UNIT III ENERGY SOURCES

PART A

1. **State critical mass.**
   Minimum mass of a lump of uranium-235 which will undergo fission in a chain reaction is called critical mass.
2. **What is meant by multiplication factor in a fission reaction?**
   The number of neutrons resulting from a single fission is called multiplication factor.
3. **What is a breeder reactor?**
   A fission reactor which produces more fissionable material than is consumed in its operation is called a breeder reactor.
4. **What is a nuclear chain reaction?**
   A process in which the products of the reaction assist in promoting the process itself such as in atomic fission is called a nuclear chain reaction.
5. **What is a battery?**
   A battery is a combination of electro-chemical cell connected in series. Any redox reaction occurring at an appropriate electrode can be employed to generate electricity in such cell.
6. **What are the advantages of alkaline battery than dry battery?**
   i. Zinc does not dissolve in basic medium
   ii. Life is longer than dry battery, because there is no corrosion on zinc.
   iii. Alkaline battery maintains its voltage (1.5V), as the current is drawn from it.
7. **How are anodic and cathodic electroactive materials made in Ni-Cd battery?**
   At anode: Cadmium is oxidized to Cd^{2+} and further it combines with OH^- ions and to form $Cd(OH)_2$
   At cathode: NiO_2 gains electrons and it undergoes reduction at the cathode from +4 to +2. Ni^{2+} ions combine with OH^- ions to form $Ni(OH)_2$
8. **Write the applications of solar cells.**

Solar energy is made use in the electrification of rural areas of tropical region where the sunlight is effective during daytime. Solar cells are useful in refrigerator, water heater, water pump and cooker.

9. **What are the characteristics of fuel cells?**
   i. They do not store chemical energy
   ii. The efficiency of a fuel cell is about twice that of a conventional power plant for generating electricity
   iii. Fuel cell generators are free of the noise, vibration, heat transfer, thermal pollution and other problems normally associated with conventional power plants

10. What are fissile and fertile nucleides?

Fissile materials: The materials which undergo fission by slow moving neutrons are called as fissile materials.

Examples: U-235, Pu-239, U-233, Pu-241.

Fertile materials: The materials which do not undergo fission easily but may be made by bombardment with fast moving neutrons are called as fertile materials.

PART B

1. Explain the essential parts of a light water nuclear reactor with neat diagram.

The arrangement or equipment used to carry out fission reaction under controlled conditions is called **nuclear reactor**. The energy released by the fission reaction in the nuclear reactor can be used to produce steam which can turn turbines and produce electricity.

The nuclear reactors in which ordinary water is used as moderator and coolant are called light water nuclear reactor. These reactors are cheaper and simpler and have excellent safety and stability when compared to other nuclear reactors.

COMPONENTS OF A NUCLEAR REACTOR

1. Fuel rods
2. Moderator
3. Control rods
4. Coolant
5. Protective screen
6. Heat exchanger / pressure vessel
7. Turbine

FUEL RODS:

The fissionable material used in the nuclear reactor is enriched U-235. It is used in the form of rods or strips.

Example: U^{235}, Pu^{239}

Function: It produces heat energy and neutrons, that neutron starts nuclear chain reaction.

CONTROL RODS:

To control the rate of fission of U-235 , movable rods made of Cd or B are suspended between fuel rods. These rods absorb the excess neutrons . So the fission reaction proceeds at steady rate. These rods are lowered and raised as of need.

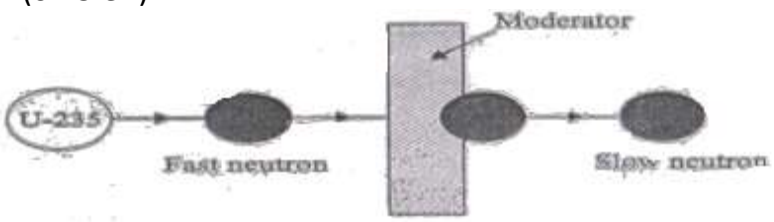
If the rods are deeply inserted inside the reactor, they will absorb more neutrons and the reaction becomes very slow. If the rods are pushed outwards, they will absorb less neutrons and the reaction will be very fast.

$$^{113}_{43}Cd + ^{1}_{0}n \rightarrow ^{114}_{43}Cd + \gamma$$
$$^{10}_{5}B + ^{1}_{0}n \rightarrow ^{11}_{5}B + \gamma$$

Example: Cadmium, Boron
Function: It controls the nuclear chain reaction and avoids the damage to the reactor.

MODERATOR:

The ordinary water used to slow down the neutrons.
Function: The kinetic energy of fast neutron (1meV) is reduced to slow neutrons (0.25 eV).



COOLANT:

In order to absorb the heat produced during fission reaction, the coolant is circulated in the reactor core. It enters the base and leaves at the top. The heat carried by outgoing liquid is used to produce steam.
Example: Water (act as coolant and moderator)
Function: It cools the fuel core.

PRESSURE VESSEL:

It encloses the core and also provides the entrance and exit passages for coolant. Function: It withstands the pressure as high as 200 atm.

PROTECTIVE SHIELD:

The moderator, control rods and fuel element are enclosed in a chamber which has a thick concrete shield(10m thick).

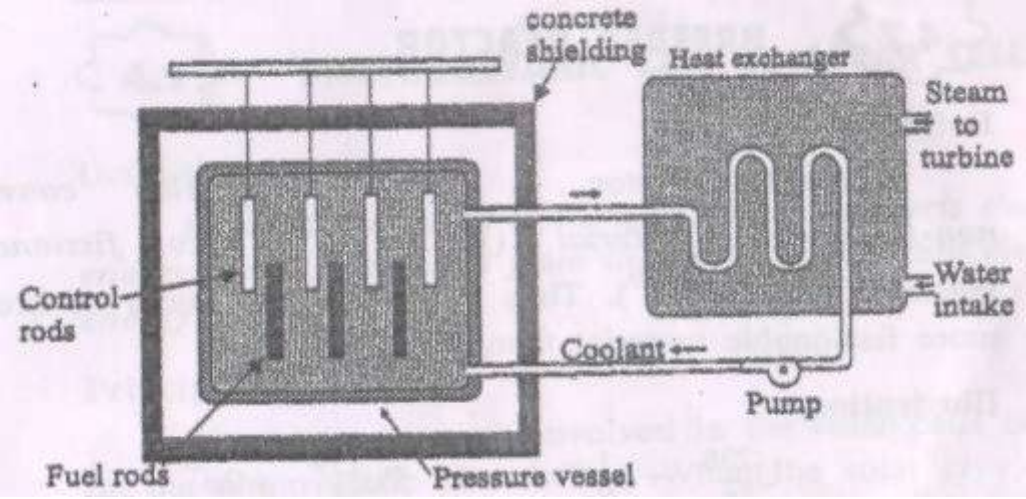
Function: The environment and the operating persons are protected from destruction in case of leakage of radiation.

HEAT EXCHANGER:

It transfers the heat liberated from the reactor core to boil water and produce steam at about 400Kg/cm2.

TURBINE:

The steam generated in the heat exchanger is used to operate a steam turbine, which drives a generator to produce electricity.



WORKING

The fission reaction is controlled by inserting or removing the control rods of B^{10} automatically from the spaces in between the fuel rods. The heat emitted is absorbed by the coolant (light water) .The heated coolant then goes to the heat exchanger containing sea water, which is converted to steam. The steam drives the turbines, generating electricity.

2(i) Write short notes on breeder reactor.

BREEDER REACTOR

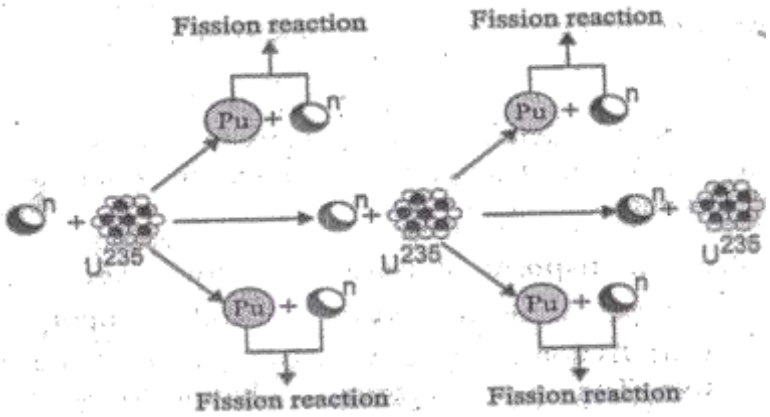
Breeder reactor is the one which converts non-fissionable material ($U^{235}Th^{232}$) Into fissionable material(U^{235}, Pu^{239}).

$$^{239}_{94}U + ^{1}_{0}n \rightarrow ^{239}_{94}Pu + 2e^{-}$$

$$^{239}_{94}PU + ^{1}_{0}n \rightarrow fission - products + 3^{1}_{0}n$$

In breeder reactor, of the three neutrons emitted in the fission of U-235, only one is used in propagating the fission of U-235.The other two are allowed to

react with U-238. Thus two fissionable atoms Pu-239 are produced for each atom of U-235 consumed. The breeder reactor produces more fissionable material than it uses.



In general

1. The fissionable nucleides such as U-235 and Pu-239 are called **fissile nucleides**.
2. The non-fissionable nucleides such as U-238 & Th-232 are called **fertile nucleides**.

(ii) Explain the characteristics of a) nuclear fission reactions b) nuclear fusion reactions

a) CHARACTERISTICS OF NUCLEAR FISSION REACTION

1. Heavy nucleus splits into two or more nuclei.
2. Two or more neutrons are produced by fission of each nucleus.
3. Large quantity of energy is produced during the nuclear fission reaction..
4. All the fission fragments are radioactive in nature, giving off gamma radiations
5. The atomic weights of nuclear fission product ranges from 70 to 160.
6. All the fission reactions are self propagating chain reaction because one of the fission products is neutron.
7. The nuclear reactions can be controlled by absorbing the neutrons using Cd, Boron.
8. Every secondary neutron released in the fission reaction does not strike the nucleus. Some escape into air. Hence a chain reaction cannot be maintained.
9. The number of neutrons resulting from a single fission is known as multiplication factor. When it is less than 1, nuclear chain reaction does not take place.

b) CHARACTERISTICS OF NUCLEAR FUSION REACTION

1. Unlike nuclear fission, there is no limit on the amount of nuclear fusion that can occur.

2. Nuclear fusion is possible only when the distance between the nuclei is of the order of one Fermi.
3. The amount of energy in fusion is four times more compared to that of fission.
4. Sufficient amount of kinetic energy must be provided to facilitate a fusion reaction.
5. As electrostatic repulsion increases with increase in atomic number of nucli, only lighter nuclei can undergo nuclear fusion reaction.

3 (i) What is reversible battery? Describe the construction and working of lead-acid battery with reaction occurring during charging and recharging.

LEAD ACID STORAGE BATTERY OR ACCUMULATOR

- It was invented by Gaston Plante in 1859.
- It acts both as voltaic cell and electrolytic cell. On supplying electrical energy, this acts as a voltaic cell. On recharging, the cell acts as an electrolytic cell**.**

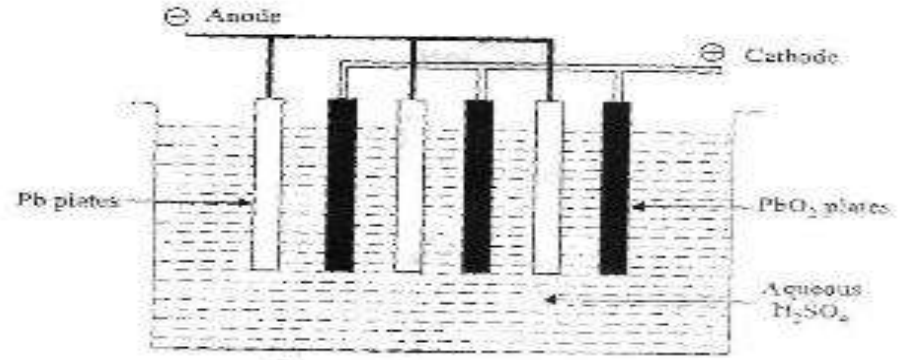


Fig. Lead storage cell

Description:

1. Anode – Lead
2. Cathode – PbO_2
3. Electrolyte - dil. H_2SO_4.
4. Insulator-rubber or glass fiber.
5. Cell representation- Pb /$PbSO_4$ // $H_2SO_{4(aq)}$ // / $PbSO_4$/ PbO_2
6. Anode reaction - $Pb+SO_4^{2-} \rightarrow PbSO_4 + 2e^-$ $\quad E^0anode = -0.36V$
7. Cathode reaction - $PbO_2 + 4H^+ + SO_4^{2-} + 2e^- \rightarrow PbSO_4+2H_2O$ $\quad E^0cathode = +1.69V$
8. The net reaction is $Pb_{(s)} + 2H_2SO_{4(aq)} + PbO_{2(s)} \rightarrow 2PbSO_4 + 2H_2O$

$$E^0cell = E^0cathode - E^0anode$$
$$= 1.69 - (-0.36) = 2.05V$$

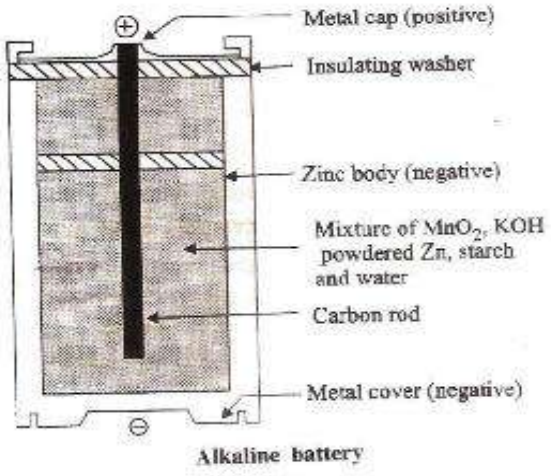
9. The cell develops an emf of 1 to 2 volts.
10. Uses:

1. It is used to supply current mainly in automobiles such as cars, Buses, trucks,etc
2. It is also used in gas engine ignition, telephone exchanges, hospitals, power stations.

(ii) Write a brief note on alkaline battery.

ALKALINE BATTERIES

1. Anode – Zinc powder
2. Cathode – Manganese dioxide
3. Electrolyte – KOH
4. Cell representation- Zn (s) /KOH (aq)/MnO_2(s)
5. Anode – reaction $Zn_{(s)} + 2OH^-_{(aq)} \rightarrow Zn(OH)_{2(s)} + 2e^-$
6. Cathode reaction $2MnO_{2(s)} + H_2O_{(l)} + 2e^- \rightarrow Mn_2O_{3(s)} + 2OH^-_{(aq)}$
7. The net reaction is $Zn_{(s)} + 2MnO_{2(s)} + H_2O_{(l)} \rightarrow Mn_2O_{3(s)} + Zn(OH)_{2(s)}$
8. The cell develops an emf of 1 volt to 1.5 volt



Alkaline battery

9. **ADVANTAGES:**

- ✓ It can deliver higher current **without** severe **voltage drop**.
- ✓ The **shelf life** of alkaline battery is 5-8 times **more** than Leclanche cell.
- ✓ Zn does not dissolve in alkaline medium readily.

10. USES: It is used in radios, tape recorders and electronic photographic flash units.

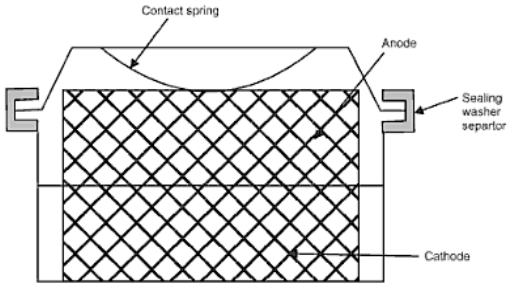
4 (i) Describe the construction and working of Ni-Cd battery with reaction occurring during charging and recharging.

Ni-Cd Battery

1. Anode – Cadmium
2. Cathode – A metal grid containing a paste of **NiO_2** acting as a cathode.
3. Electrolyte – KOH
4. Cell representation - $Cd_{(s)}$/ $Cd(OH)_2$// KOH// $Ni(OH)_2$/ $NiO_{2(s)}$
5. Anode reaction - $Cd_{(s)} + 2OH^- \rightarrow Cd(OH)_2 + 2e^-$
6. Cathode reaction - $NiO_2 + 2H_2O_{(l)} + 2e^- \rightarrow 2OH^- + Ni(OH)_2 + energy$
7. The net reaction (Discharging) is

$$Cd_{(s)} + NiO_2 + 2H_2O_{(l)} \rightarrow Cd(OH)_2 + Ni(OH)_2 + energy$$

8. Recharging: $Cd(OH)_2 + Ni(OH)_2 + energy \rightarrow Cd_{(s)} + NiO_2 + 2H_2O_{(l)}$
9. Diagram:



10. Advantages:
    - It is lighter and smaller.
    - It has longer life than lead storage cell.
    - Like a dry cell, it can be packed in a sealed container.

11. Disadvantages:
    It is more expensive than lead storage battery.
12. Uses: It is used in calculators, Electronic flash units, transistors and cordless appliances.

(ii) Write a brief note on lithium battery.

Lithium battery is a solid state battery because instead of liquid or paste electrolyte, solid electrolyte is used.

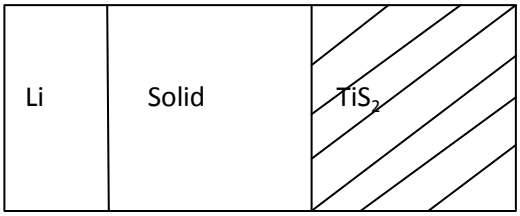
1. Anode – Lithium
2. Cathode – TiS_2
3. Electrolyte – Polymer solid electrolyte (permits the passage of ions but not electrons)
4. Cell representation- Li(s)// Polymer// TiS_2^-
5. Anode reaction - $Li(s) \rightarrow Li^+ + e^-$

6. Cathode reaction- $TiS_2 + e^- \rightarrow TiS_2^-$

7. The net reaction (Discharging) $Li(s) + TiS_2 \rightarrow Li^+ + TiS_2^-$

8. Capacity – 3V per cell

9. Applications- It is used in calculators, transistors, headphones, cordless appliances



Other types of secondary lithium batteries

(i) Li/ MnO_2
(ii) Li/V_2O_5
(iii) Li/MoO_2
(iv) Li/Cr_3O_8

Lithium battery is the cell of future, why?

1. Its cell voltage is high, 3.0V

2. Since Li is a light –weight metal, only 7g (1mole) material is required to produce 1 mole of electrons

3. Since it has the most negative E^0 value, it generates a higher voltage than the other types of cells.

4. Since all the constituents of the battery are solids, there is no risk of leakage from the battery.

5. This battery can be made in variety of sizes and shapes.

5(i) Write a brief note on hydrogen-oxygen fuel cell.

FUEL CELL

Definition:

A fuel cell is a device that converts a fuel and air directly into electricity, heat and water by means of electrochemical reactions.

Fuel + Oxygen → Oxidation products + Electricity.

Example:

Hydrogen – Oxygen fuel cell, Methyl alcohol oxygen fuel cell

Characteristics:

- In a fuel cell, the electricity can be generated as long as the fuel and oxygen are supplied into the cell.
- It consists of an electrolyte and two electrodes.
- In a fuel cell, a fuel is sent through the anode and the oxygen is supplied through the cathode. The electrolyte carries the charged particles from anode and to cathode and vice versa

Hydrogen – Oxygen Cell

1. Anode – Hydrogen gas
2. Cathode – Oxygen gas
3. Electrolyte - 25-40% KOH
4. Electrode- Two porous carbon electrodes impregnated with a finely divided platinum or nickel as catalyst.
5. Cell representation- H_2, C, Pt or Ni / KOH / C, Pt or Ni, O_2

6. Anode reaction $H_2 + 2OH^- \rightarrow 2H\ O_2 + 2e^-$

7. Cathode reaction $1/2O_2 + H_2O + 2e \rightarrow 2OH^-$

8. The net reaction is $H_2 + 1/2O_2 \rightarrow H_2O$

9. The cell develops an emf of 1.23V.
10. The efficiency of hydrogen-oxygen fuel cell is 70% .
11. The operating temperature is 60-70 °C.
12. The cell power output is 300 watts to 5 kilowatts.

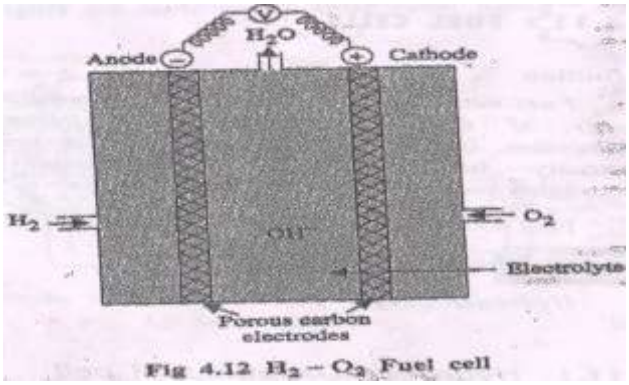


Fig 4.12 $H_2 - O_2$ Fuel cell

Advantages:

- ✓ It is highly reliable.
- ✓ It does not cause any pollution.
- ✓ It produces potable water.
- ✓ It is used in space vehicles, submarines.

14. **Applications:**

a. Used in Apollo spacecraft to produce electricity and water.
b. Used in military and other commercial vehicles of all types.

(ii) Describe the different types of nuclear reactor based on different criteria.

Classification of nuclear reactors

Nuclear reactors may be classified in different ways, based on type of neutron energy, fuel used, moderator and purpose.

I. Based on neutron energy and moderator

1. Thermal neutron reactors

In these reactors, nuclear fission reaction is brought out by slow moving (low energy) neutrons. These are further classified intro

(a) Light water moderated reactors (LWR)

In these reactors, ordinary water is used as moderator and coolant. These are cheaper and simpler and have excellent safety and stability when compared to other nuclear reactors. These are further classified into

I. Boiling water reactors (BWR)
II. Pressurized water reactors (PWR)
III. Supercritical water reactors (SWR)

(b) Heavy water moderated reactors

Here, heavy water is used as moderator.

(c) Graphic moderated reactors

Here, graphite is used as moderator.

2. Fast neutron reactors

In these reactors, nuclear fission reaction is brought out by unmoderated fast moving (high energy) neutrons. These are generally cooled by liquid metal

II. Based on fuel used

1. Natural fuel recactor

Natural uranium is used is as fuel and heavy water or graphite is used as moderator

2. Enriched uranium reactor

Uranium containing 5-10% U235 is used as fuel and ordinary water can be used as moderator

III. Based on purpose

Based on the purpose for which type of reactor is operated, these are further classified into

a) Power reactor
b) Breeder reactor
c) Materials testing reactor

IV. Based on coolant used

a) Water cooled reactors
Examples: Pressure water reactor; Boiling water reactor. Ordinary water or heavy water is used as coolants.

b) Gas cooled reactors
He, CO2,Air are used as coolants.

c) Liquid cooled reactors.
Example: Fast breeder reactor. Liquid metals such as Na, Bi, Pb are used as coolants

6 Give an account of a) wind energy b) solar cells c) nuclear fission reactions d) nuclear fusion reactions.

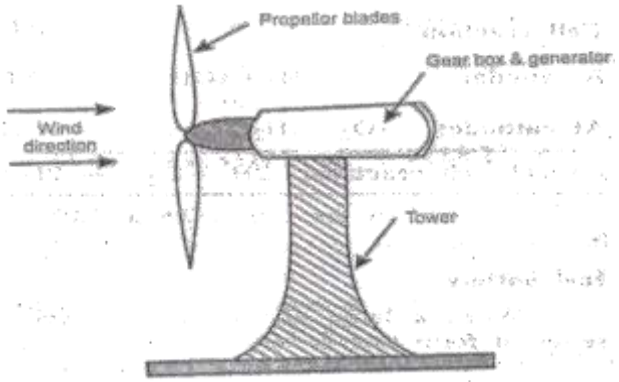
a) WIND ENERGY

Energy recovered from the force of the wind is called wind energy. The wind energy is harnessed by making use of wind mills.

WIND MILLS:

The strike of blowing wind on the blades of the wind mill makes it rotating continuously. The rotational motion of the blade drives a number of machines like water pump, flour mills and electric generators.

Nowadays windmill uses large sized propeller blades and connected to a generator through a shaft. Wind mills are capable of generating about 100kW electricity.



WIND FARMS:

When a large number of wind mills are installed and joined together in a definite pattern it forms a wind farm. The wind farms produce a large amount of electricity.

Condition: The minimum speed required for satisfactory working of a wind generator is 15Km/hr.

Advantages:

(i) It does not cause any pollution.
(ii) It is very cheap.
(iii) It is renewable.

Disadvantages:

1. Public resists for locating the wind forms in populated areas due to noise generated by the machines.

2. Wind forms located on the migratory routes of birds will hazards.

b) SOLAR CELLS

Photo conversion involves conversion of light energy directly in to electrical energy. Example: Photo galvanic cell or solar cell

PHOTOGALVANIC CELL

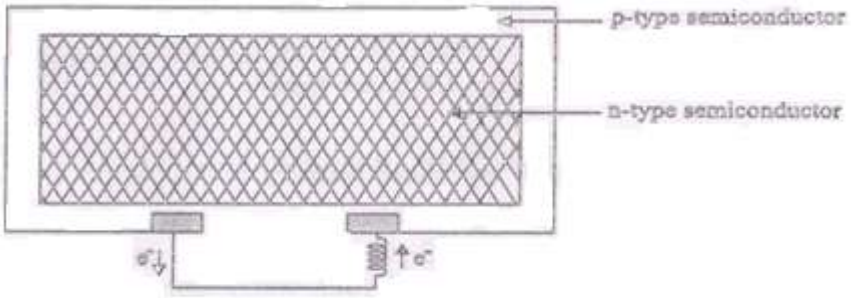
It is the one which converts the solar energy directly into electrical energy.

Principle:

The basic principle is based on the **photovoltaic effect**. When solar rays fall on a two layer of semiconductor devices, a potential difference between two layer is produced. This potential difference causes flow of electrons and produces electricity.

Construction:

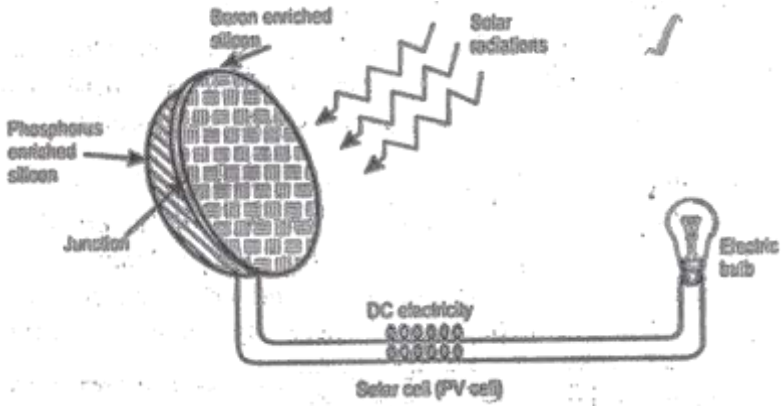
Solar cell consists of a p- type semiconductor (Si doped with B) and n-type semiconductor (Si doped with P). They are in close contact with each other.



Working:

When solar rays fall on p-type semiconductor, the electrons from the valence band get promoted to the conduction band and cross the p-n junction into n-type semiconductor. Thereby potential difference is produced which causes flow of electrons and hence current is generated.

Thus when this p and n layers are connected to an external circuit, electrons flow from n- layer to p-layer and hence current is generated.



APPLICATIONS OF SOLAR CELLS:

1. Lighting purpose.
2. Solar pumps can be run by solar battery.
3. Used in calculators, electronic watches, radios and TV.
4. Used to drive vehicles.
5. Used in space craft and satellites.

Advantages:

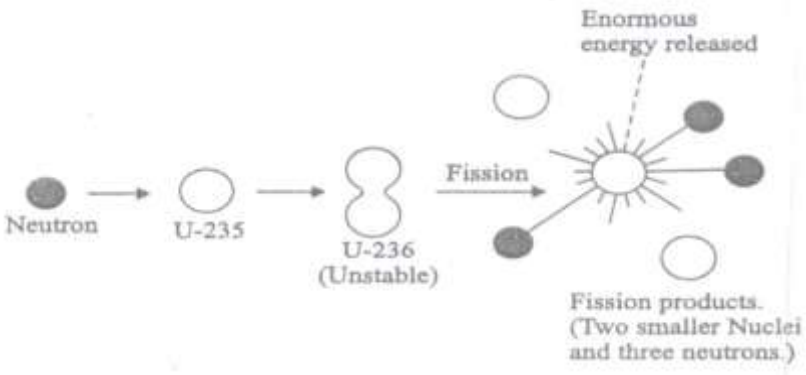
Solar cells are nonpolluting and eco-friendly.

c) NUCLEAR FISSION REACTIONS

Nuclear fission is defined as the process of splitting of heavier nucleus into two or more smaller nuclei with simultaneous liberation of large amount of energy.

Example:

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n$$



MECHANISM OF NUCLEAR FISSION

- When U-235 is bombarded by slow moving neutron, unstable U-236 is formed.

- This nucleus disintegrates into two equal nuclei with the release of huge amount of energy and few neutrons.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow \left[^{236}_{92}U\right] \rightarrow \begin{cases} \rightarrow ^{140}_{56}Ba + ^{93}_{36}Kr + 3^{1}_{0}n \\ \rightarrow ^{144}_{54}Xe + ^{90}_{38}Sr + 2^{1}_{0}n \\ \rightarrow ^{144}_{55}Cs + ^{90}_{37}Rb + 2^{1}_{0}n \end{cases}$$

d) NUCLEAR FUSION REACTIONS

The process of combination of lighter nuclei to form heavier nuclei, with simultaneous liberation of huge amount of energy is called as nuclear energy.

Example: Fusion reaction in sun

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{4}_{2}He + energy$$