Solar Energy Basics: -

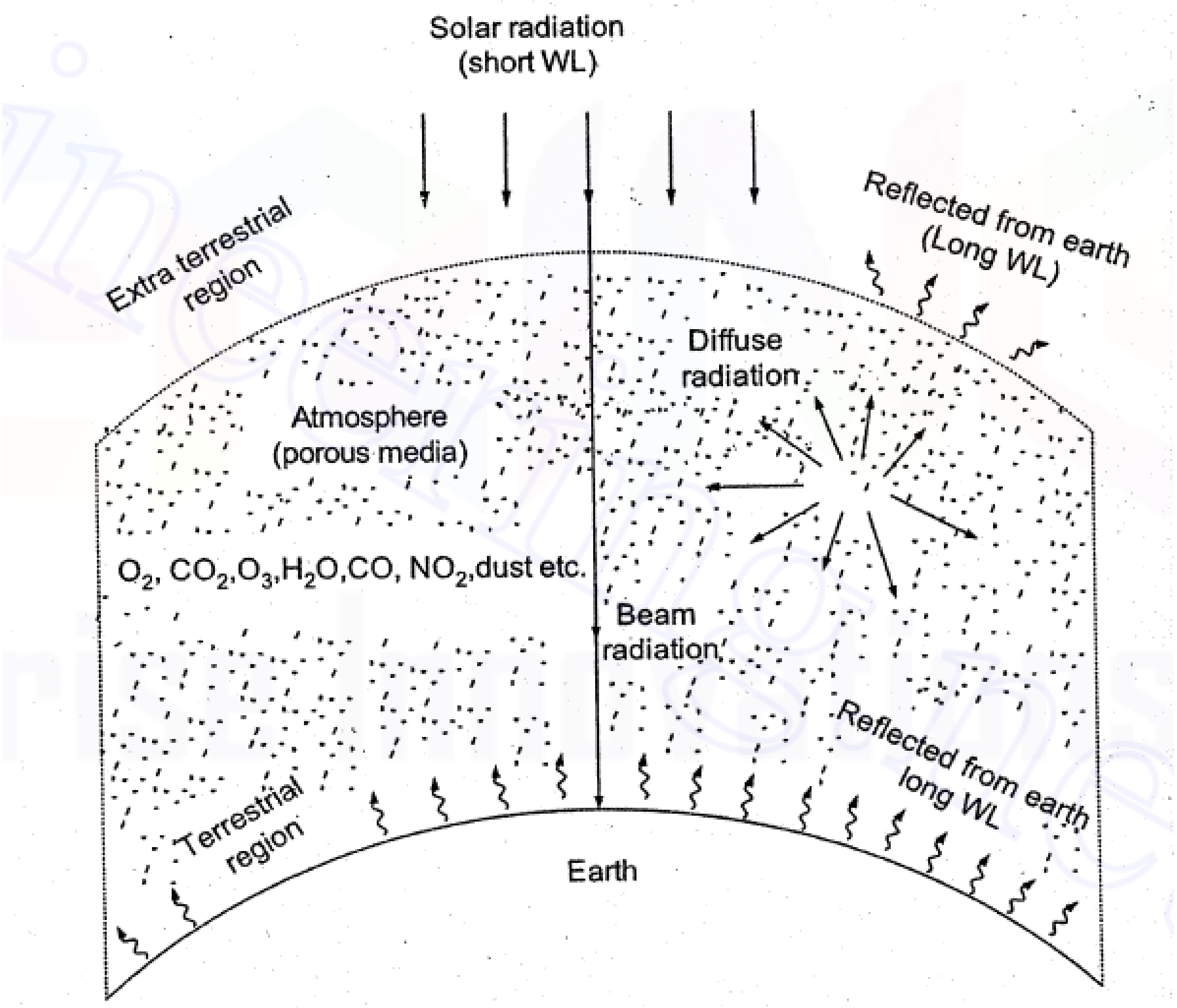
Extraterrestrial and Terrestrial Radiations: -

- **Extraterrestrial Radiation (I_{ext}): -** Solar Radiation incident upon the outer atmosphere of the earth is known as extraterrestrial radiation.
    - **Solar Constant (I_{sc}): -** It is defined as the energy received from the sun per unit time, on a unit area of surface perpendicular to the direction of propagation of the radiation at the top of the atmosphere and at the earth's mean distance from the sun. The standard value of solar constant which is adopted universally is 1367 W/m^2.
    - **Extraterrestrial Radiation** deviates from the solar constant value due to two reasons
        - First is due to Variation in the radiation emitted by the sun itself
        - Second is due to due to the variation of the earth sun distance arising the earth's elliptical path.

$$I_{ext} = I_{sc}\left(1 + 0.033 cos(360\, n/365)\right)$$

Where n = day of the year starting from, 1^{st} Jan

- **Terrestrial Radiation: -** Solar radiation that reaches the earth surface after passing through the earth's atmosphere is known as terrestrial radiation.



➢ Depletion of Solar Radiation: -

- **The extraterrestrial radiation, being outside the atmosphere, is not affected by change in atmospheric conditions.**
- **When solar radiation passes through the atmosphere, it is subjected to mechanism of atmospheric absorption and scattering depending on the atmospheric conditions, depleting its intensity.**

- **Absorption: - Due to presence of different types of gasses in the atmosphere such as Nitrogen, Oxygen, Ozone, water vapour, Carbon dioxide etc. absorbs radiation of** wavelength thus reduces the intensity of the solar radiation.

- **Scattering: -** Scattering by dust particles and air molecules involves redistribution of incident radiation. Apart of the scattered radiation is lost back to the space and the remaining is directed downward to earth's surface from the different directions as diffuse radiation. It is the scattered sunlight that makes the sky blue.

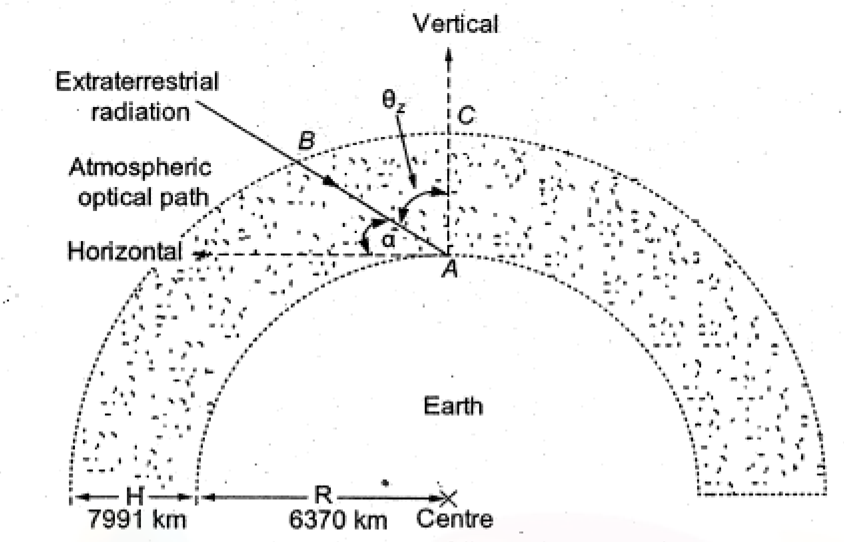
Components of the solar radiation at the earth's surface: -

- **Direct or Beam Radiation (I_b): -** Solar radiation propagating in a straight line and received at the earth surface without change of direction, i.e., in line with the sun is called beam or Direct Radiation.
- **Diffused radiation (I_d): -** Solar radiation scattered by aerosols, dust and molecules is known as diffused radiation.
- **Global Radiation (I_g): -** the sum of the beam and diffused radiation is referred as total or global radiation.

$$I_g = I_b + I_d$$

Air Mass (AM): - it is defined as the ratio of the path length through the atmosphere, which the solar beam actually traverses up to the ground to the vertical path length (which is minimum) through the atmosphere.

$$AM_0 = \frac{Path\ Length\ traversed\ by\ beam\ radiation}{Vertical\ path\ length\ of\ atmosphere}$$



$$AM = \frac{BA}{CA} = sec\theta_z = coses\ \alpha$$

$$as\ \alpha + \theta_z = 90^0$$

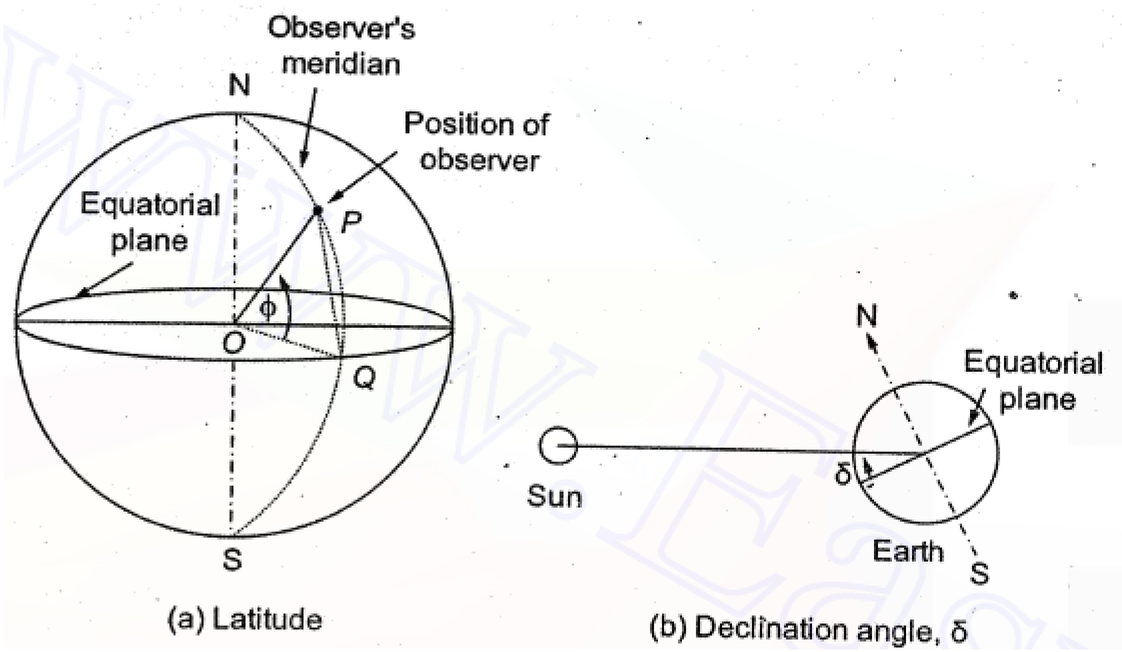
where, α *is the inclination angle*

and θ_z *is the zenith angle*

At sea level the air mass is unity when the sun is at its zenith (Highest position)

Solar Radiation Geometry: -

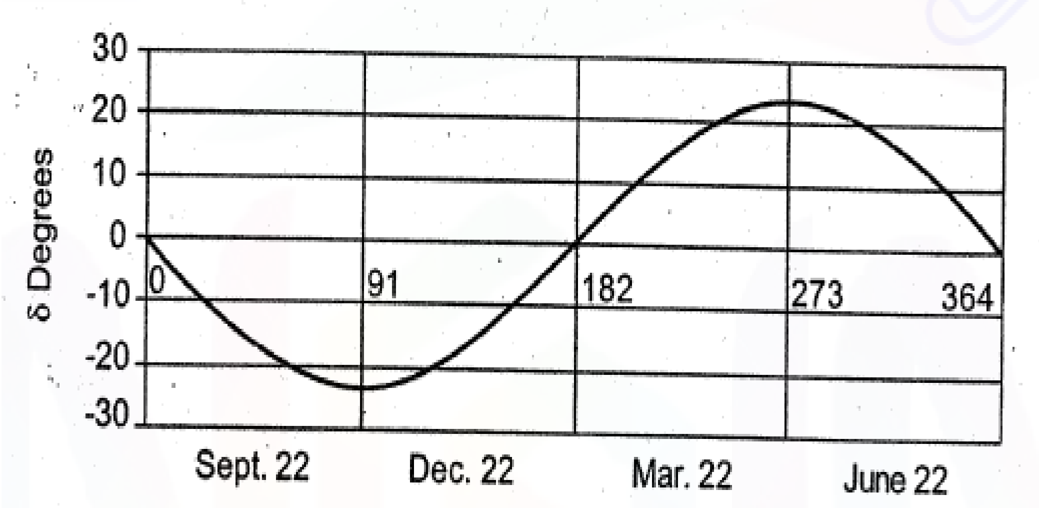
Latitude (Ø):- The latitude of a location on the earth's surface is the angle made by a radial line joining the given location to the Centre of the earth with its projection on the equator plane, the latitude is positive for northern hemisphere and negative for southern hemisphere.



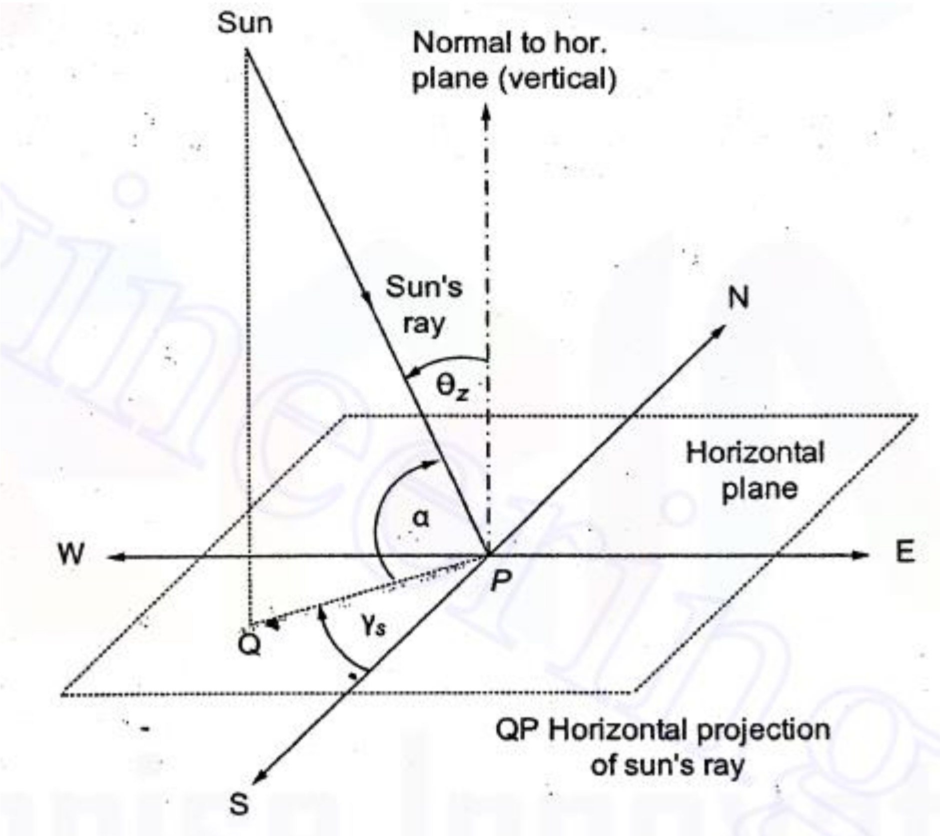
Declination angle (δ): - **It is defined as the angular displacement of the sun from the plane of the earth's equator. It is positive when measured above the equatorial plane in the northern hemisphere. The declination angle δ can be measured by equation**

$$\delta = 23.45 sin\left[\frac{360}{365}(284+n)\right]\ degrees$$

Where n = day of the year starting from, 1st Jan



Inclination angle (altitude) (α): - The angle between the sun's ray and its projection on a horizontal surface is known as inclination angle.



Zenith Angle (θ_z): - it is the angle between the sun's ray and the perpendicular to the horizontal plane.

Solar Azimuth Angle (γ_s): - It is the angle on a horizontal plane, between the line due south and the projection of the sun's ray on the horizontal plane. It is taken as +ve when measured from south towards west.

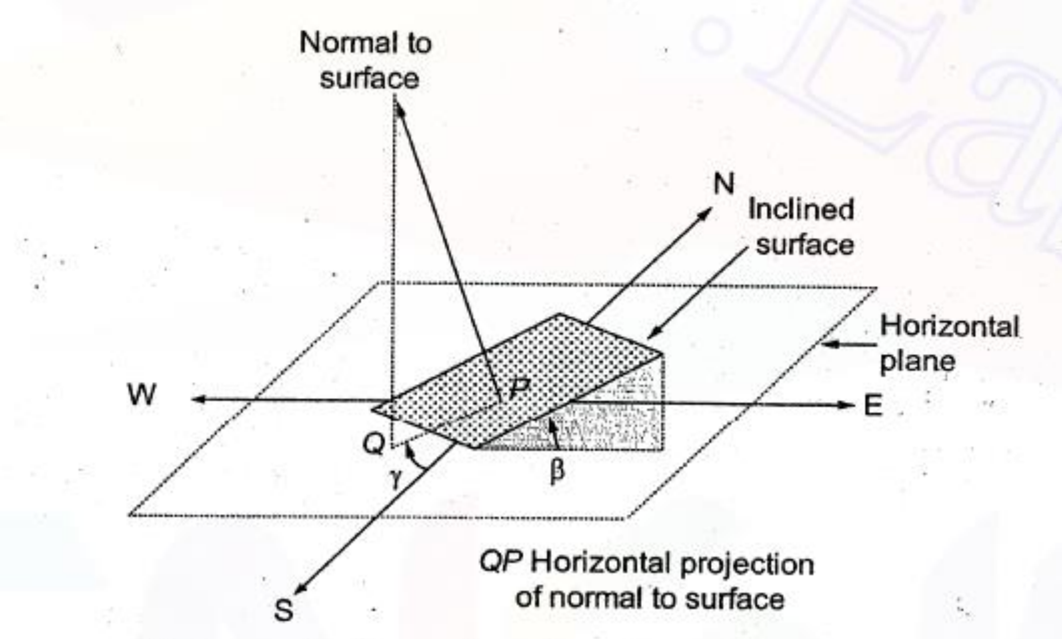


Fig. 4.17 *Surface azimuth angle and slope (tilt angle)*

Surface Azimuth Angle (γ): - It is the angle in the horizontal plane, between the line due south and the horizontal projection f the normal to the inclined plane surface (collector). It is taken as +ve when measured from south towards west.

Tilt Angle (Slope) (β): - it is the angle between the inclined plane surface (collector), under consideration and the horizontal. It is taken to be positive for the surface sloping towards south.

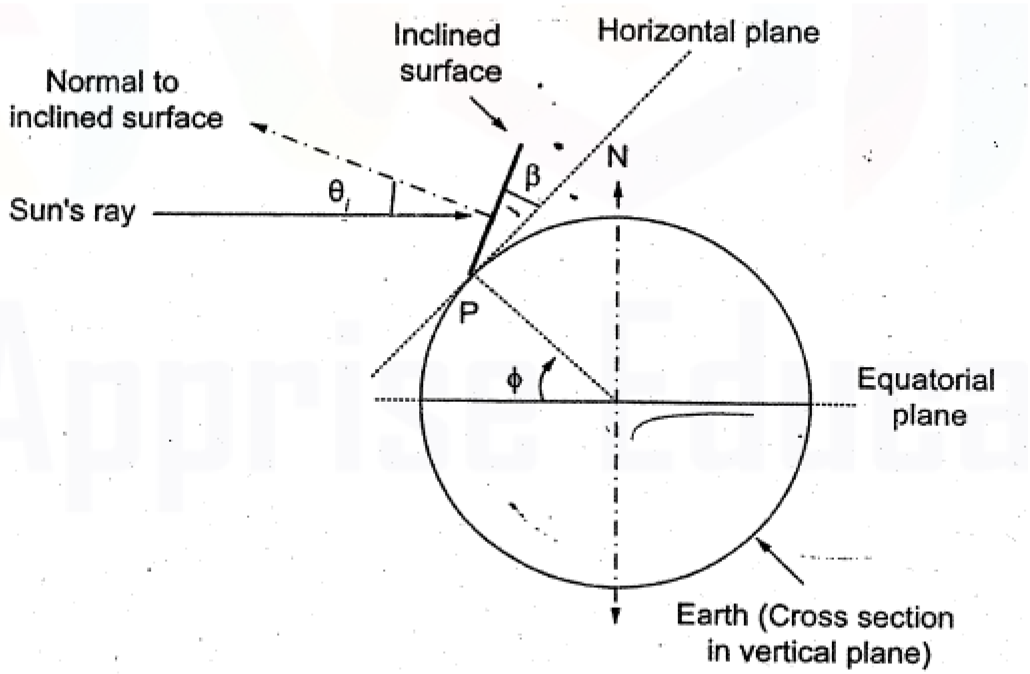


Fig. 4.18 *Angle of latitude, tilt angle, angle of incidence*

Angle of incidence (θ_i): -It is the angle between the sun's ray incident on the plane surface (collector) and the normal to the surface.

Solar Time (Local Apparent Time): - it is measured with reference to solar noon, which is the time when the sun is crossing the observer's meridian. At solar noon, the sun is at the highest position in the sky.

$$Solar\ time = Standard\ time \pm 4(L_{st} - L_{loc}) + E$$

Where, L_{st} is the standard longitude used for measuring standard time of the country and L_{loc} is the longitude of the observer's location respectively.

- **The +ve sign is used if the standard meridian of the country lies in the western hemisphere with respect to the prime meridian and -ve if that lies in the eastern hemisphere.**

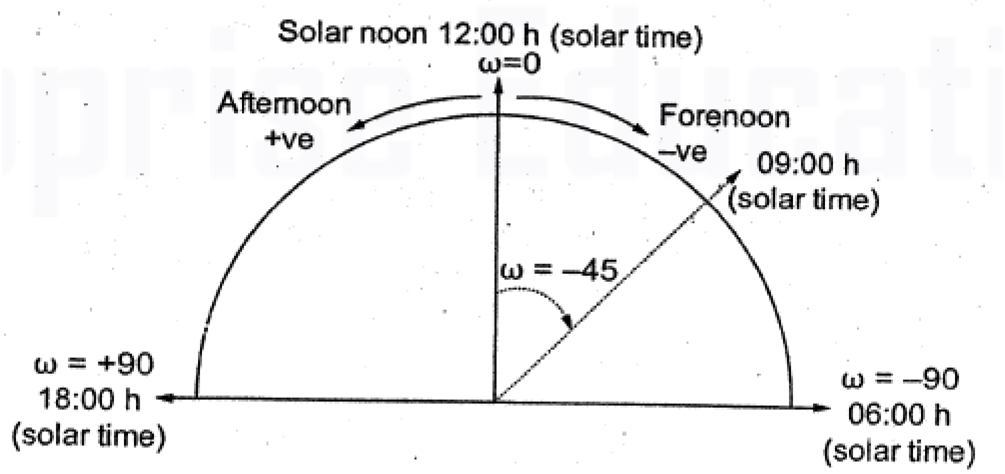
- E is the correction factor arising out of the variation in the length of the solar day due to variation in the in the earth's rotation and orbital revolution, and is called the equation of time. It can b determined by equation

$$E = 9.87 sin2B - 7.53 cosB - 1.5\ sinB \qquad \text{min}$$

$$where, \qquad B = {}^{360(n-81)}/_{364}$$

Where n = day of the year starting from, 1st Jan

Hour Angle (ω): - The hour angle at any moment is the angle through which the earth must turn to bring the meridian of the observer directly in line with the sun's rays.



- In other words, at any moment, it is the angular displacement of the sun towards east or west of local meridian.
- The earth completes one rotation in 24 hours. Therefore, one hour corresponds to 15^0 of rotation.
- At solar noon, as the sun's rays are in line with the local meridian, the hour angle is zero.

- **It is positive in the afternoon and negative in the forenoon. Thus, it is -90^0 at 06:00 hrs. and +90^0 at 18:00 hrs.**

$$\boldsymbol{\omega = [Solar\ Time - 12:00](in\ hours) \times 15\ degrees}$$