

$I_L = I_i - I_Z$

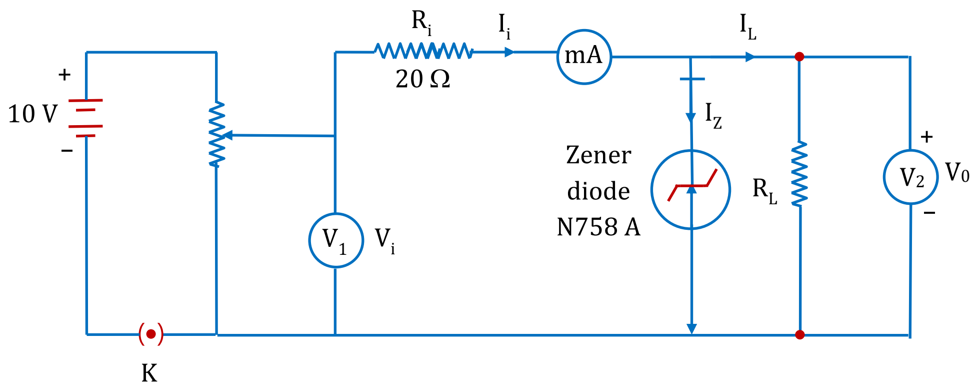
$V_0 = V_i - R_iI_i$

$V_0 = R_LI_L$

Initially as V_i increases, I_i increases hence V_0 increases linearly. At break-down, increase of V_i increases I_i by large amount, so that $V_0 = V_i - R_iI_i$ becomes constant.

This constant value of V_0 Which is the reverse breakdown voltage, is called Zener voltage.

Circuit Diagram



Procedure

(a) Make the connections as shown in figure above making sense that Zener diode is reverse biased.

(b) Bring the moving contact to rheostat to the minimum and insert the key K. Voltmeter and ammeter will read zero.

(c) Move the contact a little towards positive end to apply some reverse bias voltage (V_i). Milliammeter reading remains zero.

(d) As V_i is further increased, I_i starts increasing and V_0 becomes less than V_i. Note the values of V_i, V_0 and I_i.

(e) Keep increasing V_i in small steps of 0.5 V. Note the corresponding values of I_i and V_0.

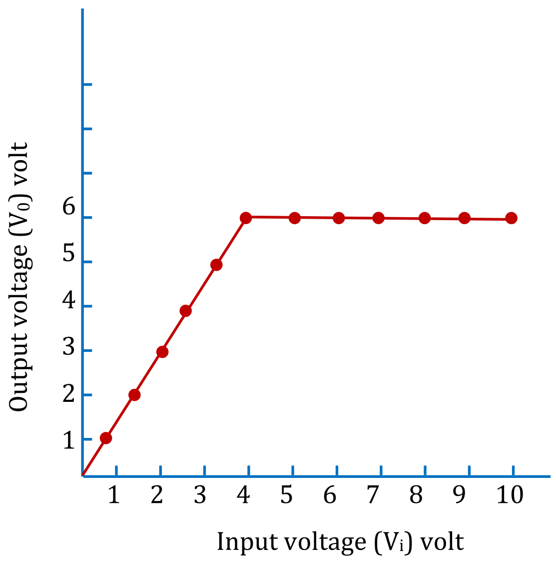
(f) At one stage as V_i is increased, I_i increases by large amount and V_0 does not increase. This is reverse break down situation.

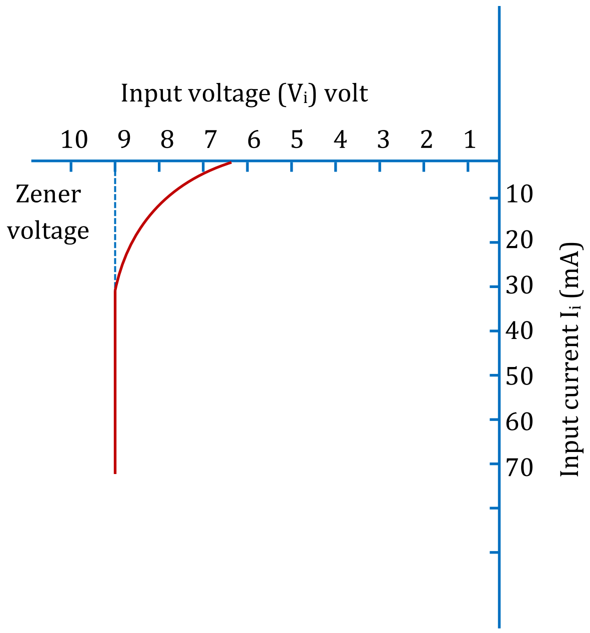
(g) As V_i is increased further, I_i will increase keeping V_0 constant. Record your observation in tabular column.

(h) Draw graph of output voltage V_0 along y-axis and input voltage along x-axis. The graph will be as shown in figure.

(i) Draw graph of input current along y-axis and input voltage along x-axis. The graph will be as shown in figure.

Graphs





Precautions

(i) Use voltmeter and milliammeter of suitable range.

(ii) Connect the Zener diode p-n junction in reverse bias.

(iii) The key should be kept open when the circuit is not in use.

CHARACTERISTIC CURVES OF A TRANSISTOR

EXPERIMENT # 3

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.

Requirements

An n-p-n transistor, a 3 V battery, a 30 V battery, two rheostats, one 0–3 V voltmeter, one 0–30V voltmeter, one 0–500μA microammeter, one 0–50 mA milliammeter, two one-way keys, connecting wires.

Theory

A transistor can be considered as a thin wafer of one type of semiconductor between two layers of another type. A npn transistor has one p-type wafer in between two n-type. Similarly, p-n-p the transistor has one n-type wafer between two p-type.

In a common emitter circuit, the emitter base makes the input section and the collector base the output section, with emitter base junction, forward bias and the collector base junction, reverse biased.

The resistance offered by the emitter base junction is called input resistance R_i and has a low value. The resistance offered by the collector base junction is called output resistance R_0 and has high value. Due to the high output resistance, a high resistance can be used as a load resistance.

The ratio $\frac{R_L}{R_i}$ or $\frac{R_0}{R_i}$ measures the resistance gain of the common emitter transistor.

The ratio of change in collector current to the corresponding change in base current, measures the current gain in common emitter transistor and is represented by β.

$$\beta = \frac{\Delta I_c}{\Delta I_b}$$

The product of current gain and the resistance gain measures the voltage gain of the common emitter transistor.

Formula Used

Input resistance, $R_i = \frac{\Delta V_b}{\Delta I_b}$

Output resistance, $R_0 = \frac{\Delta V_c}{\Delta I_c}$

Resistance gain, = $\frac{R_0}{R_i}$

Current gain, $\beta = \frac{\Delta I_c}{\Delta I_b}$

Voltage gain = Current gain × Resistance gain

i.e. $A_V = \beta \frac{R_0}{R_i}$

Circuit Diagram

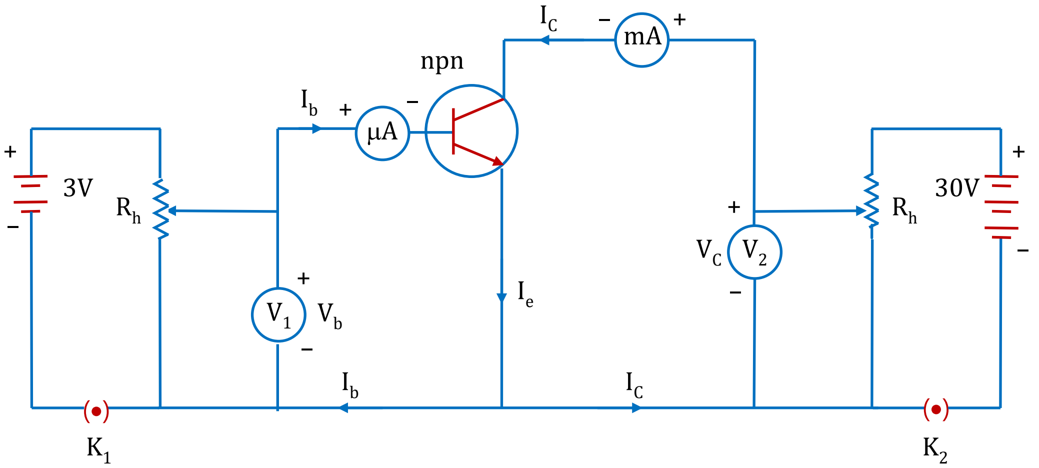


Figure: (A)

Procedure

(a) Make circuit diagram as shown in given figure (A).

(b) Drag the moveable contact of rheostat to the minimum so that voltmeters V_1 and V_2 read zero volt.

For Input Characteristics

(c) Apply the forward bias voltage at the emitter base junction note the base voltage (V_b) and the base current (I_b).

(d) Keep increasing V_b till I_b rises suddenly.

(e) Make collector voltage 10 V and repeat the above steps.

(f) Now make collector voltage 20 V, 30 V and repeat the above steps. Note the value of V_b and I_b in each case.

For Output Characteristics

(g) Make all reading zero. Keep the collector voltage zero.

(h) Make base current I_b = 100 μA by adjusting the base voltage. You will be able to read some collector current even though the collector voltage is zero.

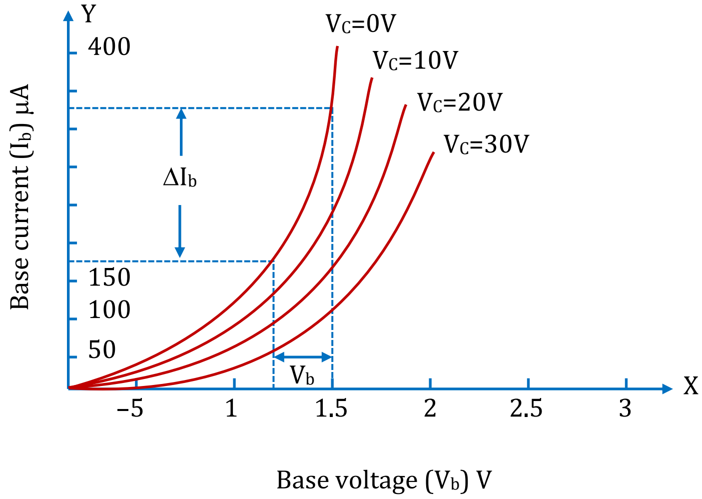
(i) Make the collector voltage 10V, 20V, 30V, etc. and note corresponding collector currents. Record your observations in the tabular form as given below.

(j) Make the current I_b equal to 200 μA, note the values of I_c corresponding to the different values of V_c.

Graphs

I. For Input Characteristics

Draw a graph of base voltage (V_b) on the x-axis and base current (I_b) on the y-axis from table no. 1. The graph will be as shown in figure.



The slope of the graph gives the value of $\frac{\Delta I_b}{\Delta V_b}$ and its reciprocal gives the value of input resistance R_i.

$$R_i = \frac{\Delta V_b}{\Delta I_b} = \text{......} \; ohms$$

II. For Output Characteristics

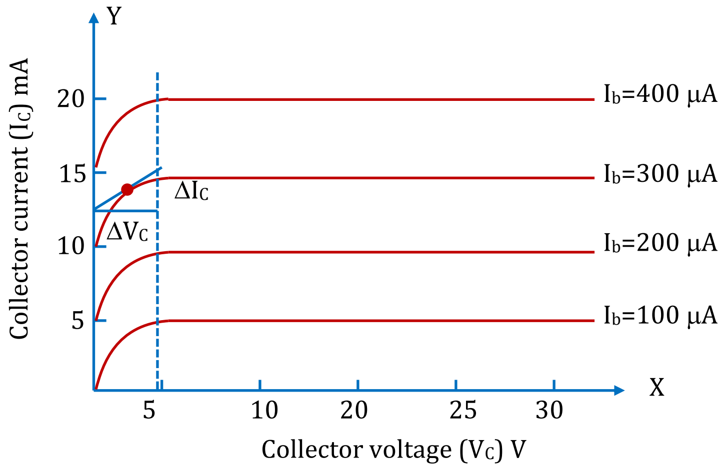
Draw the graph between collector voltage V_c and collector current I_c for 10 *mA* base current I_b taking V_c along *x*-axis and I_c along *y*-axis from table no. 2. The graph will be as shown in figure.

From the graph the slope gives the value of $\frac{\Delta I_c}{\Delta V_c}$ and its reciprocal gives the output resistance.

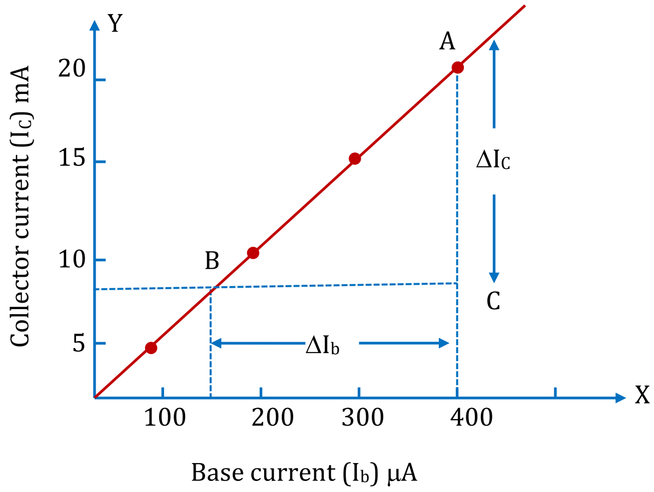
$$R_0 = \frac{\Delta V_c}{\Delta I_c} = \text{.......} \; ohm$$

III. For Calculation of Current Gain

Plot a graph of base current (I_b) on *x*-axis and collector current I_c on *y*-axis. The graph will be as shown in figure.



The slope of the graph will give the value of $\frac{\Delta I_c}{\Delta I_b}$ which is the value of current gain (β).



For calculation of voltage gain (A_v)

Voltage gain = Current gain × Resistance gain

$$A_v = \beta \times \frac{R_o}{R_i}$$

Precautions

(i) Use voltmeter and milliammeter of suitable range.

(ii) The key should be kept open when the circuit is not in use.

Possible Sources of Errors

(i) Voltmeter and ammeter may have a zero error.

(ii) All the connections may not be tight.

IDENTIFICATION OF DEVICES

EXPERIMENT # 4

Aim

To identify a diode, a L.E.D., a transistor, a resistor and a capacitor from a mixed collection of such items

Apparatus

A multimeter and a collection of a junction diode, L.E.D., a transistor, a resistor, a capacitor and integrated circuit.

Theory

For identification of different items, we have to consider both, their physical appearance and working:

1. An IC (integrated circuit) is in the form of a chip (with flat back) and has multiples terminals, say 8 or more. Therefore, it can easily be identified.
2. A transistor is a three terminal device and can be sorted out just by appearance.

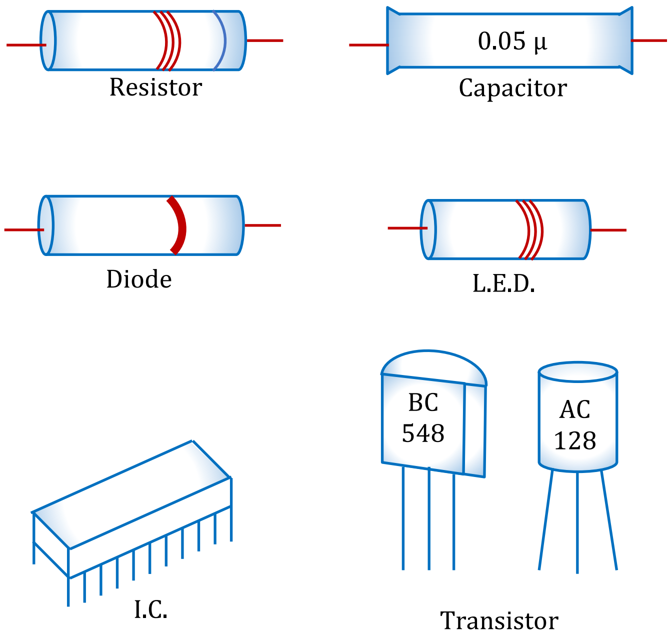
3. A resistor, a capacitor, a diode and an LED are two terminal devices. For identifying these, we use the following facts :

   (i) A diode is a two terminal device that conducts only when it is forward biased.

   (ii) An LED is a light emitting diode. It is also a two terminal device which conducts and emits light only when it is forward biased.

   (iii) A Resistor is a two-terminal device. It conducts both with D.C. and A.C. voltage. Further, a resistor conducts equally even when terminals of D.C. battery are reversed.

   (iv) A capacitor is a two terminal device which does not conduct with D.C. voltage applies either way. But, conducts with A.C. voltage.



Procedure

1. Looks at the given mixture of various components of electrical circuit and pick up the one having more than three terminals. The number of terminals may be 8, 10, 14, or 16. This component will have a flat face. This component will be the integrated circuit i.e., IC.
2. Now find out the component having three legs or terminals. It will be a transistor.
3. The component having two legs may either be a junction or capacitor or resistor or a light emitting diode. These items can be distinguished from each other by using a multimeter as an ohmmeter.
4. Touch the probes to the two ends of each item and observe the deflection on the resistance scale. After this, interchange the two probes and again observe the deflection.
5. (i) If the same constant deflection is observed in the two cases (before and after interchanging the probes), the item under observation is a resistor.

   (ii) If unequal deflections are observation, it is a junction diode.

(iii) If unequal deflections are observed in the two cases along with emission of light in the case when deflection is large, the item under observation is an LED.

(iv) On touching the probes, if a large deflection is observed, which then gradually decreases to zero the item under observation is a capacitor.

In case the capacity of the capacitor is of the order of picofarad, then the deflection will become zero within no time.

Result

When the item is observed physically

S.No.	Number of legs (or pins) of the item	Inference
1	More than three	The item is an IC
2	Three	The item is a transistor
3	Two	Junction diode, L.E.D., resistor or capacitor

With multimeter as an ohmmeter:

S.No.	Possible deflection before and after interchanging the probes	Inference
1	Same constant deflection	The item is a resistor
2	Small deflection in one case and large deflection in the other.	The item is a junction diode
3	Small deflection in one case and large deflection in the other along with emission of light	The item is an L.E.D.
4	Large deflection, which gradually falls to zero	The item is a capacitor of small capacity

Precautions

Observe all those precautions which were related to multimeter and explained at the end of multimeter.

MULTIMETER

EXPERIMENT # 5

Multimeter

A multimeter or a multi-tester, also known as a Ampere/Volt/Ohm meter or AVO meter, is an electronic measuring instrument that combines several measurement functions in one unit. A typical multimeter may include features such as the ability to measure voltage, current and resistance. There are two categories of multimeters:

(a) Analog multimeter

(b) Digital multimeter

A multimeter is a hand-held device useful for basic fault finding. It can be used to troubleshoot electrical problems in a wide array of industrial and house hold devices such as batteries, appliances, power supplies etc.

EXPERIMENT

Object

To use a multimeter to

(a) Identify base of transistor (Note: the base lead may not always be between emitter and collector).

(b) Distinguish between n-p-n and p-n-p type transistors.

(c) See the unidirectional flow of current in case of a diode and an LED.

(d) Check whether a given electronic component (e.g. diode, transistor or IC) is in working order.

Apparatus

A multimeter, transistors n-p-n and p-n-p, an IC, a diode and an LED.

Concept

Transistor can be regarded as a combination of two junction diodes joined in an opposite manner such that the middle part is common to both. When n is common to both, the transistor is p-n-p type whereas when p is common to both then it is n-p-n transistor.

(a) Identifying the base. If one of the three terminals (i.e. the legs) of the transistor is so chosen that conduction takes place in both the cases when a multimeter is connected between this chosen terminal and either of the remaining two terminals, then this chosen terminal is the base.

(b) To distinguish whether the transistor is p-n-p or n-p-n. For conduction to be possible in both the above said cases, if the common terminal has to be connected to +ve, then the transistor in n-p-n type whereas if the common terminal has to be connected to –ve for making the conduction possible in both the cases, then the transistor is p-n-p type.

(c) A diode or an LED conducts only when forward biased, and in reverse biasing, there is no flow of current.

(d) To ensure whether a diode is in working order, it will allow the current to flow in one direction, that too when forward biased.

Procedure

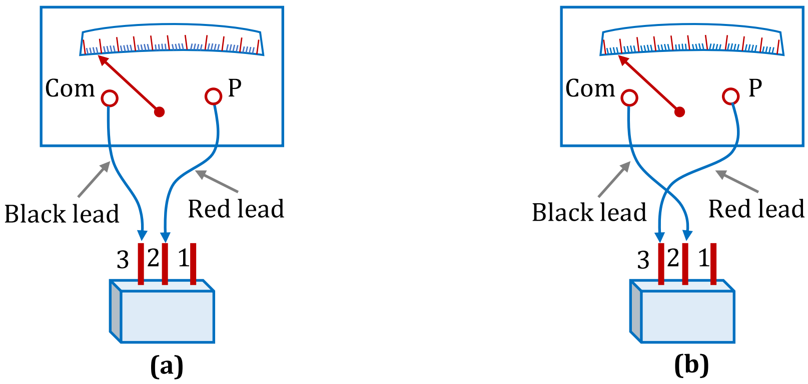
For this part of the activity, the terminal on the multimeter marked common or –ve, has to be regarded as +ve and the one marked *P* has to be regarded as –ve because the +ve of multimeter battery is connected to common and –ve of battery connected to *P*.

(a) Identification of the Base of Transistor

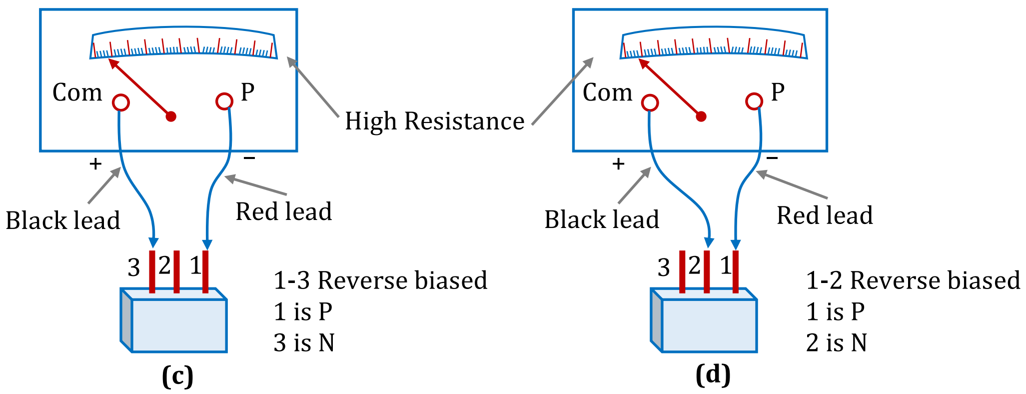
1. Use the selector switch and put the multimeter in ohm range (*R*).

2. Insert the metallic end of the black lead in common terminal of the multimeter and that of the red in the terminal marked *P*.

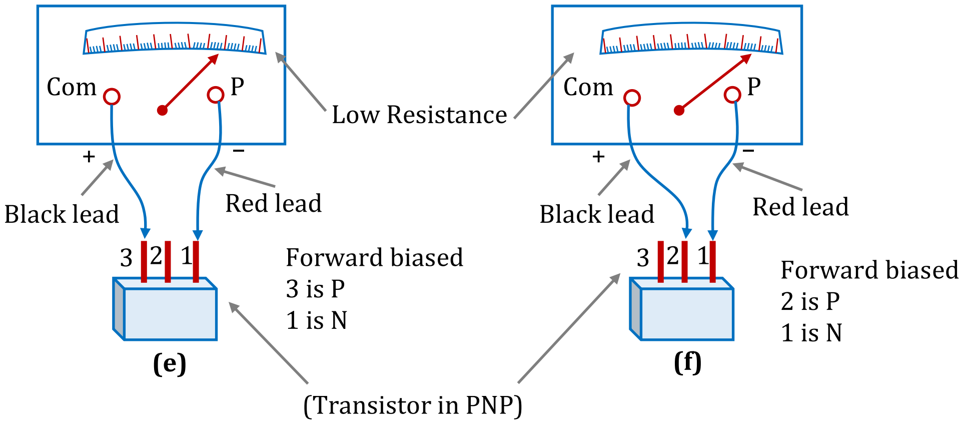
3. Now check the current conduction between the terminals of transistor marked as 1, 2 and 3 with the help of multimeter. If there is no current conduction between 3 and 2 in any case, then the terminal 1 of the transistor will be **base**.



[High Resistance in Both shows that in 3 and 2 one is Emitter and Other is Collector (1 is Base)]



(Transistor is NPN)



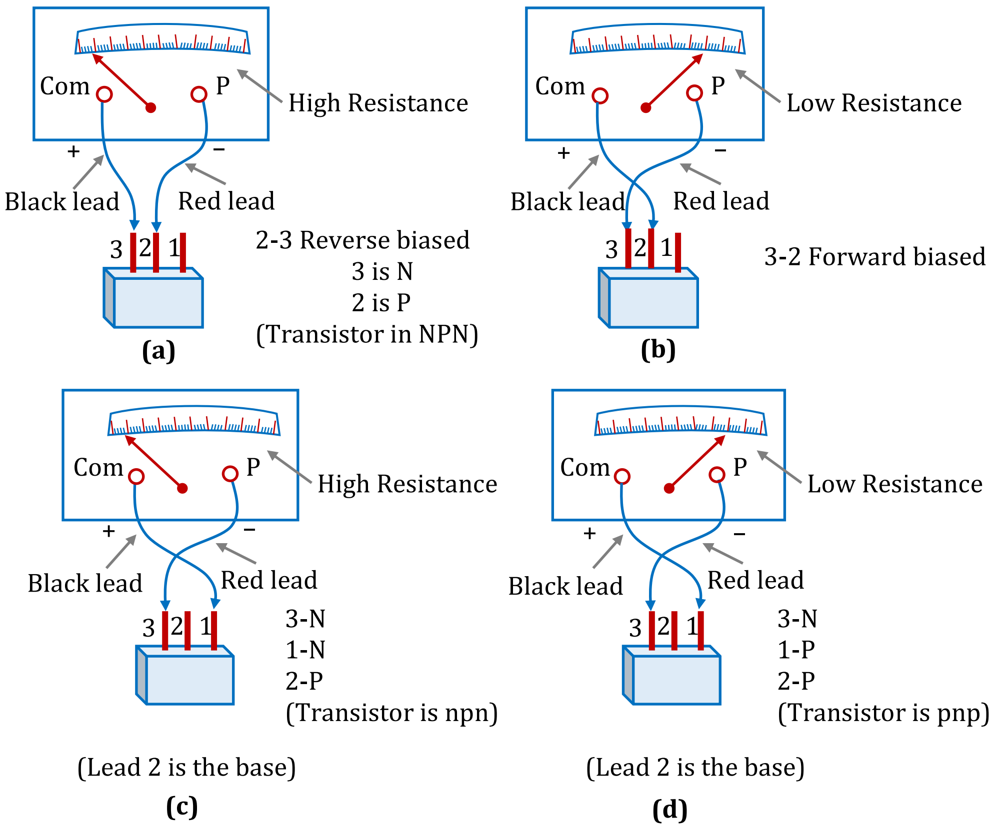
(Identifying the Base of a Transistor (a) and (b) [Ensuring whether it is n-p-n. Fig (c) and (d) and p-n-p fig. (e) and (f).]

4. Connect the other metallic end of the black lead to the leg of the transistor marked '3' and the red lead to the leg marked '2' as shown in figure (a) and note whether the resistance shown by the pointer is high or low. Now reverse the contacts of the leads with the legs '2' and '3' [i.e. leg (3) to –*ve* and (2) to +*ve*] as shown in figure (b) and note again whether the resistance shown is high or low.

5. Similarly find resistances between the terminals of transistor marked as 3 and 1 and 2 and 1.

(b) In identification of the type of transistor i.e. p-n-p or n-p-n the following two possibilities Arise

(i) The resistance is high in both the cases as in figure (a) and figure (b). Then proceed as explained further in figure (c) and (d) and locate the base leg and the type of transistor n-p-n or p-n-p.



(ii) If resistance shown as in figure (a) is high in one when 3 is +ve and 2 is –ve and low in other when 3 is –ve and 2 is +ve (figure b)], then proceed as explained in part II of the figure. Connect 3 to –ve by red lead and I to +ve by black lead as in figure (c) and (d).

(iii) A high resistance would mean 3 and 1 are both n-type and 2 is p-type the base.

(iv) A low resistance would mean a forward biasing of 3 and 1 (i.e. 3 is n, 1 is p and 2 is p).

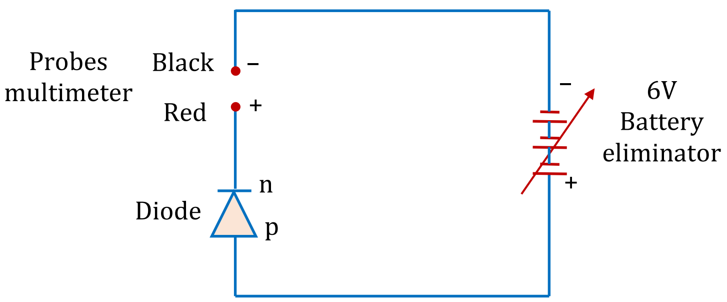
It means base is 3 and the transistor is p-n-p type.

Identifying the Emitter and Collector Leads (Having Known the Base)

We know that in a transistor, the emitter region is heavily doped relative to the collector region. Therefore, the forward resistance of emitter-base should be lower than that of collector-base. Using ohm-meter (multimeter set at R) the forward resistance of the lead with base having lower value implies that the lead is the EMITTER and the other offering higher forward resistance with base is the COLLECTOR.

(c) Unidirectional Flow of Current

1. Connect the $+ve$ marked end of the diode to $+\ ve$ terminal of a $6V$ variable D.C. battery adjusted to minimum voltage. (figure)



(Testing Unidirectional Current in a Diode)

2. Select the D.C. current at $10mA$ range by using the selector switch in multimeter. Insert one of the metallic ends of red probe in terminal $P(+)$ and the black metallic end into the terminal marked common.

3. Connect the other metallic end of red probe to the free end of the diode and the metallic end of black probe into the –ve terminal of the battery eliminator and read the value of current by varying the output of the eliminator. Since the diode is forward biased, it allows the current to pass.

4. Now reverse the terminals of the diode such that the end marked –ve is at higher potential and the end marked + is at lower potential. Again, observe the current in multimeter on the appropriate D.C. milliampere scale. No current reading in the multimeter would indicate that the diode allows the flow of current in one direction only, i.e., the current is unidirectional in a diode.

5. Now replace the diode by LED and repeat the steps 1 o 4 to establish that an LED also allows the flow of current only when it is forward biased as well as emits light.

(d) Checking Whether a Diode or a Transistor is in Working Order

(i) A diode will conduct only in one direction i.e. first connect the ends of diode to the two metal ends of the probes and reverse the connecting points. If it conducts in one case, then diode is in working order. If conducts in both cases or does not conduct in both cases, then is damaged.

(ii) Select any two terminals between which there is no conduction in forward or reverse biasing, these will be emitter and collector, if it is not so then, the transistor is damaged.