Renewable Energy Sources.

Module- 1.
Energy Sources.

Green Energy:

- Green energy sources / renewable energy sources does not dispense greenhouse gases into the air.
- Emission of greenhouse gases (GHG) are responsible for global warming which results in increasing temperature in the atmosphere.
- CO_2, Methane, chlorofluorocarbons are some of GHG.

Reasons for increasing GHG:

1. Planting less number of trees
2. Increasing waste generation (Residential & industrial sectors).
3. Increase the use of product which generates GHG.
4. More dependance on convention energy sources.

Indian energy scenario:

Renewable energy grew 27% around 30% of total increase in power demand, which is the fastest growth of renewables in last 11 years.

India is 4th largest generator of renewable energy in 2021 after China, US, and Brazil.

In 2021, solar energy grew over 48.55 GW, wind 40.03 GW out of total renewable energy capacity 150GW.

India has commited for a goal of 500GW renewable energy capacity by 2030.

Scope for Renewable Energy Sources:

1. Provide a sustainable solution for meeting energy demand.
2. Helping in the fight against climate change.
3. Inexhaustible in nature.
4. Reducing energy dependance on fossil fuel rich countries.
5. Increasingly competative with existing energy sources.
6. Helps in moving towards a low carbon economy.

<u>Importance of Energy sources:</u>

Energy is an important input in all sectors of any country economy. Standard of living of any country can be directly related to per capita energy consumption.

Energy crisis is due to

a) Population of world increased rapidly.
b) Standard of living of human being has increased.

The nation with more use of energy are in more advanced state of development.

The country having higher per capita annual energy consumption have higher literacy rates, while lower per capita energy consumption have lower literacy rates.

Per capita energy consumption is a measure of per capita income & also the prosperity of the nation.

Per capita energy consumption:

It is defined as the ratio of total energy consumed in year to the total population in a country.

Total power generation capacity has increased to 14.21GW from 11.9GW during period Jan-Oct-2022 to Jan-Oct-2021.

A total capacity addition of 1761.28 MW of wind energy achieved during the period of Jan-Oct 2022.

India's first Battery storage and Solar Power based 'Suryagram' - "Modhera" in Gujarat.

Classification of energy sources:

Energy sources can be classified in following ways:

Based on usability of energy:

a) Primary resources:

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

Eg: Fossil fuels (coal, oil & gas), Uranium, Hydro energy etc.

This form of energy cannot be used directly, these are located, explored, extracted, processed & are converted to a required form.

Energy yield: It is the ratio of energy recieved from raw energy sources to the energy spent to obtain raw energy source.

b) Intermediate resources:

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

Eg: Electrical energy, thermal energy, chemical energy etc.

Some form of energies may be categorized both in intermediate as well as secondary resources.

Eg: Electricity and hydrogen.

Based on traditional use:

a) Conventional:

Energy sources, which have been traditionally used for many decades, and were in common use around oil crisis of 1973, are called conventional energy resources.

Eg: Fossil fuels, nuclear & hydro resources.

b) Non-conventional:

Energy sources, which are considered for large scale use after the oil crisis of 1973, are called non-conventional energy sources.

Eg: Solar, wind, biomass & biogas etc.

Based on long term availability:

a) Non-renewable:

Resources, which are finite & do not get replenished after their consumption, are called non-renewable.

Eg: Fossil fuels & Uranium etc.

b) Renewable:

Resources, which are renewed by nature again & again and their supply is not affected by the rate of their consumption, are called renewable.

Eg: Solar, wind, biomass, ocean.

Based on commercial application:

a) Commercial energy resources:

The secondary usable energy forms such as electricity, petrol, diesel, gas etc are essentially used for commercial activities & are categorized as commercial energy resources.

Eg: Electricity, petrol, diesel. etc.

b) Non-commercial energy resources:

Energy derived from nature & used directly without passing thro' commercial outlet is called Non-commercial resources.

Eg: Wood, animal dung cake, crops residue etc.

Based on Origin:

The different types of energy based on their origin are as follows:

a) Fossil fuels
b) Nuclear energy.
c) Hydro energy.
d) Solar energy.
e) Wind energy.
f) Biomass energy.
g) Geothermal energy.
h) Tidal energy.
i) Ocean Thermal energy.
j) Ocean wave energy.

Disadvantages of conventional energy sources:

1. Environmental impact:

Conventional energy sources such as coal, oil and natural gas are a major contributor to pollution and climatic change. They release harmful chemicals and greenhouse gases into the air, which can harm the environment and human health.

2. Non-renewable:

Conventional sources of energy will eventually run-out, Once the resources are depleted, they cannot be replaced.

3. High carbon foot-print:

Conventional sources of energy have a high carbon footprint, which means they emit large amounts of carbon-di-oxide into the atmosphere. This contributes to climate change and global warming.

4. Costly:

It can be costly to extract and transport, and the price of these energy sources can fluctuate dramatically.

5. Geopolitical issues:

Because conventional energy sources are often located in specific regions of the world, the control & distribution of these resources can lead to geo-political issues & conflicts.

6. Possibility of accidental leakage of radio active material from reactor.

7. Nuclear plants have dangerous level of radio-activity, which is health hazard.

Advantages of renewable energy sources:

1. Renewable energy won't run out:
Renewable energy technologies use resources straight from the environment to generate power.

2. Maintenance requirements are lower for renewable energy.
Renewable energy systems require the less overall maintenance than that use traditional fuel sources.

3. Renewable saves money.
Maintenance and operational cost are both less. It depends on no of factors including the technology.

4. Renewable energy has numerous environmental benefits:
It leads to zero greenhouse gas emission, which means smaller carbon foot-print. & an overall positive impact on the natural environment.

5. Renewable lower reliance on foreign energy source.
It will help us minimize the geo-political risks associated with fossil fuels, from trade disputes to political instability.

6. Renewable energy leads to cleaner water & air.

7. Renewable energy can create new jobs:

8. Renewable energy can help solve our waste problem.
Biomass can offer a big benefit in reduce the amount of waste that goes to landfill, which helps cut down of carbon emmissions & environmental contamination.

Negative impacts / disadvantages from non-conventional energy sources:

1. Higher upfront cost:

2. Intermittency:
Renewable energy are available around the world. The unpredictable weather events that disrupt technologies. The amount of energy we get from source can be inconsistent.

3. Storage capabilities:
There's a high need for energy storage, they can be expensive. The energy storage capacity is growing as the technology progress.

4. Geographic limitations:
Not every area has resource availability 24/7. There can be unpredictable weather events which disrupt the source & make it inconsistent.

5. Not 100% carbon-free.
The manufacturing, transportation & installation of renewable energy, which create a carbon foot print.

6. Supply chain constraints:
It must have an effective distribution n/w created to transfer the energy. These n/w's need non renewable energies to be generated, which offsets the benefits of renewable energy.

Conventional	Non-conventional.
1. They are limited and exhaustible	1. They are abundant and inexhaustible.
2. They cause pollution	2. They cause little (or) no pollution.
3. Fuels produced from these sources are comparitively expensive.	3. They are comparitively cheaper.
4. They are non-renewable Eg: fossil fuels such as coal, natural gas etc.	4. They are renewable. Wind energy, Solar energy etc.
5. Low initial setup cost.	5. Moderate initial step up cost.

Classifications of Renewable energy sources:

The most popular renewable energy sources are:

1. Solar energy
2. Wind energy
3. Hydro energy.
4. Tidal energy
5. Geothermal energy.
6. Biomass energy.

Obstacles to the implementation of renewable energy systems.

1. Inadequate documentation & evaluation of past experience, lack of clear priorities for future work.
2. Policies to finance & commercialization of renewable energy systems.
3. Technical & economic uncertainities – high economic & financial costs
4. Inadequate donor contribution
5. Power quality issues
6. Availability.
7. Resources.

Solar Energy basics:

The energy produced & radiated by the sun, more specifically the term refers to the sun's energy that reaches the earth.

Solar energy, recieved in the form of radiation, can be converted directly / indirectly into other forms of energy such as heat and electricity.

Energy is radiated by the sun as electromagnetic waves which have wave lengths in the range of 0.2 to 4.0 micrometers. Solar energy reaching the top of the earth's atmosphere. It consists of;

8% of ultraviolet radiation

46% of visible light

46% of infrared radiation.

Solar Constant:

The rate at which solar energy arrives at the top of the atmosphere is called Solar constant (I_{sc}).

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

The NASA standard value for the solar constants are:

a) 1.353 KW per sq. meter.

b). 116.5 langleys (calories per sq. cm). per hour.

c). 429.2 Btu per sq. ft. per hour. (British units).

The variation in the distance between the earth and the sun causes the extra - terrestrial flux variation. The earth is closest to sun in summer and farthest away in the winter. This variation in distance produces a nearly sinusoidal variation in the intensity of solar radiation 'I' that reaches the earth.

$$\frac{I}{I_{sc}} = 1 + 0.033 \cos \frac{360(n-2)}{365}.$$

where n = day of the year.

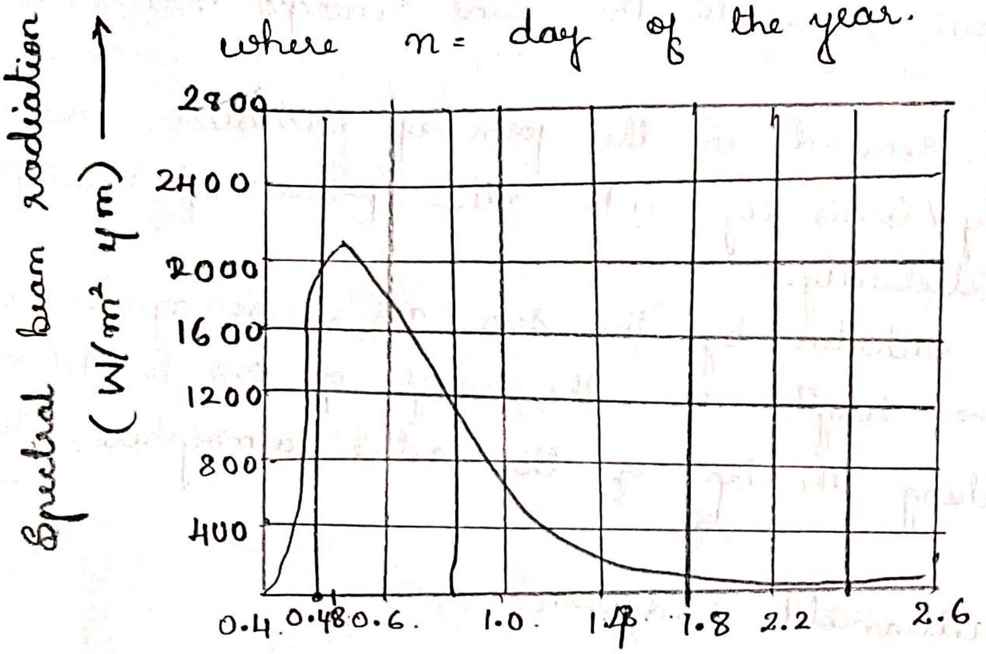


Fig : Spectral distribution of solar radiation intensity.

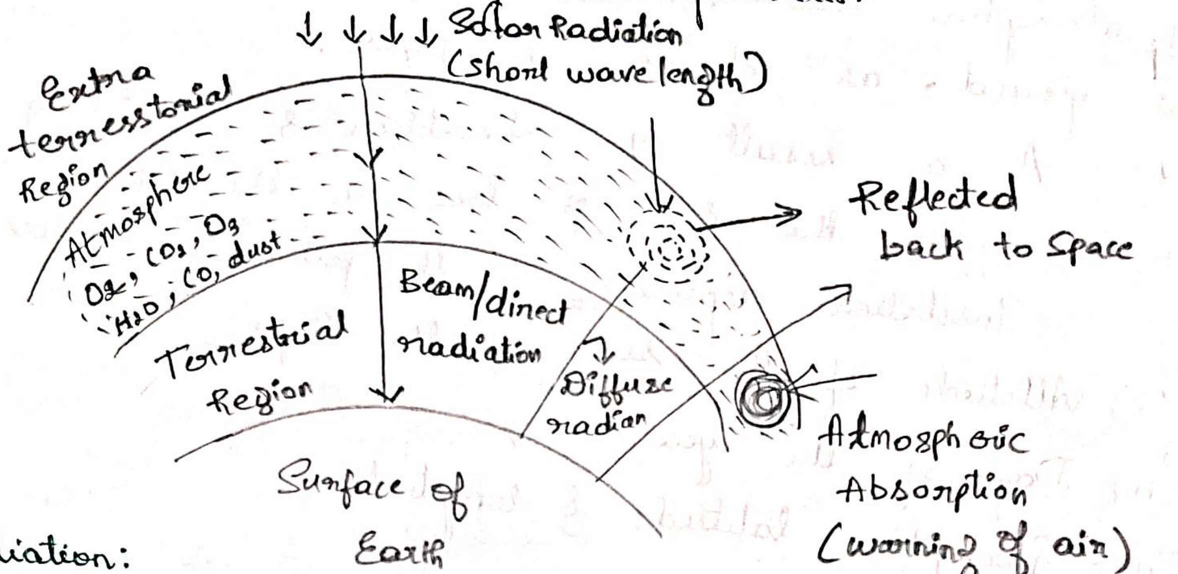
Wavelength (μ).	0 – 0.38	0.38 – 0.78	0.78 – 4.0.
Approximate energy (W/m²)	95	640.	618
Approximate percentage of total energy.	7%.	47.3%	45.7%

Solar radiation at the Earth's surface: Beam and Diffuse Solar radiations:

The solar radiation that penetrates the earth's atmosphere & reaches the surface differs in both amount and character from the radiation at the top of the atmosphere.

1. The radiation is deflected back into space, especially by clouds.
2. Oxygen and Ozone (O_3) formed from oxygen, absorb nearly all the ultra-violet radiation.
3. Water vapour & carbon-di-oxide absorb some of the energy in the infrared range.

4. Part of solar radiation is scattered by droplets in clouds by atmospheric molecules and by dust particles.



1. Beam radiation:

Solar radiation that has not been absorbed (or) scattered and reaches the ground directly from the sun is called direct radiation / Beam radiation.

2. Diffuse radiation:

Solar radiation recieved from the sun after its direction has been changed by reflection of scattering by the atmosphere.

3. Total radiation:

The solar radiation recieved at any point on the earth surface is the sum of the direct & diffuse radiation.

4. Insolation:

The total solar radiation recieved on a horizontal surface of unit area on the ground in unit time.

The insolation at a given location on the earth's surface depends on the altitude of the sun in the sky.

Altitude: It is an angle between sun's direction & the horizontal.

The smaller the sun's altitude, the greater the thickness of atmosphere thro' which solar radiation must pass to reach the ground, as shown in figure.

As a result of absorbtion & scattering, the insolation is less when the sun is low in the sky.

Insolation depends on the following factors:

i) Altitude of the sun in the sky.

ii) Day of the year.

iii) Geographic latitude & longitude.

Important definitions:

1. Sun at Zenith:

Position of the sun directly over head.

2. Air mass (m):

It is the ratio of the path of the sun's rays through the atmosphere to the length of path when the sun is at the zenith.

Case 1: When the radiation is measured at the earth surface & ~~[illegible]~~ is exactly at overhead position i.e., at sea level $\theta_z = 0$; $m = 1$. (at noon).

Case 2: When the radiation is measured at the earth surface & sun is making an angle w.r.t its zenith; $\theta_z = 60°$, $m = 2$.

Case 3: When the radiation is measured above the earth atmosphere i.e., when the sun is at horizontal surface w.r.t earth surface $\theta_z = 90°$., $m > 3$.

$m = 0$; just above the earth's atmosphere.

3. **Absorption :** As solar radiation passes through the earth atmosphere, the ~~earth~~ short wave UV ray are absorbed by ozone in atmosphere and the long wave IR waves are absorbed by the CO_2 and moisture in atmosphere. This results in narrowing of bandwidth.

4. **Irradiation :** It is the measure of energy density of sun light recieved at a location on the surface of earth & it is measured in Kwh/m^2.

5. **Irradiance :** It is the measure of power energy of the sun light recieved at a location on the surface of earth & it is measured in $Watts/m^2$.

6. **Terrestrial radiation :** Solar radiation incident on the earth atmosphere is called terrestrial radiation. It is affected by the changes in atmosphere condition.

7. **Extra-terrestrial radiation :** Solar radiation incident outside the earth atmosphere is called extra-terrestrial radiation. It is not affected by the changes in atmosphere condition.

8. **Scattering :**
As solar radiation passes through the earth atmosphere, the components of the atmosphere such water vapour & dust scatter. A portion of radiation reaches the earth surface ~~is known~~ as diffuse radiation.

Solar radiation Geometry :

Angles useful in Solar radiation analysis;

1. Latitude of location (ϕ_l).
2. Declination (δ).
3. Hour angle (ω).
4. Altitude angle (α).
5. Zenith angle (θ_z).
6. Solar Azimuth angle (γ_s).
7. Slope (s).

1. Latitude angle (ϕ_l).

The angle made by radial line joining the location to the center of the earth & the projection of that line on the equitorial plane.

It is the angular distance north (or) south of equator measured from center of earth.

Latitude will be measured as positive for the northern hemisphere.

2. Declination (δ);

The angular distance of the sun's rays north (or) south of the equator.

It is the angle between a line extending from the center of sun to the center of earth and the projection of this line upon earth's equatorial plane.

It is due to tilt of earth axis and it varies between 23.5° (Summer Solstice : June 22) to −23.5° (Winter Solstice : December 22).

At Equinoxes, the sun's declination would be zero.

It is given by,

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

Eg: Declination angle at June 19.

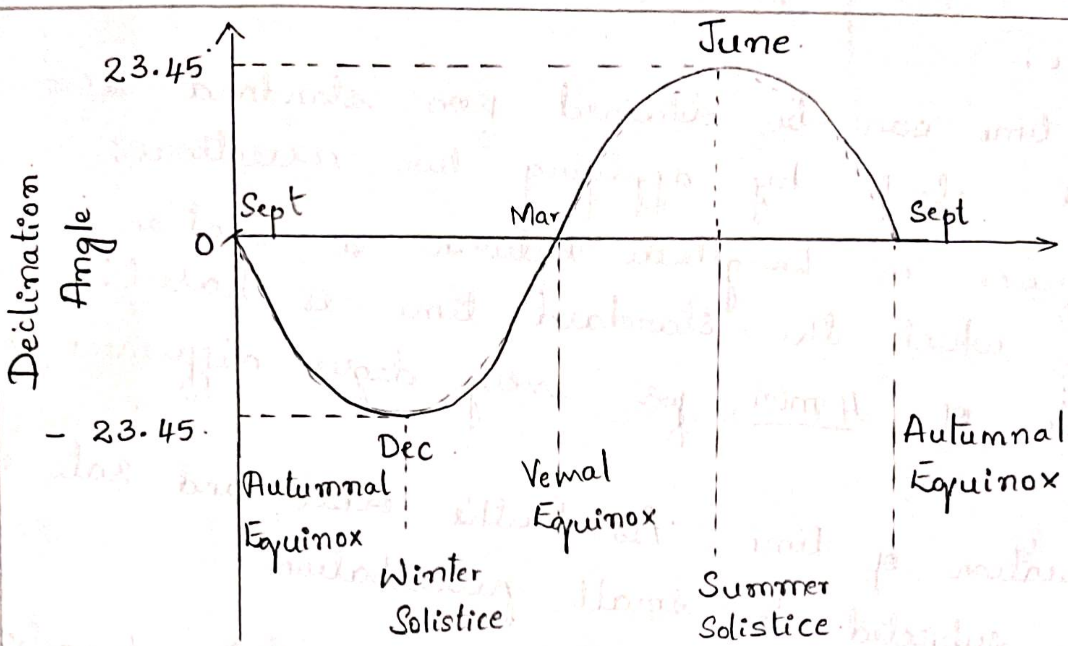
N = No of days till June 19 from January 1.

$$N = 31 + 28 + 31 + 30 + 31 + 19.$$

$$= 170.$$

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

$$\delta = 23.43^\circ.$$



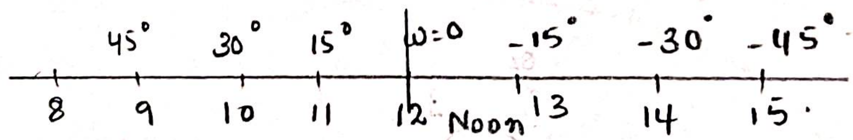
3. Hour Angle (ω):

The angle through which the earth must turn to bring the meridian of a point directly in line with the sun's rays.

It is the measure of the time of the day w.r.t solar noon.

It is measured from noon, based on the local solar time (LST), being positive in the morning & negative in the afternoon.

~~At~~ The hour angle 'ω' is equivalent to 15° per hour.



Eg: Determine the hour angle for 9:00 AM, 11:00 AM, 2:00 PM, 4:30 PM.

Hour Angle ; $\omega = 15(12 - LST)$.

i) 9:00 AM $\Rightarrow$ $\omega = 15(12-9) = 45°$.

ii) 11:00 AM $\Rightarrow$ $\omega = 15(12-11) = 15°$

iii) 2:00 PM $\Rightarrow$ $\omega = 15(12-14) = -30°$

iv) 4:30 PM $\Rightarrow$ $\omega = 15(12-16.5) = -67.5°$.

4. Local Solar Time:

Solar time can be obtained from standard time observed on a clock by applying two corrections:

a) Due to difference in longitude between a location & the meridian on which the standard time is based; has a magnitude of 4 min for every degree difference in longitude.

b) Due to Equation of time: As Earth's orbit and rate of rotation are subjected to small perturbation.

LST = Standard time ± 4 (Standard time longitude − Longitude of location)

+ (Equation of time correction).

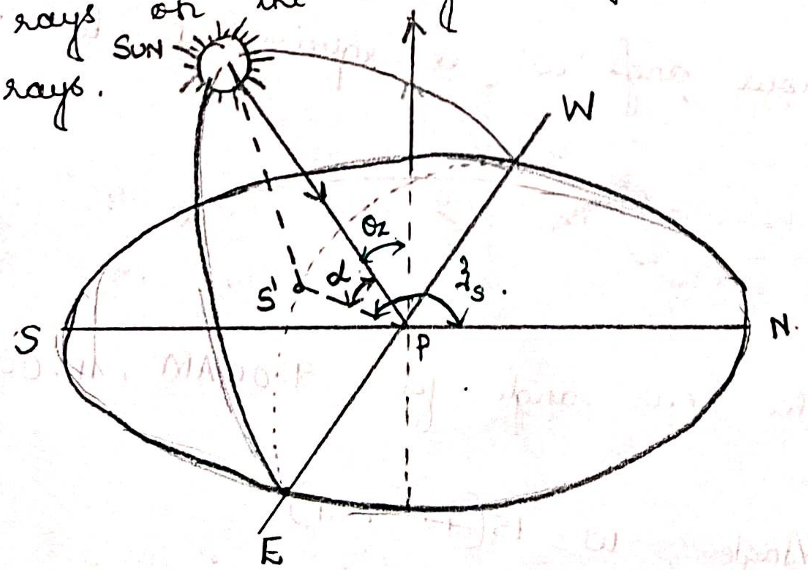
Negative sign → Eastern hemisphere.

Positive sign → Western hemisphere.

Note: Hour Angle, $\omega = 15(12 - LST)$.

5. Altitude angle / Solar altitude (α):

It is a vertical angle between the projection of the sun's rays on the horizontal plane & the directions of sun's rays.



6. Zenith angle (θ_z):

It is a complimentary angle of sun's altitude angles.

It is a vertical angle between the sun's rays and a line perpendicular to the horizontal plane through the point i.e., the angle between the beam from the sun and the vertical.

$$\theta_z = \frac{\pi}{2} - \alpha.$$

Solar Azimuth angle γ_s:

It is the solar angle in degrees along the horizon east (or) west of north (or) it is a horizontal angle measured from north to horizontal projection of the sun's rays.

It is positive when measured west wise.

Relation between basic and derived solar angles:

The expressions are:

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

$$\cos\gamma_s = \sec\alpha (\cos\phi \sin\delta - \cos\delta \sin\phi \cos\omega).$$

$$\sin\gamma_s = \sec\alpha \cos\delta \sin\omega.$$

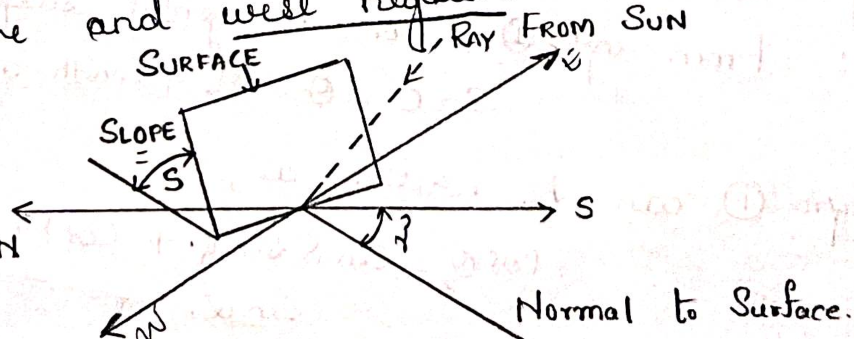
The Slope (s):

It is the angle made by the plane surface with the horizontal.

It is taken positive for surfaces slopping towards North the south and negative for surface slopping towards North.

Surface Azimuth angle (γ):

It is the angle of deviation of the normal to the surface from the local meridian, the zero point being south, east positive and west negative.



Incident angle (θ):

It is the angle being measured between the beam of rays and normal to the plane.

The relation between θ and other angles is given by equation:

$$\cos\theta = \sin\phi_l(\sin\delta\cos s + \cos\delta\cos\gamma\cos\omega\sin s)$$
$$+ \cos\phi_l(\cos\delta\cos\omega\cos s - \sin\delta\cos\gamma\sin s)$$
$$+ \cos\delta\sin\gamma\sin\omega\sin s. \quad \longrightarrow (1)$$

ϕ_l = latitude (north positive)

δ = declination (north positive)

ω = hour angle, +ve b/n solar mid night & noon, else -ve.

Day length:

The length of the day is the function of latitude & solar declination.

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

Since 15° of the hour angle are equivalent to 1 hr, the day length (in hours)

If hour angle $= \omega_s$ then hours $= \frac{\omega_s}{15}$

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

Note:

At the time of sunset (or) sun rise, the zenith angle $\theta_z = 90°$.

(1): From eqn (1), for horizontal surfaces;

$s = 0$, $\theta = \theta_z$ (Zenith angle).

Eqn (1) can be written as;

$$\cos\theta_z = \sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega. \longrightarrow (2)$$
$$= \sin\alpha.$$

i.e., $\cos\theta = \cos\theta_z = \sin\alpha$. → (3)

(2) For vertical surface,

$s = 90°$, then eqn (1) will be;

$$\cos\theta = \sin\phi \cos\delta \cos\gamma \cos\omega - \cos\phi \sin\delta \cos\gamma + \cos\delta \sin\gamma \sin\omega. \rightarrow (4).$$

(3) For surface facing due south; $\gamma = 0$.

$$\cos\theta_T = \sin\phi(\sin\delta \cos s + \cos\delta \cos\omega \sin s)$$
$$+ \cos\phi(\cos\delta \cos\omega \cos s - \sin\delta \sin s). \rightarrow (5)$$

'θ' expressed as θ_T, denotes surface as tilted one.

$$= \sin\delta \sin(\phi - s) + \cos\delta \cos\omega \cos(\phi - s). \rightarrow (6).$$

(4) Vertical surface facing south;

$s = 90°$, $\gamma = 0$.

$$\cos\theta_z = \sin\phi \cos\delta \cos\omega - \cos\phi \sin\delta. \rightarrow (7).$$

(5). Sun-rise hour (ω_s);

$\theta_z = 90°$ in eqn (2).

$$\cos\omega_s = -\frac{\sin\phi \sin\delta}{\cos\phi \cos\delta}.$$
$$= -\tan\phi \tan\delta.$$
$$\omega_s = \cos^{-1}(-\tan\phi \tan\delta). \rightarrow (8).$$

(6). $\omega_{st} < t_d$. when $\theta > 90°$.

ω_{st} = The hour angle at sun rise (or) sun set on an inclined surface.

For an inclined surface facing south;

$\theta = 90°$.

Eqn (8) will be,

$$\omega_{st} = \cos^{-1}[-\tan(\phi - s) \tan\delta].$$

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

Solar Radiation Measurements:

Measurements of solar radiation are important because of the increasing number of solar heating and cooling applications, and the need for accurate solar irradiation data to predict performance.

Two basic types of instruments are employed for solar radiation measurement.

a) Pyreheliometers: which corresponds the radiation to determine the beam intensity as a function of incident angle.

b) Pyranometer: measures the total hemispherical solar radiation.

Pyreheliometer:

It is one type of instrument, used to measure the direct beam of solar radiation. The instrument used mainly for climatic, meterological, & scientific measurements (or) observations. They provide extensive reliability & durability. It can measure upto 4000W per sq. meter. It is responsive to wavelength bands that range from 280 nm to 3000 nm.

Sunlight enters the instrument through a window & is directed onto a thermopile which converts heat to an electrical signal that can be recorded. The signal voltage is converted via a formula to measure watts per sq metre.

Angstrom compensation Pyrheliometer:

It consists of 2 identical strips. One junction of a thermocouple is connected to strip S_1 & the other junction is connected to strip S_2. A sensitive galvanometer is connected to thermocouple.

A thin blackened shaded manganin strip of size 20 X 2 X 0.1 mm is used as shown in the figure. It is heated electrically until it is at the same temperature as a similar ~~sp~~ strip which is exposed to solar radiation.

The thermocouple on the back of each strip, connected in opposition thro' a sensitive galvanometer are used to test the equality of temperature. The energy H of direct radiation is calculated by,

$$H_{DN} = K i^2.$$

where H_{DN} = Direct radiation incident on an area normal to sun's rays.

i = heating current in amperes.

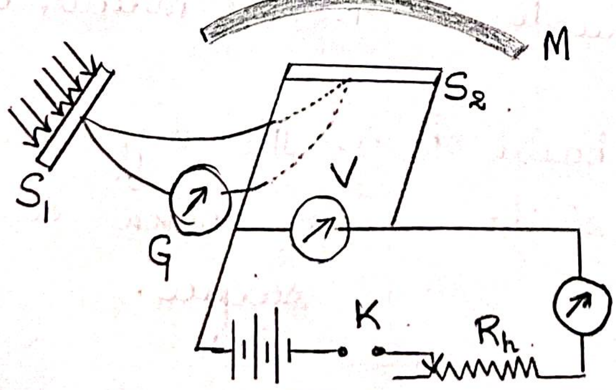
K is a dimension & instrument constant

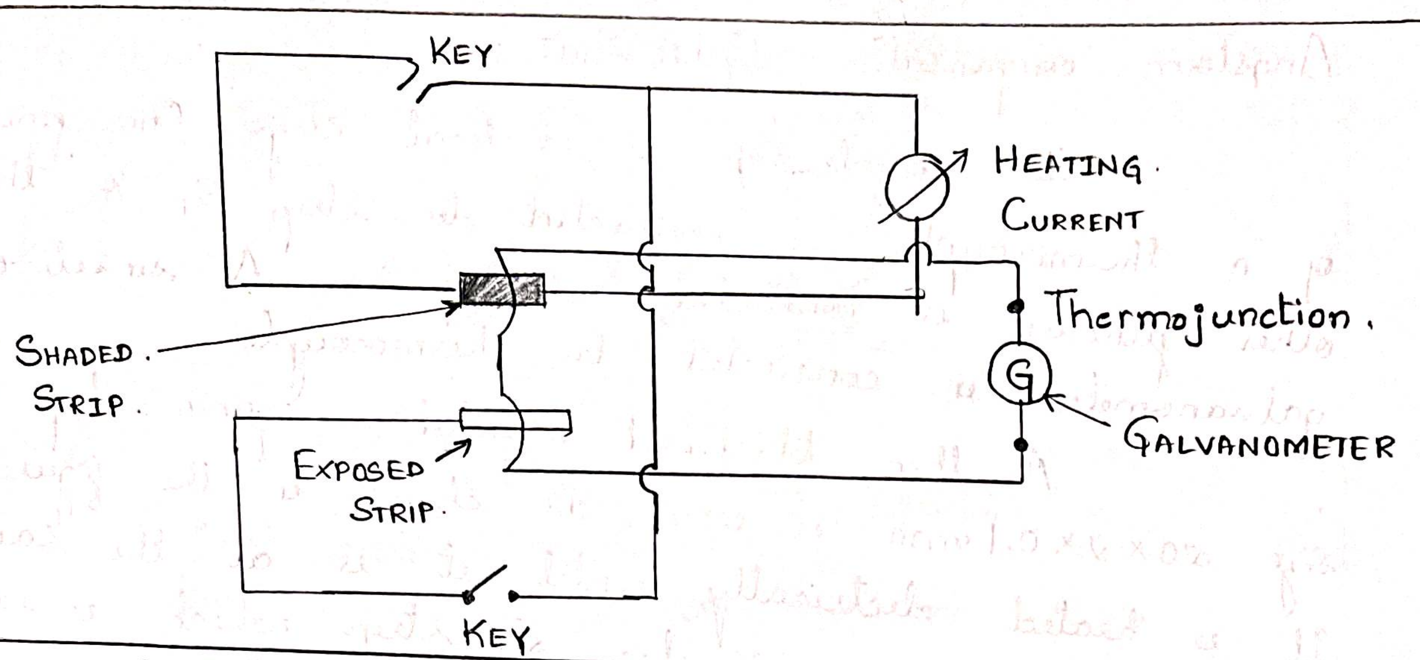
$$K = \frac{R}{W\alpha}.$$

R = resistance per unit of the absorbing strip (Ω/cm)

W = mean width of the absorbing strip.

α = absorbing co-efficient of absorbing strip.





Pyrheliometer	Pyranometer.
1. It is an instrument which measures only beam (or) direct radiation.	1. It is an instrument which measures only diffused radiation and avoid the direct radiation
2. The recieving surface must be normal to direct solar rays. i.e., the line joining the sun & reciever.	2. The recieving surface may not be normal to solar rays.
3. Types of Pyrheliometer. a> Angstron. b> Abbot silver disc. c> Eppley.	3. Types of Pyranometer. a> Eppley b> Yellot solarimeter c> Moll - Gorczyhski solarimeter d> Bimetallic Actionographs of the Rabitzsch type. e> Velochme Pyranometer. f> Thermoelectric "
4. More maintenance due to tracking.	4. Less maintenance.
5. Principle operation: based on thermopile effect & similar to pyranometer.	5. The difference b/n the tempr of black surface & white surface.

Estimation of Total Solar Radiation :

To estimate the amount of solar radiation falling on a solar collector at a given time & location, the direct (or) beam radiation & diffuse radiation should be either measured (or) estimated using empirical eqns. The monthly average daily global radiation on a horizontal surface H_{av} is,

$$H_{av} = H_o \left[a + b \frac{\bar{n}}{N} \right].$$

a & b = constants depending upon the location.

H_o = the average monthly insolation at the top of atmosphere.

$\bar{n}$ = average daily hours of bright sunshine

N = maximum daily hours of bright sunshine.

The day length can be obtained from a Nomograph (Shown in fig 2.7.2.) (or) can be calculated from the eqn;

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

H_o can be obtained from charts (or) it can be calculated by;

$$H_o = \frac{24}{\pi} I_{sc} \left[\left\{ 1 + 0.033 \cos\left(\frac{360 n}{365}\right) \right\} \left\{ \cos \delta \cos \phi \sin \omega_s + \frac{2\pi \omega_s}{360} \sin \phi \sin \delta \right\} \right]$$

I_{sc} = solar constant per hour.

n = day of the year.

ω_s = sunrise hour angle.

$\omega_s = - \tan \phi \tan \delta$.

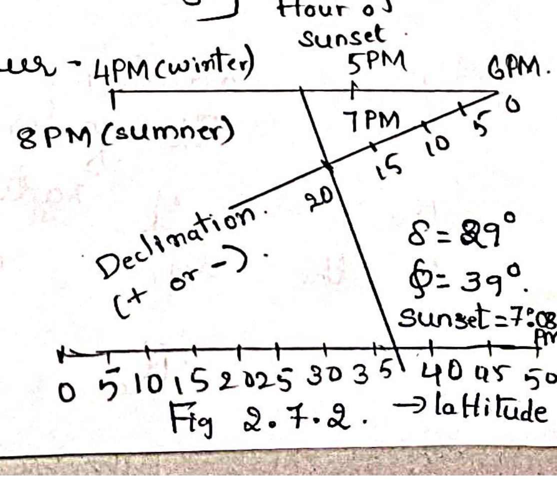


Fig 2.7.2.

Note: The date at which $H_o = H_{av}$ are: January 17, February 16, March 16, April 15, May 15, June 11, July 17, August 16, September 15, October 15, November 14 & December 10.

Solar radiation on Tilted Surface:

Solar collectors are installed tilted for better energy collection. The radiation falling on tilted surface will be sum of direct, diffuse & reflected radiation.

Beam radiation:

The tilted surface faces due south i.e, $\gamma = 0$, for this;

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

for horizontal surfaces ($\theta = \theta_z$).

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

The ratio of direct solar radiation falling on tilted surface to that falling on a horizontal surface is called the tilt factor R_b.

$$R_b = \frac{H_T}{H} = \frac{\cos\theta}{\cos\theta_z}.$$

$$= \frac{\sin\delta \sin(\phi - s) + \cos(\phi - s)\cos\delta \cos\omega}{\sin\phi \sin\delta + \cos\phi \cos\delta \cos\omega}.$$

Diffuse radiation:

Tilt factor for the diffuse radiation is defined as the ratio of radiation flux falling on the tilted surface to the diffuse radiation falling on the horizontal surface.

$$R_d = \frac{1 + \cos s}{2}.$$

Reflected radiation.

The tilt factor for reflected radiation is given by

$$R_r = \rho \left(\frac{1 - \cos s}{2} \right).$$

The total radiation on the tilted surface is;

$$H_T = H_b R_b + H_d \frac{(1 + \cos s)}{2} + (H_b + H_d) \frac{(1 - \cos s)}{2} \rho .$$

$$R = \frac{H_b}{H} R_b + \frac{H_b}{H} \frac{(1 + \cos s)}{2} + \frac{(1 - \cos s)}{2} \rho .$$

where $\rho = 0.2$ when there is no snow

$= 0.7$ when there is snow cover.

Note:

Solistice

Summer solistice in Northern hemisphere.

- June 21 (or) 22.
- North pole is leaning 23.5° towards the sun.
- North of equator have day lengths greater than 12 hrs.
- South of equator have day lengths less than 12 hrs.

Winter solistice in southern hemisphere.

- Dec 21 (or) 22.
- South pole is leaning 23.5° towards the sun.
- North of equator have day lengths less than 12 hrs.
- South of equator have day lengths more than 12 hrs.