Semiconductor Electronics

In day-to-day life we use so many **electronic devices** and also, we control flow of current by using these devices and it can be obtained by basic building blocks of all the electronic devices. **Semiconductors** are materials that have electrical conductivity between that of conductors (metals) and insulators. They play a crucial role in modern electronics.

Formulae:

Classification of Metals, Conductors and Semiconductors:

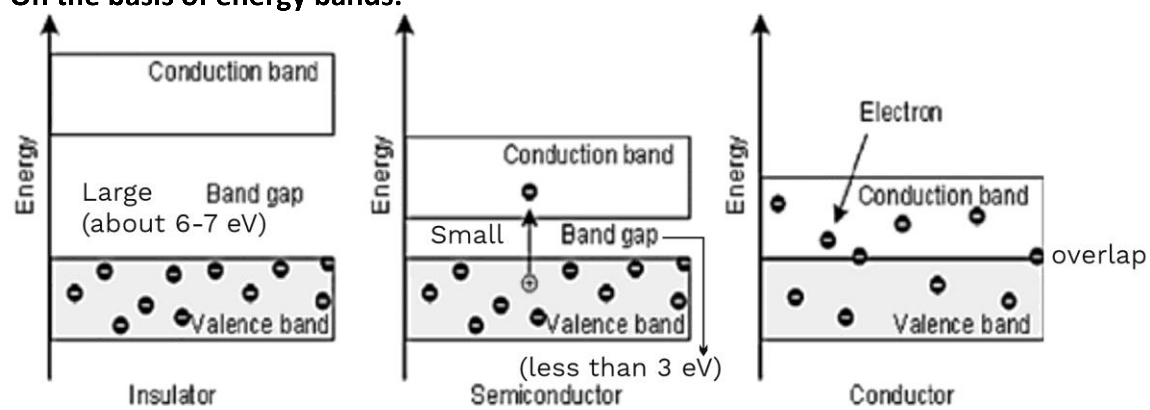
- **On the basis of conductivity:**

  a. Metals: They have high conductivity or low resistivity, $\rho = 10^{-2} - 10^{-8}\,\Omega m$
  $\sigma = 10^{2} - 10^{8}\, Sm^{-1}$

  b. Semiconductors: They are between metals and insulators, $\rho = 10^{-5} - 10^{6}\,\Omega m$
  $\sigma = 10^{5} - 10^{-6}\, Sm^{-1}$

  c. Insulators: They have high resistivity or low conductivity, $\rho = 10^{11} - 10^{19}\,\Omega m$
  $\sigma = 10^{-11} - 10^{-19}\, Sm^{-1}$

- **On the basis of energy bands:**



Concentration of Charge and Current:

- **Intrinsic Semiconductor:** $n_e = n_h = n_i$

  Where, n_e = Free electron density in the conduction band

  n_h = Density of hole in the valence band

  n_i = number of Intrinsic carriers

And, The total current flow through intrinsic semiconductor: $I = I_e + I_h$

I_e = Current due to electrons

I_h = Current due to holes

- **Extrinsic Semiconductor:** $n_e \approx N_d > n_n (n - type)$ and $n_n \approx N_d > n_e (p - type)$ where N_d is the number density Hence, number of electrons reaching to conduction band is-

$$n = AT^{\frac{3}{2}} e^{-\frac{E_g}{2kt}}$$

Where, A= Material Constant, E_g = Bandwidth and T= Temperature

Note: The electron and hole concentration in a semiconductor in thermal equilibrium is given by $n_e n_h = n_i^2$

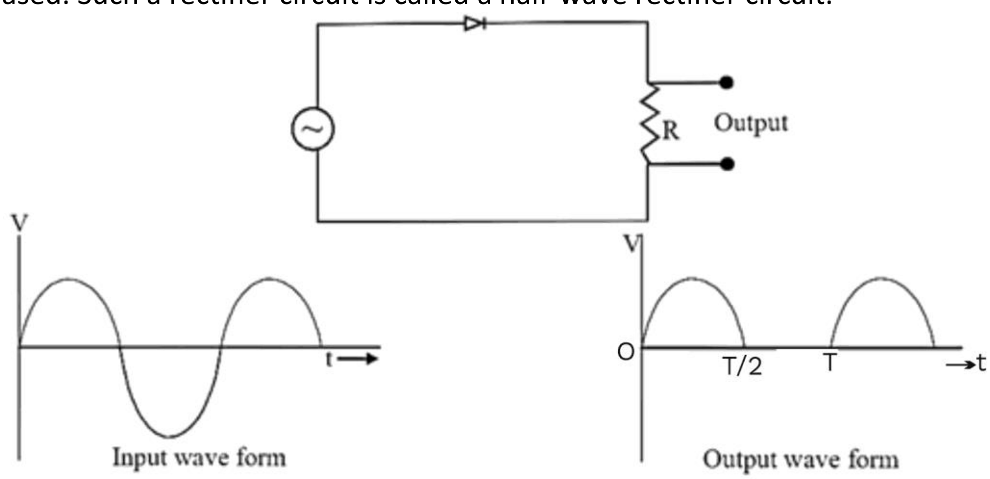
Mobility: $\mu = \frac{V_d}{E}$, where V_d = Drift velocity and E = Electric field

Electrical conductivity of a semiconductor: $\sigma = \sigma_o e^{(-\frac{E}{2K_B T})}$

Dynamic Resistance: $R = \frac{\Delta V}{\Delta i}$, ΔV = small change in the applied potential difference

Δi = change in current

Half Wave Rectifier: If an AC voltage is applied to a diode in series with the load, the pulse voltage will appear across the load only during the half cycle of the AC input during which the diode is forward biased. Such a rectifier circuit is called a half-wave rectifier circuit.



Average output current= $\frac{I_o}{\pi}$, where I_o = amplitude of the output current

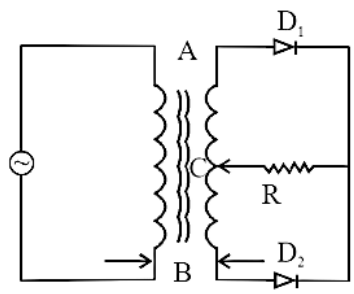
R.M.S. value of output current= $\frac{I_o}{2}$

} For one cycle

Full Wave Rectifier: The circuit uses two diodes and produces a rectified output voltage corresponding to both the positive and negative half of the AC cycle. This is why it is called a full-wave rectifier.

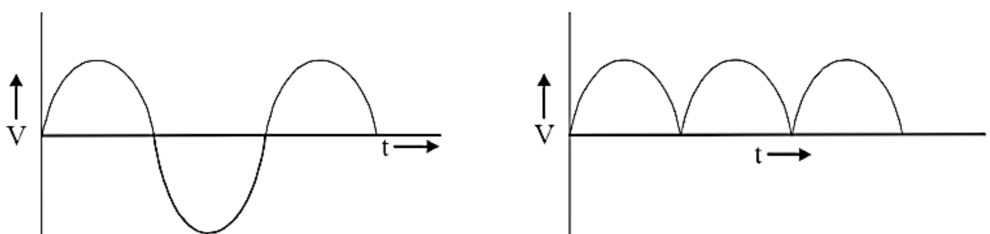
Average output current= $\frac{2I_o}{\pi}$ } For one cycle

R.M.S. value of the output current= $\frac{I_o}{\sqrt{2}}$



If $V_A > V_C > V_B$ D_1 Conducts

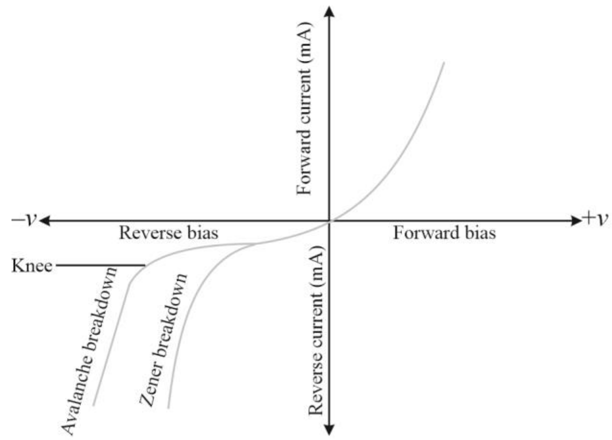
If $V_B > V_C > V_A$ D_2 Conducts



Input wave form Output wave form

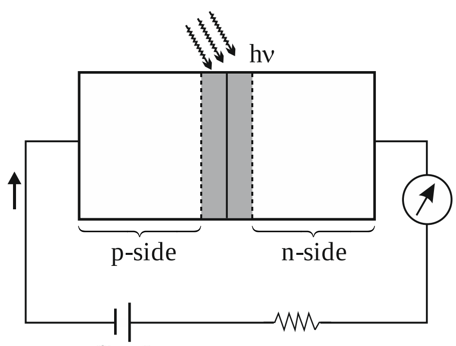
Zener Diode :

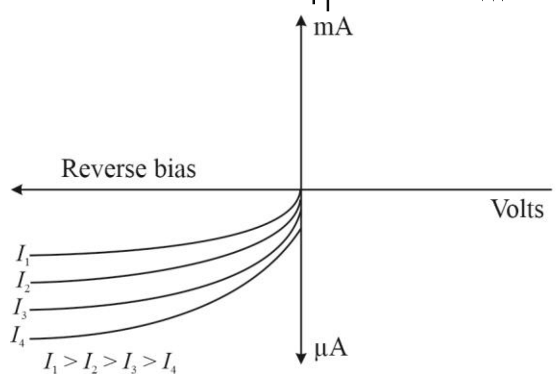
- If the input voltage increases, the current through R and Zener diode also increases.
- This increases the voltage drop across R without any change in the voltage across the zener diode. Similarly, if the input voltage decreases the current through R and zener diode also decreases. The voltage drop across R decreases without any change in the voltage across the zener diode.
- Thus any increase/decrease in the input voltage results in increase/decrease of the voltage drop across R without any change in voltage across the zener diode (and hence across load resistance R,). Thus, the zener diode acts as a voltage regulator.

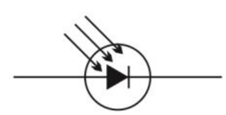


When reverse-biased voltage is applied to a Zener diode, it allows only a small amount of leakage current until the voltage is less than Zener voltage.

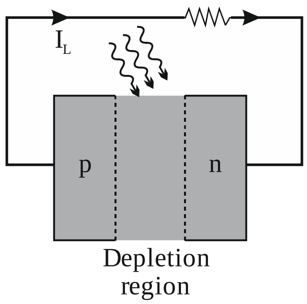
Photodiode : It is used in reverse bias. When a photodiode is illuminated with light photons having energy hν > E_g, it creates electron-hole pair in the depletion region causing an increase in drift current. It is easier to observe the change in the current with change in the light intensity, if a reverse bias is applied. Thus photodiode can be used as a photodetector to detect optical signals. Circuit diagram, I - V characteristic graphs for various intensities (I) and symbol of photodiode shown below.

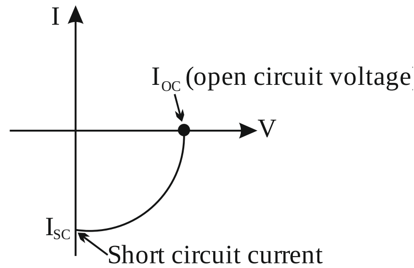






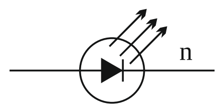
Solar Cell : It converts solar energy into electrical energy. No external voltage is applied here. Active junction area is kept large. The materials most commonly used for solar cell are silicon and Ga, As. The solar radiations received by us has a maxima near 1.5 eV. So, semiconductors with E_g < 1.5 eV are more useful so that they can absorb a maximum of radiation. Si has E_g of the order of 1.1 eV and Ga As has E_g ~ 1.5 eV. Ga As is better than silicon as its absorption coefficient is more. Circuit diagram, i – V characteristic graphs for solar cell is shown below.





Note that the I – V characteristic of solar cell is drawn in the fourth quadrant of the coordinate axes. This is because a solar cell does not draw current but supplies the same to the load.

Light Emitting Diode (LED): They are used in forward bias and emit radiations by spontaneous emission. When electron falls from higher to lower energy level containing holes, energy in the form of radiation is released. This is called radiative transition.



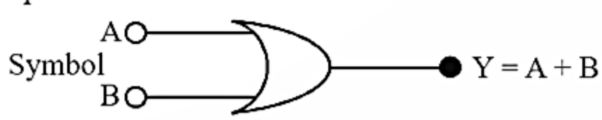
LEDs have the following advantages over conventional incandescent low power lamps :

(i) Low operational voltage and less power.
(ii) Fast action and no warm-up time required.
(iii) The bandwidth of emitted light is 100A to 500A or in other words it is nearly (but not exactly) monochromatic.
(iv) Long life and ruggedness.
(v) Fast on-off switching capability.

Logic Gates:

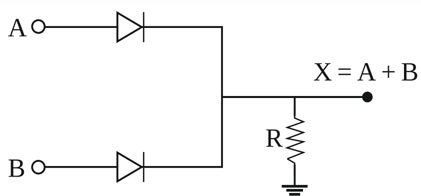
- **OR Gate:**

Boolean expression $Y = A + B$



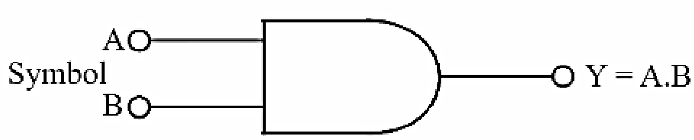
Truth table

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



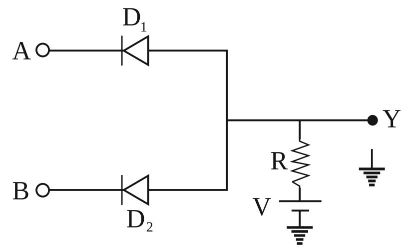
- **AND Gate:**

Boolean expression $Y = A \cdot B$



Truth table

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

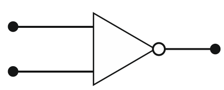


- **NOT Gate:** $Y = \overline{A}$

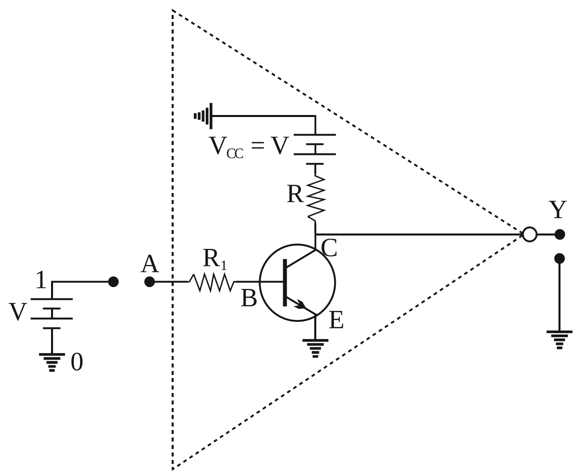
Truth table

A	*Y*
0	1
1	0

(a)



(b)



(c)

Combinations of Basic Gates

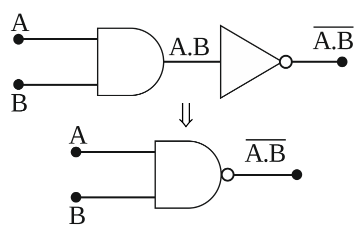
De Morgan's theorem : It states the complement of the whole sum is equal to the product of individual complements and vice versa, i.e.,

- **NAND :** $Y = \overline{A.B} = \overline{A} + \overline{B}$

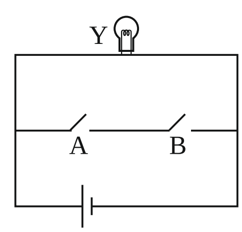
Truth table

A	*B*	*A . B*	$\overline{A . B}$
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0

(a)



(b)



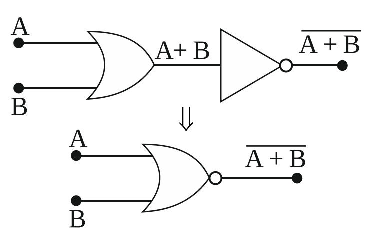
(c)

- **NOR :** $Y = \overline{A + B} = \overline{A} \cdot \overline{B}$

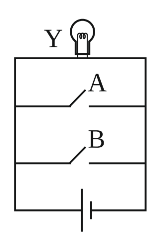
Truth table

A	*B*	*A + B*	$\overline{A + B}$
0	0	0	1
0	1	1	0
1	0	1	0
1	1	1	0

(a)



(b)



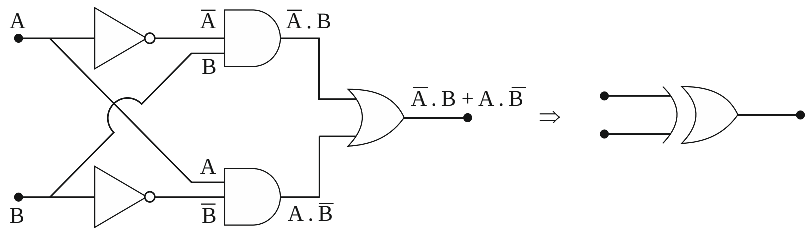
(c)

- **XOR Gate:** $Y = \overline{A} \cdot B + A \cdot \vec{B}$ -

Truth table

A	B	$\bar{A}$	$\bar{B}$	$\bar{A}.B$	$A.\bar{B}$	$\bar{A}.B+A.\bar{B}$
0	0	1	1	0	0	0
0	1	1	0	1	0	1
1	0	0	1	0	1	1
1	1	0	0	0	0	0

(a)



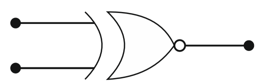
(b)

- **NAND Gate and NOR Gate:** $Y = (\overline{\bar{A}\cdot B + A\cdot\bar{B}}) = \bar{A}\cdot\bar{B} + A\cdot B = (\bar{A}+B)\cdot(A+\bar{B})$

Truth table

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

(a)



(b)