# Module 1

***Introduction**: Energy source, India's production and reserves of commercial energy sources, need for non-conventional energy sources, energy alternatives, solar, thermal, photovoltaic. Water power, wind biomass, ocean temperature difference, tidal and waves, geothermal, tar sands and oil shale, nuclear (Brief descriptions); advantages and disadvantages, comparison (Qualitative and Quantitative).*

***Solar Radiation**: Extra-Terrestrial radiation, spectral distribution of extraterrestrial radiation, solar constant, solar radiation at the earth's surface, beam, diffuse and global radiation, solar radiation data.*

***Measurement of Solar Radiation**: Pyrometer, shading ring pyrheliometer, sunshine recorder, schematic diagrams and principle of working.*

## Contents

# 1 Introduction

The word 'energy' itself is derived from the Greek word 'en-ergon, which means 'in-work' or work content. The work output depends on the energy input. Energy is the most basic infrastructure input required for economic growth & development of a country. Thus, with an increase in the living standard of human beings, the energy consumption also accelerated.

A systemic study of various forms of energy & energy transformations is called energy science. While fossil fuels will be the main fuel for thermal power, there is a fear that they will get exhausted eventually in the next century. Therefore, other systems based on non-conventional & renewable sources are being tried by many countries. These are solid, wind, sea, geothermal & bio-mass

## 1.1 The need for alternatives:

1. The average rate of increase of oil production in the world is declining & a peak in production may be reached around 2015. There after the production will decline gradually & most of the oil reserves of the world are likely to be consumed by the end of the present century. The serious nature of this observation is apparent when one notes that oil provides about 30% of the world's need for energy from commercial sources & that oil is the fuel used in most of the world's transportation systems.
2. The production of natural gas is continuing to increase at a rate of about 4% every year. Unlike oil, there has been no significant slowdown in the rate of increase of production. Present indications are that a peak in gas production will come around 2025, about 10 years after the peak in oil production.
3. As oil & natural gas becomes scarcer, a great burden will fall on coal. It is likely that the production of coal will touch a maximum somewhere around 2050.
4. Finally, it should be noted that in addition to supplying energy, fossil fuels are used extensively as feedstock material for the manufacture of organic chemicals. As resources deplete, the need for using fossil fuels exclusively for such purposes may become greater.

# 2 India's production & reserves of commercial sources:

## 2.1 Coal:

Coal is the end product of a natural process of decomposition of vegetable matter buried in swamps & out of contact with oxygen for thousands of years. The word 'coal' denotes a wide variety of solid fuels. The varieties in approximate order of their formation are peat, lignite, bituminous and anthracite coal. The rate of production of coal in India over the last 50 years is shown in fig (a). It can be seen that there has been an eleven-fold increase in production from 1951 to 2004 & that the average annual growth rate has been about 4.5%. In 2000, India's production was 300mt, which was about 6.7% of the world's production. India has fairly large reserves of coal.

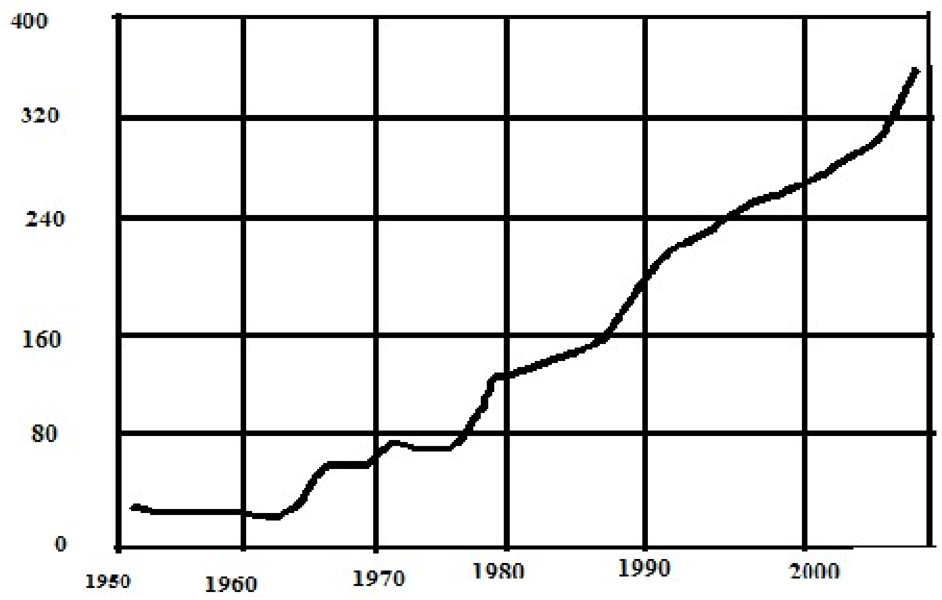



*Figure 1: Annual production of coal in India [production rate [Production Rate (Mt/Year) v/s Year]*

**Table 1: Coal reserves in India (in Mt)**

| Year | Proved reserves | Indicated & inferred reserves | Total reserves ( Resources) |
|---|---|---|---|
| 1972 | 21360 | 59590 | 80950 |
| 1981 | 27912 | 87490 | 115402 |
| 1985 | 35030 | 120870 | 155900 |
| 1992 | 64800 | 129000 | 193800 |
| 2006 | 95866 | 157435 | 253301 |

## 2.2 Oil:

Below fig.2. Represents presents data on the annual consumption of petroleum products in India (curve 3) from 1951 onwards. It also shows the variation in the domestic production of crude oil (curve 1) & the import of crude (curve 2) over the years.

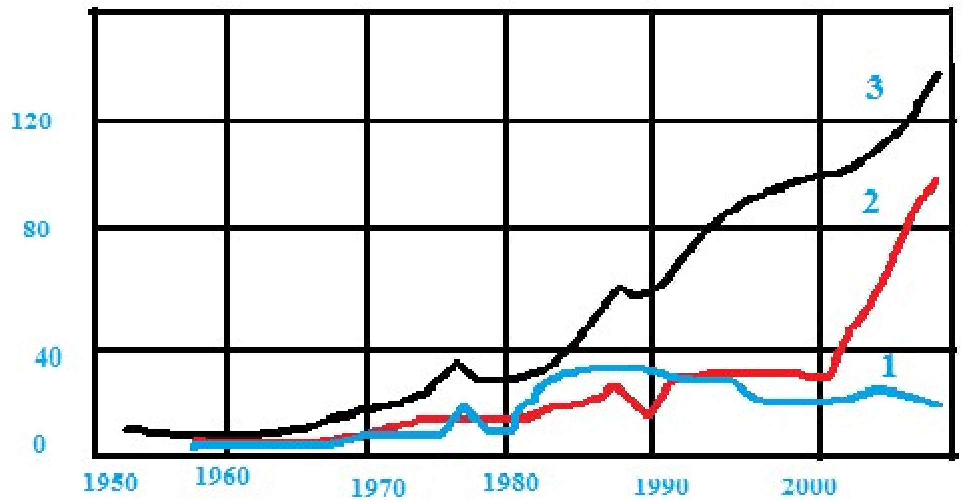



*Figure 2: Annual production, import & consumption of oil in India [Production Rate (Mt/Year) v/s Year]*

Curve 1. Domestic production of crude, Curve 2. Import of crude, Curve 3. Consumption of products

## 2.3 Natural gas:

presents data on the annual useful production of natural gas in India from 1969 onwards. In 1969, the production was only 0.516 billion $m^3$. It did not change much till 1973. However,

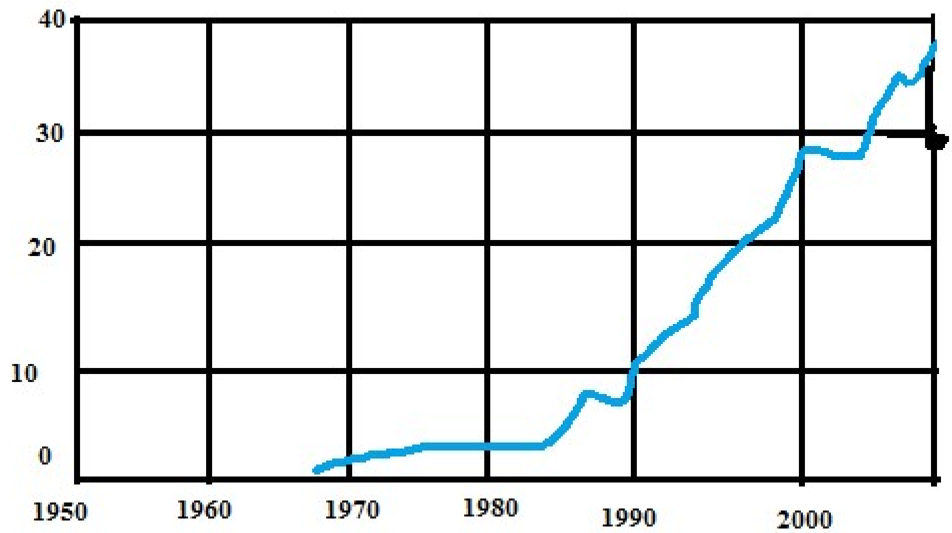



*Figure 3: Annual production of natural gas in India [Production rate (10^9 m^3/year v/s year*

subsequently, the production increased rapidly. It was 8.913 billion $m^3$ in 1989, 13.5% from 1989 to 1997 & 3.1% from 1997 to 2005.

## 2.4 Water –power:

It is one of the indirect ways in which solar energy is being used. Water- power is developed by allowing water to fall under the force of gravity. It is used almost exclusively for electric power generation. Data on the installed capacity of hydropower in India & the electricity produced from it from 1947 onwards is presented in below fig. 4.

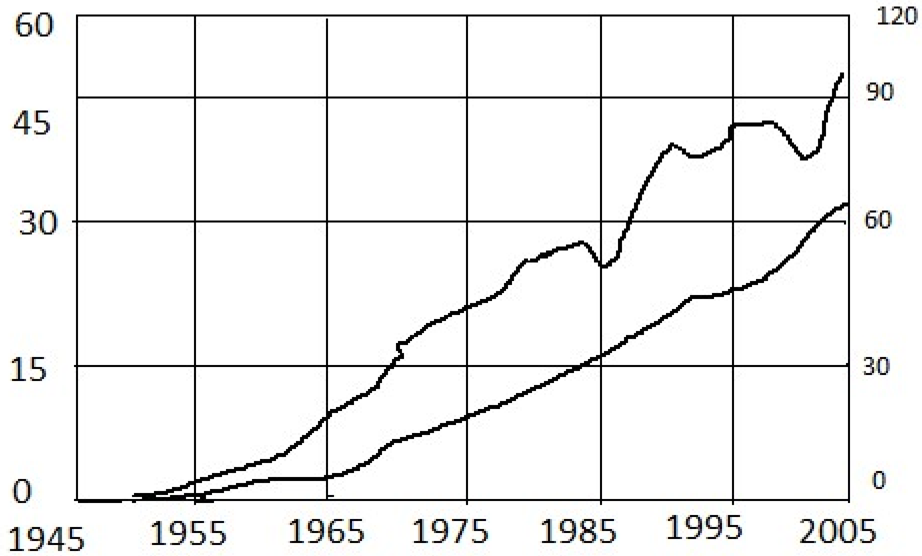



*Figure 4: installed capacity & electricity generation from water-power in India 10^3 GW*

## 2.5 Nuclear power:

Data on the electricity production from nuclear power is plotted below fig .5. It is seen that the electricity produced has been generally increasing over the years, as more units are getting commissioned. The higher amount, viz 19242 GWh was produced in 2002. The fall in certain years is because of some units being down for maintenance.

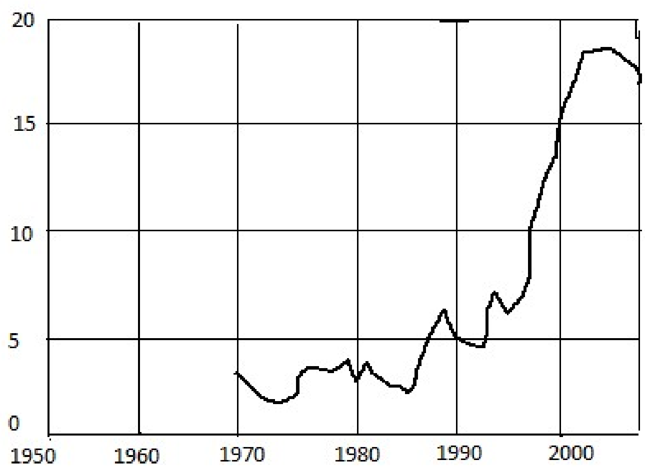



*Figure 5: Electricity produced from nuclear power in India in GW*

# 3 Classification of energy resources:

1. Based on the usability of energy:
    a. Primary resources: Resources available in nature in raw form is called primary energy resources. Ex: Fossil fuels (coal, oil & gas), uranium, hydro energy. These are also known as raw energy resources.
    b. Intermediate resources: This is obtained from primary energy resources by one or more steps of transformation & is used as a vehicle of energy.
    c. Secondary resources: The form of energy, which is finally supplied to consume for utilization. Ex: electrical energy, thermal energy (in the form of steam or hot water), chemical energy (in the form of hydrogen or fossil fuels). Some form of energy may be classified as both intermediate as well as secondary sources. Ex: electricity, hydrogen.
2. Based on traditional use:
    a. Conventional: energy resources that have been traditionally used for many decades. Ex: fossil fuels, nuclear & hydro resources
    b. Non-conventional: energy resources which are considered for large scale & renewable. Ex: solar, wind & bio-mass
3. Based on term availability:
    a. Non-renewable resources: resources that are finite, & do not get replenished after their consumption. Ex: fossil fuels, uranium
    b. Renewable resources: resources which are renewed by nature again & again & their supply are not affected by the rate of their consumption. Ex: solar, wind, bio-mass, ocean ( thermal, tidal & wave), geothermal, hydro
4. Based on commercial application:
    a. Commercial energy resources: the secondary useable energy forms such as electricity, petrol, and diesel are essential for commercial activities. The economy of a country depends on its ability to convert natural raw energy into commercial energy. Ex: coal, oil, gas, uranium, & hydro
    b. Non-commercial energy resources: the energy derived from nature & used – directly without passing through the commercial outlet. Ex: wood, animal dung cake, crop residue.
5. Based on origin :
    a. Fossil fuels energy f) bio-mass energy
    b. Nuclear energy g) geothermal energy

c. Hydro energy h) tidal energy
d. Solar energy i) ocean thermal energy
e. Wind energy j) ocean wave energy

# 4 Consumption trend of primary energy resources

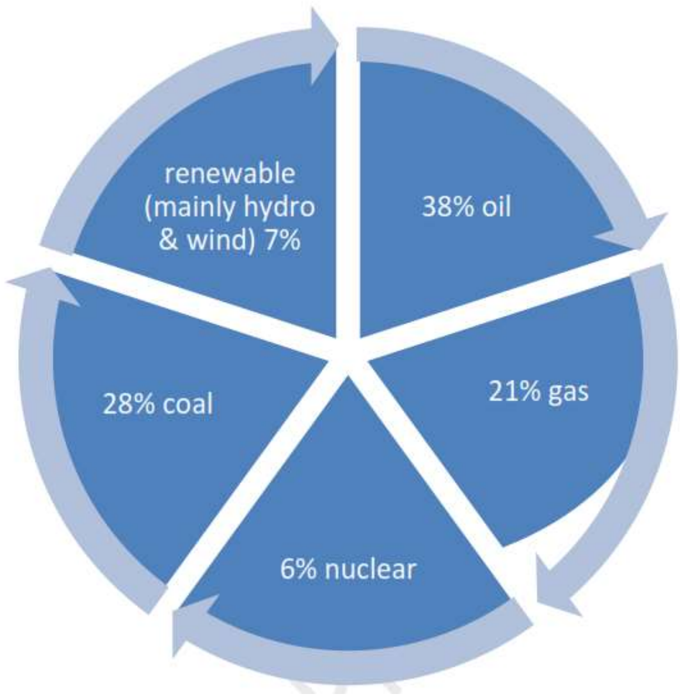



*Figure 6: percentage consumption of various primary energy resources*

The average % consumption trend of various primary energy resources of the world is indicated in the above fig, though the trend differs from country to country. Looking at figure the heavy dependence on fossil fuels stands out clearly. About 87% of the world's energy supply comes mainly from fossil fuels. The share of fossil fuels is more than 90% in case

of India.

# 5 Importance of Non-commercial energy resources:

The concern for environmental due to the ever-increasing use of fossil fuels & rapid depletion of these resources has led to the development of alternative sources of energy, which are renewable & environmental friendly. Following points may be mentioned in this

connection.

1. The demand of energy is increasing by leaps & bounds due to rapid industrialization & population growth, the conventional sources of energy will not be sufficient to meet the growing demand.

2. Conventional sources (fossil fuels, nuclear) also cause pollution; there by their use degrade the environment.
3. Conventional sources (except hydro) are non-renewable & bound to finish one day.
4. Large hydro-resources affect wild-life, cause deforestation & pose various social problems, due to construction of big dams.
5. Fossil fuels are also used as raw materials in the chemical industry (for chemicals, medicines, etc.,) & need to be conserved for future generations. Due to these reasons it has become important to explore & develop non-conventional energy resources to reduce too much dependence on conventional resources. However, the present trend development of nces indicates that these will serve as supplements rather than substitute for conventional sources for some more time to time.

## 5.1 Salient features of non-conventional energy resources

**Merits:**

1. NCES are available in nature, free of cost.

2. They cause no or very little pollution. Thus, by and large, they are environmental friendly.

3. They are inexhaustible.

4. They have low gestation period.

**Demerits:**

1) Though available freely in nature, the cost of harnessing energy from NCES is high, as in general, these are available in dilute forms of energy.

2) Uncertainty of availability: the energy flow depends on various natural phenomena beyond human control.

3) Difficulty in transporting this form of energy.

## 5.2 Advantages & disadvantages of conventional energy resources:

**ADVANTAGES:**

1) Coal: as present is cheap.

2) Security: by storing certain quantity, the energy availability can be ensured for a certain period.

3) Convenience: it is very convenient to use.

**DISADVANTAGES:**

1) Fossil fuels generate pollutants: CO, $CO_2$ NOX, SOX. Particulate matter & heat. The pollutants degrade the environment, pose health hazards & cause various other problems.

2) Coal: it is also valuable petro-chemical & used as source of raw material for chemical, pharmaceuticals & paints, industries, etc. From long term point of view, it is desirable to conserve coal for future needs.

3) Safety of nuclear plants: it is a controversial subject.

4) Hydro electrical plants are cleanest but large hydro reservoirs cause the following problems

a) As large land area submerges into water, which leads to deforestation

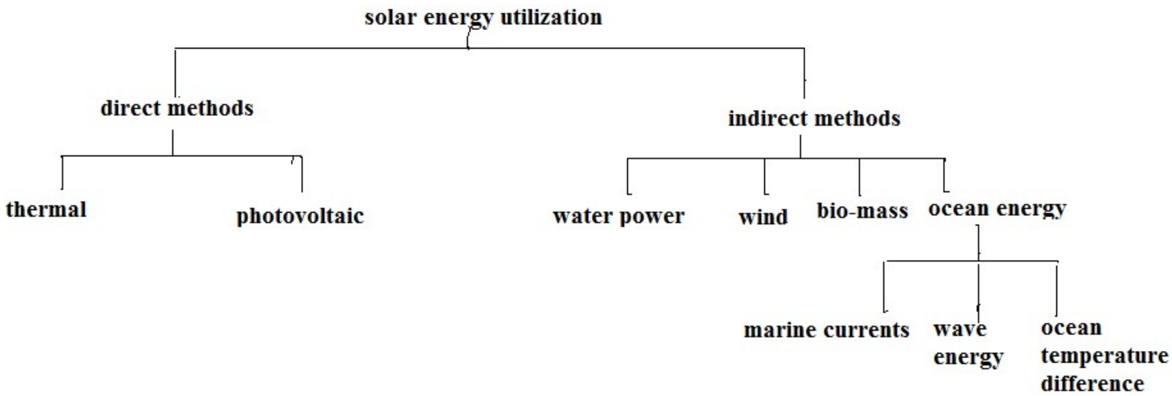
b) Causes ecological disturbances such as earthquakes

c) Causes dislocation of large population & consequently their rehabilitation problems.

# 6 Solar energy:

Solar energy is a very large, inexhaustible source of energy. The power from the Sun intercepted by the earth is approximately $1.8 \times 10^{11}$ MW which is many thousands of time larger than the present consumption rate on the earth of all commercial energy sources. Thus, in principle solar energy could supply all the present & future energy needs of the world on a continuing basis. This makes it one of the most promising of the unconventional energy sources. Solar energy is received in the form of radiation, can be converted directly or indirectly into other forms of energy, such as heat & electricity. This energy is radiated by the Sun as electromagnetic waves of which 99% have wave lengths in the range of 0.2 to 4 micro meters. Solar energy reaching the top of the Earth's atmosphere consists about 8% U.V radiation, 46% of visible light, 46% Infrared radiation.

## 6.1 Classification of methods for solar energy utilisation:




**Merits of solar energy:**

1. It is an environmental clean source of energy
2. It is free & available in adequate quantities in all most all parts of world where people live.

**Demerits of solar energy:**

1. It is a dilute source of energy because even in hottest region the radiation flux is available only 1 KW/m² & total radiation over a day is 7 KW/m². These are low values from the point of view of technological utilization.
2. It is required large collecting areas are required in many applications & these results increase of cost.

3. Solar energy availability varies widely with time, it occurs because of the day-night cycle & also seasonally because of the Earth's orbit around the Sun [even local weather condition].

**Solar applications:**

✓ Solar heating

✓ Solar cooling

✓ Solar pumping

✓ Solar furnace

✓ Solar production of hydrogen

✓ Solar green houses

✓ Solar distillation

✓ Solar energy

✓ Solar cooking

## 6.2 Thermal Energy:

Thermal energy refers to the internal energy present in a system in a state of thermodynamic equilibrium by virtue of its temperature. The average transitional kinetic energy possessed by free particles in a system of free particles in thermodynamic equilibrium. This energy comes from the temperature of matter.

Thermal energy is the total energy of all the molecules in an object. The thermal energy of an object depends on the 3 things:

1. The number of the molecules in the object

2. The temperature of the object (average molecular motion)

3. The arrangement of the object molecules (states of matter)

**There are 3 modes of thermal energy**

1. Conduction, 2. convection, 3. radiation

1. **Conduction**: Heat is transferred from one molecule to another without the movement of matter.

2. **Convection**: Fluids (liquids & gases) transfer heat by convection, a process that causes mixing of the warmer regions with the cooler regions of liquid or gas.

The main difference between convection & conduction is that convection involves the movement of matter & conduction does not.

3. **Radiation**: it is the transfer of energy by electromagnetic waves.

**ADVANTAGES**:

1. It is eco friendly
2. Renewable sources
3. No/less pollution
4. By using this produce electricity
5. Its help full for oil refining in Industry & home heating

**DISADVANTAGES**:

1. Producing greenhouse gas
2. Collecting of energy is a big problem, it requires sophisticated technology hence cost is more.

**Applications**:

1. Steam engine
2. Gasoline engine

## 6.3 Photovoltaic (PV) or Solar Cell:

It is a device that converts solar energy into electric current using the photoelectric effect. The first PV was introduced by Charles Frilt in the 1880's. In 1931 a German engg Dr.Bruno Lange developed PV by using Silver Solenoid in place of Copper oxide. Photovoltaic power generation employs solar panels, composed of number of solar cells containing photovoltaic material. Photovoltaics are made up of semiconductors & it converts solar radiation into direct current electricity.

Photovoltaic system consists of

a) Solar cell array, b) load leveler, c) storage system, d) tracking system (where necessary)

**Working Principle:**

PV's are made up of semiconductors that generate electricity when they absorb light. As photons are received, free electrical charges are generated that can be collected on contacts applied to the surface of the semiconductors. Because of solar cells are not heat engines, & therefore, do not need to operate at higher temperature, they are adapted to the weak energy flux of solar radiation, operating at room temperature.

**Advantages:**

1. Compare to fossil fuels nuclear energy sources, very little research money has been invested in the development of solar cells.
2. It gives long duration period (operation)
3. Operating costs are extremely low compared to existing power technologies.

**Applications:**

1. Space craft (silicon solar cell)
2. It can be applicable to either small or large power plants
3. These solar cells are used to operate irrigation pumps, navigational signals, highway emergency call systems, rail road crossing warnings & automatic metrological station.

## 6.4 Water power (hydro power):

Power derived from the energy of falling water & running water, which may be harnessed for useful purposes. In ancient years hydropower has been used for Irrigation & the operation of various mechanical devices such as water mills, saw mills, textile mills, domestic lifts, power house & paint making.

**How the generator works:** A hydraulic turbine converts the energy of flowing water into mechanical energy. A hydro-electric generator converts this mechanical energy into electricity. The operation of generator is based on the principle discovered by Faraday. He found that when a magnet is moved past a conductor it causes electricity to flow.

In large generator electro magnets are made by circulating d.c through loops of wire wound around stacks of magnetic steel laminations. These are called field poles & are mounted on the perimeter of the rotor. The rotor is attached to the turbine shaft & rotates at a fixed speed. When rotor turns, it causes the field poles (electromagnetic) to move past the conductors mounted in the stator. This is turn causes electricity to flow & a voltage to develop at the generation output terminals.

**Classification of hydro power:**

1. Conventional hydroelectric, referring hydroelectric dams
2. Run of the river hydroelectricity, which captures the kinetic energy in rivers or streams without use of dams.
3. Small hydro projects are 10 MW or less & often have no artificial reservoirs.
4. Micro hydro projects a few KW to a few hundred KW isolated homes, villages or small industries.

The power available from falling water can be calculated from the flow rate & density of water, the height of fall & the local acceleration due to gravity

**$P=\eta\rho Qgh$**

Where, P – Power in Watts

$\eta$- dimension less efficiency of the turbine

$\rho$ –density of water in $Kg/m^3$

Q- Flow in $m^3/sec$

g- Acceleration due to gravity

h- Height difference between inlet & outlet

## 6.5 Wind energy:

Energy of wind can be economically used for the generation of electricity. Winds are caused from 2 main factors:

1. Heating & cooling of the atmosphere which generates convection currents. Heating is caused by the absorption of solar energy on the Earth's surface & in the atmosphere.

2. The rotation of the Earth with respect to atmosphere & its motion around the sun

The energy available in the wind over the Earth's surface is estimated to be $1.6\times10^7$ MW In India, high wind speeds are obtainable in coastal areas of Saurashtra, Western Rajasthan & some parts of Central India. Wind energy which is an indirect source of solar energy conversion can be utilized to run wind mill, which in turn drives a generator to produce electricity. The combination of wind turbine & generator is sometimes referred as an AERO-GENERATOR. A step-up transmission is usually required to match the relatively slow speed of the wind rotor to the higher speed of an electric generator. Data quoted by some scientists that for India wind speed value lies between 5 Km/hr to 15-20 Km/hr Wind forms are operating successfully & have already fed over 150 lakh units of electricity to the respective state grids. Wind speed increases with height.

**The power in wind:**

Wind possesses energy by virtue of its motion. There are 3 factors determine the output from a wind energy converter,

1. The wind speed,
2. The cross section of wind swept by rotor &
3. The overall conversion efficiency of the rotor, transmission system & generator or pump.

Only 1/3rd amount of air is decelerating by the rotors & 60% of the available energy in wind into mechanical energy. Well-designed blades will typically extract 70% of the theoretical max, but losses incurred in the gear box, transmission system & generator or pump could decrease overall wind turbine efficiency to 35% or loss. The power in the wind can be computed by using the concept of kinetics. The wind mill works on the principle of converting kinetic energy of the wind to mechanical energy.

Kinetic energy = k.E= $\frac{1}{2} mv^2$

But $m = \boldsymbol{\rho} Av$

Available wind Power = $\mathbf{P_a = 1/8\ \rho \pi D^2 V^3}$ ......Watts

**Major factors that have led to accelerated development of the wind power are as follows:**

1. Availability of high strength fiber composites for constructing large low-cost rotor blades.
2. Falling prices of power electronics
3. Variable speed operation of electrical generators to capture maximum energy
4. Improved plant operation, pushing the availability up to 95%
5. Economy of scale, as the turbines & plants are getting larger in size.
6. Accumulated field experience (the learning curve effect) improving the capacity factor.
7. Short energy payback ( or energy recovery) period of about year,

**Power coefficient:**

The fraction of the free flow wind power that can be extracted by a rotor is called the power coefficient.

$$\text{Power coefficient} = \frac{\textit{power of wind rotor}}{\textit{power available in the wind}}$$

The max theoretical power coefficient is equal to 16/27or 0.593.

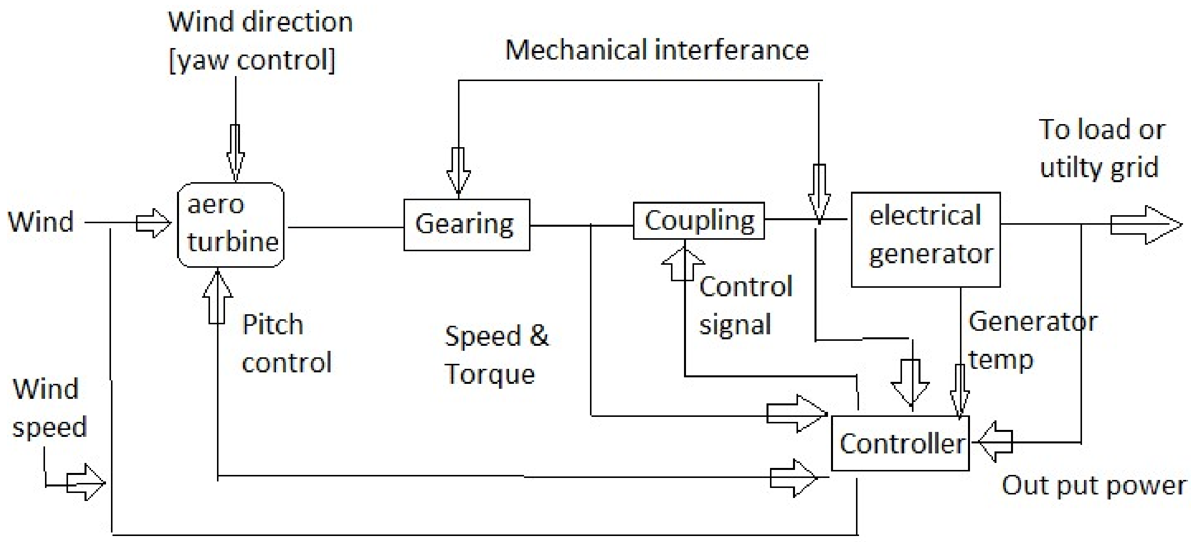



*Figure 7: Basic components of wind electric system*

**Applications:**

A] Applications require mechanical power

i] Wind power, ii] Heating, iii] Sea transport

B] As of grid electrical power source

**Types of wind turbines:**

1] Horizontal axis wind turbines

2] Vertical axis wind turbines

## 6.6 Bio mass:

Bio-mass means organic matter. The energy obtained from organic matter, derived from biological organisms (plants & animals) is known as bio-mass energy. The average efficiency of photosynthesis conversion of solar energy into bio mass energy is estimated to be 0.5% - 1.0%. To use biomass energy, the initial biomass maybe transformed by chemical or biological processes to produce intermediate bio-fuels such as methane, producer gas, ethanol & charcoal etc. It is estimated that the biomass, which is 90% n tress, is equivalent to the proven current extractable fossil fuel reserves in the world. The dry matter mass of biological material cycling in biosphere is about $250 \times 10^9$ tons/Y. Animals feed on plants, & plants grow through the photosynthesis process using solar energy. Thus, photosynthesis process is primarily responsible for the generation of bio mass energy. In simplest form the reaction is the process of photosynthesis in the presence of solar radiation, can be represented as follows

$$H_2O + CO_2 \xrightarrow{\text{Solar energy}} CH_2O + O_2$$

In the reaction, water & carbon dioxide are converted into organic material i.e., $CH_2O$, which is the basic molecule of forming carbohydrate stable at low temperature, it breaks at high temperature, releasing an amount of heat equal to 112,000 Kcal/mole (469 KJ/mole).

$$CH_2O + O_2 \longrightarrow CO_2 + H_2O + 112 \text{ Kcal/mole}$$

The biomass energy is used directly by burning or is further processed to produce more convenient liquid & gaseous fuels.

**Bio-mass resources fall into three categories:**

1. bio-mass in its traditional sold mass (wood & agricultural residue), &
2. bio-mass in non-traditional form (converted into liquid fuels)
    a. The first category is to burn the bio-mass directly & get the energy.
    b. In the second category, the bio-mass is converted into ethanol & methanol to be used as liquid fuels in engines.
3. The 3rd category is to ferment the biomass an aerobically to obtain a gaseous fuel called bio- gas (bio-gas contains 55to 65% Methane, 30-40% $CO_2$ & rest impurities i.e., $H_2$, $H_2S$, & some $N_2$).

**Bio-mass resources include the following:**

1] Concentrated waste- - municipal solids, sewage wood products, industrial waste, and manure of large lots.

2] Dispersed waste residue—crop residue, legging residue, disposed manure.

3] Harvested bio-mass, standby bio-mass, bio-mass energy plantation.

**ADVANTAGES:**

1] It is renewable source.

2] The energy storage is an in-built feature of it.

3] It is an indigenous source requiring little or no foreign exchange.

4] The forestry & agricultural industries that supply feed stocks also provide substantial economic development opportunities in rural areas.

5] The pollutant emissions from combustion of biomass are usually lower than fossil fuels.

**DISADVANTAGES:**

1] It is dispersed & land intensive source.

2] Low energy density

3] Labour intensive & the cost of collecting large quantities for commercial applications are significant.

**Bio-mass conversion technologies:**

A] Incineration,

B] Thermo-chemical,

C] Bio-chemical

i] Ethanol fermentation, ii] Anaerobic fermentation.

## 6.7 Tidal energy:

The tides in the sea are the result of the universal gravitational effect of heavenly bodies like SUN & MOON on the Earth.

Periodic rise & fall of the water level of sea is called TIDE. These tides can be used to produce electrical power which is known as tidal power.  When the water is above the mean sea level called flood tide. When the water is below the mean sea level called ebb tide

**Basic principle of tidal power**:

Tides are produced mainly by the gravitational attraction to the moon & the sun on the water of solid earth & the oceans. About 70% of the tide producing force due to the moon & 30% to the sun. The moon is thus the major factor in the tide formation. Surface water is pulled away from the earth on the side facing the moon & at the same time the solid earth is pulled away from the water on the opposite side. Thus, high tides occur in these two areas with low tides at intermediate points. As the earth rotates, the position of a given area relative to the moon changes, & so also do the tides. The difference between high & low water level is called the range of the tide.

**Limitations of tidal energy:**

1) Economic recovery of energy from tides is feasible only at those sites where energy is concentrated in the form of tidal range of about 5m or more, & geography provide a favourable site for economic construction of tidal plant, thus it is site specific.

2) Due to mis-match of lunar driven period of 12 hrs 25 min & human (solar) period of 24 hrs, the optimum tidal power generation is not in phase with demand,

3) Changing tidal range in 2 weeks period produces changing power,

4) The turbines are required to operate at variable head.

5) Requirement of large water volume flow at low head necessitates parallel operation of many times &

6) Tidal plant disrupts marine life at the location & can cause potential harm to ecology.

- To hardness the tides, a dam would be built, across the mouth of the bay. It will have large gates in it & also low head hydraulic reversible turbines are installed in it. The constructed basin is filled during high tide & emptied during low tide passing thorough sluices turbine respectively.
- By using reversible water turbine, turbine can run continuously, both during high & low tide.
- The turbine is coupled to generator, potential energy of the water stored in the basin as well as energy during high tide, is used to drive the turbine, which is couple d to generator, generate electricity.
- Above arrangement of harnessing tidal energy called single basin plant. The plant continues generate power till the tide reaches, its lower level.
- By using bypass valve to drain the remaining basin water to sea.
- Single basin plant cannot generate power continuously.
- The potential in ocean tides resource is estimated as 550 billion KWh/year [120,000 MW power.]

## 6.8 Waves energy:

Waves are caused by the transfer of energy from surface winds to sea. The rate of energy transfer depends upon the wind speed & the distance over which interacts with water. The energy flux in waves is more than that available from solar, wind & other renewable sources. The power in the waves is proportional to the square if its amplitude & to the period of its motion. The energy stored is dissipated through friction at shore & turbulence at rates depending on characteristics of wave & water depth. Wave energy in open oceans is likely to be inaccessible. The resource potential near coastlines is estimated as in excess of 20, 00,000 MW. Wave power is usually expressed in KW/m, repressing the rate at which energy is transferred across a line of 1 m length parallel to the wave front.

**ADVANTAGES**:

1. The availability of large energy fluxes
2. Productivity of wave conditions over periods of days,

**DIFFICULTIES**:

1. Irregularity of wave patterns in amplitude, phase & direction, which makes it difficult to extract power efficiently
2. The power extraction system is exposed to occasional extreme stormy conditions.
3. Peak power of deep water waves is available in open sea, where is difficult to construct, operate & maintain a system & transmit power to the store,
4. The slow & irregular motion of wave is required to be coupled to be electrical generator requiring high & constant speed motion.

## 6.9 Geothermal energy:

Geothermal energy is energy coming out of the molten interior (in the form of heat) of the earth towards the surface. Volcanoes, Geysers, Hot springs & boiling mud pots are visible evidence of the great reservoirs of heat that lies within the earth. Most Geothermal energy produces low grade heat at about 50-70˚cwhich can be used directly for thermal applications. Occasionally, geothermal heat is available at temperature about 90˚c & so electrical power production from turbines can be contemplated. Because of non-homogeneous in the earth crust, there are numerous local hot spots just below the surface where the temperature is in fact much higher than the average value expected. Ground water comes into contact with the hot rocks in some of those locations & as a result, dry steam wet & hot water or hot water alone is formed. A well drilled to these locations causes the steam/water to emerge at the surface where its energy can be utilised either for generating electricity or for space heating.

The earth's heat content is about $10^{31}$ J. This heat naturally flows to the surface by conduction at a rate of 44.2 Tetra watts. The heat inside the earth is intense enough to melt rocks. Those molten rocks are called Magma. Because magma is less dense than the rocks so it rises to the surface. Sometimes magma escapes through cracks in the earth's crust, emptying out of volcanoes as part of lava. But most of the time magma stays beneath the surface, heating surrounding rocks & the water that has become trapped within these rocks. Sometimes that water escapes through cracks in the earth to form pools of hot water [hot springs] or burst of hot water & steam [geysers]. The rest of the heated water remains in pools under the earth's surface is called geothermal reservoirs.

**Types of geothermal reservoirs:**

a] Dry steam power plant, b] Flash steam power plant, c] Binary cycle power plant.

**ADVANTAGES:**

1. It is reliable source of energy
2. It is available 24 hours/day
3. It is available is independent of weather
4. It has an inherent storage future, so no extra storage facility is required
5. Geo thermal plants require little land area.

**DISADVANTAGES:**

1. Generally, energy is available as low-grade heat
2. Continuous extraction of heated ground water may lead to subsidence [setting or slumping of land]
3. Geo thermal fluid also brings with it the dissolved gases & solute [as high as 25 Kg/$m^3$] which leads to air & land pollution.
4. Drilling operation leads to noise pollution
5. Thermal energy cannot be distributed easily over long distances [longer than 30 Km]
6. Corrosive & abrasive geo thermal fluid reduces the life of plants.

**Applications:**

1] Direct heat use, 2] Electric power generation.

## 6.10 Tar sands:

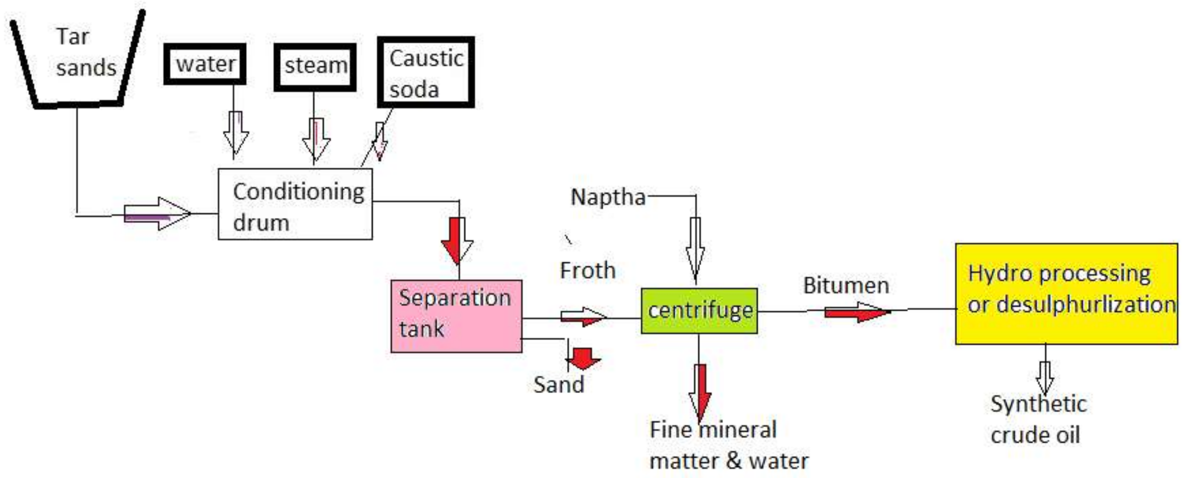



*Figure 8: production of synthetic crude oil from tar sands*

Tar sand or oil sands is an expression used to describe porous sandstone deposits impregnated with heavy viscous oils called bitumen or simply deposits of heavy oils. The above schematic diagram indicating the processes involved in producing synthetic crude oil from tar sands made up of sand stone deposits containing bitumen. The sands obtained from surface mining are first passed through a conditioning drum where water, steam & caustic soda are added & slurry is formed. The slurry passes into a separation tank where the coarse sand settles at the bottom & a froth of bitumen, water & fine mineral matter forms on the top. The froth is diluted with naptha & subjected to centrifugal action. As a result, fine mineral matter & water is removed. After this, the naptha is recovered & recycled, & the bitumen obtained is subjected to hydro processing & desulphurization to produce synthetic crude oil.

## 6.11 Oil shale:

Oil shale [a sedimentary rock] refers to a finely textured rock mixed with a solid organic material called kerogen. When crushed, it can be burnt directly [like coal] & has a heating value ranging from 2000 to 17,000 KJ/Kg. It is used in this manner for generating electricity & supplying heat.

Alternatively, the oil shale can be converted to oil. This is done by heating crushed oil shale to about 500 ˚c in the absence of air. Under the conditions, pyrolysis occurs & the kerogen is converted to oil.

**Demerits:**

1] The use of oil shale is the environmental degradation associated with surface mining & with the disposal of large amounts of sand & spent shale rock which remains after the crude oil is obtained.

2] A large amount of energy is consumed in producing oil from these sources.

## 6.12 Nuclear power:

Under the nuclear option, the 2 alternatives under study are, 1] the breeder reactor, 2] nuclear fusion

1] The breeder reactor: In order to understand the working of a breeder reactor, it is necessary to understand the fission reactions. Naturally occurring uranium contains 3 isotopes, $U^{234}$, $U^{235}$ & $U^{238}$. The relative % of these isotopes is $U^{234}$ – 0.006%, $U^{235}$- 0.711% & $U^{238}$-99.283% of these isotopes, only $U^{235}$ undergoes spontaneous fission when subjected to bombardment by slow neutrons. It is in fact that only naturally occurring fissile material.

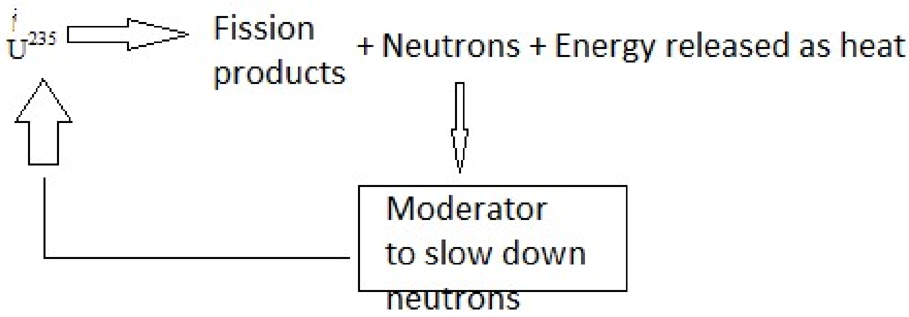



*Figure 9: Fission reaction of U235*

The break-up of $U^{235}$ when subjected neutrons & the release of a large amount of energy as heat [$8.2 \times 10^7$ KJ/gm of $U^{235}$]. The neutrons are slowed down by a moderator, & used to bombard the $U^{235}$ nucleus again, there by setting up a controlled chain reaction. Although $U^{238}$ is not a fissile material, it is a fertile material, i.e., it can be converted by neutron bombardment into a fissile material, plutonium-239. Similarly, naturally occurring thorium-232 is also a fertile material. It can be converted into $U^{233}$ which is a fissile material. It will be seen that the neutrons generated by the fission reaction serve two purposes. They help in converting a fertile material to a fissile material & also sustain the fission reaction for the fissile material formed. The above reactions are called breeder reactions if they produce more fissile material than they consume & the nuclear reactor in which they are caused to occur is called a breeder reactor.

Breeding is achieved by having both fissile & fertile materials in the reactor core under conditions which provide enough neutrons to propagate chain reactions in the fissile material as well as to convert more fertile material into fissile material than was originally present.

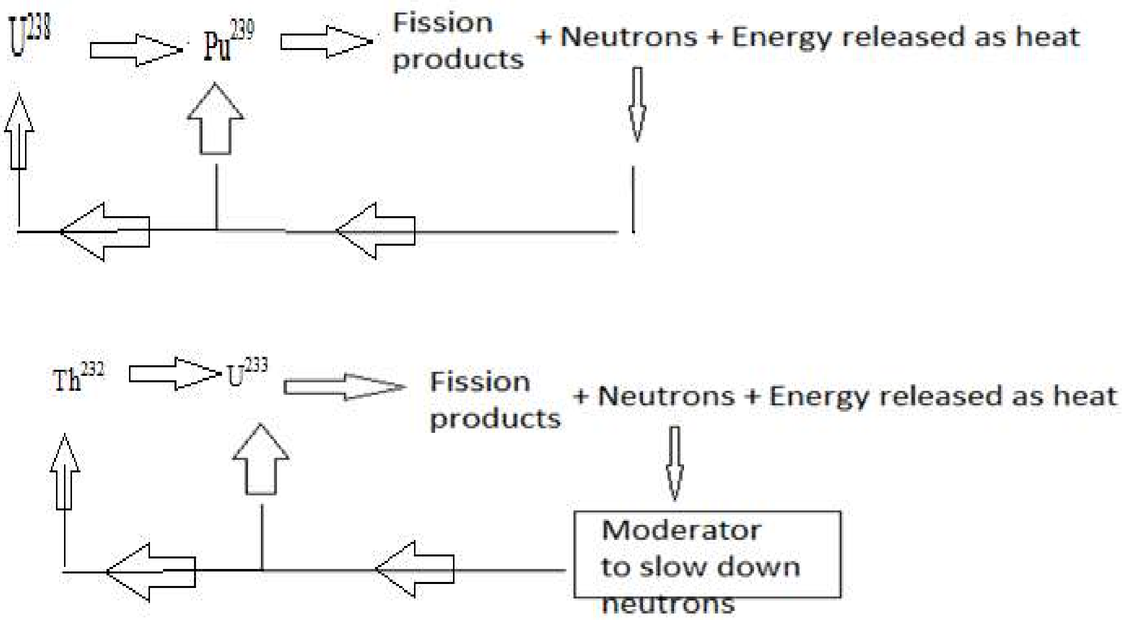



*Figure 10: Breeder reactor for U 238 & Th 232*

Reactors working on various breeder cycles have been built. However, the major effort has been on liquid-metal cooled, fast breeder reactors working on the $U^{238}$ to $Pu^{239}$ cycle.

**NUCLEAR FUSION:**

In nuclear fusion, energy is released by joining very light atoms. The reactions of interest involve the fusing of the heavy isotopes of hydrogen [deuterium D & tritium T] into the next heavier element, viz, helium. They are as follows.

$$D + D \Rightarrow T + P + 4.0 \text{ MeV} \qquad \text{.............} [1]$$

$$D + D \Rightarrow He^3 + n + 3.2 \text{ MeV} \qquad \text{.............} [2]$$

$$D + T \Rightarrow He^4 + n + 17.6 \text{ MeV} \qquad \text{.............} [3]$$

$$D + He^3 \Rightarrow He^4 + p + 18.3 \text{ MeV} \qquad \text{.............} [4]$$

$$6D \Rightarrow 2\ He^4 + 2p + 2n + 43.1 \text{ Me} \qquad \text{.............}[5]$$

Equation [1] & [2] show that 2 nuclei of deuterium can fuse in 2 ways. Both ways are equally probable. In the first, tritium & one proton are formed, while in the second, helium-3& one neutron is formed. The energy released by the fusion reaction is indicated. Tritium is unstable & combines with deuterium to form helium-4& one neutron, Equation [3], while helium-3 combines with deuterium to form helium-4& one proton, Equation [4]. The net result Equation [5], is the addition of all the 4 reactions. It indicates that 6 deuterium nuclei are converted to 2 helium 4 nuclei, 2 protons & 2 neutrons with an energy release of 43.1 MeV.

Deuterium occurs naturally in sea water & it is estimated that the fusion of all the deuterium in just one cubic metre of sea water would yield energy of $12\times10^{9}$ KJ.

The development of nuclear fusion reactor are the attainment of the required high temperature by initially heating the fuel charge & the confinement of the heated fuel for a long enough time for the reaction to become self-sustaining. The research being conducted to solve these problems is proceeding broadly along 2 conceptual directions- magnetic confinement & laser induced fusion.

In the first concept, the fuel charge [in the form of a charged particle gas composed of positively charged nuclei & free electrons] is contained in a hermetically sealed vacuum chamber & is heated to the required high temperature by passing an electric current through it. At this temperature, the fusion reaction takes place successfully only if the gas is confined within a certain volume for a specified time & not allowed to come into contact with containing chamber's walls. This confinement is achieved by the application of a very strong, specially shaped magnetic field.

In the second concept, the fuel charge in the form of very small pellets. These are positioned one by one at a specific location & subjected to intense focused laser beams which heat the pellets to the required temperature & cause fusion to occur. By adopting this method, the confinement time is substantially reduced & the need for a magnetic field is removed.

Of the reactions given in equation [1] to [4], the D-T reaction takes place at the lowest temperature; about $10^{7}$ K. since tritium does not occur naturally, the D-T reaction should be supplemented by one using lithium as follows:

$$D + T \longrightarrow He^{4} + n + 17.6\ MeV \qquad \text{............. [6]}$$

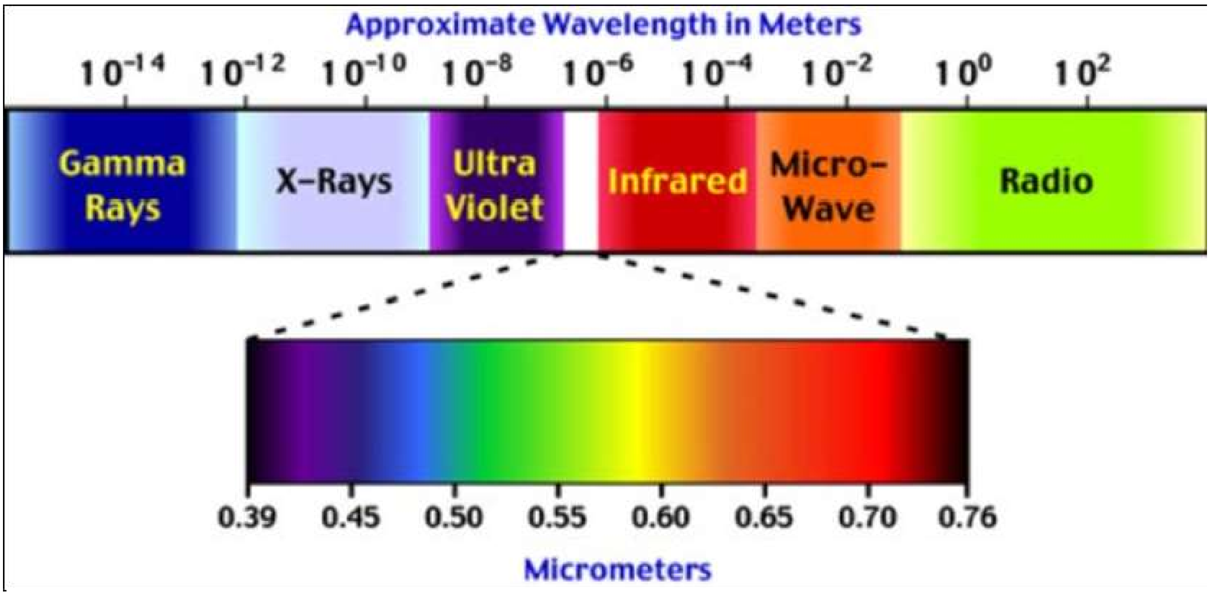
$$N + Li6 \longrightarrow He^{4} + T + 4.8\ MeV \qquad \text{............. [7]}$$

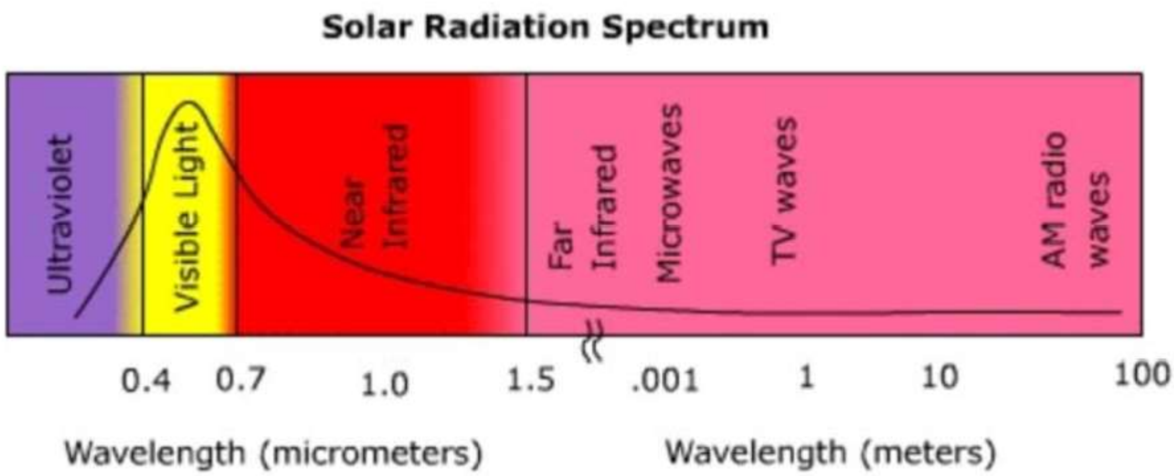
$$D + Li6 \longrightarrow 2\ He^{4} + 22.4\ MeV \qquad \text{............. [8]}$$

# 7 Solar Radiation

## 7.1 Solar Radiation Outside the Earth's Surface:

Sun is a large sphere of very hot gases; the heat being generated by various kinds of fusion reactions. Its diameter is $1.39X10^6$ km, while that of the earth is $1.27X10^4$ km. It subtends an angle of 32minutes at the earth's surface. This is because it is also at a large distance. Thus, the beam radiation received from the sun on the earth is almost parallel. The brightness of the sun varies from its centre to its edge. However, for engineering calculations. It is customary to assume that the brightness all over the solar disc is uniform.



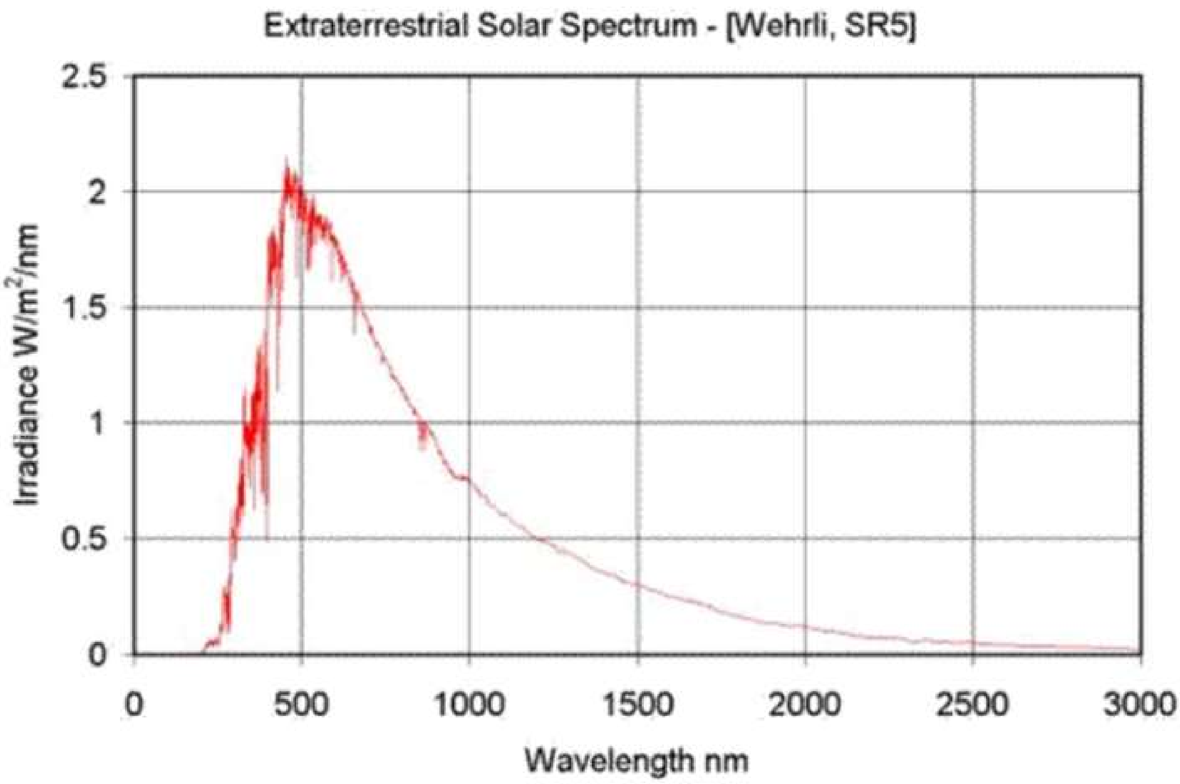

## 7.2 Radiation:

The transfer of energy via electromagnetic waves that travel at the speed of light. The velocity of light in a vacuum is approximately 3 x $10^8$ m/s. The time it takes light from the sun to reach the Earth is 8 minutes and 20 seconds. Heat transfer by electromagnetic radiation can travel through empty space. Anybody above the temperature of absolute zero (-273.15° C) radiate energy to their surrounding environment. The many different types of radiation are defined by their wavelength. Electromagnetic radiation can vary widely.

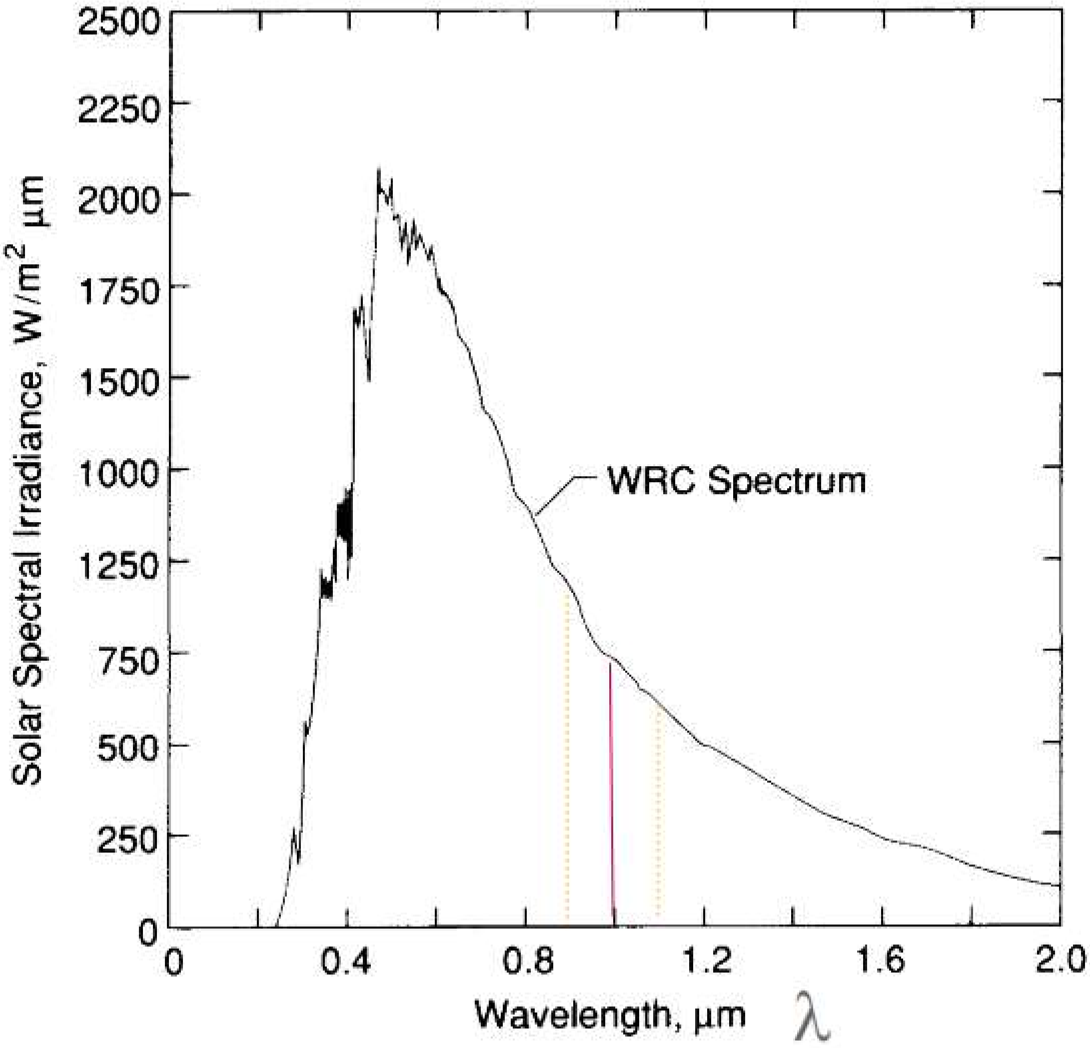
## 7.3 Sun Radiation Spectrum

Visible light has a wavelength of between 0.40 to 0.71 micrometers (μm). The sun emits only a portion (44 %) of its radiation in this range. Solar radiation spans a spectrum from approximately 0.1 to 4.0 micrometers. About 7 % of the sun's emission is in the 0.1 to 0.4 micrometers wavelength band (UV). About 48 % of the sun's radiation falls in the region between 0.71 to 4.0 micrometers (near-infrared: 0.71 to 1.5 micrometers; far-infrared: 1.5 to 4.0 micrometers).

Solar radiation incident outside the earth's atmosphere is called extra-terrestrial radiation. On average the extra-terrestrial irradiance is 1367 $W/m^2$ This value varies by ±3% as the earth orbits the sun.



## 7.4 Spectral Distribution of Extra-terrestrial Radiation



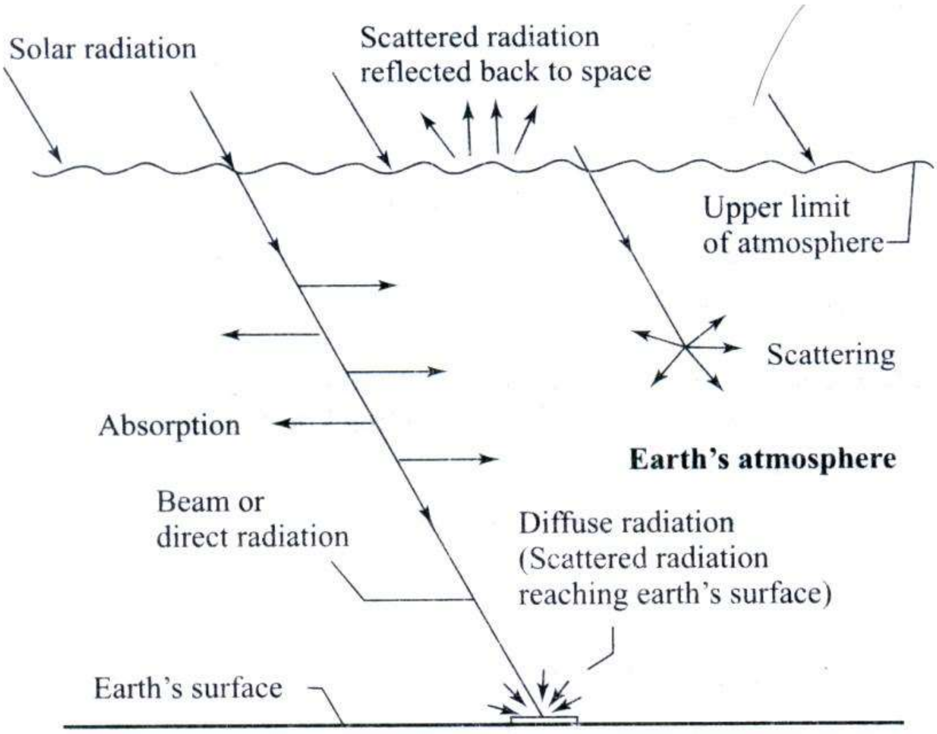

## 7.5 Solar Constant ($I_{SC}$):

It is the rate at which energy is received from the sun on a unit area perpendicular to the rays of the sun, at the mean distance of the earth from the sun. Based on the measurements made up to 1970 a standard value of 1353W/m$^2$ was adopted in 1971. However, based on subsequent measurements, a revised value of 1367 W/m$_2$ has been recommended. The earth revolves around the sun in an elliptical orbit having a very small eccentricity and the sun at the foci. Consequently, the distance between earth and sun varies a little through the year. Because of this variation, the extra-terrestrial flux also varies. The value on any day can be calculated from the equation.

$$I = I'_{sc}\left\{I + 0.033\cos\frac{360n}{365}\right\}$$

## 7.6 Solar Radiation Received at the Earth's surface:

Solar radiation received at the earth's surface is in the attenuated form because it is subjected to the mechanisms of absorption and scattering as it passes through the earth's atmosphere (Figure below).




Absorption occurs primarily because of the presence of ozone and water vapor in the atmosphere and lesser extent due to other gases (like $CO_2$, $NO_2$, CO, $O_2$, and $CH_4$) and particulate matter. It results in an increase in the internal energy of the atmosphere. On the other hand, scattering occurs due to all gaseous molecules as well as particulate matter in the atmosphere. The scattered radiation is redistributed in all directions, some going back to space and some reaching the earth's surface. Solar radiation received at the earth's surface without change of direction i.e., in line with the sun is called ***direct radiation or beam radiation***. The radiation received at the earth's surface from all parts of sky's hemisphere (after being subjected to scattering in the atmosphere) is called ***diffuse radiation***. The sum of beam radiation and diffuse radiation is called as ***total or global radiation.***

**Diffused radiation:**

The scattered reflected and refracted radiation that is sent to the earth's surface from the sun in all directions (reflected from particles, molecules, clouds, etc) is indirect radiation is called diffuse radiation. The intensity of the diffused radiation is represented by Id.

**Beam radiation:**

The radiation that comes directly from the sun is direct radiation and is called beam radiation. The intensity of the beam radiation is represented by Ib.

**Irradiance:**

The irradiance is the flux of radiant energy per unit area which is measured in W/m$^2$. The irradiance will be normal to the direction of the flow of radiant energy through a medium.

**Insolation:**

Insolation can be measured in J/m2which is the amount of solar radiation reaching a given area.

**Terrestrial and extraterrestrial radiation:**

**Terrestrial radiation:**

Terrestrial radiations are those radiations that flow throughout the year.

**Extra-terrestrial solar radiation:**

The extra-terrestrial radiation is the radiation which is incident outside the earth atmosphere. The extra-terrestrial radiation is 1367 watts/m$^2$.

## 7.7 Measurement of solar radiation:

### 7.7.1 Pyranometer:

A pyranometer is an instrument that measures either global or diffuse radiation falling on a horizontal surface over a hemispherical field of view. A sketch of one type of pyranometer as installed for measuring global radiation is shown in the following figure.

1.Black surface, 2. Glass domes ,

3. Guard plate 4. Leveling screws,

5.mounting plate, 6. Grouted bolts,

7.platform.

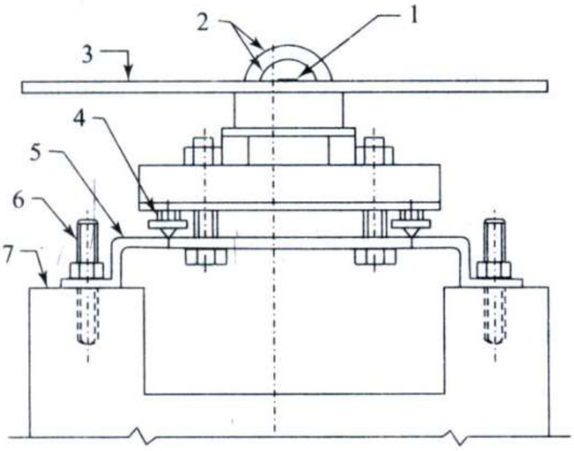
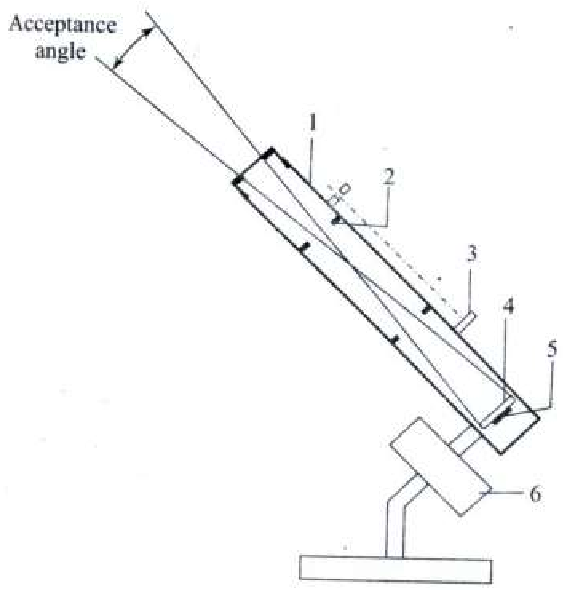



*Figure 11: Pyranometer*

Pyranometer consists of a black surface that heats up when exposed to solar radiation. Its temperature increases until the rate of heat gain by solar radiation equals the rate of heat loss by convection, conduction, and radiation. The hot junctions of thermopiles are attached to the black surface, while the cold junctions are located under a guard plate so that they do not receive the radiation directly. As a result, an emf is generated. This emf which is usually in the range of 0 to 10mv can be read, recorded, or integrated over a period of time and is a measure of global radiation. The pyranometer can also be used for the measurement of diffuse radiation. This is done by mounting it at the center of a semi-circular shading ring. The shading ring is fixed in such a way that its plane is parallel to the plane of the path the of sun's daily movement across the sky and it shades the thermopile element and two glass domes of pyranometer at all the times from direct sun shine. Consequently, the pyranometer measures only the diffuse radiation received from the sky.

### 7.7.2 Pyrheliometer:

This is an instrument which measures beam radiation falling on a surface normal to the sun's rays. In contrast to a pyranometer, the black absorber plate (with hot junctions of a thermopile attached to it) is located at the base of a collimating tube. The tube is aligned with the direction of the sun's rays with the help of a two-axis tracking mechanism and alignment indicator. Thus, the black plate receives only beam radiation and a small amount of diffuse radiation falling within the acceptance angle of the instrument. The Following figure shows a pyrheliometer.




1.tube blackened on inside surface,

2.baffle, 3.Alignment indicator,

4. Black absorber plate

5.thermopile junctions

6.two-axis tracking mechanism

*Figure 12: Pyrheliometer*

### 7.7.3 Shading ring Pyranometer

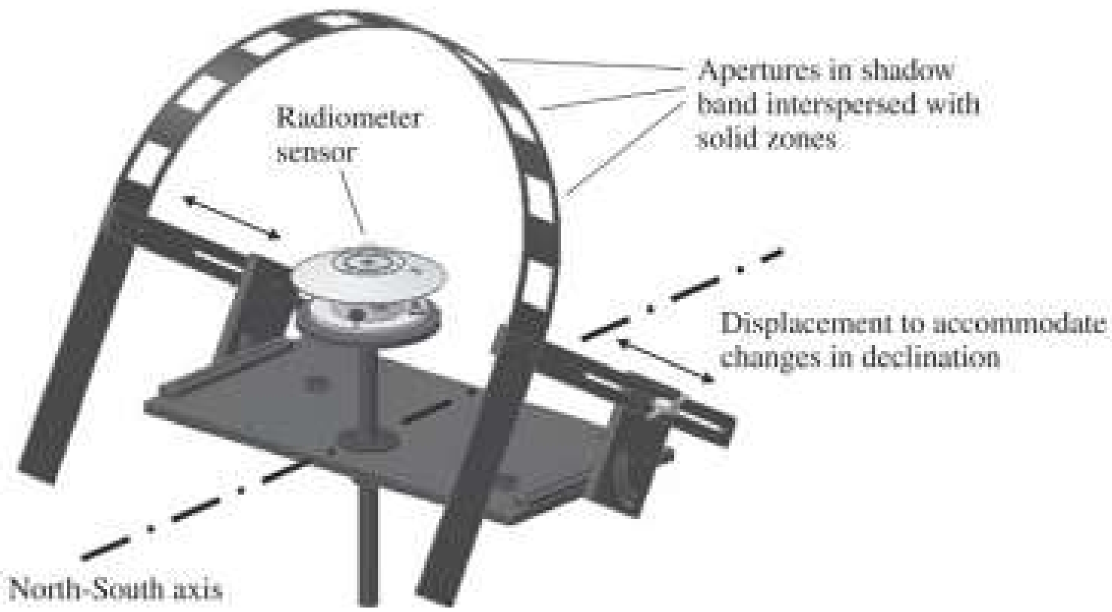



*Figure 13: Shading ring Pyranometer*

Pyranometers may be modified to measure only the diffuse component of the global horizontal radiation Idh. Providing a "shadowing" device just large enough to block out the direct irradiance coming from the sun's disc does this. An example of this technique is shown in Figure.

To avoid moving a shadowing disc throughout the day, a shadow band is often incorporated. This band must be adjusted often during the year to keep it in the ecliptic plane. Since the shadow band blocks part of the sky, corrections for this blockage must be used.

Recently, rotating shadow band pyranometers have come into general use. With this design, the shadow band rotates slowly about the pyranometer blocking the direct irradiance from the sun every time it passes in front of the pyranometer. The signal from the pyranometer read global horizontal irradiance most of the time, with reductions down to the diffuse irradiance level when the shadow band passes between the sun and the pyranometer. This design gives the advantage of using a single pyranometer to measure both global horizontal and diffuse horizon irradiance. The rotating shadow band pyranometer also avoids the constant adjustment of the plane of the band.

### 7.7.4 Other measurements

**Sunshine Recorders**.

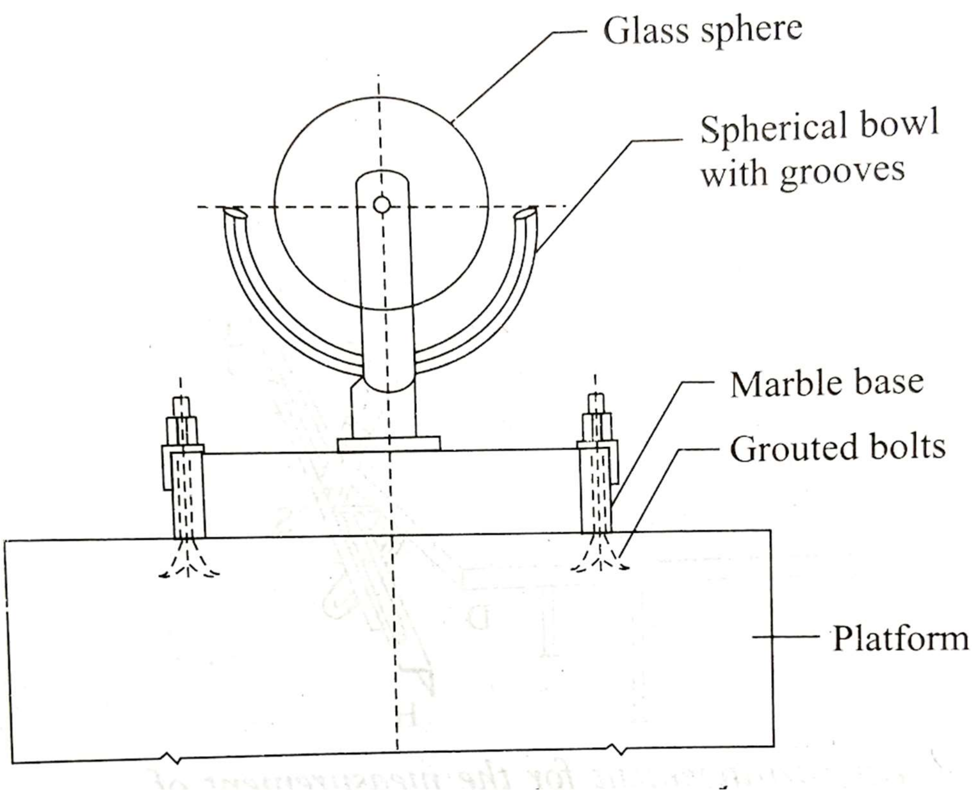



*Figure 14: Sunshine Recorders*

In addition to the pyranometer and the normal incidence pyrheliometer, which measure the global and direct solar irradiance respectively, there is traditional measurement often-reported in meteorological observations. This is the "duration of sunshine." The traditional standard instrument used to measure this parameter is the Campbell-Stokes sunshine recorder. This instrument consists of a glass sphere that focuses the direct solar radiation and burns a trace on a special pasteboard card. These recorders have been replaced in most installations by photo detector activated *sunshine switches.' The data produced by these instruments are of minimal use to engineers because there is no measure of intensity other than a threshold intensity. However, attempts have been made to correlate these data with daily or monthly solar radiation levels.

**Cloud -cover Observations.** Another source of solar irradiance data is from periodic ground observations of cloud-cover. These are made at least hourly at weather observation stations around the world. Examining the SOLMET weather data tape format discussed below will show the detail to which these observations are carried out in the United States. Cloud-cover data along with other weather data have been used to predict solar irradiance levels for the locations without solar irradiance measurement capabilities.