# Ch. 2 Solar Photovoltaic System

## 1. Introduction to Photo-Voltaic Systems:

The Solar photo-voltaic cells (PV Cells) convert the incident solar energy directly to the electrical energy in DC form.

A single cell has a rated voltage of about 0.5 V and rated power about 0.3 W.

The schematic of photo-voltaic cells as shown in fig (a)

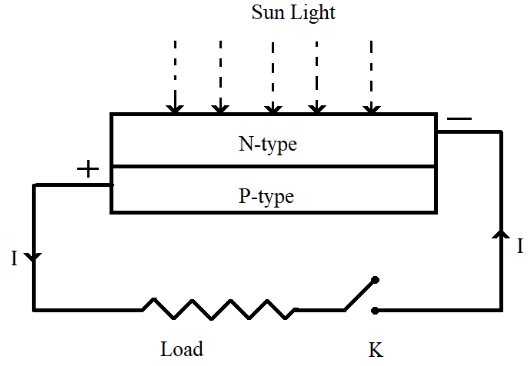



Fig. (a)

A solar cell consists of a small semiconductor device which has a light sensitive P-N junction. When solar light rays incident on the P-N junction DC emf is generated with P-terminal as positive and N-terminal as negative. Nominal rating of typical single PV-cell when exposed to full sunlight are

Voltage 0.45V, DC

Current 0.75 A, DC

Power 0.33 W

Actual power delivered varies with the intensity of sunlight and load resistance. When exposed to sunlight, the solar cell acts like a tiny DC cell. Several solar cells are connected in series, parallel to get desired voltage, current and power.

Several solar cells are connected in series to form a string. Several strings are connected in parallel to form module. Several modules are connected in series, parallel, series-parallel configuration to form an array. The arrays installed on the structure to form a solar PV-collector.

The schematic of solar PV system as shown in fig (b).

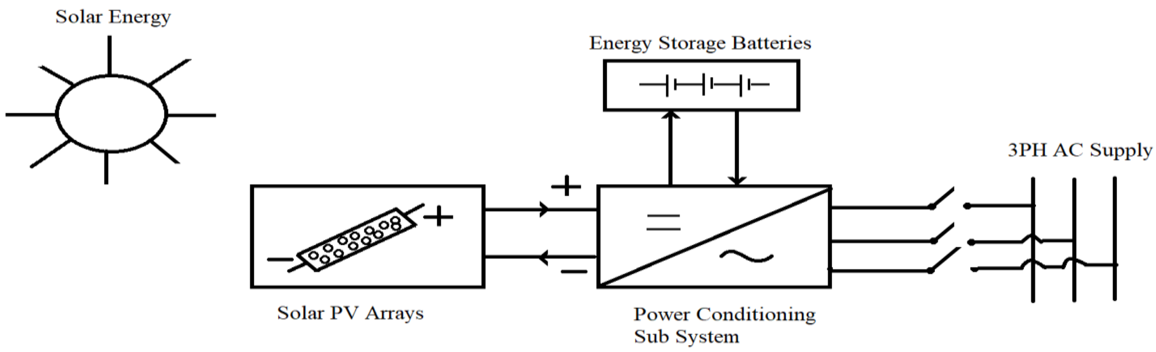


Fig. (b) Schematic of a solar PV systems

A solar PV arrays delivers certain DC current at certain DC voltage for certain intensity of incident solar energy. The DC output power depends upon total number of cells and power per cell. The current and voltage are influenced by the circuit connections and external resistance. Solar PV panels are installed outdoors in a position to receive a maximum sunlight during the day and year. Solar PV panels may be fixed type or tracking type.

The Solar PV panels deliver DC electrical power only during favourable conditions of Sunlight. To obtain electrical power during cloudy weather or during nights the energy storage batteries are necessary. The Storage batteries supply the electrical energy to the load. Some of the electrical loads require 50 Hz AC supply. Hence DC power supplied by the Solar PV panel and storage battery should be converted to single phase or three phase 50 Hz, AC power. DC to AC conversion is achieved by means of static inverters.

## 2. Solar cell fundamentals

Depending on the ability of the material to carry the current, the materials are grouped into three categories: conductor, insulator and semiconductor.

In a conductor, the electrons in the outer shells are free to move and are not bound to the specific site and conduct electricity. The conductivity of a conductor is of the order of$10^{6}$ mho/cm.

In an insulator, the outer shells of the atom contain six or seven electrons and the electrons are tightly bound and are unable to carry electric current. The conductivity of insulator is of the order of$10^{-10}$ mho/cm.

A semiconductor, which lies between conductor and insulator, the atoms may have three, four or five electrons in the outer shell and these electrons can be free only if some additional energy is supplied. The conductivity of a semiconductor can be changed by introducing new virgin foreign elements called dopants.

**Semiconductor materials:**

A substance whose electrical conductivity lies between conductor and insulator is called as semiconductor.

The most commonly used semiconductors in electronic devices are Germanium and silicon. Since single crystal Silicon cell is widely used in solar cells.

This semiconductor element belongs to $IV^{th}$ group of periodic tables and have four electrons in outermost cell. In a pure Si crystal, there are four valence electrons shared with adjacent four electrons in atoms and forms covalent bond. Crystal structure of silicon as shown in fig (a).

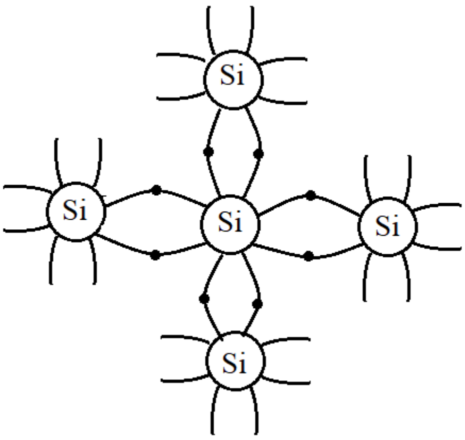



Fig. Crystal structure of Si

At 0°K all valence electrons are firmly bounded in covalent bonds and there are no free electrons available for electrical conduction. Thus, at 0°K a semiconductor has completely filled valence band and an empty conduction band thus it behaving as an insulator.

At room temperature, the crystal lattice is thermally excited and the valence electrons get additional energy. When electrons receive sufficient energy, it breaks the covalent bonds and wander in lattice space as free negative charge carriers. The energy required to break a covalent bond is about 1.1 eV for Si and 0.72 eV for Ge. This energy is called as bond energy or energy gap $E_g$.

If the temperature of crystal is increased and more covalent bonds are broken and more free electrons are available in the crystal showing an increase in the conductivity. When an electron becomes free by breaking a covalent bond, it leaves behind a space called a hole, acting as positive charge carrier. Hence, there is always an attractive force between a hole and electron at any given temperature. The rate of combination of holes and electrons is always equal to rate of production of new holes and electrons. Semiconductors are classified as intrinsic and extrinsic. The intrinsic semiconductors are those that are very pure. If an extremely small amount of impurity is introduced into the pure semiconductor, its electrical conductivity increases. This process of introducing impurity in pure semiconductor is known as doping and the crystal obtained is called as extrinsic semiconductor.

Depending upon the impurity atoms, the extrinsic semiconductors are further divided into two groups as N-type and P-type semiconductor.

## N-type Semiconductor:

If the impurity belongs to V$^{th}$ group of periodic table added to pure semiconductor material, the semiconductor is called as N- type semiconductor. For example- arsenic, antimony, Phosphorus etc. The crystal structure of N-type semiconductor is as shown in figure.

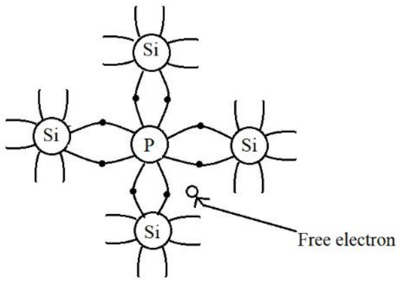



Fig. Crystal structure of N-type Semiconductor

Elements such as Phosphorus (P) belongs to V$^{th}$ group of periodic table have five valence electrons in outermost orbit. Four valence electrons of the Phosphorus atom form covalent bond with four electrons of the neighbouring Si atoms and fifth electron of the impurity atom becomes free to move in a lattice. Since each impurity atom has donated free electron to the crystal. This pentavalent impurity is known as a donor impurity. The crystal is said to be N-type semiconductor as the number of electrons or negative charge carriers in the crystal is much greater than the number of holes produced by thermal agitation.

In N-type semiconductor, the recombination rate of electrons and holes also increases because of the presence of an increased number of electrons donated by donor and as a result, the number of holes decreases.

**P type semiconductor:**

If the element belongs to III$^{rd}$ group of periodic table is added to pure semiconductor material, then that semiconductor is called as P-type semiconductor.

The elements in III$^{rd}$ group periodic table is the indium, aluminium, gallium, boron etc. The crystal structure of P-type semiconductor is as shown in figure.

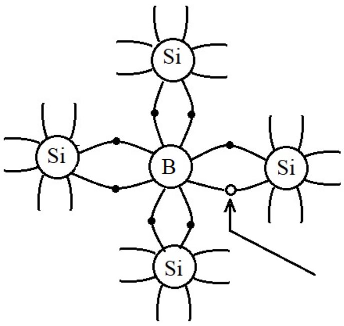



Fig. Crystal structure of P -type Semiconductor

Suppose Boron (B) is added to pure semiconductor material silicon (Si). There are three electrons in outermost orbit form covalent bond. The fourth covalent bond has a missing of electron. Thus, a hole is introduced for each impurity atoms. since each impurity atom has a tendency to accept one electron, this trivalent impurity is called as an acceptor impurity. The crystal is said to be P-type semiconductor as the holes or positive charge carriers are in the majority.

The N-type or P-type semiconductor is electrically neutral because each impurity atom is itself neutral. In N-type semiconductor the electrons are majority charge carriers and holes are the minority charge carriers. In P-type semiconductor the electrons are minority charge carriers and holes are majority charge carriers.

**P-N Junction:**

If a P-type semiconductor material is joined with N-type semiconductor material boundary joining the two regions is known as PN junction. This device is known as PN junction diode.

Formation of a PN junction is as shown in figure.

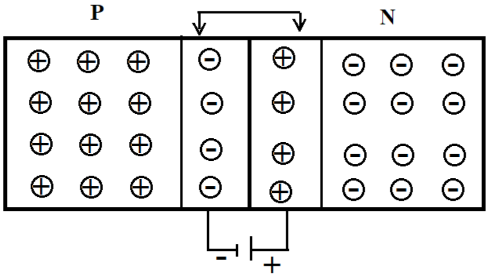



**Fig. Formation of P-N junction**

Initially, holes are present in the majority to the left of the junction and electrons in the majority to the right of the junction. These holes and electrons are free to move randomly in the lattice. Since there are more electrons to the right of the junction and more holes to the left of the junction. There is a density gradient across the junction. Therefore, more holes diffuse to the right of the junction and more electrons diffuse to the left of the junction. As a result of electrons leaving the N-type material, donor ions are produced on the N-side of the junction. When these electrons fill holes on the P-side of the junction, the acceptor ions are produced. The space occupied between these ions is called space charge region or depletion region. The movement of holes and electrons across the junction constitutes a current known as diffusion current. Thus, the region just to left of junction becomes negatively charged and the region just to right of junction becomes positively charged and potential difference is established across the PN junction. This potential is called as barrier potential. Any charge carriers entering the space charge region are rapidly swept out of it and hence this region is called as depletion region.

**Forward Biasing of a P-N Junction:**

When positive terminal of a battery is connected to the P-side and negative terminal is connected to the N-side of a PN junction, then PN junction is said to be forward biased.

The forward biasing of a PN junction is as shown in figure.

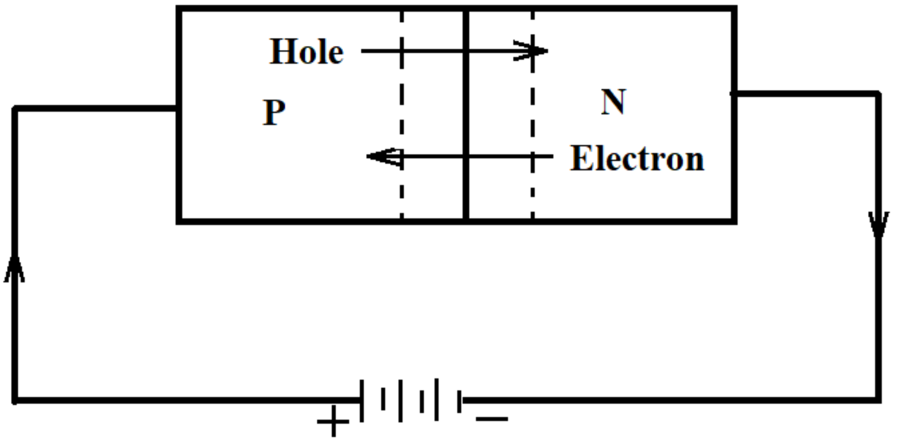



**Fig. Forward biasing of P-N Junction**

During forward bias, the holes in the P-region and electrons in the N-region of the diode experience a repulsive force from the battery and drift towards the junction. This drift of holes and electrons towards the junction reduces the width of depletion region and also junction potential barrier. This helps the holes of relatively lower energy in the P-region to cross the junction and combines with the electrons in the N-region. Similarly, more free electrons in the N-region cross the junction and combine with the holes in the P-region. The holes and electrons continuously diffusing across the junction. This diffusion of majority charge carriers constitutes a current across the junction and total current is sum of hole and electron currents. Thus, in a forward biasing current is flow through the diode.

## Reverse biasing of a PN-junction:

When positive terminal of a battery is connected to the N-side and negative terminal is connected to the P-side of a PN junction, then PN junction is said to be reverse biased.

The reverse biasing of a PN junction is as shown in figure.

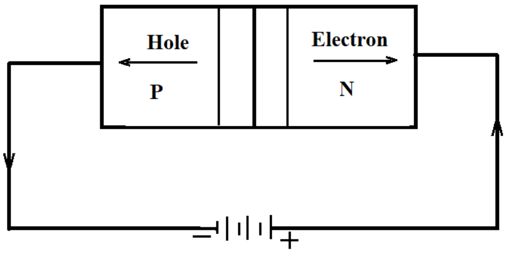
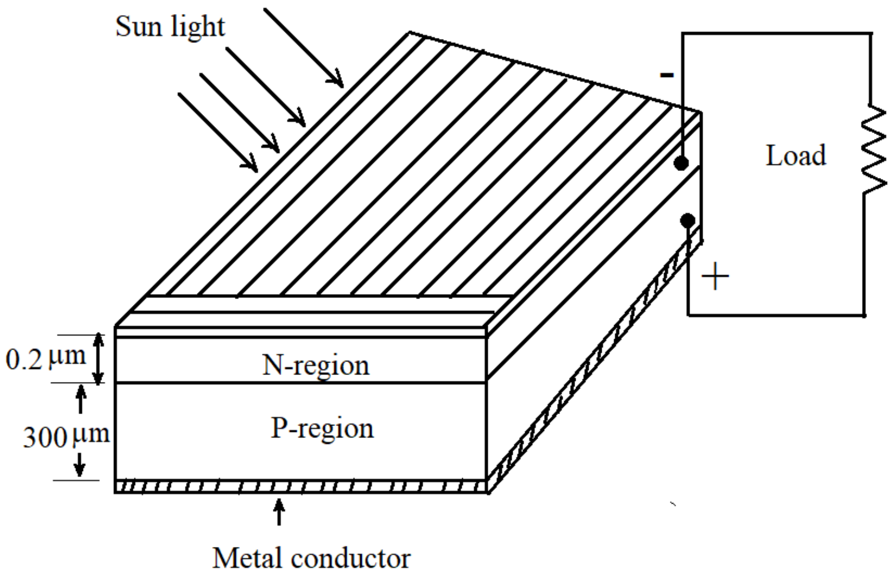



**Fig. Reverse biasing of P-N Junction**

In reverse biasing, the holes in the P-region and electrons in the N-region of the PN junction experiences attractive forces from the battery and drift away from the junction. This drift of holes and electrons away from the junction increases the width of the depletion region and also the junction potential barrier. Some of the holes in the P-region and electrons in the N-region have sufficient energy to overcome the junction potential and majority charge carrier current decreases. Since, the minority charge carrier current is constant, the resultant current flows across the junction from N-region to P-region. This current is known as reverse saturation current.

## Principle of a Photovoltaic Cell:



The PV cell (solar Cell) is a light sensitive, two terminals semiconducting PN junction made of semiconducting material such as silicon. A Solar cell has two layers called as N- type and P- type and two corresponding electrodes, negative and positive. N-type material is obtained by doping silicon crystal with pentavalent impurity and P- type material is obtained by doping silicon crystal with trivalent impurity.

The N-type layer is thin and transparent, the p-type layer is a thick. The junction of P-type and N-type material provides an inherent electric field which separates the charge created by the absorption of Sunlight. This PN junction is usually obtained by putting a P-type base material into a diffusion furnace containing a gases N-type dopant such as Phosphorus and allowing the N-type dopant to diffuse into the surface about 0.2 μm. The junction is formed slightly below the planar surface of the cell and light strikes perpendicular to the junction. The positive and negative charges created by the absorption of photons are encouraged to drift to the front and back of solar cell. The back is completely covered by a metallic contact to remove charges to the electric load. The collection of charges from the front of the cell is aided by a fine grid of narrow metallic pipes. The surface coverage of conducting collectors is typically about 5% in order to allow as much light as possible to reach the junction area. An anti-reflective coating is applied the top of the cell.

When sun light strikes the N-type thin layer some of the waves of light energy penetrate up to P-type layer. The energy from photons in the light waves is imparted to the molecules and atoms in PN junction resulting in liberation of electron-hole pairs. Electrons are released from N-type material and holes are created in P-type material.

When external electric circuit is completed by connecting electrodes to the load, the electrons flow in the closed external circuit from N-type terminal to P-type terminal. Direction of current is from positive terminal to negative terminal in external circuit.

Within the PN junction electron-hole pairs are continuously generated during the incidence of the sunlight. Energy from solar rays is captured by the solar cell and is converted directly to electrical energy.

**Generation of electron-hole pairs by Photon Absorption:**

Light is responsible for photovoltaic effect in a semiconductor. Light is composed of tiny bundles of energy called as photons which move at an extremely high but finite speed and the energy of photon known as photon energy is the product of its mass and square of its speed. When photon strikes an atom, they interact with the electrons and get absorbed. This added energy may drive off one of the atoms outer electrons. Depending on the number of photons and their energy, the number of electrons will be freed. Generally, it is assumed that all the light incident on a semiconductor having energy more than band gap get absorbed and converted into electron-hole pairs. If the semiconductor is thin, a number of photons may pass entirely through the semiconductor. The absorption of light in a semiconductor is a function of wavelength and is a related to the photon flux $f_0(\lambda)$ at a distance *x=0* in absorbing media by,

$$f(\lambda, x) = f_0(\lambda) \exp\left[-\alpha(\lambda)x\right]$$

Photon flux is measured in $mW/cm^2$ and $\alpha(\lambda)$ is absorption coefficient.

The intrinsic absorption of two types: direct and indirect absorption. The absorption process in a direct band gap semiconductor is as shown in figure (a).

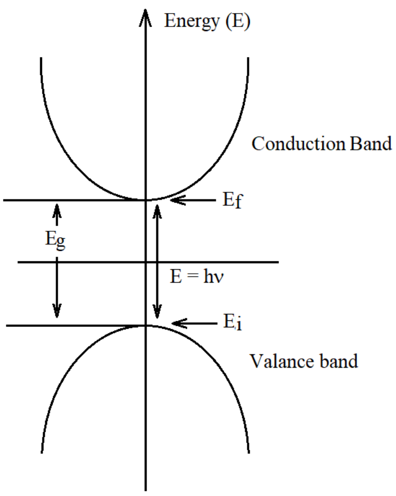



Fig. (a)

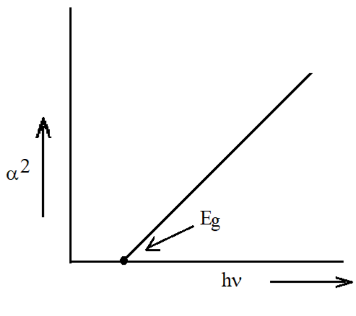



Fig. (b)

In this case, since the photon momentum is small compared to crystal momentum, the latter is conserved in the transition. The absorption starts at photon energy $E_g$=hν and electron is transferred vertically from valance to conduction band without change in momentum. The absorption coefficient near the minimum energy for absorption $E_g$ is given by,

$$\alpha = c(h\nu - E_g)^{1/2}$$

Where c is a constant

The absorption Coefficient for forbidden transitions is a

$$\alpha = c'(h\nu - E_g)^{1/2}$$

Where c′ is a function of energy.

A plot between the photon energy hν and $\alpha^2$ is a straight line for direct absorption as shown in figure (b). A cut on the abscissa gives the direct band gap of semiconductor material.

In an indirect gap semiconductor, the maximum energy in valence band and minimum energy in conduction band occur at different values of crystal momentum. As compared to photon, the photons have high momentum but low energy. In this case the minimum photon energy required to excite electron from valence band to conduction band is,

$$h\nu = E_g - E_p$$

where $E_p$ is the energy of absorbed photon of required momentum. In an indirect absorption, the absorption coefficient is low and the photon has to pass a reasonable distance before it is observed. The absorption Coefficient is

$$\alpha = \alpha_a + \alpha_e$$

Where $\alpha_a$ is due to photon absorption and becomes zero if $h\nu < (E_g - E_P)$ and second term is contribution due to photon emission and can be taken as zero if $h\nu < \left(E_g + E_P\right)$.

If a plot between the photon energy hν and $\alpha^2$ is made in case of indirect absorption, we get two straight line segment as shown in figure (c).

The upper line intercept $h\nu_2$ on photon energy axis corresponds to emission of photon while lower line intercept $h\nu_1$ corresponds to absorption of photon.

The indirect band $E_g$ and photon energy $E_p$ are given by,

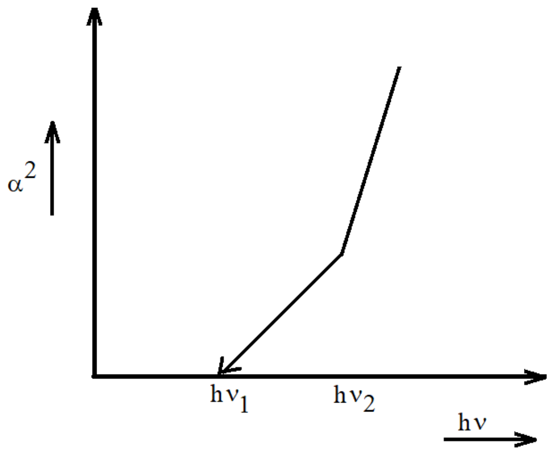


Fig. (c)

$$E_g = \frac{1}{2}(h\nu_1 + h\nu_2) \quad and\ E_p = \frac{1}{2}(h\nu_1 - h\nu_2)$$

The direct band gap is small in case of materials like CdS, GaAs, InP etc. while indirect band gap is small in case of Si and AlAs.

In case of indirect band gap material is used for solar cell, then a large material thickness will be required to absorb most of light and since large carriers are generated away from collecting junction, long minority diffusion lengths are required for the carriers to reach the junction before recombination. To absorb most of solar spectrum typical thickness in such indirect gap materials in the range of 20 to 50μm. While in case of a direct gap material the typical thickness absorbs most of solar spectrum can be 1 to 3μm. Therefore, in such a thin material, the homojunction should have very small area on the surface so that light can penetrate to the junction. Therefore, the direct band gap material homojunction shows higher surface recombination losses.

To overcome this heterojunction structure of larger band gap material is used on direct band gap absorbing material.

**V-I Characteristics of a Solar Cell:**

The circuit diagram to study V-I characteristics of solar cell as shown in figure (a). The sunlight is illuminated on solar cell. The voltage, current delivered by solar cell are influenced by conditions of sunlight, intensity, wavelength, angle of incidence etc. The voltmeter is connected in parallel to solar cell to measure voltage and milliammeter is connected in series with load resistance to measure current. The voltage and current are direct voltage and direct current measured in PV cell circuit during full sunlight.

When external load resistance R is very high (few mega ohms) the condition is called open circuit. The open circuit voltage $V_{oc}$ of a solar cell is about 0.5VDC. It is a maximum voltage across a PV-cell open circuit current is zero. External resistance R is very high in Mega-ohms range or infinity.

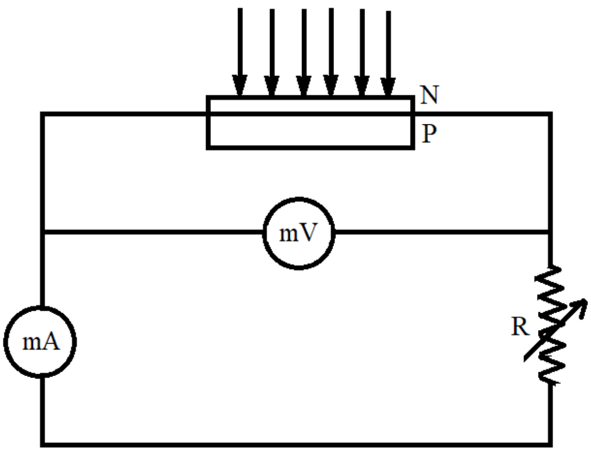


Fig (a)

If external resistance R is reduced gradually and readings of terminal voltage V and load current I are taken. Plot graph between V and I to get V-I characteristics of PV cells as shown in fig (b).

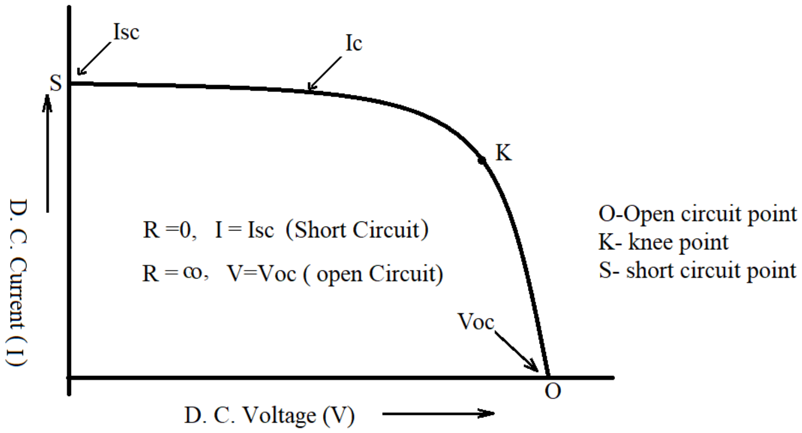


Fig. (b)

An external resistance is reduced from high value to low value, the terminal voltage of the cell falls and current increases. A steep characteristic 'OK' is obtained.

At knee point 'K' the characteristic under goes a smooth change and becomes flat for the position 'K-S'. When the external resistance is completely shorted, the short circuit $I_{sc}$ is obtained. The terminal voltage for the short circuit conditions is zero. Maximum current delivered by solar cell is $I_{sc}$. The current curve is almost flat between the knee point and short circuit. Hence a solar cell is called a constant current source with current output nearly equal to short circuit current.

Operating point voltage ($V_c$) is dictated by the external resistance (R) but current remain almost constant for the portion S-K.

For constant current $I_c$,

$$V_c = I_c.R$$

Solar cell delivers electrical power Pc is given by

$$P_c = V_c.I_c$$

Where $P_c$- is power of one cell.

$V_c$- is voltage at terminal of cell.

$I_c$- is current delivered by the cell.

For full incident light, a single PV cell delivers power Pc which varies with position of operating point $V_c$-$I_c$ characteristic.

Let n - No. of solar cells in a module

m -No. of modules in an array

Pc- power per solar cell

Therefore, power per modules = $nP_c$

Power per array =m×n×Pc

For full light, solar panel will deliver power Pc. With power Pc and external resistance (R), the voltage and current can be calculated.

$$P_p = V_p.I_p \qquad But\ V_p = I_pR$$

$$P_p = I_pR.I_p = I_p^2.R$$

$$P_p = V_p.I_p = V_p.\frac{V_p}{R} = \frac{{V_P}^2}{R}$$

## Electrical Storage:

### i) Basic Battery Theory:

A battery is defined as a combination of individual cells. A cell is the elemental combination of materials and electrolyte constituting the basic electro-chemical energy storage. A storage cell is one that can be recharged after discharge by passing a direct current through the cell in the opposite direction to the discharge current.

The chemical reaction takes place in the cell when it is charged and is reversed when the cell is discharged. Thus, in the charged cell, electrical energy is stored as chemical energy which can be recovered as the electrical energy when the cell is discharged.

There are two types of battery:

i) Primary batteries: It is non-chargeable. For example, dry cell, flashlight batteries. In primary batteries the chemical reactions are non-reversible.

ii) Secondary batteries: It is rechargeable. For example, lead acid battery. The chemical reactions are reversible in secondary batteries. Secondary batteries are used in solar electrics for electrical storage.

In a Storage battery, individual cells are connected in various ways to provide the desired power output. Since storage batteries are generally portable, they are common mobile sources of energy. A major use of in the starting-lighting Ignition (SLI) system of automobiles. Among the many other applications are those in the operation of mine locomotives, forklift trucks, golf carts, road vehicles and submarines and other underwater craft.

Storage batteries are expected to play an important role in energy resources conservation.

Among the potential uses are:-

i) storage of electrical energy produced from the solar energy and wind energy

ii) propulsion of road vehicles

iii) load levelling and peak saving in the electrical utilities.

A generalized cell consists of two electrodes called cathode and anode immersed in a suitable electrolyte. When an electrical load is connected between the electrode, charge separation occurs at the interface between one electrode and the electrolyte, feeding both an electron and ion. The electron flows through the external load and ion through the electrolyte recombining at another electrode. The polarity and magnitude of the cell terminal voltage is function of electrode materials, electrolyte, cell temperature and other factors.

In a Storage battery, individual cells are connected in various ways. Like all electrical cells, a storage cell has positive and negative electrodes. Individual cells may be connected in series with the positive electrode of each cell connected to negative electrode of adjacent cell. The total electromotive force or voltage of battery is sum of separate voltages. For example, six cells each with an emf of 2V are connected in series to provide a 12V output having total current drawn from the series of cells is same as that of each cell. Storage cells in a battery can also be combined in parallel, all the positive electrodes of individual cells are connected together and also all negative electrodes combined. The battery voltage is same as that of single Cottage but current is sum of currents supplied by individual cells. By combining appropriate number of cells in both series and parallel the battery can be delivered the desired voltage and current.

**Lead acid Battery:**

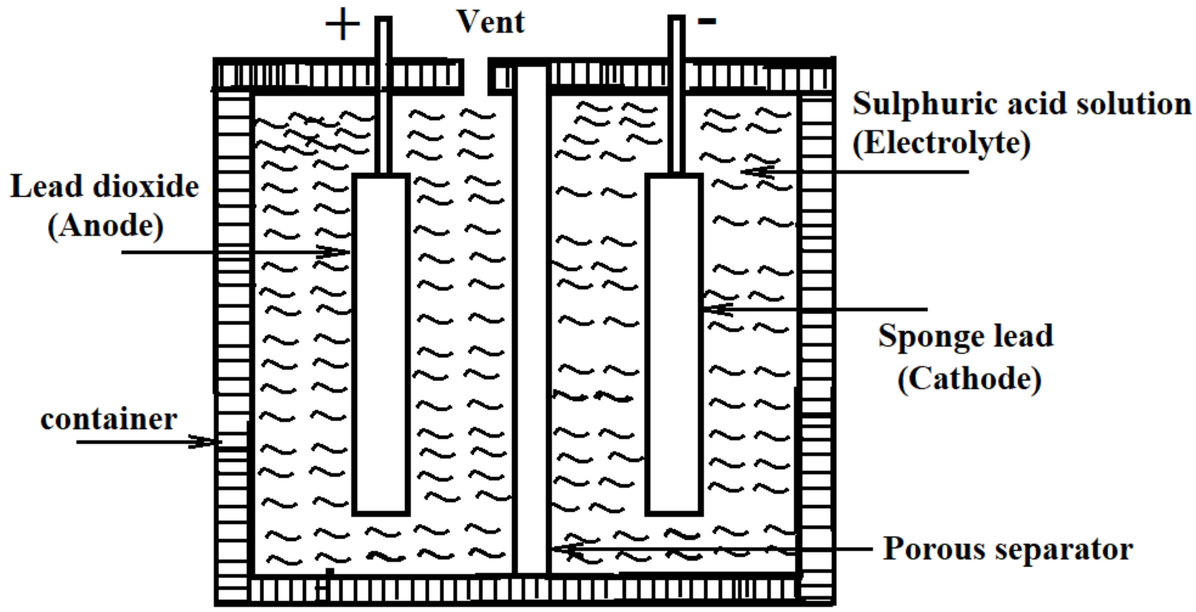



**Fig. Lead acid Battery cell**

The lead acid battery was the first practical storage battery, it is still, in spite of its defects, the one in widest use, especially for the SLI (Starting-lighting ignition) system of road automobiles and farm vehicles. The name arises from the chemical nature of the electrodes (lead) and electrolyte (acid) in which electrodes are immersed in the charged battery. The active material of the positive electrode is lead dioxide ($PbO_2$) acts as anode where as that of negative electrode is metallic lead (Pb) acts as cathode. The electrolyte is an aqueous solution of sulphuric acid.

When connected in a circuit, the cell sends a current from positive terminal to the negative terminal through the external circuit. Inside the cell current flows from negative terminal to positive terminal. Due to very small resistance, it gives sufficiently large current. While delivering the current, the cell gets slowly discharged.

When the cell is discharged, the active materials of both electrodes are converted into lead sulphate ($PbSo_4$). The process is reversed when the cell is charged, lead dioxide is regenerated at the positive electrode and lead at negative electrode. The net chemical reaction taking place upon discharging and charging the battery are as follows

$$\underset{(+)}{PbO_2} + \underset{(-)}{Pb} + 2H_2SO_4 \underset{\textbf{charging}}{\overset{\textbf{discharging}}{\rightleftharpoons}} \underset{(+)}{PbSO_4} + \underset{(-)}{PbSO_4} + 2H_2O$$

The (+) and (-) sign below the symbols refer to positive and negative electrodes respectively. The emf of a lead acid cell is independent of the amount of active material present on the electrode but it does depend on the concentration of sulfuric acid, the concentration is indicated by specific gravity of the electrolyte. In a fully charged cell, the specific gravity is about 1.26 to 1.28 at 25°C, the emf of a lead cell is then close to 2.1 volts. An increase or decrease in the specific gravity (i.e., acid concentration) is accompanied by an increase or decrease respectively in the emf.

When the lead acid cell is discharged sulfuric acid is consumed at both electrodes as the lead dioxide (+ve) and lead (-ve) are converted into lead sulphate. Further water ($H_2O$) which dilutes the acid, is produced in the discharge, this occurs at positive electrode. As a result, decrease in the acid concentration, the emf of lead acid cell decreases steadily as it is discharged. The cell is fully discharged when a specific gravity is about 1.08 at 25°C and emf is roughly 1.7V. Both acid concentration and emf are restored when the is charged.

The electrodes in a lead-acid cell are commonly in the form of plates upon which active materials are deposited. The amount of materials determine the energy storage capacity of the cell. In order to increase the storage capacity, it is necessary to increase amount of active material. However, for efficient utilisation of this material the plate must be thin. Hence storage capacity is increased by using the area of active material exposed to electrolyte. This is achieved by connecting in parallel combination of number of plates. A large area of accessible active materials can be obtained within a cell of reasonable size.

**Multiple Choice question:**

1. Solar energy can be directly converted to electrical energy using-

    **a) Photovoltaic cell**

    b) Photoelectric cell

    c) photodiode

    d) LED Cell

2. Nominal voltage rating of single photovoltaic cell is---

    **a) 0.5 to 0.6 V**
    b) 0.1 to 0.2 V
    c) 1.5 to 2.0 V
    d) 2 to 5 V

3. Output voltage of solar cell is in the form of---

    a) AC
    **b) DC**
    c) Both AC and DC
    d) None of these

4.Which element is used in solar cells?

a) Carbon

**b) silicon**

c) germanium

d) phosphorus

5. A solar cell is a ____________

a) P-type semiconductor

b) N-type semiconductor

c) Intrinsic semiconductor

**d) P-N Junction**

**6.** Several solar cells are connected in series to form a -------.

**a) string**

b) module

c) array

d) all of the above

7. Several strings are connected in parallel to form--------.

a) string
**b) module**
c) array
d) all of the above

8. At 0°K a semiconductor has a

**a) Completely filled valance band and empty conduction band**
b) partially filled valance band and empty conduction band
c) Completely filled valance band and partially conduction band
d) empty valance band and completely filled conduction band

9. In a semiconductor by shearing of electron ------ bonds are formed.

a) Ionic
b) Vander wall
c) metallic
**d) covalent**

10**.** When a trivalent impurity is added to a pure semiconductor, it becomes ………

a) An insulator

b) An intrinsic semiconductor

**c) p-type semiconductor**

d) n-type semiconductor

11. When a pentavalent impurity is added to a pure semiconductor, it becomes ………

a) An insulator

b) An intrinsic semiconductor

c) p-type semiconductor

**d) n-type semiconductor**

12. The majority charge carriers in P-type semiconductor is------

a) electrons

b) negative ions

**c) holes**

d) both electrons and holes

13. The majority charge carriers in n-type semiconductor is------

**a) electrons**

b) positive ions

c) holes

d) both electrons and holes

14. A hole in a semiconductor is defined as …………….

a) A free electron

**b) The incomplete part of an electron pair bond**

c) A free proton

d) A free proton

15. The battery connections required to forward bias a pn-junction are ……

**a) +ve terminal to p-type and –ve terminal to n-type**

b) -ve terminal to p-type and +ve terminal to n-type

c) -ve terminal to p-type and –ve terminal to n-type

d) +ve terminal to p-type and +ve terminal to n-type

16. The leakage current across a pn junction is due to …………..

**a) Minority charge carriers**

b) Majority charge carriers

c) Junction capacitance

d) None of these

17. What should be the band gap of the semiconductors to be used as solar cell materials?

a) 0.5 eV

b) 1 eV

**c) 1.5 eV**

d) 2.5 eV

18. Electrical power is the product of---

a) Voltage and resistance

**b) voltage and current**

c) current and resistance

d) voltage and potential

19. If n be number of solar cells in a module, m is number of modules in an array, P is power per solar cell then power per array is---

a) $n \times p/m$

b) $m \times n/p$

**c) $m \times n \times p$**

d) $m+n+p$

20. Primary batteries are-----

a) rechargeable

b) reversible

**c) non rechargeable**

d) both chargeable and rechargeable

21. When lead acid battery is discharged, the active materials of both electrodes are converted into

a) $Pb_2O_4$

b) Pb

**c) $PbSO_4$**

d) $PbO_2$

22. Active materials of a lead acid cell are

a) Spongy lead

b) Lead peroxide

c) Dilute $H_2SO_4$

**d) All of the above**

23. E.m.f of a fully charged lead acid cell—

a) 1V

**b) 2.1V**

c) 3V

d) 4V

24. The storage battery generally used in electric power station is-----

a) Nickel-cadmium battery

b) Zinc carbon battery

**c) Lead-acid battery**

d) None of the above

25. Active materials of a positive electrode are

a) $Pb_2O_4$

b) Pb

c) $PbSO_4$

**d) $PbO_2$**