Zenith angle (θ_z): It is the angle between the sun ray and the zenith. (Zenith is a vertical line extending from the horizontal surface at the point where the east-west and North-South axis intersect.

The complement of Zenith angle is the SOLAR ALTITUDE ANGLE (α)

$$\boxed{\theta_z = \pi/_2 - \alpha.}$$

SOLAR AZIMUTH ANGLE (γ_s): It is the angle between the horizontal projection of the sun's rays and the due-south line going in a clockwise direction.

SURFACE AZIMUTH ANGLE: (γ): It is the angle made between the horizontal projection of the normal to the tilted surface and the due south line measured in a clockwise direction.

By convention, the azimuth angles are taken to be positive when measured south to east and negative when measured south to west.

Angle of declination (δ) : It is the angle between the sun's rays and earth's equator. It is the angle made by the line joining the centres of the sun and the earth with its projection on the equitorial plane, This angle is made as the earth rotates about a titled axis, which is about 23.5° with a vertical passing through the earth. The declination angle varies between

$\delta = +23.45°$ on June 21

$\delta = -23.45°$ on December -21

$\delta = 0$ on two equinox days (march 21 and september 22).

The declination angle for any given day of the year can be obtained by cooper's equation

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

where n = day of the year.

slope (β) :- It is the angle made by the plane surface (receiving the solar radiation) with the horizontal. It is taken as positive for surfaces sloping towards the south, and negative for surfaces sloping towards the north.

Latitude angle (ϕ):- It is the angle made by the radial line joining the location of the centre of the earth with the projection of the line on the equatorial plane. Generally the Latitude is measured as positive for northern hemisphere.

Hour angle (ω): It is a measure of time and is equivalent to 15° per hour.

It is the angle measured from noon based on the local solar time (L.S.T) or Local apparent time, being positive in the morning and negative in the afternoon.

$$\boxed{\omega = 15(12 - L.S.T) \text{ degrees.}}$$

Note { points to remember }.

The earth is divided into 360° imaginary longitudinal lines.

From one longitude to the next

$1^\circ = 4$ min.

$360^\circ = 24$ hours

1 hr = 15 degree.

1 degree = 4 minutes

} to be remembered (pre-requisite).

LOCAL Apparent time: It is the time required to calculate the hour angle.

Local apparent time (Local solar time) doesnot coincide with the local clock time. This solar apparent time or LAT can be obtained based on 2 corrections

(1) The first correction is due to the difference in longitude between the location and the meridian on which the standard time is fixed. Thus the correction is 4 minutes for every degree difference in the longitude.

(2) The second correction is due to the perturbations in the earth's orbit and the rate of rotation. This correction is based on experimental results.

LOCAL APPARENT TIME = standard time ±4(standard time longitude − longitude of location) + equation of time correction.

Note: standard time longitude = 82.5°E for I.S.T (Indian standard time).

{this value will not be given in the question, but you are required to know}, Problems

Calculate the declination angle at New delhi ($28^\circ 35'N$, $77^\circ 12'E$) on Dec 1.

Solution: here December 1; $n = 335$.

By cooper's equation the angle of declination can be calulated as

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

$$\boxed{\delta = -22.11^\circ.}$$

cooper's equation

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

where n = day of the year.

$\therefore$ for $\boxed{\text{Dec 1 } n = 335}$

Determine the local apparent time and declination angle at a location latitude $23^\circ 15' N$, longitude $77^\circ 30' E$ at 12:30 I.S.T on June 22, Equation of time correction = $-(1'01'')$.

In the problem the value of $\phi = 23^\circ 15' N.$ (ii)

Latitude angle $(\phi) = 23^\circ 15' N.$

this data is not required to find the declination angle.

Declination "δ" can be calculated using Cooper's equation

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

$$= 23.45 \sin\left\{\frac{360}{365}(284+173)\right\}$$

$$\delta = 23.44^\circ \quad = 23^\circ 26' 53''.$$

To find L.A.T

LAT = I.S.T − 4(standard time longitude − longitude of location) + equation of time correction

$$= 12{:}30 - 4(82^\circ 30' - 77^\circ 30') - 1'01''$$

$$= 12{:}30 - 4(5) - 1'01''$$

$$= 12{:}30 - 20' - 1'01'$$

$$LAT = 12\,h\,30' - 20' - 1'01'$$

$$\boxed{L.A.T' = 12h\,8'\,59''}$$

* **Hour angle (ω):-** Hour angle (ω) is a measure of time and is equivalent to 15° per hour. It is measured from noon based on the local solar time (L.S.T) or Apparent time, being positive in the morning and negative in the afternoon.

$$\boxed{\omega = 15(12 - LST) \text{ degrees}}$$

(#) Calculate the hour angle (ω) for 11:00AM at Bengaluru.

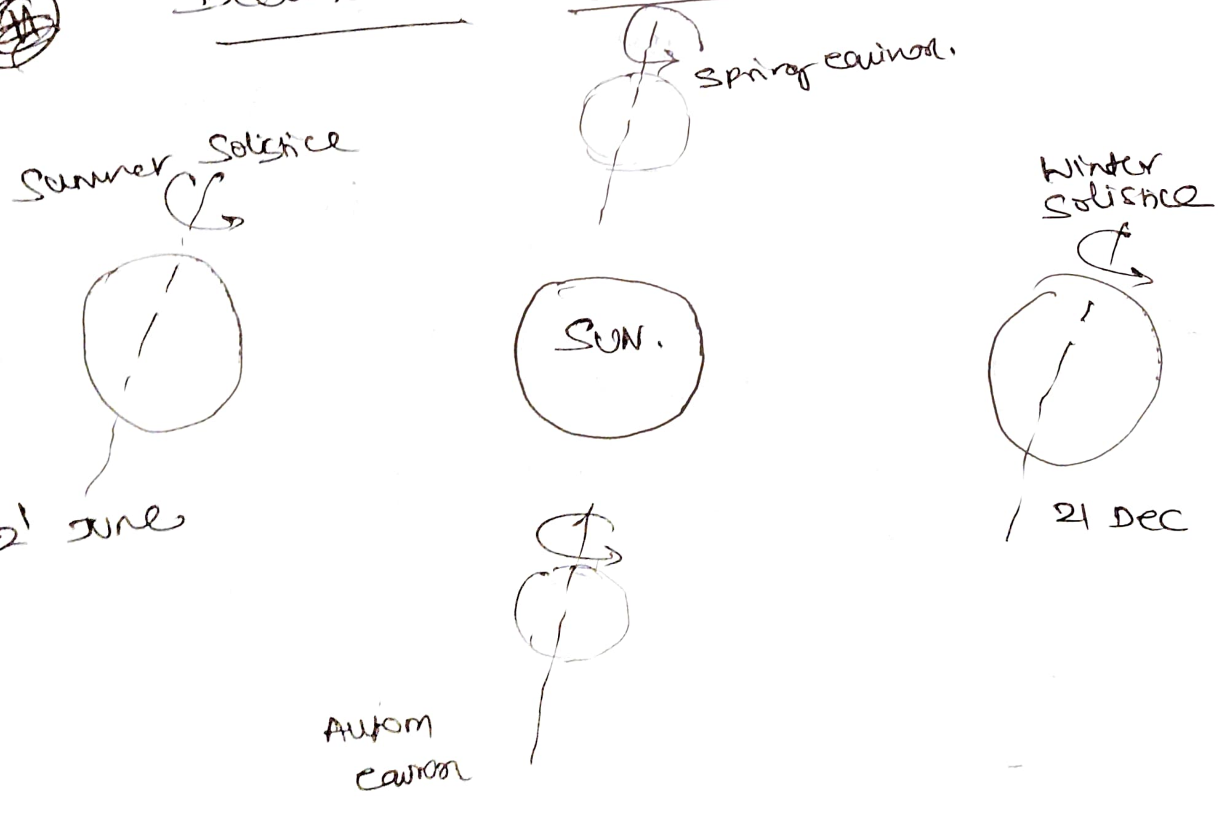
Soln

$\omega = 15(12 - L.S.T)$ degrees.

$\omega = 15(12 - 11) = 15°$.

$\therefore \boxed{\omega = 15°}$

(#) Declination angle on equinox days



SOLAR RADIATION MEASUREMENT.

Pyrheliometer:- It is an instrument used to measure beam radiation.

PYRANOMETER:- It is an instrument used to measure diffuse radiation.

Explain Angstrom type pyrheliometer.

In this type of pyrheliometer, a thin blackened shaded manganin strip is heated electrically until it is at same temperature as that of the strip which is exposed to solar radiation. Under steady state condition the energy used for heating is equal to the solar energy absorbed. The Thermocouple on the back of each strip connected in opposition through sensitive galvanometer are used to test for the equality of temperature. The energy "H" of direct radiation is calculated by means of formula.

$H_{DN} = ki^2$.

Where H_{DN} = Direct radiation incident on an normal to sun rays.

i = Heating current in amperes.

K = instrument constant.

$= R/w\alpha$

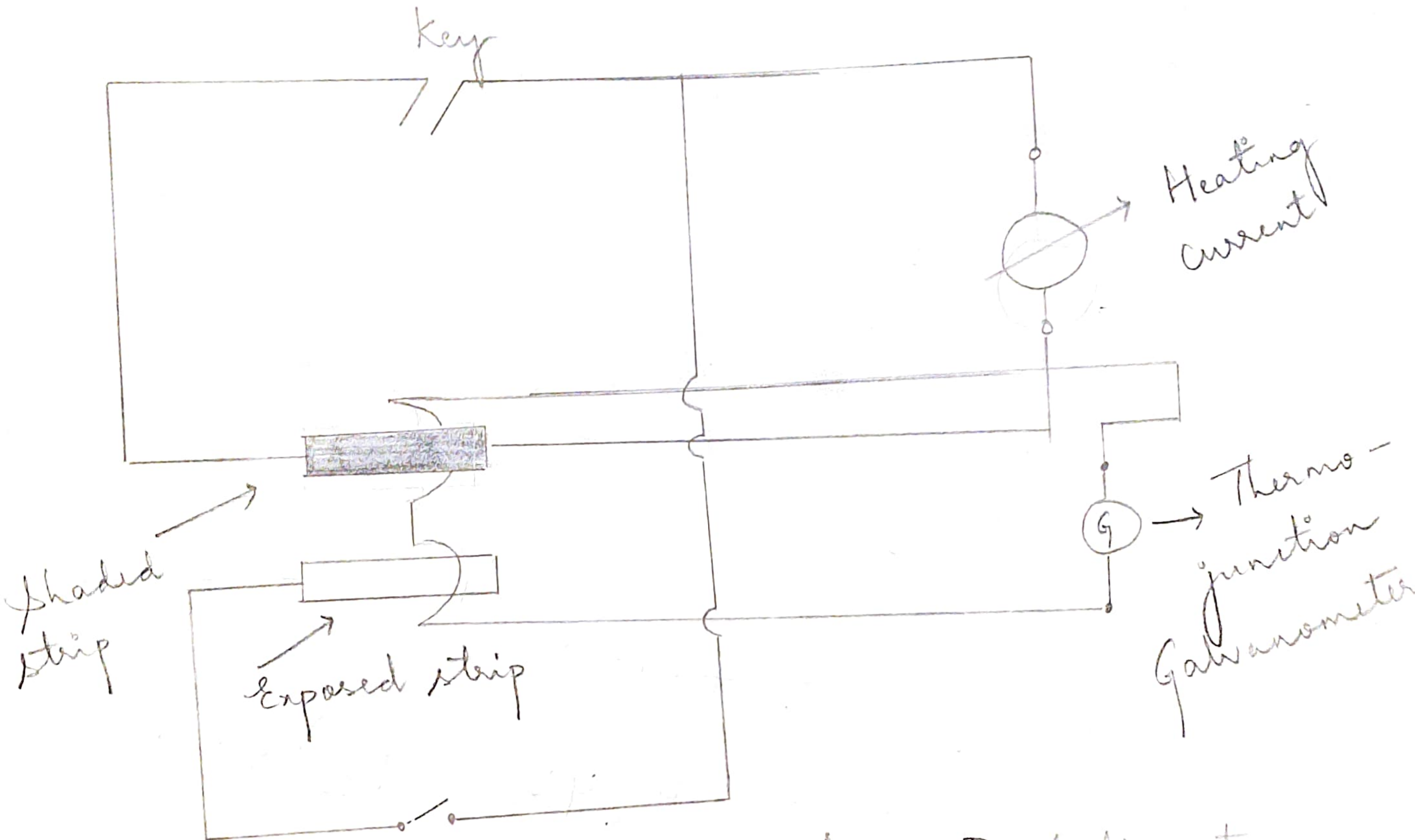
where $R \rightarrow$ Resistance/unit length of the strip (Ω/cm)

w = mean width of the strip

α = absorbing co-efficient of the strip.

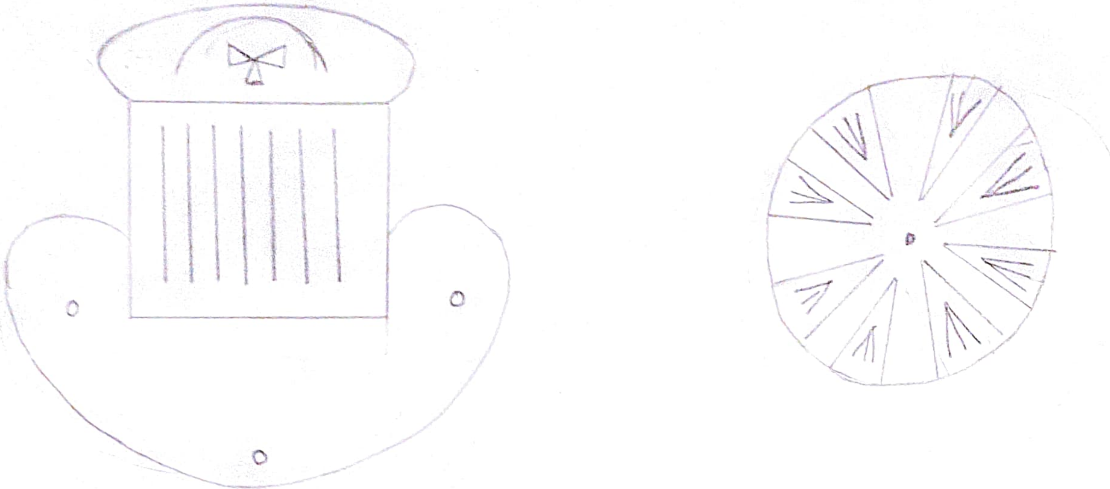
Difference between pyrheliometer and pyranometer

Pyrheliometer	Pyranometer
1) It is the instrument used to measure beam radiation	(1) It is an instrument used to measure diffuse radiation
2) The sensor disc is located at the base of the tube to avoid diffuse	(2) A shading ring is attached to avoid the beam radiation from the sensor surface
3) Direct solar radiation is measured by attaching the instrument to an electrically driven equational mount for tracking the sun.	(3) The sun radiation is made to fall on the black surface to which hot functions of a thermopile are attached.
	Accuracy $\pm 2\%$



Electric circuit for Angstrom Pyrheliometer

PYRHELIO METER.



Pyranometer with alternate black and white sensor segments

Local apparent time :

$$LAT = IST - 4(\psi_{std} - \psi_L) + E.$$

E = Equation of time Correction

$$E = 9.87 \sin 2B - 7.53 \cos B - 1.5 \sin B$$

$$B = (n-81)\left(\frac{360}{364}\right).$$

Degree minute seconds to Degrees

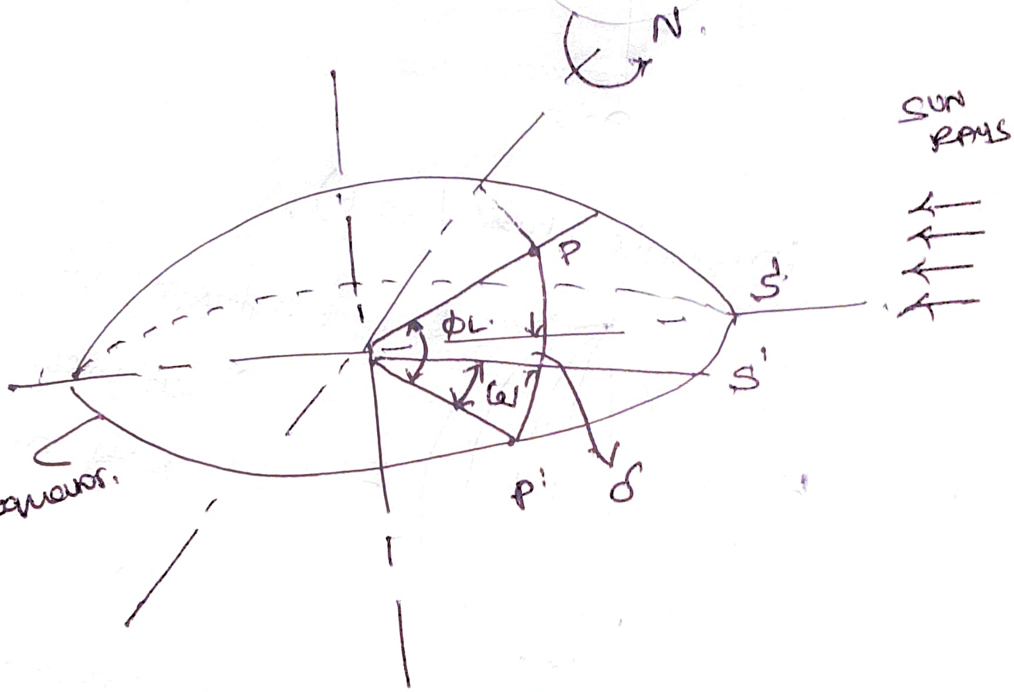
$1 \text{ hr} = 15^\circ$

$$45^\circ\, 28'\, 32'' = 45 + \frac{28}{60} + \frac{32}{3600}$$

$$= 45.4756^\circ$$

longitude is measured in degrees east (or) west of prime meridian. half of the world is measured in degrees of east longitude upto 180°. other half in degrees of west longitude upto 180°.

SOLAR Radiation geometry.



ϕ_L = latitude of location.

δ = declination.

ω = hour angle

γ_s = solar azimuth angle

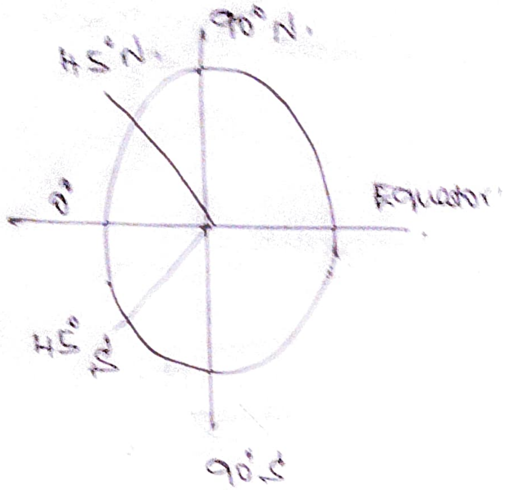
s = slope.

α = altitude angle

θ_z = zenith angle.

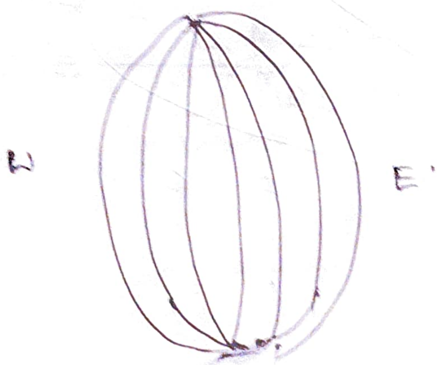
Longitudes & Latitudes.

Latitudes. (North/South).



Latitude varies from 0° at the equator to 90° north and south at the poles.

Longitude (West/East).



Longitude varies from 0° at Greenwich to 180° East and West.

Longitude & Latitudes are imaginary (unreal) lines drawn on maps to easily locate places on the Earth.

Prime meridian (an imaginary line running from north to south through Greenwich, England)

Equator is the line of 0° latitude.

45° 28' →

= 45.475

PROBLEMS ON SOLAR GEOMETRY.

1) Calculate hour angle when it is 3 h after solar noon?

Solution: Hour angle (w) = 15 × (ts − 12)

Solar time = 12 + 3 = 15:00

Therefore, hour angle (w) = 15 × (ts − 12) = 15 × (15 − 12) = 45.

2) Calculate the declination angle delta on JUNE 1, 2012.

Solution:

The declination on June 1 (n = 153)

Delta = 23.45 × sin [360 × (284 + 153)/365] = 22.17°

****

LOCAL SOLAR TIME=Standard time ± 4 × (LSTM − Longitude of location (LOL) + EOT

In India, standard time is based on 82.5°E. Twelve noon LST is defined as when the sun is the highest in sky. LSTM = Local standard meridian time zone = 82.5°E (in India) LLOL = Longitude of location in degrees EOT = EOT in minute.

The hour angle increases by 15o every hour. An expression to calculate the hour angle from solar time is, $\omega = 15 \times (t_s - 12)$ (Where ts is the solar time in hours.

$w = 15 \times (ts - 12)$; (in degrees)

Where, ts is the solar time in hours.

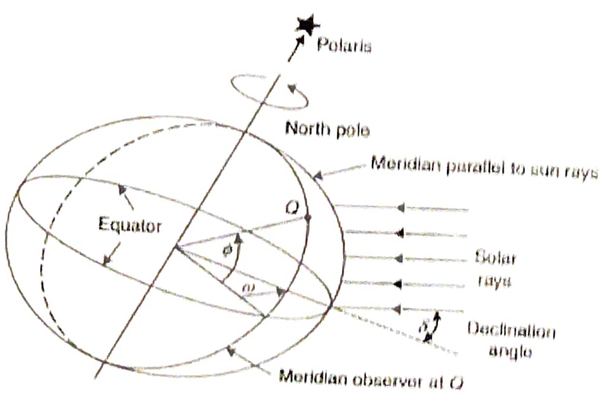
Hour angle (w) can be calculated simply as follows:

Since the earth makes one revolution on its axis in 24 h, then 15 minutes will be equal to 15/60 = 1/4 min

Therefore, $w = 1/4 \times tm$; (in degrees) .

Where, tm is the time in minutes after local solar noon. w will be +ve if solar time is after solar noon.

w will be –ve if solar time is before solar noon.



Polaris is so **important** is because the axis of Earth is pointed almost directly at it.

Equation of Time

FORMULAS USED

EOT = 9.87 sin 2B – 7.53 cos B – 1.5 sin B.

B = 360 (n – 81)/365; (in degrees).

Another formula equation for EOT

- EOT = 9.8 × sin (2A) + 7.6 × sin (A – 0.2)

A = K × (n + 10) + 0.033 × sin [K (n – 2)] K = 2p/365 .

n is the total number of days of the year .

(e.g., n = 1 on Jan 1 and n = 33 on Feb 2).

Another formula equation for EOT.

$$EOT = 0.258 \times \cos(\alpha_d) - 7.416 \times \sin(\alpha_d) - 3.648 \times \cos(2\,\alpha_d) - 9.228 \times \sin(2\,\alpha_d);$$

(in minutes).

Where the angle (α_d) is defined as a function of n.

$\alpha_d = 360 \times (n - 1)/365.242$; (in degrees)

n = the number of days counted from January 1

For a city located at 80.50 longitudes, calculate the solar time on March 15, 2011, at 10:30 am Indian Standard Time.

The standard meridian for IST zone is 82.50 E. Total Number of days on March 15 counted from January 1, 2011, n = 74.

, B = 360 (n – 81)/365 B = 360 (74 – 81)/365 = –6.9 (in degrees).

EOT = 9.87 sin 2B – 7.53 cos B – 1.5 sin B =

9.87 × sin (–2 × 6.9) – 7.53 cos (–6.9) – 1.5 sin (–6.9) = –9.65 min.

LST = Standard time ± 4 × [LSTM – Longitude of location (LOL)] + EOT.

LSTM = 82.5°E; LLOL = 80.5°; standard time = 10:30 am.

LST = 10:30 – 4 × (82.5 – 80.5) + (–9.65) = 10:30 – 17.65 = 10:12.35 am

Equinox : The time or date (twice in each year) at which the sun crosses the celestial equator when day and night are approximately equal length (about 22 sept & 20 march).

Solstice: → one of the two times of the year resulting in most amount of day light time or least amount of daylight time in a single day. Solstices mark the start of summer & winter.

Dec - 21/22 → The winter solstice is the day with fewer hours of sunlight in the whole year making shortest day

Summer solstice → longest day June 20, 21 or 22
sun reaches northern most point from in 2023 equator.

6

PAGE
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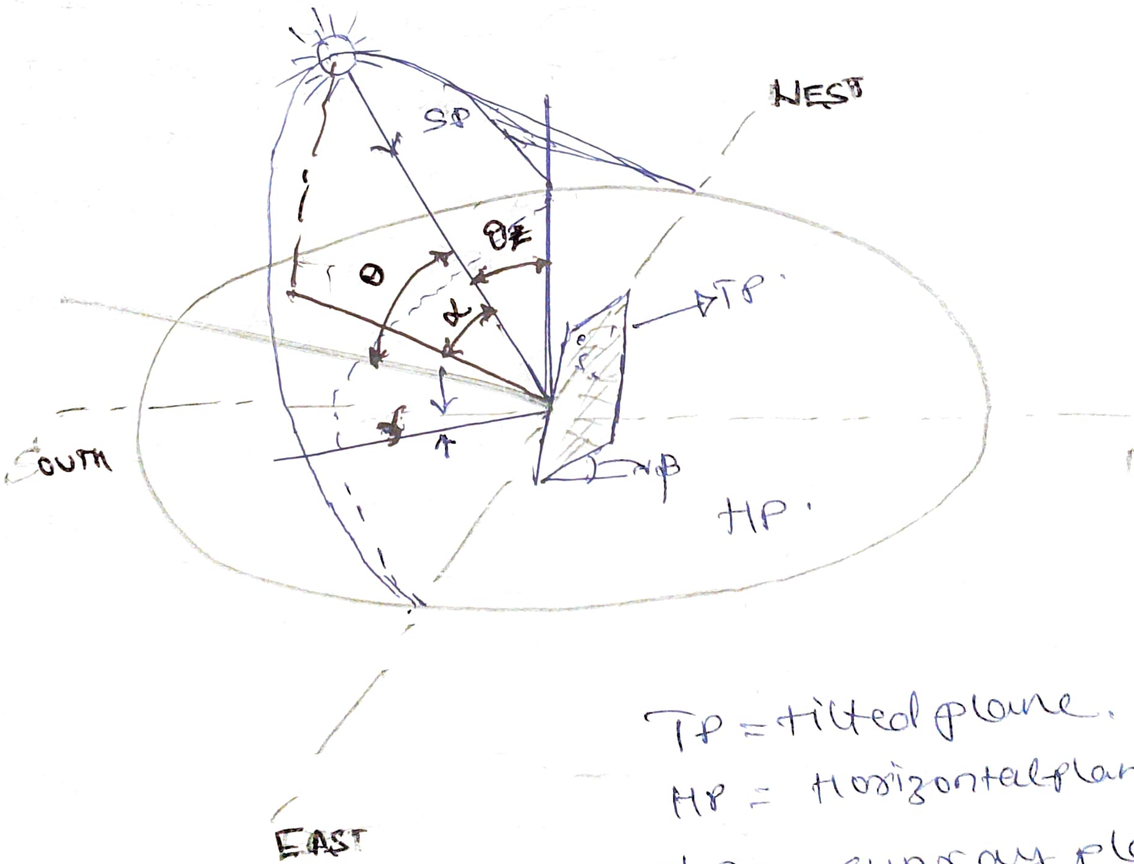
(#) Calculate the "δ" for beam radiation
(2) on December 1.

Soln Declination angle "δ" can be obtained with the help of cooper equation.

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

$$= -22.11^\circ //.$$



TP = tilted plane.
HP = Horizontal plane.
S.P = sunray plane.

consider a horizontal plane (HP) on the earth's surface. let the sun rays pass through a plane (S.P). {sunray's plane} consider a tilted plane (TP) on which the sun rays are falling.

with reference to these planes the different solar angles can be defined as follows.

PAGE:
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Incident angle 'θ' :- It is the angle mode between the incident beam and the normal to the tilted plane. If I = Intensity of solar radiation, with incident angle θ, then the flux or radiation intensity falling normal to the surface is given by $I\cos\theta$.

Altitude angle or solar altitude angle. (α).
It is the vertical angle mode between the projection of the sun's rays on the Horizontal plane and the direction of the sun's rays.

ZENITH ANGLE (θ_z) :- It is the angle b/w sun ray and the zenith.

zenith : It is a vertical line extending from the horizontal surface at the point where east - west and north - south axis intersect.).

solar altitude angle (α) is the complement of the zenith angle.

$$\boxed{\theta_z = \pi/2 - \alpha.}$$