2.1 SOLAR RADIATION:

2.1.1 EXTRATERRESTRIAL AND TERRESTRIAL RADIATIONS:

- The intensity of solar radiation keeps on attenuating as it propagates away from the surface of the sun, though the wavelengths remain unchanged. Solar radiation incident on the outer atmosphere of the earth is known as Extraterrestrial Radiation.

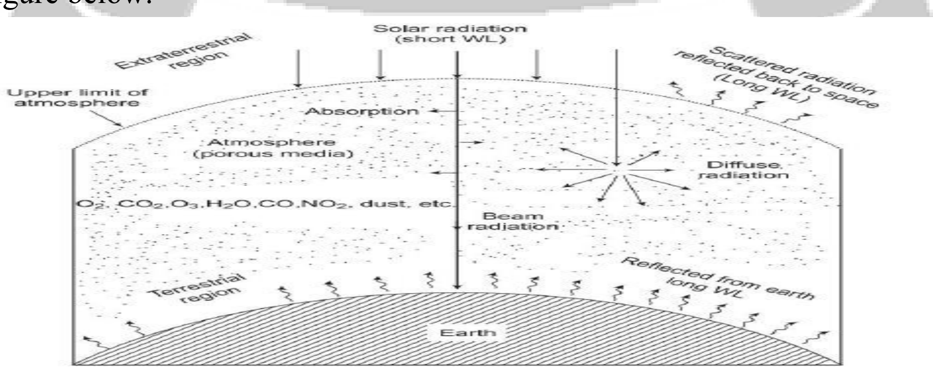
- The extraterrestrial radiation deviates from solar constant value due to two reasons. The first is the variation in the radiation emitted by the sun itself. The variation due to this reason is less than ±1.5 per cent with different periodicities. The second is the variation of earth–sun distance arising from earth‟s slightly elliptic path. The variation due to this reason is ±3 percent and is given by:

$$I_{ext}=I_{sc}[1+0.033\cos(360n/365)]\ W/m_2$$

Where, n is the day of the year starting from January 1.

- The extraterrestrial radiation, being outside the atmosphere, is not affected by changes in atmospheric conditions. While passing through the atmosphere it is subjected to mechanisms of atmospheric absorption and scattering depending on atmospheric conditions, depleting its intensity. A fraction of scattered radiation is reflected back to space while remaining is directed downwards. Solar radiation that reaches earth surface after passing through the earth‟s atmosphere is knownas Terrestrial Radiation.

- The terrestrial radiation expressed as energy per unit time per unit area (i.e. W/m2) is known as **Solar Irradiation**. The term **Solar Insolation** (incident solar radiation) is defined as solar radiation energy received on a given surface area in a given time (in J/m2 or kWh/m2). The positions of extraterrestrial and terrestrial regions are indicated in figure below.



Propagation of solar radiation through atmosphere

Figure: 2.1.1

[Source: "Solar Photovoltaics: Fundamentals,Technologies andApplications" by ChetanSingh Solanki, Page: 192]

2.1.2 DEPLETION OF SOLAR RADIATION:

The earth‟s atmosphere contains various gaseous constituents, suspended dust and other minute solid and liquid particulate matter. These are air molecules, ozone, oxygen, nitrogen, carbon dioxide, carbon monoxide, water vapour, dust, and water droplets. Therefore, solar radiation is depleted during its passage through the atmosphere. Different molecules do different things as explained below:

Absorption:

- Selective absorption of various wavelengths occurs by different molecules. The absorbed radiation increases the energy of the absorbing molecules, thus raising their temperatures:
- Nitrogen, molecular oxygen and other atmospheric gases absorb the X-rays and extreme ultraviolet radiations.
- Ozone absorbs a significant amount of ultraviolet radiation in the range (l < 0.38 μm).
- Water vapour (H2O) and carbon dioxide absorb almost completely the infrared radiation in the range (l > 2.3 μm) and deplete to some extent the near infrared radiation below this range.
- Dust particles and air molecules also absorb a part of solar radiant energyirrespective of wavelength.

Scattering:

Scattering by dust particles, and air molecules (or gaseous particles of different sizes) involves redistribution of incident energy. A part of scattered radiation islost (reflected back) to space while remaining is directed downwards to the earth‟s surface from different directions as diffuse radiation. It is the scattered sunlight that makes the sky blue. Without atmosphere and its ability to scatter sunlight, the sky would appear black, as it does on the moon.

In cloudy atmosphere, (i) a major part of the incoming solar radiation is reflected back into the atmosphere by the clouds, (ii) another part is absorbed by theclouds and (iii) the rest is transmitted downwards to the earth surface as diffuse radiation.

- The energy is reflected back to the space by (i) reflection from clouds, plus (ii) scattering by the atmospheric gases and dust particles, plus (iii) the reflectionfrom the earth‟s surface is called the **albedo** of earth-atmosphere system and has a value of about 30 per cent of the incoming solar radiation for the earth as a whole. Thus on the surface of earth we have two components of solar radiation:
- direct or beam radiation, unchanged in direction and (ii) diffuse radiation, the direction of which is changed by scattering and reflection. Total radiation at any location on the surface of earth is the sum of beam radiation and diffuse radiation, what is known as global radiation. These terms may be properly definedas follows:

➢ Beam radiation: Solar radiation propagating in a straight line and received at the earth surface without change of direction, i.e., in line with sun is called beam or direct radiation.

➢ Diffuse radiation: Solar radiation scattered by aerosols, dust and molecules is known as diffuse radiation. It does not have a unique direction.

➢ Global radiation: The sum of beam and diffuse radiation is referred to as total or global radiation.

2.2 MEASUREMENT OF SOLAR RADIATION

Solar radiation data are measured mainly by the following instruments:

✓ **Pyranometer**: A pyranometer is designed to measure global radiation, usuallyon a horizontal surface but can also be used on an inclined surface. When shaded from beam radiation by using a shading ring, it measures diffuse radiation only.

✓ **Pyrheliometer**: An instrument that measures beam radiation by using a long and narrow tube to collect only beam radiation from the sun at normal incidence.

✓ **Sunshine recorder** measures the sunshine hours in a day.

Pyranometer:

- A precision pyranometer is designed to respond to radiation of all wavelengths and hence measures accurately the total power in the incident spectrum. It contains a thermopile whose sensitive surface consists of circular, blackened, hot junctions, exposed to the sun and cold junctions are completely shaded.

- The temperature difference between the hot and cold junctions is the function of radiation falling on the sensitive surface. The sensing element is covered by two concentric hemispherical glass domes to shield it from wind and rain. This also reduces the convection currents.

- A radiation shield surrounding the outer dome and coplanar with the sensing element, prevents direct solar radiation from heating the base of the instrument. The instrument has a voltage output of approximately 9 µV/W/m2 and has an output impedance of 650 W. A precision spectral pyranometer (model: PSP) of Eppley laboratory is shown in figure below.

- The pyranometer, when provided with a shadow band (or occulting disc) to prevent beam radiation from reaching the sensing element, measures the diffuse radiation only. Such an arrangement of shadow bandstand (model: SBS) is shown below.

- Many inexpensive instruments are also available for measuring light intensity, including instruments based on cadmium sulphide photocells and silicon photodiodes. These instruments give good indication of relative intensity but their spectral response is not linear and thus cannot be accurately calibrated.

Pyranometer
(*Courtesy:* Eppley Laboratory)

Figure: 2.1.2

A pyranometer with shadow band
(*Courtesy:* Eppley Laboratory)

Figure: 2.1.3

[Source: "Solar Photovoltaics: Fundamentals,Technologies andApplications" by ChetanSingh Solanki, Page: 196]

Pyrheliometer:

- The normal incidence pyrheliometer uses a long collimator tube to collect beam radiation whose field of view is limited to a solid angle of 5.5° (generally) by appropriate diaphragms inside the tube.
- The inside of the tube is blackened to absorb any radiation incident at angles outside the collection solid angle. At the base of the tube a wire wound thermopile having a sensitivity of approximately 8 mV/W/m2 and an output impedance of approximately 200 W is provided.
- The tube is sealed with dry air to eliminate absorption of beam radiation within the tube by water vapour. A tracker is needed if continuous readings are desired.

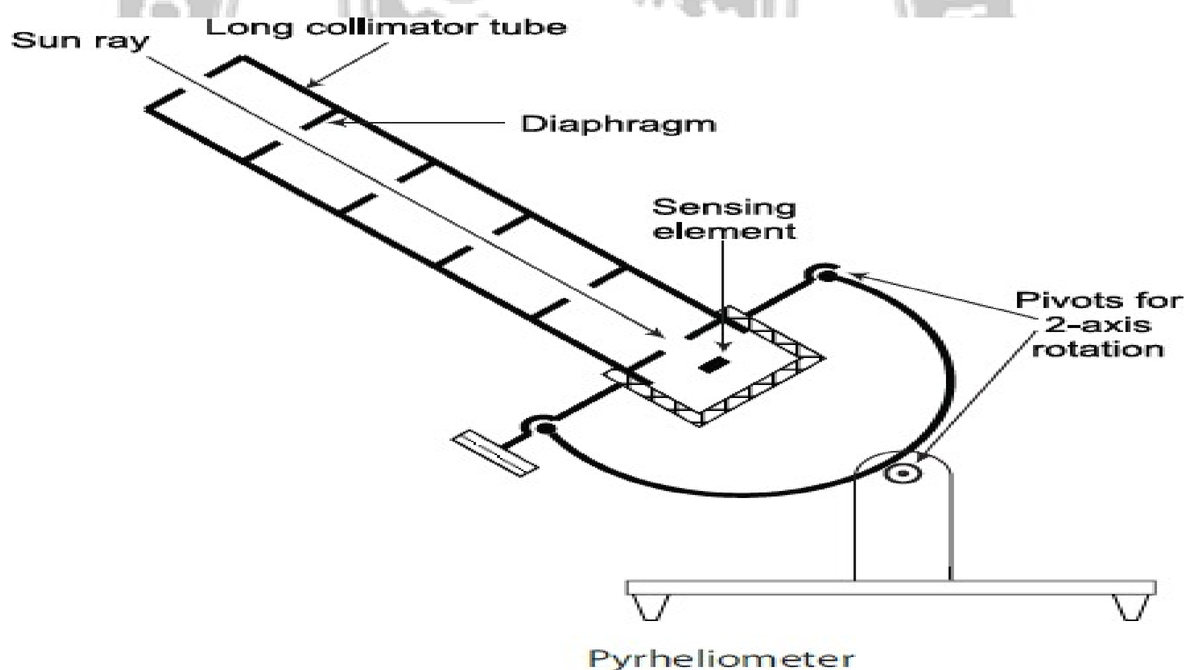


Figure: 2.1.4

[Source: "Solar Photovoltaics: Fundamentals,Technologies andApplications" by ChetanSingh Solanki, Page: 197]

Sunshine Recorder:

- This instrument measures the duration in hours, of bright sunshine during the course of the day. It essentially consists of glass sphere (about 10 cm in diameter) mounted on its axis parallel to that of earth, within a spherical section (bowl).

- The bowl and glass sphere is arranged in such a way that sun's rays are focused sharply at a spot on a card held in a groove in the bowl. The card is prepared from special paper bearing a time scale. As the sun moves, the focused bright sunshine burns a path along this paper.

- The length of the trace thus obtained on the paper is the measure of the duration of the bright sunshine. Three overlapping pairs of grooves are provided in the spherical segment to take care of the different seasons of the year.

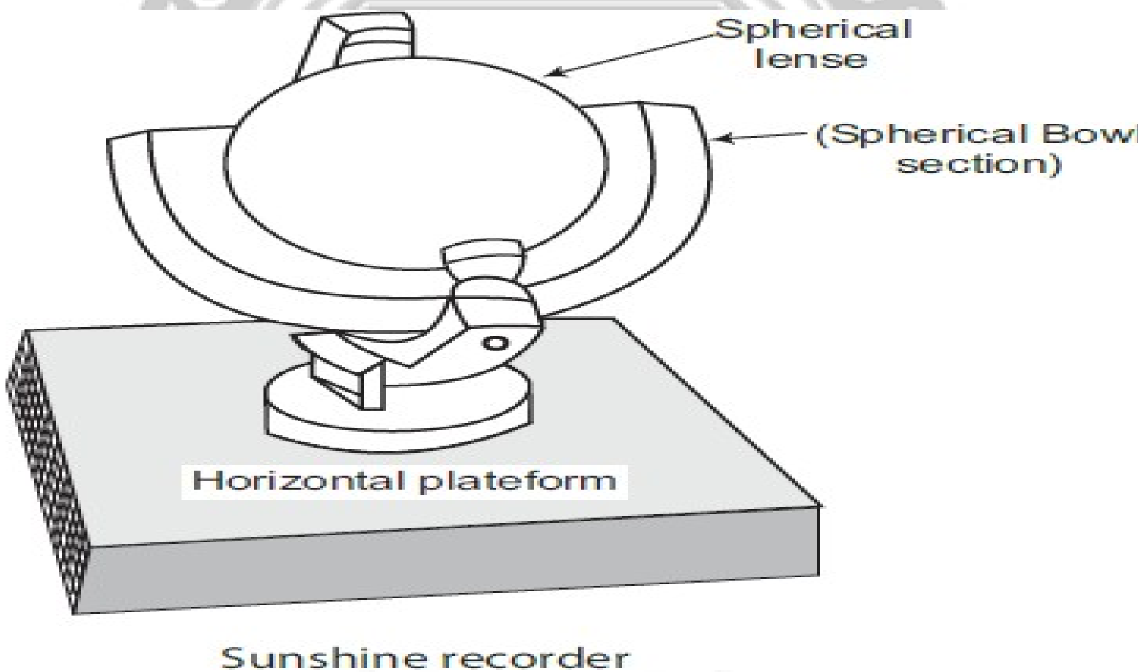


Figure: 2.1.5

[Source: "Solar Photovoltaics: Fundamentals,Technologies andApplications" by ChetanSingh Solanki, Page: 198]