UNIT - 1 : FUNDAMENTALS OF ENERGY SYSTEMS.

Introduction :-

Energy is derived from the greek word en-ergon. which means "In-work" or "work content".

→ Any activity physically done wheather by human beings or by nature is caused due to the flow of energy.

" Energy can be neither be created nor be destroyed but it can transfer from one form to the another form".

→ Energy is required for economic growth & development of a country.

→ Before the industrial revolution which began around 200 years ago people dependent on manual & animal Labour. Life was simple, un sophisticated & environment was relatively clean.

→ In 1785 Invention of steam engine by James watt of scotland brought industrial revolution. It is the beginig of mechanical age of machines.

→ In 18th, 19th century development of internal combustion engines was a new trend.

→ Industrial revolution spread to the whole wold gradually.

→ In 1888 Nikolaq Tesla invented commercial Induction motoqs. The introduction of electrical machineqs along with commercial availability power started the new electrical age.

→ All these lead to the increaqe of energy requirementqs.

→ By the begining of industrial revolution & the discovery of steam engine man began to use new source of energy namely coal in large quantitieqs.

→ By the development of internal combustion engineqs man began to uqe oil & natural gaqs.

→ A new source of energy called nvcleas energy came after the second world war.

⊛ Human - Energy sectoqs :-

→ Human activitieqs requiring energy are

⊛ Domestic sectoq (houses & officeqs)

⊛ Transportation sectoq

⊛ Agricultural sectoq

⊛ Industry sectoq

→ Every country draws its energy needs from a veriety of sourceqs. They are commercial & non commercial.

⊛ commercial :-

→ Fosil fuels [coal, oil, natural gas]

→ Hydro electric power

→ Nuclear power
→ Wind power

* Non commercial :-

→ Wood
→ Animal wastes
→ Agricultural wastes

* classification of Energy Resources :-

→ Based on the usability of energy

① Primary Resources :-

Resources available in nature in raw form are called primary energy resources. These are known as raw energy resources.

→ These are located, extracted, processed & are converted from one form to the another form.

* Energy yeild ratio = $\frac{\text{Energy recieved from raw energy source}}{\text{Energy spent to obtain raw energy source.}}$

② Intermediate Resources :-

This is obtained from primary energy by one or more steps of transformation.

③ Secondary Resources :-

The form of energy which is finally supplied to consumer for utilization is known as secondary or usable energy.

Ex :- Electrical energy, Thermal energy [In the form of steam or hot water].

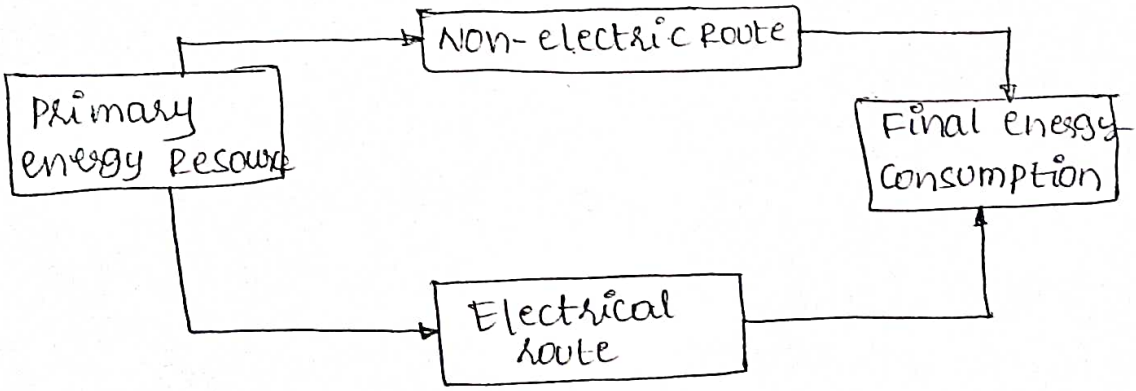
Energy chain :-

Primary energy $\xrightarrow{\text{Processing}}$ Electrical energy

Electrical energy $\xrightarrow{\text{Transmission}}$ Consumer

Primary energy $\xrightarrow{\text{Processing}}$ Secondary energy

Secondary energy $\xrightarrow[\text{Rail, Road, Ocean}]{\text{Transported by}}$ Consumer



(*) Fossil fuels :-

① Coal :- Coal is the end product of natural process of decomposition of vegetables, matter burried in the earth without oxygen for thousand of years.

② Natural gas :- Natural gas is a mixture of various compounds of carbon & hydrogen & small quantities of non-hydro-carbons existing in the liquid & gaseous form.

③ Water power :- (&) Hydro power :-
Water power is developed by allowing water to fall under the force of gravity. It is used for electrical power generation. [16%]

④ Nuclear power :- Nuclear power is developed by fission reactions in nuclear reactor. It is used for power generation.

II. Based on Traditional Use :-

a) Conventional :- Energy resources which are being traditio - nally used for many decades. Ex :- Fossil fuels, nuclear & hydro resources.

b) Non-conventional :- Energy resources which are considered for large scale use Ex :- Solar, wind, biomass etc.

III. Based on long term availability :-

a) Non-Renewable :- Resources are finite & do not get replenished after their consumption. Ex :- fossil fuels, uranium etc.

b) Renewable :- Resources which are renewed by nature again & again & their supply is not affected by the rate of their consumption. Ex :- solar, wind, ocean, etc.

IV. Based on commercial application :-

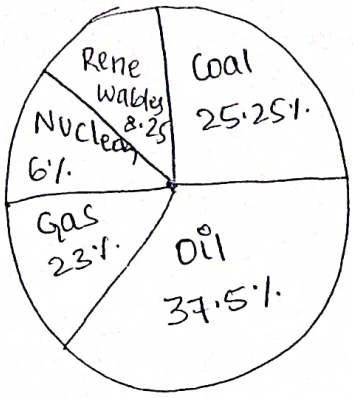
a) commercial Energy Resource :- The secondary usable energy forms such as Electricity, petrol, diesel, gas etc.

b) Non-commercial Energy :- The energy derived from nature & used directly. Ex :- wood, animal, crop residue et.

V. Based on origin :-

1. Fossil fuels energy
2. Nuclear energy
3. Hydro energy
4. solar energy
5. wind energy
6. Geothermal energy
7. Ocean wave energy
8. Tidal energy etc.

⊛ Consumption of Energy Resources.



Renewables

Biomass 4%
Solar heat 0.5%
Geothermal 0.2%
Solar PV 0.05%
Hydro 3%
Wind 0.3%
Biofuel 0.2%

⊛ Sector wise Energy consumption :-

Sector	% Energy consumption
Industry	49%
Transport	22%
Domestic	10%
Agricultural	5%
Others	14%

Total = 100%

⑧ Various Aspects of Energy conservation :-

Saving of usable energy, which is otherwise wasted, has direct impact on the economy.

Energy conservation implies reduction in energy consumption by reducing losses & wastage.

① Economic aspect :-

a) Reduction in cost of Product :-

We must strive for good economy using energy - efficient technologies. This will reduce the manufacturing cost & leads to production cheaper & better quality products.

b) New equiment replacement :-

→ Replace the old inefficient by efficient equipments for energy conservation.

II. Environmental Aspect :-

Every type of energy generation (or) utilization process affects the environment to some extent, either directly or indirectly. Adoption of Energy conservation means can minimize this damage.

III. Conservation of Non-Renewable Energy Assects :-

→ The vast bulk of energy used in the world today comes from fossil fuels, which are non-renewable.

→ These are depleting day by day. so these consumption must be reduced.

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(*) Principles of Energy Conservation :-

The various energy conservation principles are

① Recycling of waste :

It helps in reusing a material as energy source, without excess loss of energy.

→ This facilitates in saving the energy & minimising the waste disposal problem.

② Modernization of Technology :-

It reduces the energy consumption. Developed countries are using modern & more efficient equipments, which consumes less energy.

Ex :- energy consumption of indian steel industry is 9.50 million Kcal per ton, where as Italy & Japan uses 4 million Kcal per tonne.

③ Waste Heat utilization :-

Various industrial processes require heat of different grades. The waste heat released by one process may be useful for other process.

Ex :- In glass Industry, the glass is melted with high grade heat of 1500°c & releases waste heat in the form of flue gases about 400°c to 500°c. The heat from flue gases is utilised for generating electric power.

④ Proper House keeping

⑤ Proper use of Types of Energy :-

Some of the energy forms are

① Electrical energy [Top-grade energy]

② Mechanical energy

③ Thermal energy.

For economic reasons, depending upon the requirement, energy must be suitably used.

6. Proper use of type of fuel :-

Costly sources can be replaced by the cheaper sources

Ex:- oil & gas can be replaced by coal & bio fuels.

7. Cogeneration :-

It means generation of useful heat & electricity at a time, in a single system. This reduces the fuel consumption.

8. Training of man power :-

Proper training should be given to man power, so that the energy is used efficiently.

9. Adopting Daylight saving time :-

It is adopted for reducing the energy consumption during summer season in every year.

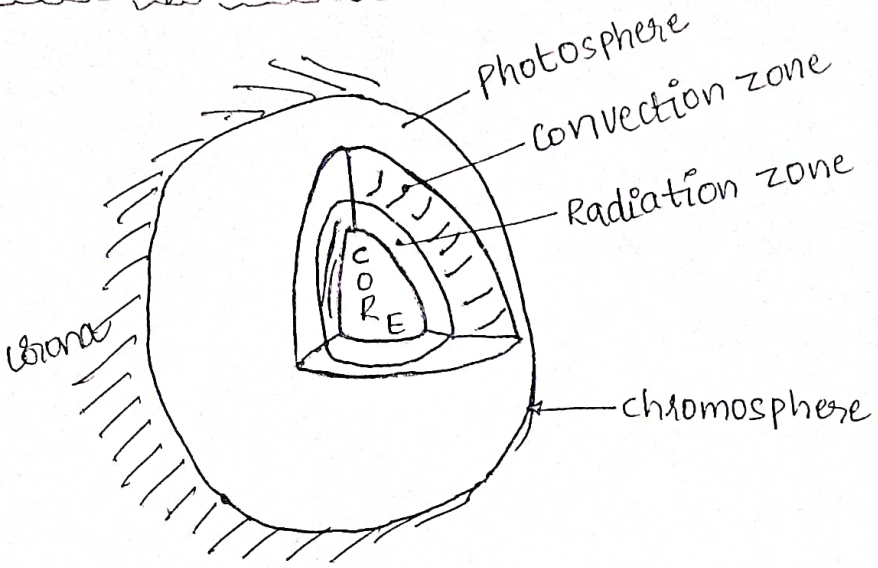
→ It refers effective utilisation of day light hours, for performing activities, there by reducing the consumption of energy.

10. Proper operation & maintenance :-

→ Leakages must be carefully avoided.

* Proper lubrication should be maintained in moving parts.

The structure of the sun :-



CORE :- The sun core has a tremendously high temperature & pressure. the temperature is about 15 million°c. At this temperature nuclear fusion occurs hydrogen is turning into helium plus lot of energy.

→ This hydrogen burning releases gama rays. & neutrons.

Radiation zone :-

Energy travels in the form of electromagnetic radiation as light. The temperature ranges from 15 million°c to 1 million°c.

The convection zone :-

The photons are coming outwards via convection. The temperature ranges from 1 million°c to 6000°c.

The photosphere :- This is the lower atmosphere of the sun. The layer is about 500km thick. The temperature is about 5,500°c.

The chromosphere :- This reddish layer is an area of rising temperature. The temperature ranges from 6000°c to 5000°c.

It appears in red because hydrogen atoms are in excite state & emits radiation. ©

The corona :- This is the outer layer of the suns atmosphere. The corona extends for million of miles.

⊛ The Sun-Earth Relationship :-

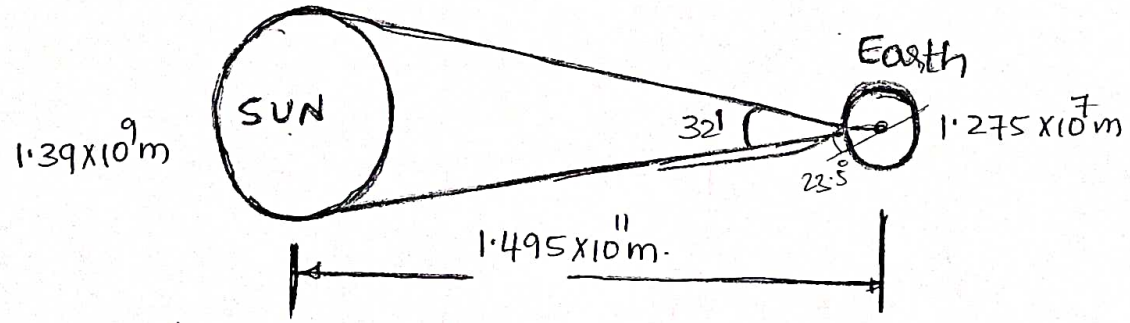
→ The sun, which is the largest member of the solar system, having a diameter 1.39×10^9 m.

→ The diameter of the earth is 1.275×10^7 m.

→ The earth makes one rotation about its axis every 24 hours & complete a revolution about the sun in a period of 365 days.

→ Its axis is inclined at an angle of 23.5°. As a result, the length of days & nights keep changing.

→ The earth reflects 30% of sunlight falls on it. This is known as the earth's albedo.

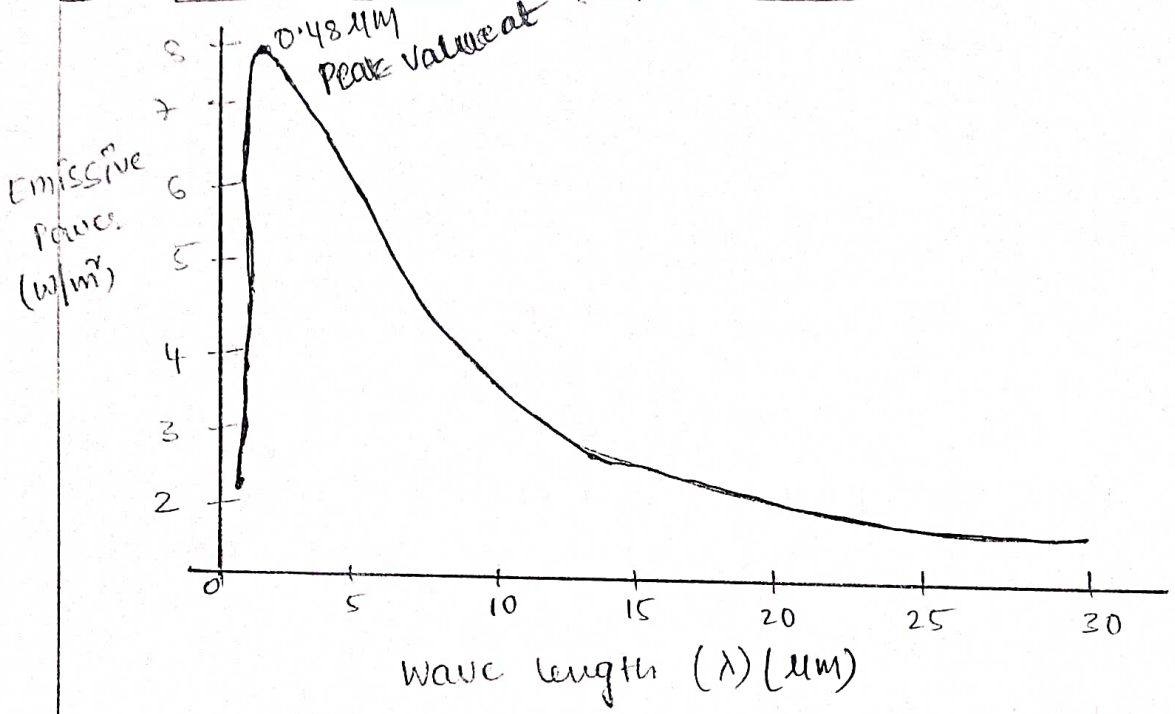


The distance between the sun & earth varies by ± 1.7%.

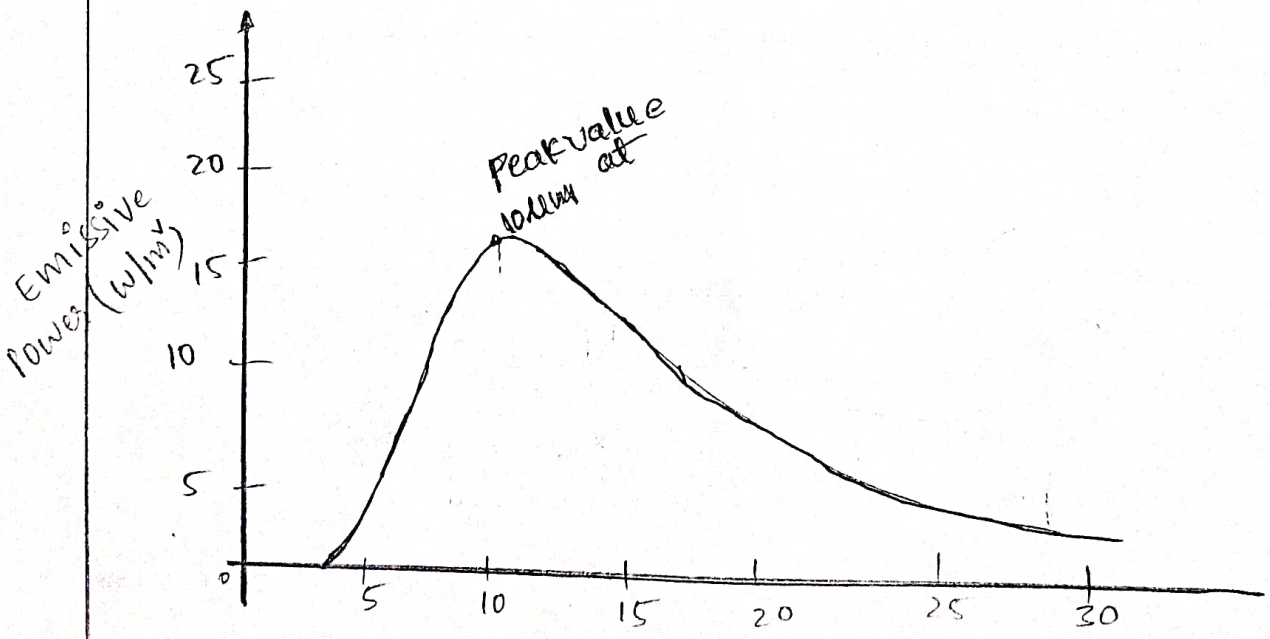
→ The sun subtents an angle of 32' on earth at an average distance of 1.495×10^{11} m. a distance of

One astronomical unit.

SUN, Earth Radiation Spectrums:



Emissive power at T = 5760°K (surface of sun)



Emissive power at T = 288°K (surface of earth)

Irradiance :-

The term Irradiance is the measure of power density of sunlight received at a location on the earth & is measured in w/m^2.

Irradiation is the measure of energy density of sun-light measured in kwh/m^2.

It is denoted by the symbol H.

Radiation :-

The energy emitted by the sun, travells in the form of electromagnetic waves as light. The temperature ranges 6000°K.

⊛ Extra Terrestrial & Terrestrial Radiations :-

→ The intensity of solar radiation keeps on attenating as it propagates away from the surface of the sun.

Extra Terrestrial :-

Solar radiation incident on the outer atmosphere of the earth is known as Extra terrestrial radiation. Iext.

* solar constant (Isc) :-

This is the amount of energy recieved in unit time on a unit area perpendicular to the sun's direction at the mean distance of the earth from the sun.

→ The value of solar constant is 1367 w/m^2.

→ The extra terrestrial radiation deviates from the solar constant value due to two reasons.

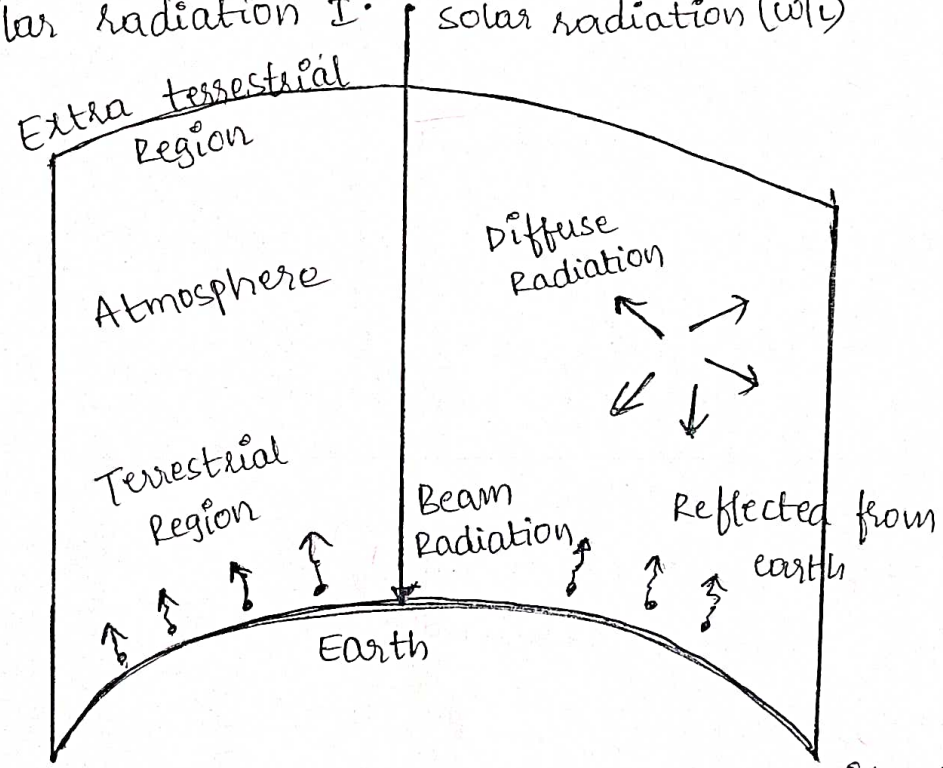
① Variation in the radiation emitted by the sun itself. (less than ±1.5%)

② Variation of the earth-sun distance. [±3%]

$$I_{ext} = I_{sc}\left[1 + 0.033 \cos\left[\frac{360n}{365}\right]\right] \text{ w/m}^2$$

where n = day of the year.

→ The earth is closest to the sun in the summer & farthest away in the winter. This variation in distance produces a nearly sinusoidal variation in the intensity of solar radiation I.



→ The extra terrestrial radiation, being outside the atmosphere is not affected by changes in the atmospheric conditions.

→ while passing through the atmosphere, it is subjected to mechanisms of absorption & scattering which depleting its intensity.

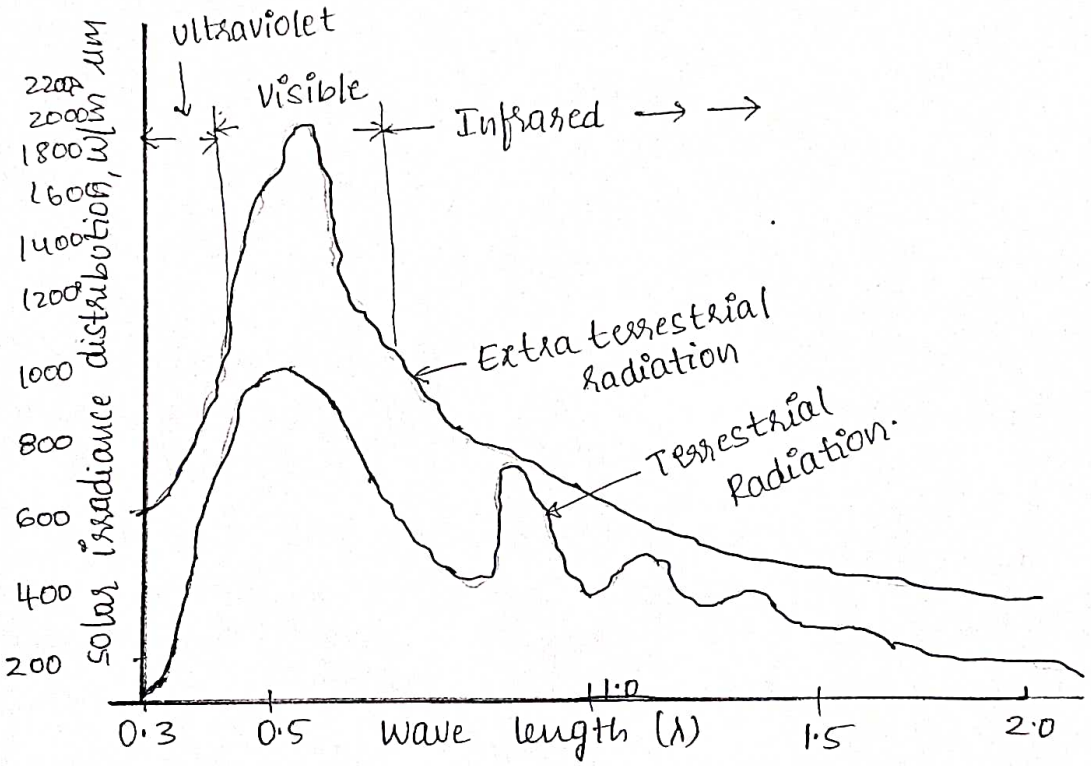
⊛ Terrestrial Radiation :- The solar radiation that reaches the earth surface after passing through the earth's &

atmosphere is known as terrestrial radiation.

Solar Insolation :-

Solar radiation received on a flat horizontal surface on the earth is called solar Insolation.

Distribution of solar Radiation :-



→ Solar Radiation covers a continuous spectrum of electromagnetic radiation in a wide frequency range.

→ About 99% of the extraterrestrial radiation has wave length in the range from 0.2 to 4 μm with maximum spectral intensity of 0.48 μm.

→ About 6.4% of Extraterrestrial radiation contained in the ultraviolet region ($\lambda < 0.38$ μm).

→ another 48% is contained in the visible region ($0.38\ \mu m < \lambda < 0.78\ \mu m$).

→ The remaining 45.6% is contained in the infrared region ($\lambda > 0.78$ μm).

→ There is almost complete absorption of short-wave radiation in range ($\lambda < 0.29$ μm).

→ Terrestrial applications of solar energy, the radiation only in the range of wave lengths between 0.29 – 2.3 μm is significant.

④ Depletion of solar Radiation:-

The earth's atmosphere contains air molecules, ozone, oxygen, carbon dioxide, carbon monoxide, water vapour, dust. Therefore, solar radiation is depleted during its passage through the atmosphere. It causes

① Absorption:-

The absorbed radiation increases the energy of absorbing molecules.

a) Nitrogen, oxygen & other atmospheric gases absorb the x-rays & ultraviolet radiations.

b) ozone absorbs a significant amount of ultraviolet radiation range ($\lambda < 0.38$ μm)

c) water vapour (H_2O) & carbon dioxide absorb infrared radiation ($\lambda > 2.3$) to some extent.

d) Dust particles & air molecules also absorb a part of solar radiation, irrespective of wave length.

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② Scattering :-

Scattering by dust particles & air molecules involves redistribution of incident energy.

In a cloudy atmosphere

① A major part of the incoming solar radiation is reflected back into the atmosphere by clouds.

② Another part is absorbed by the clouds.

③ The rest is transmitted downwards to the earth surface.

→ we have two components.

a) Beam radiation (or) Direct radiation :-

Solar radiation propagating in a straight line & received at the earth surface without ~~of~~ change of direction. is called beam (or) direct radiation.

b) Diffused Radiation :-

→ solar radiation scattered by dust & molecules is known as diffused Radiation. It does not have unique direction.

→ Global Radiation :-

The sum of beam & diffused radiation is referred as total & global radiation.

⊛ MEASUREMENTS OF SOLAR RADIATION :-

Solar Radiation data are measured mainly by the following instruments :

a. Pyranometer
b. pyrheliometer
c. Sunshine Recoder.

1. **Pyranometer :-** A pyranometer is designed to measure global radiation, usually on a horizontal surface, but can also be used on an inclined surface.

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

3. **Sunshine Recoder :-** It measures the sunshine hours in a day.

⊛ Pyranometer :-

It contains a thermopile whose sensitive surface consists of circular, blackened, hot Junctions, exposed to the sun, the cold junctions being completely shaded.

The temperature difference between the hot & cold Junctions is the function of radiation falling on the sensitive surface.

→ The instrument has a voltage up to $q\mu V/w/m^2$ & has output impedance of 650Ω.

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Pyrheliometer :-

It consists of long tube, inside of the tube is blackened to absorb any radiation incident at angles.

→ At the base of the tube a sensing element is present.

→ The instrument having a $8\mu v/w/m^2$ & an output impedance of 200Ω. 200~

(*) Sunshine Recorder :-

This instrument measures the duration in hours of bright sunshine during the course of a day. It essentially consists of a glass sphere mounted on its axis parallel to that of earth. with in a bowl.

→ The bowl & glass sphere are arranged in such a way that sun rays are focused sharply at a spot on a card.

→ The card is prepared from a special paper bearing a time scale.

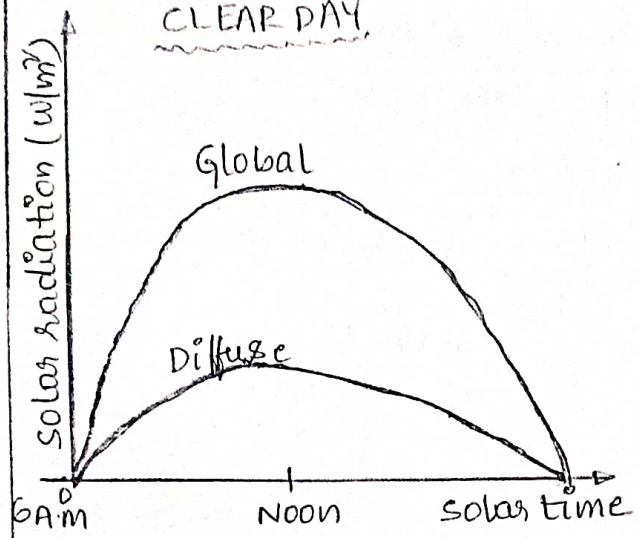
→ As the sun moves, the focused bright sunshine burns a path along this paper.

→ That length is the measure of the duration of the bright sunshine

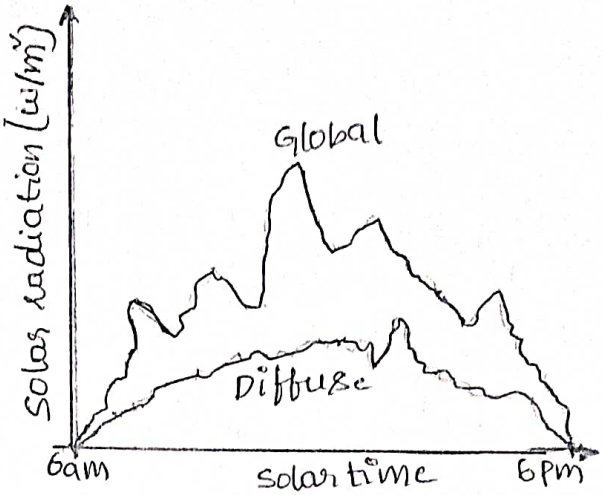
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Solar Radiation Data :-

CLEAR DAY



CLOUDY DAY



Solar time :-

Solar time is measured with reference to solar noon, At solar noon, the sun is at the highest position in the sky. The sun travers each degree of longitude in 4 minutes.

$$\text{Solar time} = \text{standard time} \pm 4\left[L_{st} - L_{Loc}\right] + E$$

$+ \rightarrow$ western hemisphere [W]
$- \rightarrow$ Eastern hemisphere. [E]

→ Equation of time [E]

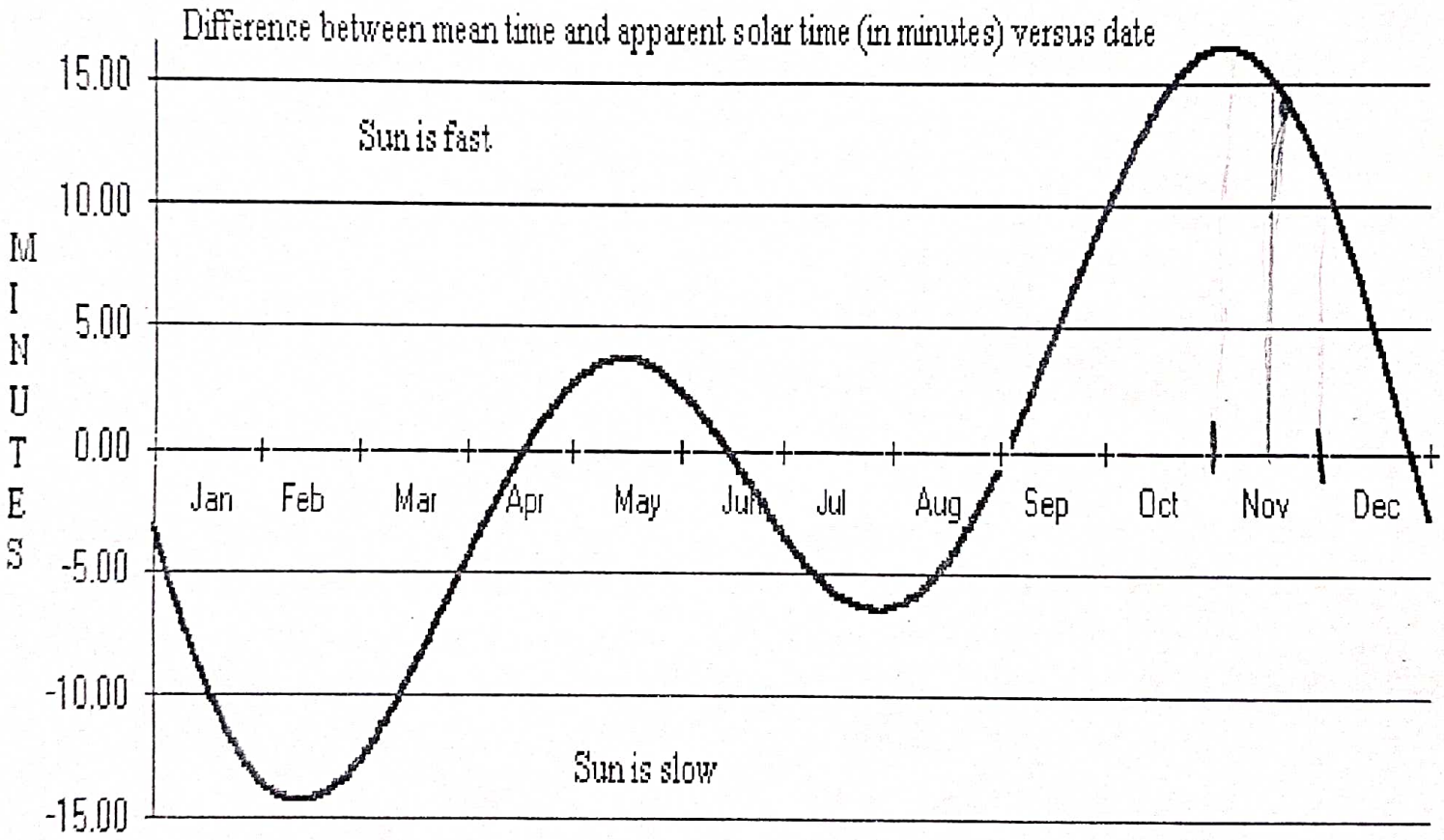
$$E = 9.87 \sin 2B - 7.53 \cos B - 1.5 \sin B \ (\text{min})$$

Where $B = \frac{360}{364}(n-81)$

n = day of the year, counting from 1st January

10.A

Graph of the Equation of Time



① Determine the local solar time corresponding to 10·AM IST on february 8 for a location at 87·5° East longitude?

Sol:- Local time = 10:00AM, longitude of location = 87·5°

n = 39, standard longitude of india = 81°54' = 81·9°

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

$B = \frac{360}{364}(n-81)$, n = day of the year

$E = -7\text{min}$

Local solar time = $10.00\text{hr} \pm 4[81.9^\circ - 87.5^\circ] - 7$

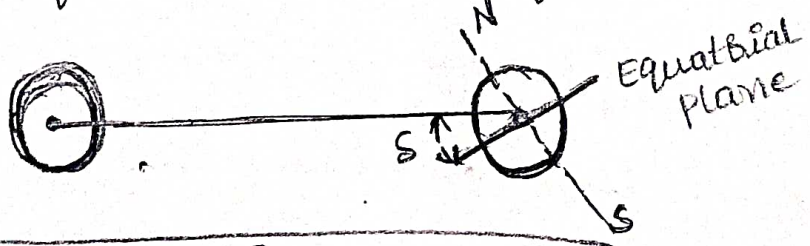
$= 10.00\text{hr} - 4[5.6] - 7$

$= 10.00\text{hr} + 22.4 - 7$

LST = 10:00hr + 15·4 = 10hr 15.4 min

⑧ 1. Declination angle :- (δ)

It is defined as the angular displacement of the sun from the plane of the earth's equator.

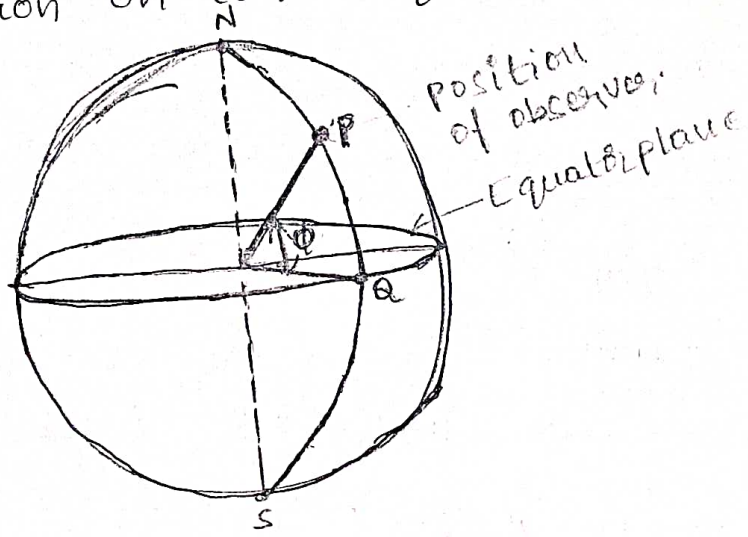


$$\delta = 23.45 \times \sin\left[\frac{360}{365}(284+n)\right]$$

where n = day of the year counted from 1st January

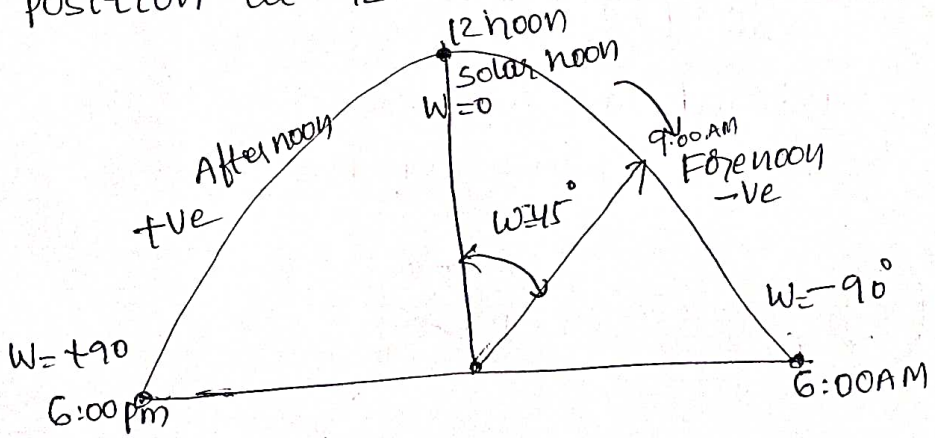
2. Latitude (ϕ):-

It is the angle made by the radial line joining from location to the centre of earth with its projection on to the equator plane.



3. Hour angle, (w):-

It is the angle representing the position of the sun with respect to clock hour with reference to sun's position at 12 noon.



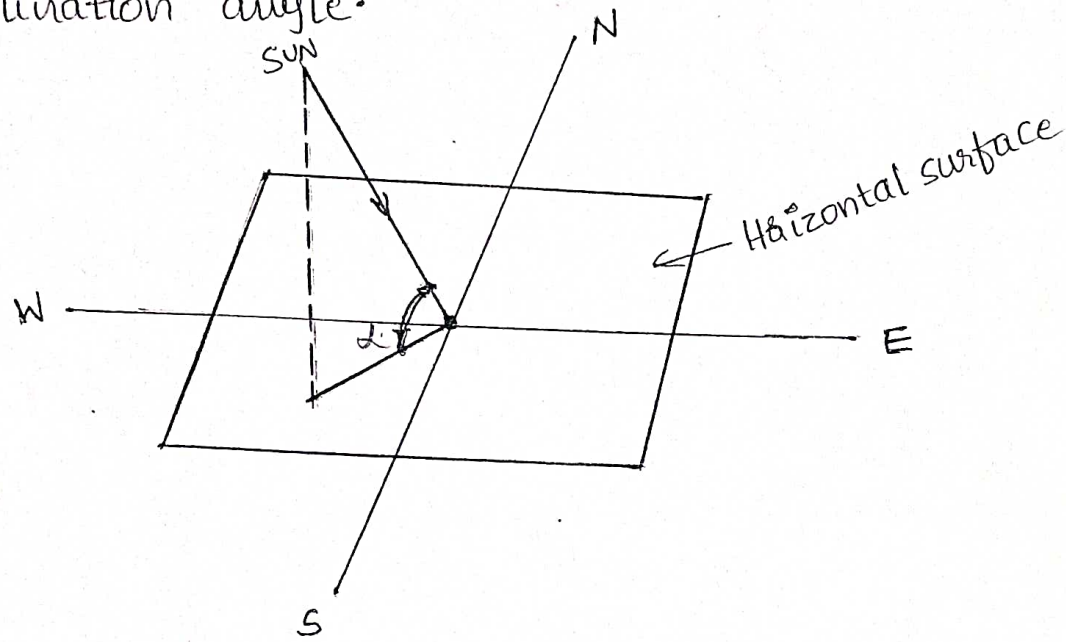
1 hr = 15°

It can be calculated as

$$w = (\text{solar time} - 12{:}00) \times 15^\circ$$

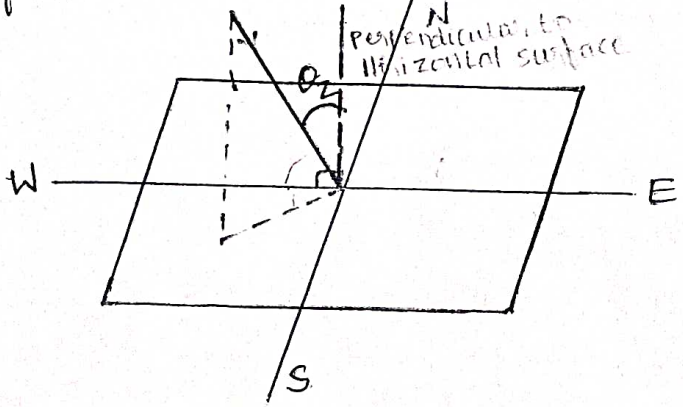
4. Inclination Angle (α) :- (altitude)

The angle between the sun's ray & its projection on a horizontal surface is known as the inclination angle.



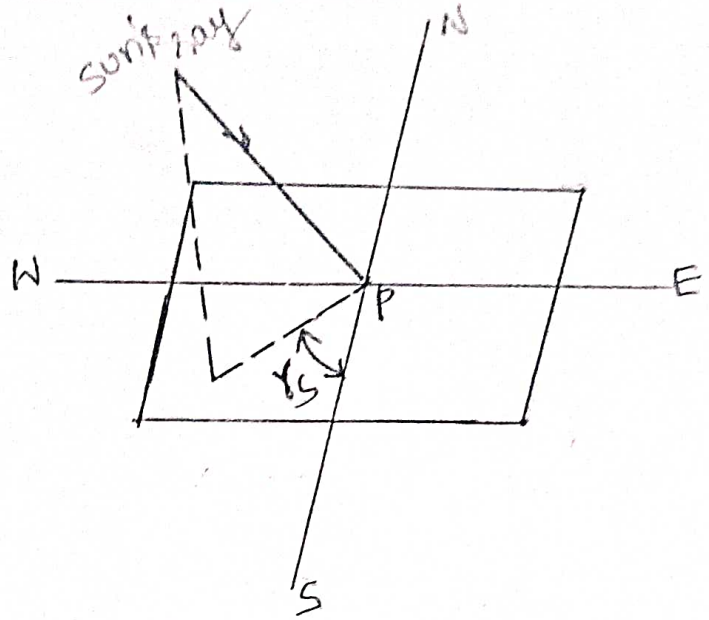
5. Zenith angle (θ_z) :-

It is the angle between the sun's ray & the perpendicular to the horizontal plane.



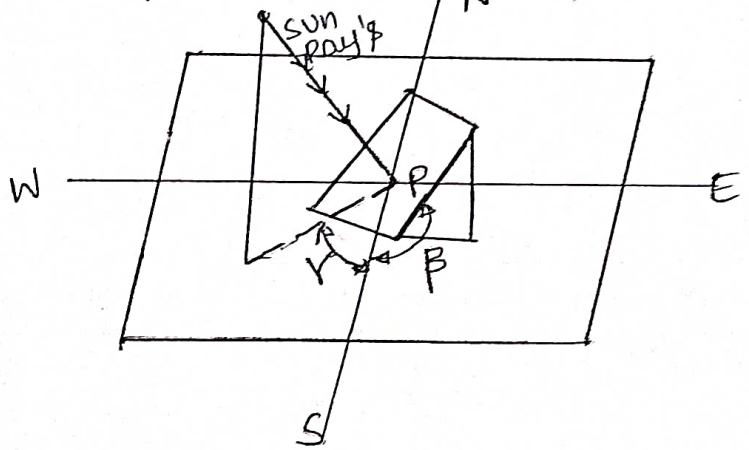
6. Solar Azimuth angle :- (γ_s)

It is the angle on a horizontal plane, between the South & the projection of sun's ray on the horizontal plane.



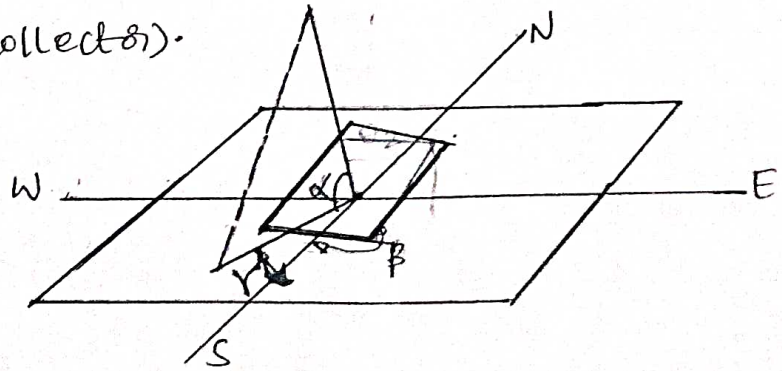
⊛7. slope (Tilt angle) β :-

It is the angle between the inclined plane surface & the horizontal.



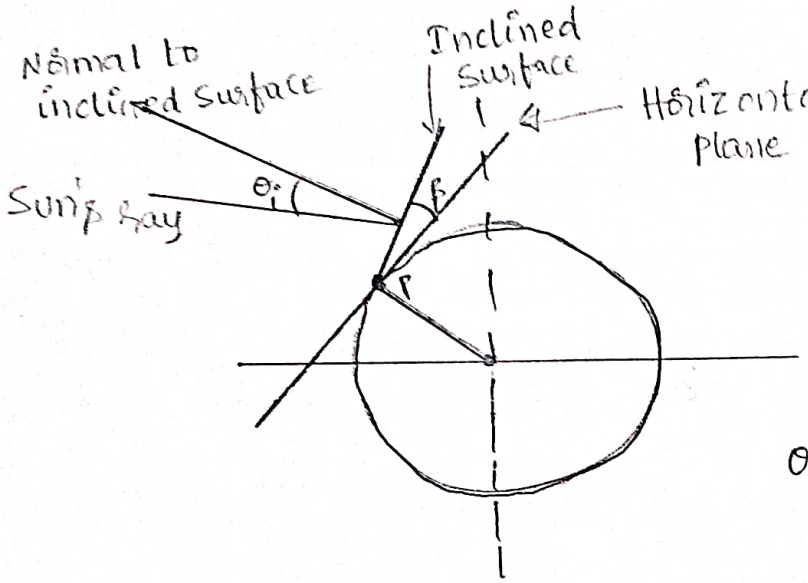
8. surface Azimuth angle :- (γ)

It is the angle in the horizontal plane, between the line due south & normal to the inclined plane surface (collector).



9. Angle of incidence (θ_i) :-

It is the angle between the sun's ray incident on the plane surface (collector) & the normal to that surface.



θ_i = function of $(\phi, \delta, \beta, \gamma, \omega)$

Angle of incidence

$$\cos\theta_i = A + B\cos\omega + C\sin\omega$$

$$A = \sin\delta\left(\sin\phi\cdot\cos\beta - \cos\phi\cdot\sin\beta\cos\gamma\right]$$

$$B = \cos\delta\left(\cos\phi\cdot\cos\beta + \sin\phi\sin\beta\cos\gamma\right]$$

$$C = \cos\delta\cdot\sin\beta\cdot\sin\gamma.$$

$$\cos\theta_i = \sin\delta\left(\sin\phi\cdot\cos\beta - \cos\phi\cdot\sin\beta\cos\gamma\right) +$$
$$\cos\delta\cos\omega\left(\cos\phi\cdot\cos\beta + \sin\phi\sin\beta\cos\gamma\right) +$$
$$\cos\delta\cdot\sin\omega\cdot\sin\beta\cdot\sin\gamma.$$

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Special cases :-

① For a surfacing facing due south, $\gamma = 0$

$$\cos\theta_i = \sin\delta\left(\sin\phi - \beta\right) + \cos\delta \cdot \cos\omega \cos(\phi - \beta) \quad -①$$

② For a horizontal surface, $\beta = 0$, $\theta_i = \theta_z$

$$\cos\theta_z = \sin\delta \cdot \sin\phi + \cos\delta \cdot \cos\omega \cdot \cos\phi \quad -②$$

③ For a vertical surface facing due south, $\gamma = 0$, $\beta = 90^\circ$

$$\cos\theta_i = -\cos\phi \sin\delta + \sin\phi \cos\delta \cdot \cos\omega \quad -③$$

→ At sunrise, the sun rays are parallel to the horizontal surface. Hence the angle of incidence $\theta_i = \theta_z = 90^\circ$

$$\cos\theta_i = 0 = \sin\delta \cdot \sin\phi + \cos\delta \cdot \cos\omega_s \cos\phi$$

$$\cos\omega_s = \frac{-\sin\delta \cdot \sin\phi}{\cos\delta \cdot \cos\phi}$$

$$\boxed{\omega_s = \cos^{-1}\left[-\tan\phi \cdot \tan\delta\right]}$$

→ The duration of sunshine hours (or) day light hours is given by

$$\boxed{t_d = \frac{2}{15}\left[\cos^{-1}\left(-\tan\phi \cdot \tan\delta\right)\right]}$$

① Calculate the angle of incidence on a horizontal plane surface of a location whose longitude & latitude are 88°20' E & 22°32' N, r.p at 11:00 hrs (IST) on June 1. The standard IST longitude is 81°44' E.

Sol:- $\phi = 22.32$

Day of the year $n = 31+28+31+30+31+1 = 152$

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

$\delta = 23.45 \sin\left[\frac{360}{365}(284+152)\right]$

$\boxed{\delta = 22.03^\circ}$, $\omega = (11-12)\times 15 = -15^\circ$

$\cos\theta_i = \cos\theta_z = \sin\delta \cdot \sin\phi + \cos\delta \cdot \cos\omega \cdot \cos\phi$

$\cos\theta_i = \sin(22.03) \cdot \sin(22.32) + \cos(22.03) \cdot \cos(-15) \cdot \cos(22.32)$

$\cos\theta_i = 0.9707 \Rightarrow \boxed{\theta_i = 13.9^\circ}$

② Calculate the sunset hour angle & day length at a location Latitude of 38°, on February 18.

Sol:- Latitude $\phi = 38^\circ$

$\cos^{-1}(-\tan\phi \tan\delta)$

$n = 31+18 = 49$

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

$\boxed{\delta = -12.274^\circ}$

$\omega_s = \cos^{-1}[-\tan\phi \cdot \tan\delta]$

$\omega_s = \cos^{-1}[-\tan(38) \cdot \tan(-12.274^\circ)]$

$\boxed{\omega_s = 80.21^\circ}$

$$\text{Day length} = \frac{2\omega_s}{15} = \frac{2 \times 80.21}{15}$$

$$\boxed{t_d = 10.695 \text{ hours}}$$

③ Calculate the angle of incidence of beam radiation on a surface at 10:30 (solar time) on February 13, if the surface is tilted 45° from the horizontal & pointed 15° west of south ?

Sol:-

Slope $\beta = 45^\circ$

Latitude $\phi = 43^\circ$

$\gamma = 15^\circ$

Day of the year $n = 31 + 13 = 44$

Hour angle $w = 15^\circ h$

$= 15 \times (-1.5) = -22.5^\circ$

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

$$\boxed{\delta = -14^\circ}$$

→ the angle of incidence

$$\cos\theta_i = \sin\delta\left[\sin\phi \cdot \cos\beta - \cos\phi \cdot \sin\beta \cdot \cos\gamma\right] +$$
$$\cos\delta \cos w \left(\cos\phi \cdot \cos\beta + \sin\phi \cdot \sin\beta \cos\gamma\right] +$$
$$\cos\delta \cdot \sin w \cdot \sin\beta \cdot \sin\gamma$$

$$\cos\theta_i = 0.818$$

$$\boxed{\theta_i = 35.115^\circ}$$

④ Calculate the number of daylight hours in Srinagar on January 1st & July 1st. The latitude of Srinagar is 34° 15' N.

Sol:- $n = 1$ & $n = 182$ for January 1st, July 1st

$\delta = -23.01°$ & $\delta = 23.12°$ for January 1st, July 1st

→ on January 1st $t_d = \frac{2}{15}\cos^{-1}[-\tan\phi \cdot \tan\delta]$

$$t_d = \frac{2}{15}\cos^{-1}[-\tan(34.083)\cdot\tan(-23.01°)]$$

$\boxed{t_d = 9.77 \text{ hours}}$

on July 1st, $t_d = \frac{2}{15}\cos^{-1}[-\tan(34.083)\cdot\tan(23.12)]$

$\boxed{t_d = 14.24 \text{ hours}}$

⑤ Calculate the angle of incidence of beam radiation on a plane surface, tilted by 45° from the horizontal plane & pointing 30° west of south located at mumbai at 1:30 PM [IST] on 15th november. The longitude & latitude of mumbai are 72°49'E & 18°54' N r.p. The standard Longitude for IST is 81°44' E?

Sol:- $n = 319$

$\delta = 23.45 \sin\left(\frac{360}{365}(284+319)\right) = -19.148°$

$E = 14.74 \text{ min}$

Standard time = 1:30pm = 13h30min

Solar time = $13\text{h}30\text{min} - 4(81.733 - 72.816)° + 14.74\text{min}$

$= 13\text{h}9.072\text{ min}$

$W = 17.27 \Rightarrow w = [1.1512 \times 15] = 17.27^\circ$

$\gamma = 30^\circ, \beta = 45^\circ, \phi = 18.54' = 18.9^\circ$

$$\cos\theta_i = [\cos(18.9)\cos(45) + \sin(18.9)\sin(45)\cos(30)] + \sin(-19.148)[\sin(18.9)\cos(45) - \cos(18.9)\sin(45)\cos(30)]$$

$$\theta_i = \cos^{-1}[0.9968] = 4.54^\circ$$

⑥ Calculate the variation of day length over a year in Trivendrum [8°29'N, 76°57'E] & plot the same?

Sol:-

Latitude $\phi = 8^\circ 29' = 8.483^\circ$

Longitude $76^\circ 57' =$

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

For January $n=1$, $\delta = -23.012^\circ$, $td = \frac{2}{15}w\phi = 11.516$ hrs

For February 1, $n=32$, $\delta = -17.516^\circ$, $td = 11.640$ hrs

For March 1, $n=60$, $\delta = -8.294^\circ$, $td = 11.833$ hrs

For April 1, $n=91$, $\delta = 4.017^\circ$, $td = 12.08$ hrs

For May 1, $n=121$, $\delta = 14.901^\circ$, $td = 12.303$ hrs

For June 1, $n=152$, $\delta = 22.040^\circ$, $td = 12.462$ hrs

For July 1, $n=182$, $\delta = 23.120^\circ$, $td = 12.487$ hrs

For August 1, $n=213$, $\delta = 17.913^\circ$, $td = 12.368$ hrs

For September 1, $n=244$, $\delta = 7.725^\circ$, $td = 12.155$ hrs

For October 1, $n=274$, $\delta = -4.216^\circ$, $td = 11.916$ hrs

For November 1, $n=305$, $\delta = -15.363^\circ$, $td = 11.687$ hrs

For December 1, $n=335$, $\delta = -22.108^\circ$, $td = 11.537$ hrs.

(7) Calculate the incidence angle on December 1, at 9:00 AM solar time for a location at 28°35' N. The collector is tilted at an angle of latitude plus 10°, with the horizontal & is pointing due south?

Sol:-

$\gamma = 0$

$\cos\theta_i = \cos(\phi-\beta)\cdot\cos\delta\cdot\cos\omega + \sin\delta\cdot\sin(\phi-\beta)$

December 1st, $n = 335$

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

$\delta = -22.11°$

$\omega = (9-12)\times 15 = -45°$

$\cos\theta_i = 0.7104 \Rightarrow \boxed{\theta_i = 44.72°}$

(8) Solar Radiation on tilted surfaces :-

→ The total solar radiation incident on a tilted surface are

① Beam Radiation
② Diffuse Radiation
③ Reflected Radiation.

→ Beam Radiation :- It is the ratio of Radiation incident on inclined surface to that on a Horizontal surface

$$\cos\theta = \sin\delta\sin(\phi-\beta) + \cos\delta\cdot\cos\omega\cdot\cos(\phi-\beta)$$

For Horizontal surface:-

$$\cos\theta_z = \sin\phi \cdot \sin\delta + \cos\phi \cdot \cos\delta \cdot \cos\omega$$

$$r_b = \frac{\cos\theta}{\cos\theta_z} = \frac{\sin\delta \cdot \sin(\phi-\beta) + \cos\delta \cdot \cos\omega \cdot \cos(\phi-\beta)}{\sin\phi \cdot \sin\delta + \cos\phi \cdot \cos\omega \cdot \cos\delta}$$

→ Diffuse Radiation:-

It is the ratio of diffused radiation incident on inclined surface to that on a horizontal surface. It is denoted by R_d.

$$R_d = \frac{1+\cos\beta}{2}$$

→ Reflected solar Radiation:-

It is defined as the radiations obtained from the ground & surrounding objects.

$$r_r = \left(\frac{1-\cos\beta}{2}\right)\rho$$

where ρ = Reflection coefficient of the ground.

$\rho = 0.2$ for ordinary ground

$\rho = 0.7$ for snow covered ground.

→ The total radiation incident on an inclined (or) tilted surface at any instant is given by

$$I_T = I_b r_b + I_d r_d + (I_b + I_d) r_r$$

$$\frac{I_T}{I_g} = \left[1 - \frac{I_d}{I_g}\right] r_b + \frac{I_d}{I_g} r_d + r_r$$

Example 4.6 *Estimate the hourly global, beam and diffused radiations at New Delhi (28° 35′ N, 77° 12′ E) between 1300 to 1400 hours (LAT) on May 15 and compare these data with measured values given in Tables C1 and C2 in Appendix C.*

Solution Given data:

$\phi = 28.58°$

For May 15, $n = 135$

$$\delta = 23.45 \times \sin\left[\frac{360}{365}(284 + 135)\right]$$

$$= 18.79°$$

We shall consider hour angle ω for the middle of the hour, i.e., 1330 hours.

ω = [Solar Time–1200] (in hours) × 15 degrees = 22.5°

From Eq. 4.9,

$$\cos\theta_z = \cos\phi \cos\delta \cos\omega + \sin\delta \sin\phi$$

$$= \cos 28.58° \cos 18.79° \cos 22.5° + \sin 18.79° \sin 28.58°$$

$$= 0.768 + 0.154$$

$$= 0.922$$

From Table 4.2, the values of A, B and C are obtained as

$A = 1106$ W/m² = 3.6 × 1106 kJ/m²-h = 3981.6 kJ/m²-h

$B = 0.177$

$C = 0.130$

From Eq. 4.24,

$I_{bn} = A \exp(-B/\cos\theta_z) = 3981.6 \times \exp(-0.177/0.922)$

$= 3285.63$ kJ/m²-h

From Eq. 4.25, the diffused radiation,

$I_d = C I_{bn} = 0.130 \times 3285.63 = 427.13$ kJ/m²-h

From Eq. (4.22), the beam radiation,

$I_b = I_{bn} \cos\theta_z = 3285.63 \times 0.922 = 3029.35$ kJ/m²-h

The global radiation $I_g = I_b + I_d = 3456.48$ kJ/m²-h

Comparison

	Estimated	*Measured*
Diffused radiation	427.13 kJ/m²-h	1108.4 kJ/m²-h
Beam radiation	3029.35 kJ/m²-h	1930 kJ/m²-0068
Global radiation	3456.48 kJ/m²-h	3038.4 kJ/m²-h

Thus

Local solar time (LST)

= Standard time ± 4 (Standard time longitude – longitude of location) + (Equation of time correction) ...(2.4.15)

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

= IST – (Standard time longitude – longitude of location) + 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

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

$= 12^h\ 8'\ 59'$. **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)

$= 23.45 \sin 86°$

$= 23.43°$. **Ans.**

or $= 23°\ 25'\ 56''$.

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°.

10. Define declination angle, hour angle, zenith angle, solar azimuth angle and angle of incidence.
11. Derive an expression for solar day length.
12. Define beam, diffused and global radiation. Derive an expression for total radiation on an inclined surface. Show that a horizontal surface receives no ground-reflected radiation.
13. Explain the working principle of a pyranometer.
14. How does the collection of solar energy get affected by tilting a flat-plate collector with respect to the ground?
15. How does sun tracking help in energy collection by a flat-plate solar collector?
16. What are the basic features required in an ideal pyranometer?

Problems

1. Calculate the day length (in hours) at Bangalore on 21 June and 21 December in a leap year. The latitude of Bangalore is 12° 58′ N.

(Ans. 12:056 h, 11:944 h)

2. Calculate the angle made by beam radiation with the normal to a flat-plate collector, tilted by 30° from the horizontal, pointing due south, located at New Delhi, at 11:00 h (IST), on 1 June. The latitude and longitude of New Delhi are 28° 35′ N and 77° 12′ E respectively. The standard IST longitude is 81° 44′ E.

(Ans. 29.88°)

3. Calculate the angle of incidence on a horizontal surface at Kolkata, at 14:00 h (IST) on 21 March in a leap year. The longitude and latitude of Kolkata are 88° 20′ E and 22° 32′ N respectively. The standard longitude of IST is 81° 44′ E.

(Ans. 40.6°)

4. An inclined surface, facing due south, tilted at 60° with the horizontal, is location at Aligarh (latitude 27° 54′ N, longitude 78° 05′ E) on 22 March at 1 p.m. (IST). The reflection coefficient ρ of the ground is 0.2. Calculate the total radiation received at the surface. Also, calculate the values of R_b, R_r, R_d and R'.

(Ans. 929.72W/sq. m, 0.964, 0.75, 0.05, 0.9877)

5. Calculate the monthly average of the daily global radiation on the horizontal surface at Gulmarg (34.05° N, 74.38° E), during the month of October if the average sunshine hour per day is 5 hours.

(Ans. 13562.859 kJ/m²-day)

6. From the data given in Problem 5 for Gulmarg, estimate the monthly average of the daily diffused and beam radiations on a horizontal surface.

(Ans. 7083.35 kJ/m²-day, 6479.5 kJ/m²-day)

7. From the data given in Problem 5 above for Gulmarg, calculate the monthly average of the hourly global and hourly diffused radiations on a horizontal surface during 13:00 to 14:00 hours (LAT).

(Ans. 1151.284 kJ/m²-h, 800 kJ/m²-h)