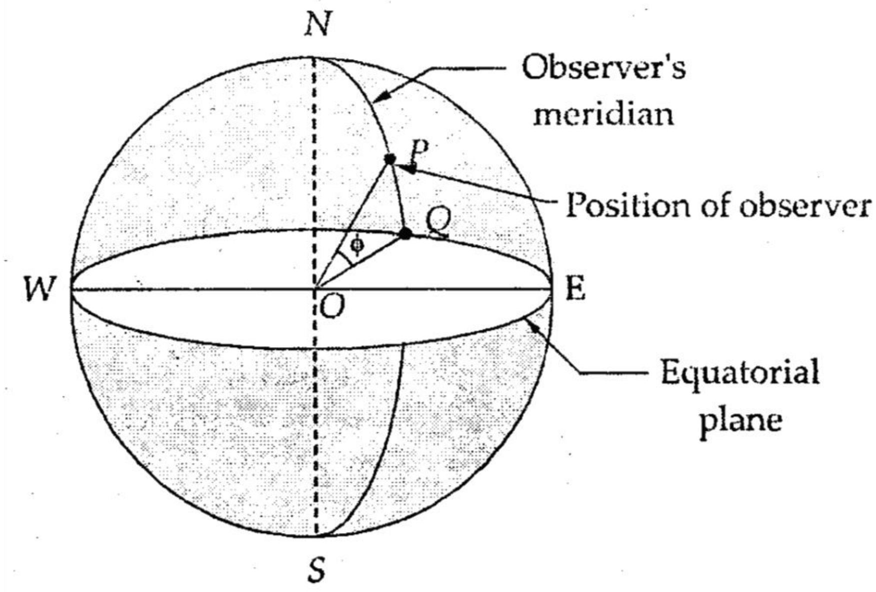
BASIC SUN-EARTH ANGLES

Latitude angle ≻

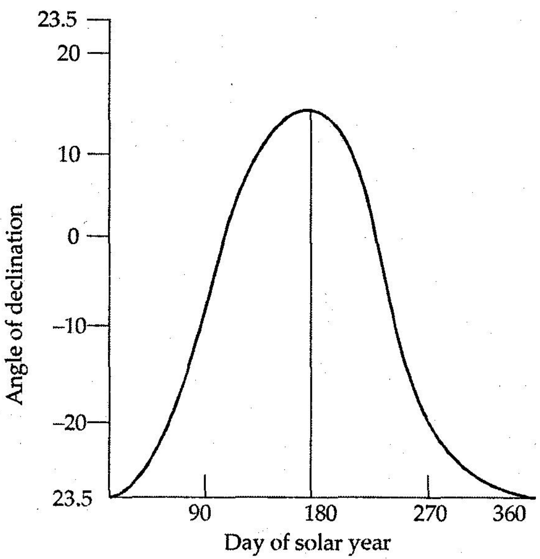
Angle made by radial line joining the given location to the centre of earth with its projection on the equator plane. Latitude angle is denoted by

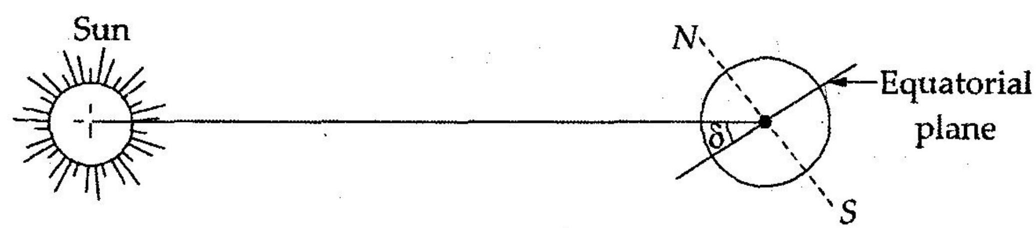
It is Positive in northern hemisphere and negative in southern hemisphere.



Declination angle ( )

It is the angular displacement of the sun from the plane of earth's equator. It is positive when measured above the equatorial line in the northern hemisphere.





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

where n is day of the year counted from 1st Jan. For example the value of n on June 21 in 1980

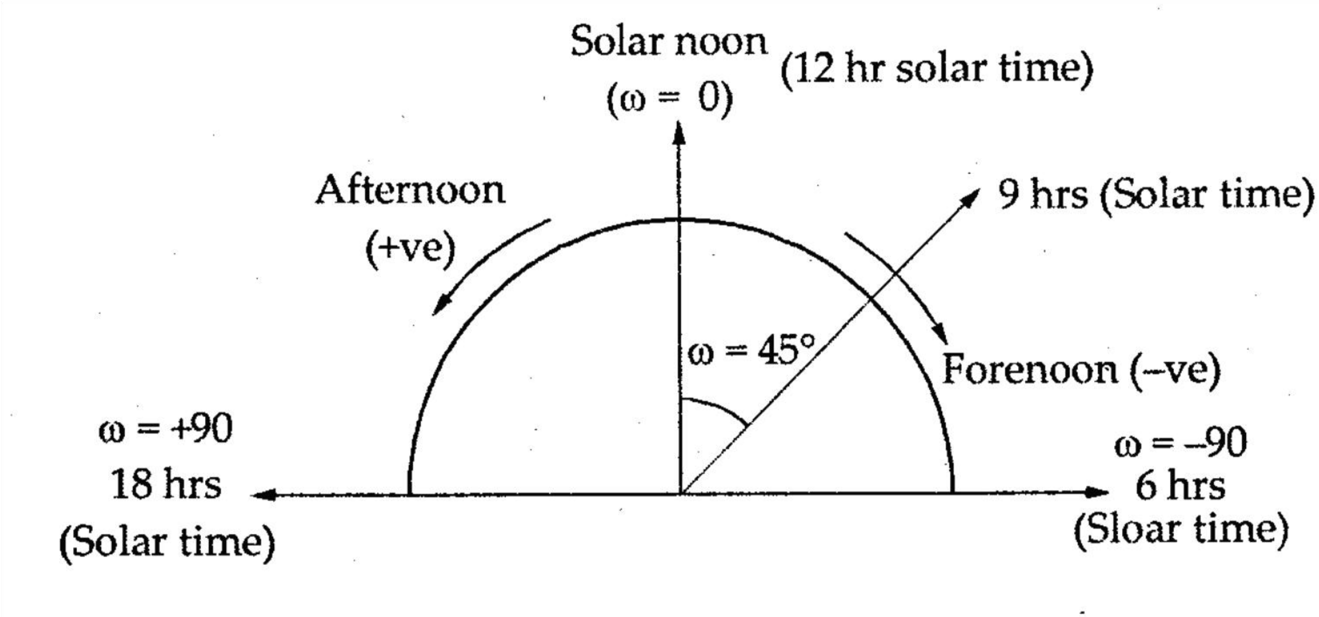
$= 31 + 29 + 31 + 30 + 31 + 21 = 173.$

Hour angle

It is the angular displacement of sun towards the east or west of local meridian (Due to rotation of earth about its axis) at any moment. Since the earth rotates about its axis once during 24-hours, therefore

$$w \text{ (hour angle)} = \frac{360}{24} = 15°/\text{hr}$$

Hour angle



local is negative in fornnoon and positive in afternoon. Thus at 6 Hrs. (A.M.) it is -90 and at 18 hrs(PM) it is $+90$.

Inclination Angle

The angle between sun’s rays and it’s projection on horizontal surface is known as inclination angle

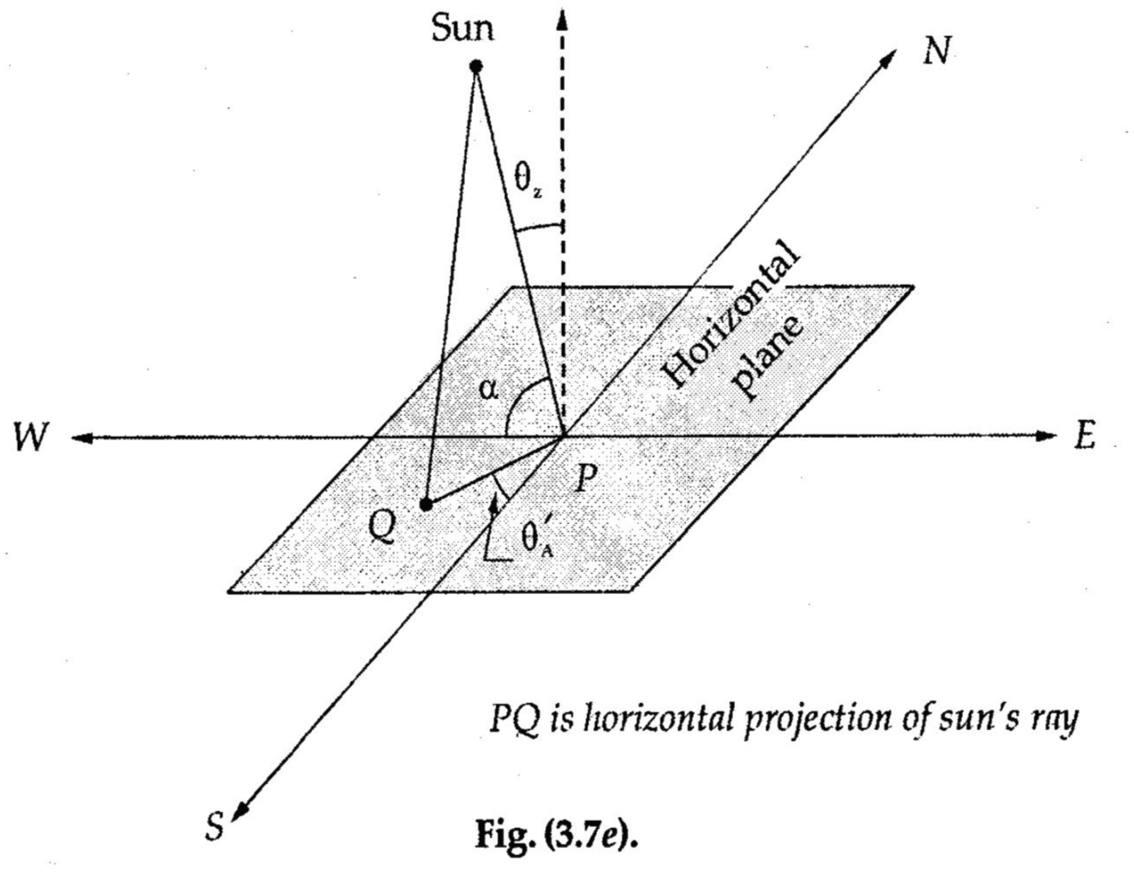


Fig. (3.7e).

Zenith Angle _z

Zenith Angle _z

It is the angle between sun's rays and perpendicular to the horizontal.

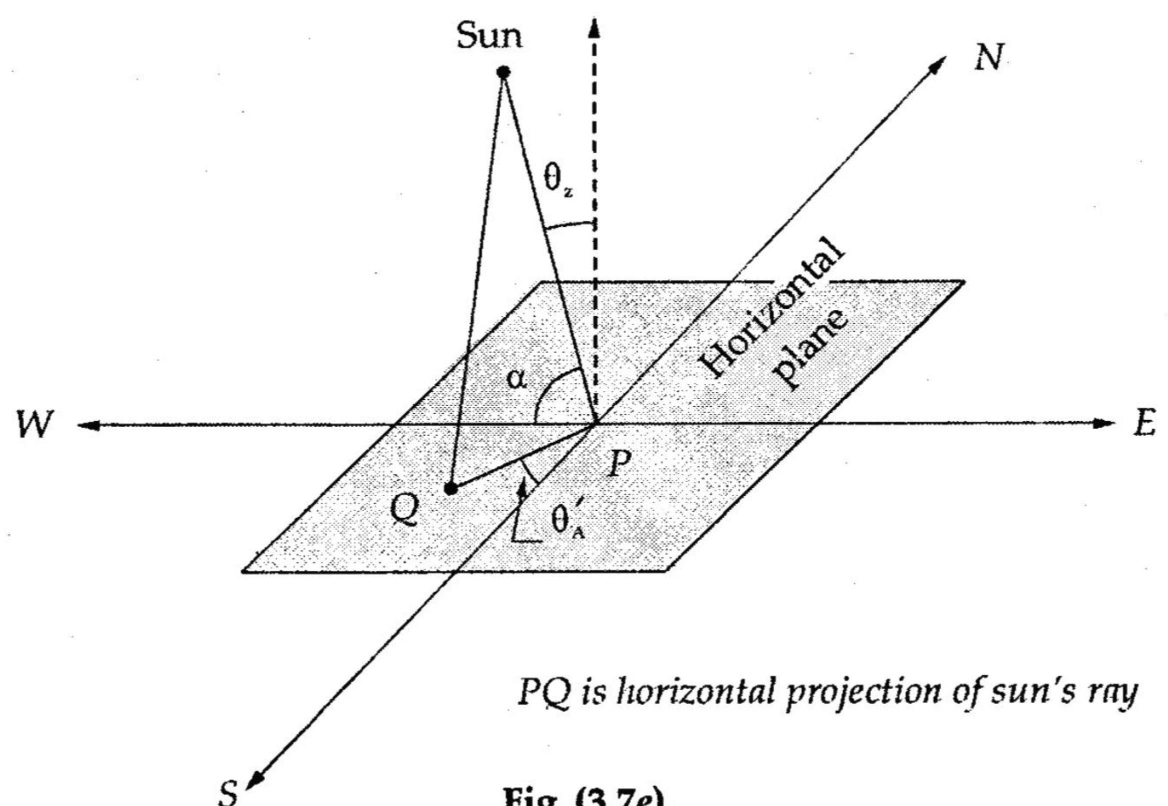
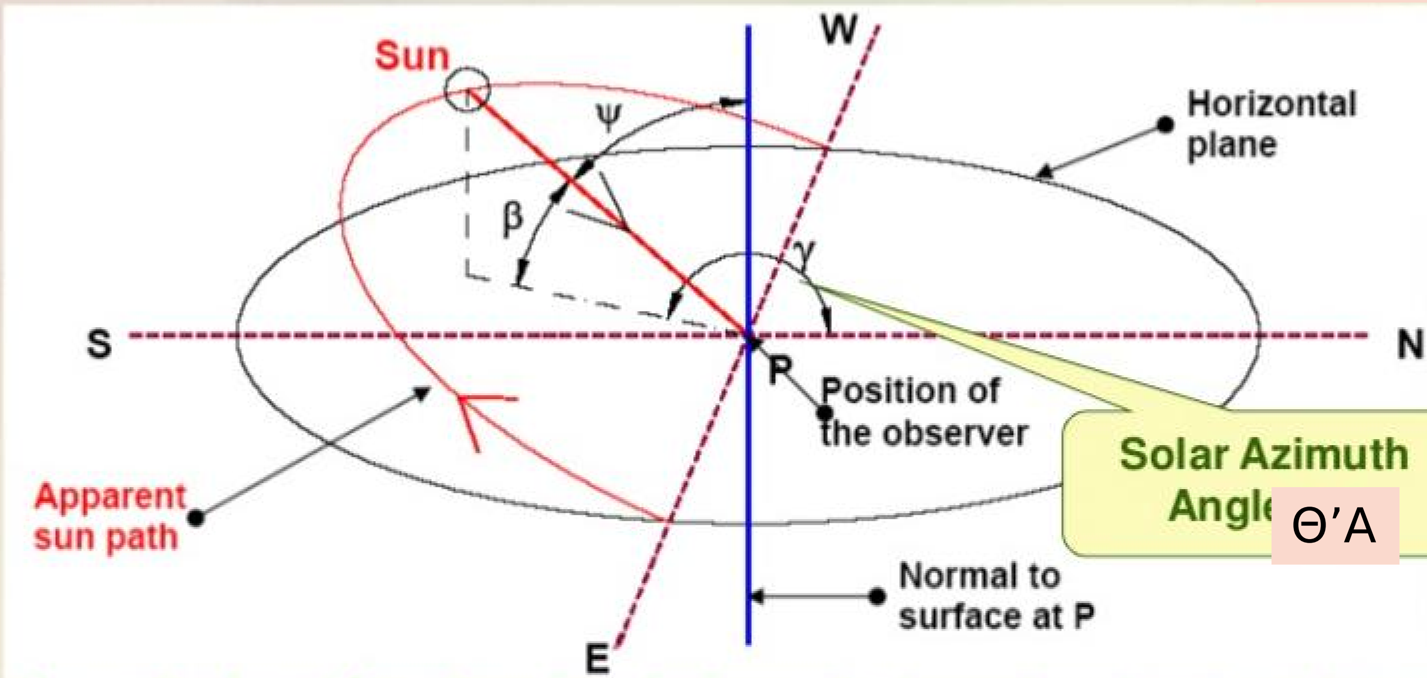


Fig. (3.7e).

Solar Azimuth Angle (_’A)

SOLAR AZIMUTH ANGLE Θ’A



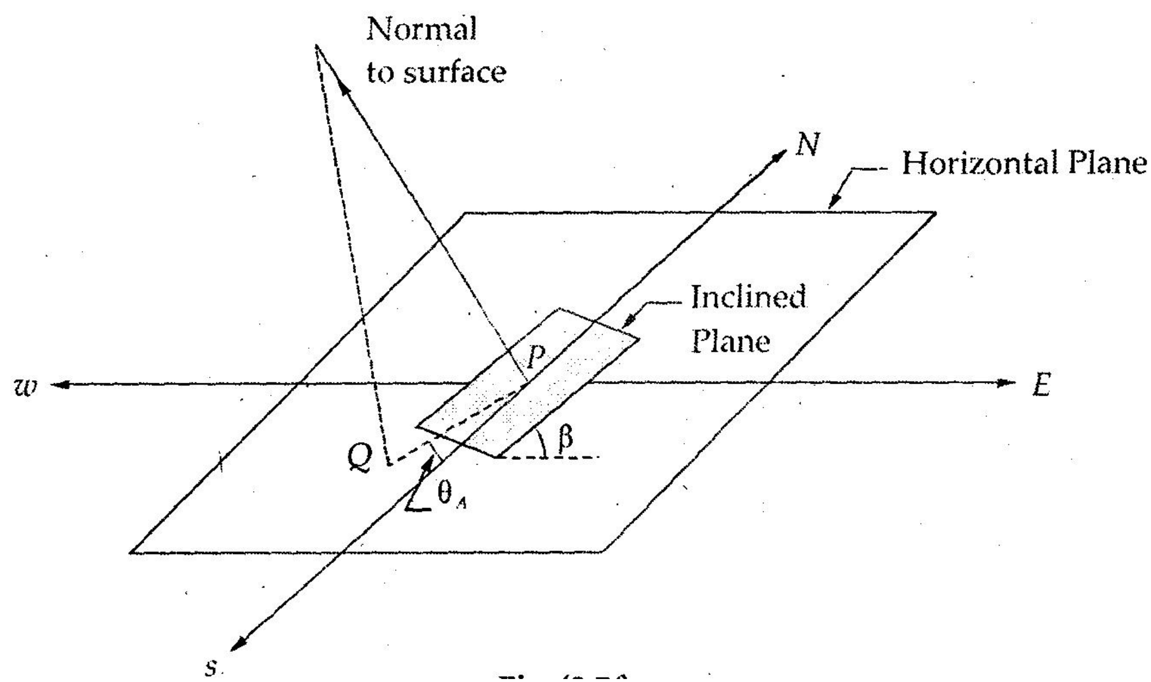
Solar Azimuth Angle Θ’A **:** Solar Angle in degrees **along the horizon east or west of North.**

It is a **horizontal angle** measured **from North** to **horizontal projection of sun’s rays**.

It is consider **+ve west-wise.**

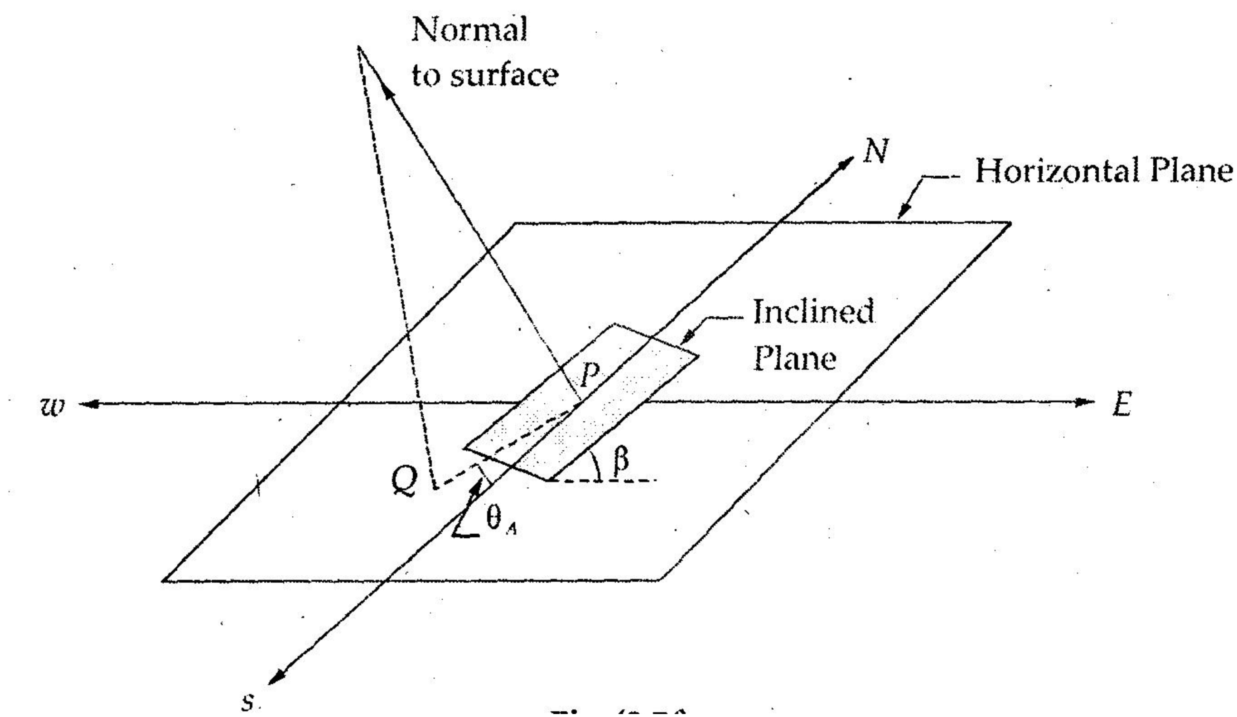
Slope of the plane (↕) or tilt angle

It is the angle between inclined plane (Collector) and the horizontal. It is taken positive(+Ve) for surface sloping towards south and negative (-Ve) for surfacing sloping towards north.



Surface azimuth angle –A

Surface azimuth angle –A : It is the angle in horizontal plane between the line due south and horizontal projection of the normal to the inclined plane (Collector). It is taken as +ve when measured from south towards west.



Angle of incidence (←i)

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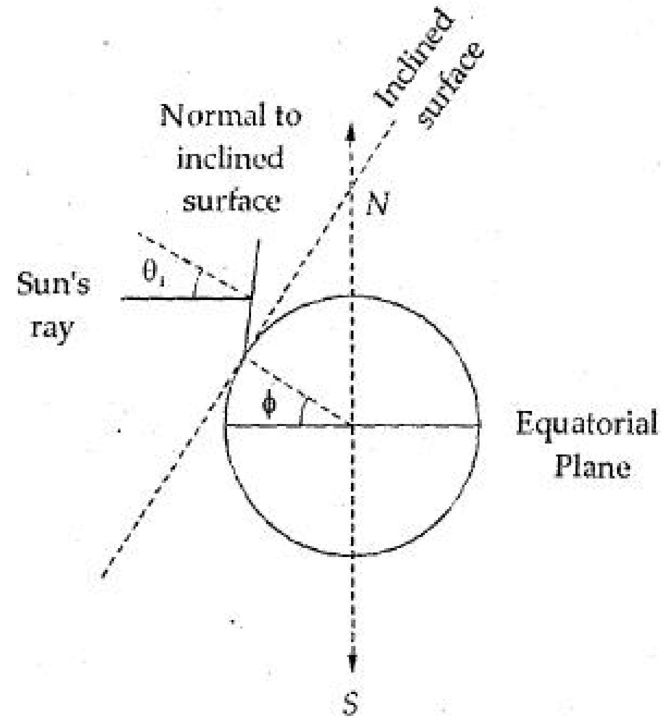
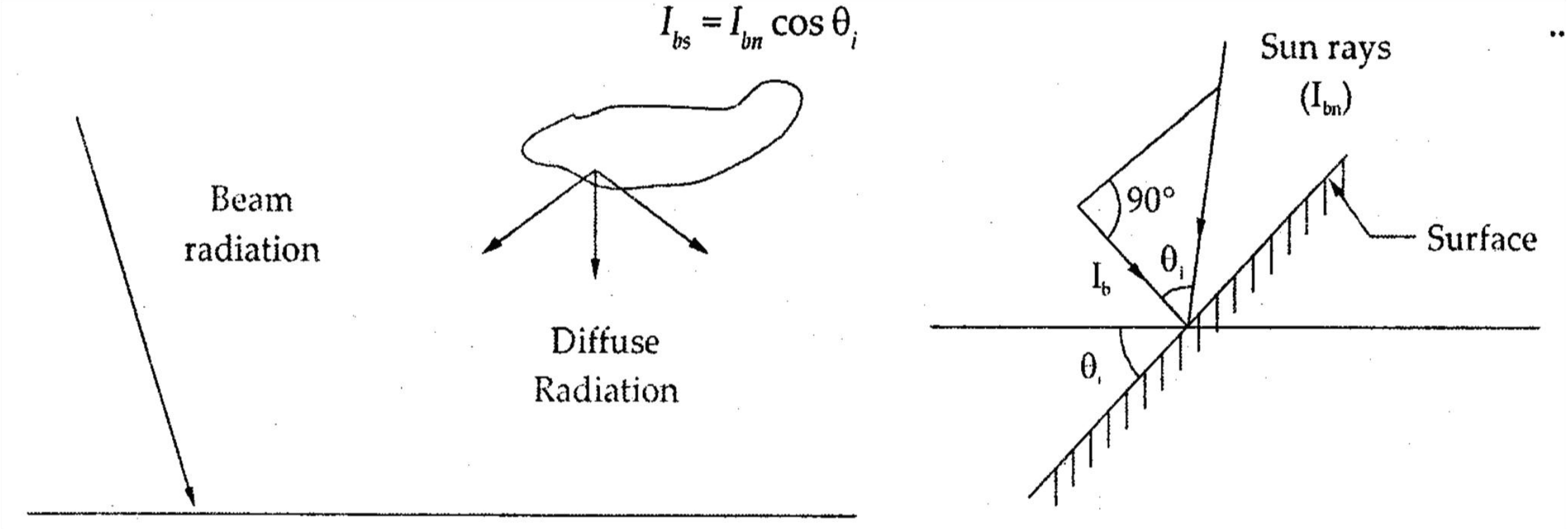
It is the angle between the sun’s rays falling on the plane surface (Collector) and normal to the surface. The incidence angle is most important as it decides how much solar energy falls on the collecting surface.



Beam and diffuse radiation



Beam radiation on inclined plane

Therefore, the angle θ_i (angle of plane on the earth surface is always related to the above mentioned angles by the following equation as

$$\begin{aligned}\text{Cos}\,\theta_i = {} & \sin\phi\,[\sin\delta.\cos\beta + \cos\delta.\cos\theta_A.\cos w.\sin\beta] \\ & + \cos\phi\,[\cos\delta.\cos w.\cos\beta - \sin\delta.\cos\theta_A.\sin\beta] \\ & + [\cos\delta.\sin\theta_A.\sin w.\sin\beta]\end{aligned}$$

where θ_2 = zenith Angle. θ_A = Axinuth angle

δ = Declination angle w = Hour angle.

ϕ = Latitude of the place where plane exits.

β = Angle made by the plane surface with the horizontal.

The azimuth angle θ_A is given by an equation

$$\cos\theta_A = \frac{\sin\delta - \sin\phi\,.\cos\theta_z}{\cos\phi\,.\sin\theta_z}$$

where θ_z (zenith angle is given by)

$$\cos\theta_z' = \sin\delta.\sin\phi + \cos\delta.\cos\phi.\cos w$$

The angles θ_A (surface azimuth angle) and β are known as derived angles and the angles ϕ, δ and w are known as basic angles

Value of Angle of incidence for any surface

This equation can be simplified for the following cases which are normally required:

1. Vertical surface ($\beta = 90°$)

$$\cos\theta_i = \sin\phi.\cos\delta.\cos\theta_A.\cos w - \cos\phi.\sin\delta.\cos\theta_A + \cos\delta.\sin\theta_A.\sin w$$

If vertical surface facing due south, then $\theta_A = 0$

$$\therefore \quad \cos\theta_i = \sin\phi.\cos\delta\cos w - \cos\phi.\sin\delta$$

2. Horizontal surface ($\beta = 0$)

$$\therefore \quad \cos\theta_i = \sin\phi.\sin\delta. + \cos\phi.\cos\delta.\cos w$$

In this case, the angle θ_i is called zenith angle and denoted by θ_z. The complement of the zenith angle is also used often in calculation. It is called solar altitude angle and denoted by α_s.

3. Surface Facing Due South ($\theta_A = 0$)

$$\cos\theta_i = \sin\phi\,[\text{Sin}\,\delta.\cos\beta + \cos\delta.\cos w.\sin\beta] + \cos\phi\,[\cos\delta.\cos w.\cos\beta - \sin\delta.\sin\beta]$$

$$= \sin\delta\sin(\phi - \beta) + \cos\delta.\cos w.\cos(\phi - \beta)$$

4. Vertical surface Facing Due South ($\beta = 90°$ and $\theta_A = 0$)

$$\therefore \quad \cos\theta_i = \sin\phi.\cos\delta.\cos w - \cos\phi.\sin\delta.$$

Sunrise, Sunset & Day–Length

SUNRISE, SUNSET AND DAY LENGTH

The period during sunrise and sunset decides the length of the day. This is essential requirement to know about the period during which sun's energy availability.

The hour angle corresponding to sunrise or sunset on a horizontal surface can be found using an equation (3.7) and substituting

$$\theta_i = \theta_z = 90$$

$$\therefore \quad 0.0 = \sin\phi . \sin\delta + \cos\phi . \cos\delta . \cos w$$

$$\therefore \quad \cos w = -\frac{\sin\phi}{\cos\phi} . \frac{\sin\delta}{\cos\delta} = -\tan\phi \tan\delta$$

$$\therefore \quad w = \cos^{-1}(-\tan\phi \tan\delta) \text{ in degrees}$$

As 15° corresponds to 1 hr, then the corresponding day length in hours in given

$$T \text{ (day length in hrs. loss)} = \frac{2}{15} w$$

$$= \frac{2}{15} \cos^{-1}(-\tan\phi . \tan\delta)$$

It is clear from the above equation that the day length depends upon the latitude of the place and solar declination.

Numerical–1

The negative sign is applicable for the eastern hemisphere.

Example 2.4.1. *Determine the Local Solar time and declination at a location latitude 23° 15′ N, longitude 77° 30′ E at 12.30 IST on June 19. Equation of time correction is given from standard table or chart = –(1′ 01″).*

Solution. ∴ The local solar time

$$= \text{IST} - (\text{Standard time longitude} - \text{longitude of location}) + \text{Equation of time correction}$$

$$= 12^h\, 30^1 - 4\,(82°\,30' - 77°\,30') - 1'\,01''$$

Indian Standard Time (IST) is the local civil time corresponding to 82.5° E longitude

$$= 12^h\, 30' - 4 \times 5 - 1'\,01''$$

$$= 12^h\, 8'\, 59'. \quad \textbf{Ans.}$$

Declination δ can be obtained by Cooper's equation *i.e.*,

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

$$= 23.45 \sin\left[\frac{360}{365}(284 + 170)\right]$$

(n is the day of the here = 170 on June 19)

$$= 23.45 \sin 86°$$

$$= 23.43°. \quad \textbf{Ans.}$$

or

$$= 23°\, 25'\, 56''.$$

Example 2.4.2. Calculate the angle made by beam radiation

Numerical-2

or

Example 2.4.2. *Calculate the angle made by beam radiation with the normal to a flat collector on December 1, at 9.00 A.M., solar time for a location at 28° 35′ N. The collector is tilted at an angle of latitude plus 10°, with the horizontal and is pointing due south.*

Solution. $\gamma = 0$ since collector is pointing due south. For this case we have the equation

$$\cos \theta_T = \cos (\phi - s) \cos \delta \cos \omega + \sin (\phi - s) \sin \delta$$

Declination δ can be obtained with the help of Cooper equation on December 1, $n = 335$.

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

$$= 23.45 \sin \left[\frac{360 \times (284 + 335)}{365} \right]$$

$$= -22.11°.$$

Hour angle ω corresponding to 9.00 hour = 45°.

Hence

$$\cos \theta_T = \cos (28.58° - 38.58°) \cos (-22.11°)$$
$$\cos 45° + \sin (-22.11°) \sin (28.58° - 38.58°)$$
$$= \cos 10° \cos 22.11° \cos 45° + \sin 22.11° \sin 10°$$
$$= 0.6451 + 0.0653$$
$$= 0.7104$$
$$\theta_T = 44.72°. \quad \textbf{Ans.}$$

Assignment

Q 1. Define the following:

Latitude Angle

Declination Angle

Hour Angle Inclination Angle

Zenith Angle

Solar Azimuth Angle

Surface azimuth angle

Angle of incidence

Q 2. Write a note on Sunrise, Sunset and Daylenth.