CHAPTER 2

PRINCIPLES OF RADIATION

2.1. SOLAR ENERGY–GENERAL ASPECTS

2.1.1. Sun and Earth

Sun:

- It is a sphere of very hot gases and is largest members of the solar system.
- The diameter of the sun is 1.39×10^6 km.
- The distance between 'sun' and 'earth' is 1.50×10^8 km.
- It completes its one rotation in four weeks when observed from earth. But the equator of the 'sun' takes 27 days and polar regions takes about 30 days for each rotation.
- The heat generation is mainly due to various kinds of fusion reactions but most of the energy is released in which hydrogen (*i.e.*, four protons) combine to form helium. An *effective* black body temperature of sun is 5577 K.

The fusion reaction is as follows:

$$4({}_1H^1) \rightarrow {}_2He^4 + 26.3 \text{ MeV}$$

This energy is produced in the interior of the solar sphere and transmitted out by the radiation into system.

Net energy radiated, $E = \varepsilon\sigma T_s^4$

where ε = Emissitivity of surface, σ = Stefan's Boltzmann constant, and T_s = Effective black body surface temperature of sun.

Earth:

- It is almost round in shape and has a diameter of 1.27×10^4 km.
- Its real shape is a sphere flattened at the poles and buldged in the plane normal to the poles.

- The earth's *inner core* is a solid mass made of *iron and nickel* and the next outer core is melted state of iron and nickel. The *outermost portion* is made of *rocks*.
- The existence of blue green algae indicates beginning of photosynthesis at least 3×10^9 years ago. As a result of photosynthesis, the level of O_2 and O_3 is increased in the atmosphere which block the ultra violet (UV) solar radiation coming from the 'sun'. Half the earth is lit by the sunlight at a time. It reflects one-third of the sunlight that falls on it, is known as *earth's albedo*.
- The length of days and nights keep changing because the earth is spinning about its axis which is inclined at an angle of 23.5°.

2.1.2. Solar Energy – An Introduction

The sun emits radiant energy as a *spectrum* corresponding to a 'black body' at a temperature of about 5500°C of which *only a small amount is intercepted by the earth*. Solar radiation is absorbed in the atmosphere and at the earth surface at a rate of 10.3×10^6 W.

The solar irradiance just outside the atmosphere is about 1353 W/m^2. Because solar radiation is *attenuated* as it travels through the atmosphere, the total power falling on horizontal surface, known as the global irradiance, achieves a *maximum of about* 1000 W/m^2 (*i.e.*, 1kW/m^2) at sea level.

Global irradiance is actually made up of two components.

(*i*) *"Direct beam radiation" from the sun* and

(*ii*) *"Diffuse radiation" from the sky* (radiation that has been *scattered* by the atmosphere).

- The amount of radiation received varies throughout the day as the *path of solar radiation* through the atmosphere *lengthens* and *shortens*. For the same reason, seasonal and *lattitudal variations* can cause the total solar energy received (known as **insolation** or **solar irradiation**) to range from an average of 2 $MJ/m^2/day$ (or 0.55 $kWh/m^2/day$) in a northern winter to an average of 20 $MJ/m^2/day$ (or 5.55 $kWh/m^2/day$) in the tropical regions of the world.

— The *diffuse energy* may amount to only 15–20 percent of global irradiance on a clear day and 100 percent on a *cloudy day*.

- The solar energy *variability* is important in *system design* and *economics*. Unlike conventional fossil fuel technologies, the performance of solar systems can vary markedly from one location to another. Consequently, to design a system to convert solar energy, one *must have data on the solar radiation received at a particular site*, preferably on a month-to-month basis.

- Solar radiation can be converted to other useful forms of energy, principally: **(*i*) Heat:** This can be used directly to heat or distil water or to dry crops. The relatively simple conversion can be carried out by means of a variety of solar thermal collectors. **(*ii*) Mechanical or Electrical power:** These two forms, which are easily and efficiently interconvertible, can serve a variety of end-uses, including water pumping, lighting and refrigeration.

However, the *energy conversion technology is much more complex than that of heat production*. Conversion can be achieved by *two* completely different routes:

(*i*) Solar thermodynamics.

(*ii*) Solar photovoltaic.

☞ • *Conditions for utilization of solar energy, in India, are favourable* since for nearly six months of the year sunshine is uninterrupted during the day, while in the other six months cloudy weather and rain provide conditions suitable for water power. Thus, a *coordination of solar energy with water power can provide a workable plan for most places in India.*

Following *renewable energy sources find their origin in 'Sun'*.

(*i*) Wind
(*ii*) Ocean thermal
(*iii*) Ocean wave
(*iv*) Ocean tide
(*v*) Geothermal
(*vi*) Biomass
(*vii*) Organic chemicals
(*viii*) Fossil fuels.

2.1.3. Advantages, Disadvantages and Applications of Solar Energy

Following are the advantages, disadvantages and applications of solar energy:

Advantages:

1. It is *clean, cheap* and *abundantly available*.
2. It is *re-usable* source of energy.
3. It is *eco-friendly* (*i.e.,* pollution free)
4. It *decreases* green house gas emissions.

Disadvantages:

1. *High capital cost* due to requirement of large area.
2. *Limited* to sunshine hours.
3. *Need of tracking* due to change in position of sun.
4. There is a need of *storage*.

Applications:

Solar energy is used in:

(*i*) Solar cooling;
(*ii*) Solar water heating;
(*iii*) Solar distillation;
(*iv*) Solar pumping;
(*v*) Electric power generation.

- **Solar energy conversion systems and their applications:**
  1. ***Passive heating systems:***

     Low temperature ($t < 150°C$): Cooling; Residential heating; Water heating; Drying; Biomass energy processes; Energy conservation of conventional non-renewables; Green-houses.
  2. ***Solar thermal Systems:***

     Medium temperature ($150°C < t > 300°C$): Process heat supply; Hot-water; Steam supply, Heat for chemical industry; Desalination plants.
  3. ***Solar thermal systems:***

     High temperature ($t > 300°C$): High temperature steam for industry; Electrical power generation.
  4. ***Solar to electrical energy conversion by PV systems:***

     Very small *mV*, *mW* applications; small low voltage, low wattage applications; Medium voltage and medium power applications in kW range upto about 350 kW; Extremely useful for remote, stand-alone applications.
  5. ***Solar-diesel hybrid system:***

     Stand-alone power plants rated 1 kW to 350 kW for remote applications, farms, villages, off-shore, mountain, desert *etc.*
  6. ***Solar central receiver thermal power plants:***

     Feed power into electrical network, range 1 MW to 200 MW.

2.2 SOLAR ENERGY TERMS AND DEFINITIONS

2.2.1. Solar Radiation

Solar radiation is the *energy radiated by the sun*.

— The *radiated energy received on earth surface is called* ***Solar irradiation***.

— *Solar radiation received on a flat horizontal surface on earth* is called ***Solar insolation***.

The solar radiation is of the following two types:

1. ***Extraterrestrial solar radiation*:**

The *intensity of sun's radiation outside the earth's atmosphere* is called *"extraterrestrial"* and has no *diffuse components*.

Extraterrestrial radiation is the *measure* of solar radiation that would be received in the *absence of atmosphere*.

2. ***Terrestrial solar radiation*:**

The *radiation received on the earth surface* is called *"terrestrial radiation"* and is nearly 70 percent of extraterrestrial radiation.

2.2.2 Solar Constant (I_{sc}):

The *"solar constant" (I_{sc}) is the energy from the sun received on a unit area perpendicular to solar rays at the mean distance from the sun (1.5×10^8 km) outside the atmosphere.*

Solar constant is characterised by the following:

(*i*) It is constant and *not* affected by daily, seasonal, atmospheric condition, clarity of atmosphere etc.

(*ii*) It is on a *unit area on imaginary spherical surface around earth's atmosphere for mean distance between the sun and the earth.*

(*iii*) It is on surface *normal* to sun's rays. Sun rays are practically parallel (beam radiation).

(*iv*) It has a measured value of *"1353 W/m²"*.

- Isc in terms of kJ/m². hour $= \dfrac{1353 \times 3600}{1000} = 4870.8$ kJ/m² hour
- The value of solar constant remains constant throughout the year. *However*, this value changes with location because earth-sun distance changes seasonally with time. The extraterrestrial relation observed on different days is known as *apparent extraterrestrial solar irradiance* and can be calculated on any of the year using the following relation:

$$I_0 = I_{sc}\left[1 + 0.033 \cos\left(\frac{360\,(n-2)}{365}\right)\right] \quad ...(2.2)$$

Or,

$$I_0 = I_{sc}\left[1 + 0.033 \cos\left(\frac{360\,n}{365}\right)\right] \quad ...[2.2\,(a)]$$

where,

I_0 = Apparent extraterrestrial solar irradiance (W/m²),

n = Number of days of the year counting January 1 as the first day of the year, and

I_{sc} = Solar constant = 1353 W/m².

2.2.3. Clarity Index and Concentration Ratio

Clarity Index:

The ratio of radiation received on earth's horizontal surface over a given period to radiation on equal surface area beyond earth's atmosphere in direction perpendicular to the beam is called *"Clarity index"*.

It depends upon the clarity of atmosphere for passage of solar beam radiation. Clarity index can be between 0.1 to 0.7.

Concentration ratio:

It is the *ratio* of *solar power per unit area of the concentrator surface* (kW/m^2) *to power per unit area on the line focus or point focus* (kW/m^2).

2.2.4. Solar Radiation Geometry

The various angles which are useful for conversion of beam radiation on the arbitrary surface are:

Refer to Fig 2.3:

(*i*) **Latitude angle (ϕ):**

The *'latitude of a place'* is the angle *subtended by the radial line joining the place to the centre of the earth, with the projection of the line on the equatorial plane.*

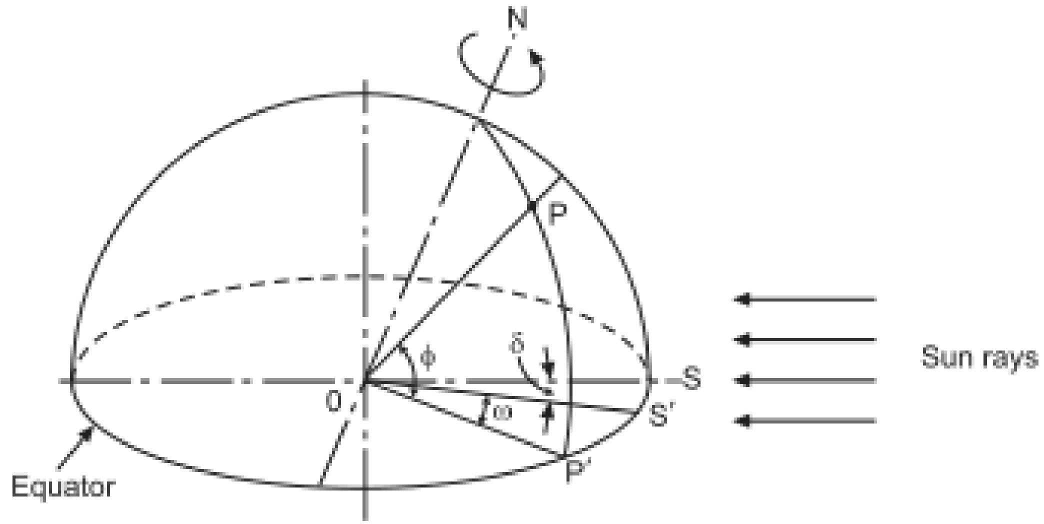


Fig. 2.3. Latitude, sun's declination δ and hour angle ω.

(*ii*) **Declination angle (δ):**

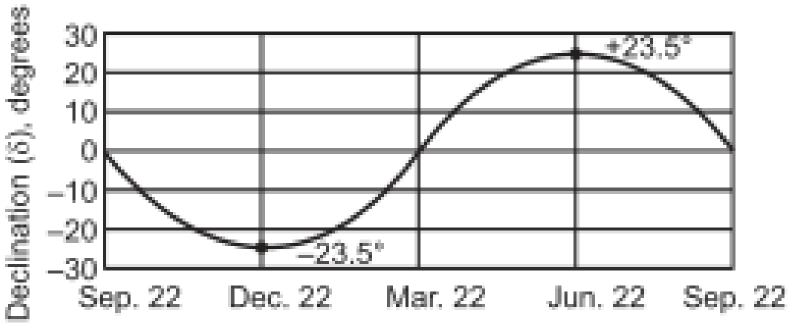
It is the angle made by the line *joining the centres of the sun and the earth with its projection on the equatorial plane.* This angle varies from a *maximum* value of +23.5° on *June 21* to *minimum* of –23.5° on *December 21.*

The declination (in degrees) for any day may be calculated from the approximate equation of "*Cooper*".

$$\delta = 23.45 \sin \left[\frac{360}{365}(284 + n)\right] \quad \text{...(2.3)}$$

where, n is the day of the year.

Fig. 2.4. shows the variation of declination angle.



(*iii*) **Hour angle (ω):**

It is angle through which the earth must be rotated to bring the meridian of the plane directly under the sun. In other words, it is the angular displacement of the sun, east or west of the local meridian, due to rotation of the earth on its axis at an angle of 15° per hour.

It is measured from noon based on the local solar time (LST) or local apparent time (LAT), being *positive in the morning* and *negative in the afternoon*. It *is the angle* measured in the earth's equilateral plane, between the projection $\overline{O}P$ and the projection of a line from the centre of the sun to the centre of the earth.

(*iv*) **Altitude angle (α) or solar altitude:** Refer to Fig. 2.4.

It is a vertical angle between the projection of the sun rays on the horizontal plane and direction of the sunrays, passing through the point.

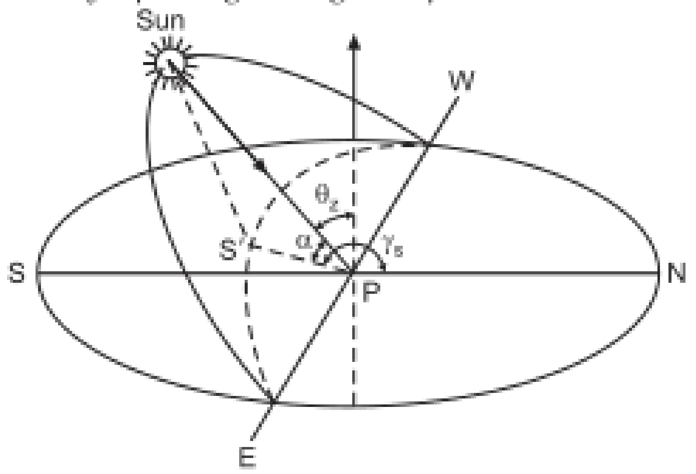


Fig. 2.5. Sun's altitude, zenith and solar azimuth angles.

(*v*) **Zenith angle (θ_z):**

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

Mathematically, $$\theta_Z = \frac{\pi}{2} - \alpha \quad ...(2.4)$$

(*vi*) **Solar azimuth angle (γ_s):**

It *is the polar angle (in degrees) along the horizontal east or west of north.*

Or

It is a horizontal angle measured from north to the horizontal projection of the sun's rays.

This angle is *positive* when measured *west wise.*

The following expressions hold good for angles θ_z and γ_s in terms of *basic angles* φ, δ and ω:

$$\cos \theta_z = \cos \phi \cos \omega \cos \delta + \sin \phi \sin \delta \quad ...(2.5)$$

$$\cos \gamma_s = \sec \alpha (\cos \phi \sin \delta - \cos \delta \sin \phi \cos \omega) \quad ...(2.6)$$

and, $$\sin \gamma_s = \sec \alpha \cos \delta \sin \omega \quad ...(2.7)$$

(*vii*) **Surface azimuth angle (γ):** Refer to Fig. 2.6.

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.*

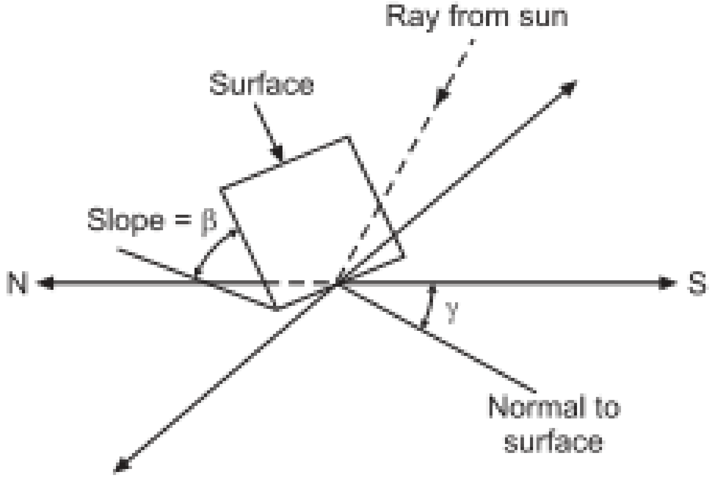


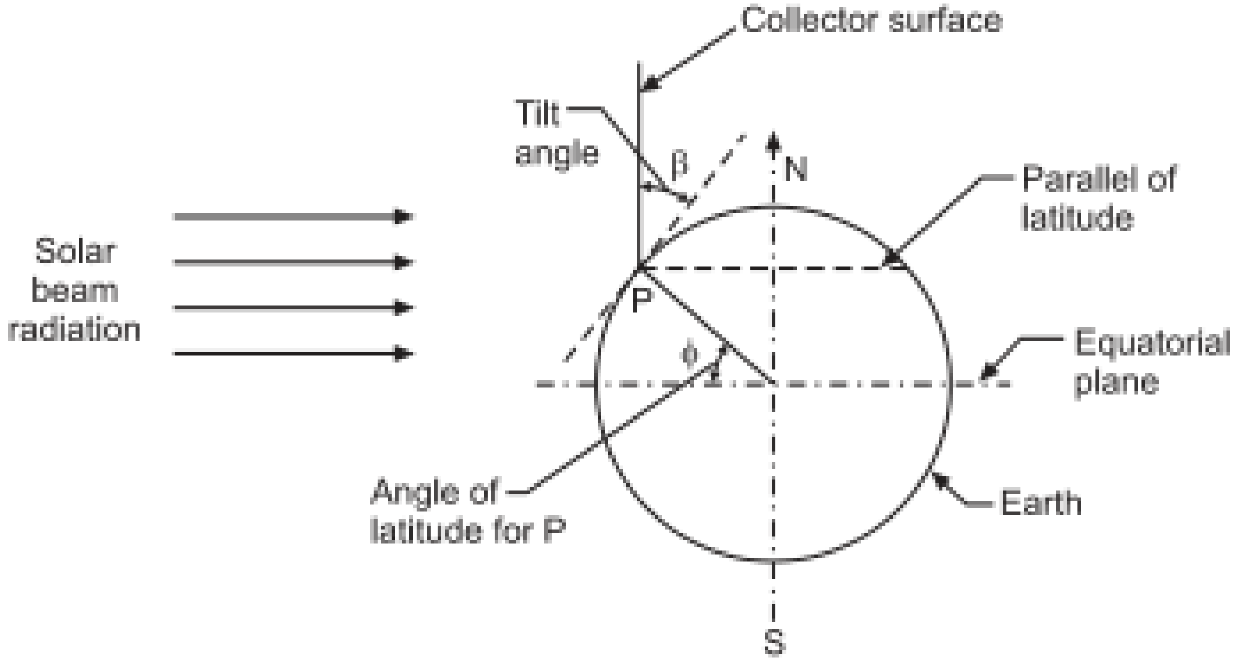
Fig. 2.6. Surface azimuth angle slope.

(*viii*) **Slope or tilt angle** (β):

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

(*ix*) **Incident angle (θ):**

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



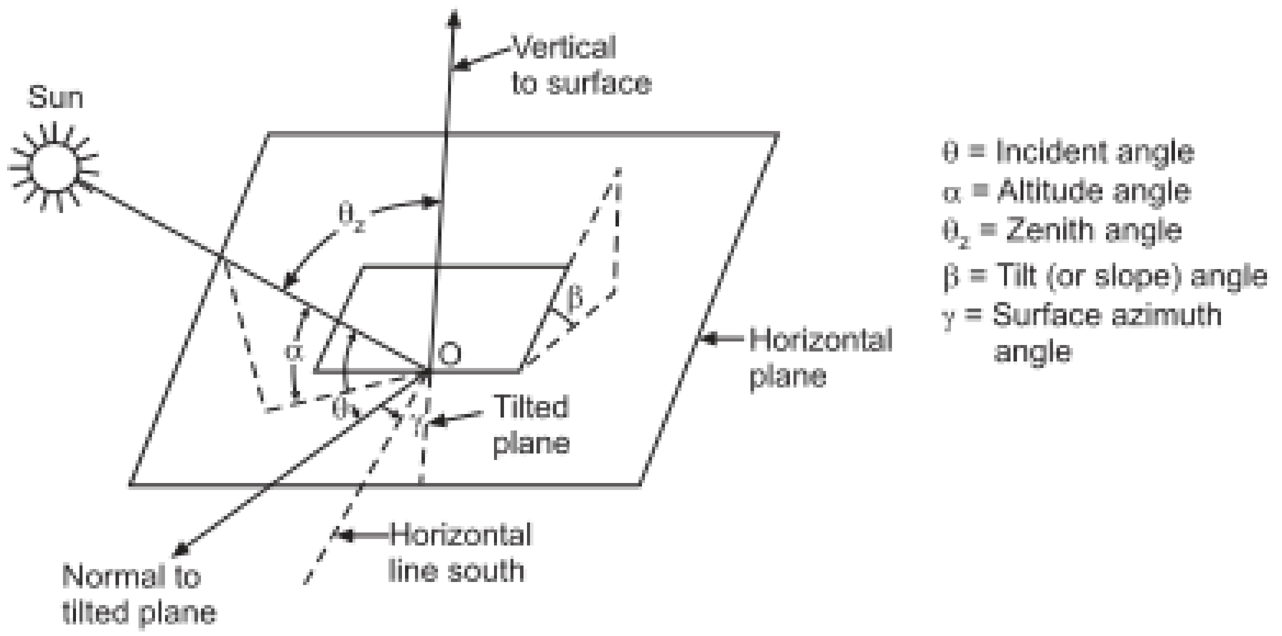


Fig. 2.8. Schematic representation for different angles.

2.2.5. Solar Day-Length, Sunrise and Sunset

We make the following observations:

(i) During '*winter*' the sun rises late and sets early, the *day length is shorter*.

(ii) During '*summer*' sun rises early, sets late and *day length is longer*.

(iii) With the increase of the angle of latitude (from equator to north pole) the *difference* in day length between summer and winter becomes more and more prominent.

The '*sunrise hour*' '*sunset hour*' and '*day-length*' depend upon *latitude of the location* and *season and day in the year*.

The ***expressions*** are derived as follows:

For a horizontal surface on the ground Eqn. (2.10) is written as:

$$\cos\theta = \sin\phi\sin\delta + \cos\phi\cos\delta\cos\omega_s \qquad ...(2.15)$$

(For sunrise and sun set the hour angle is designated as ω_s)

The hour angle ω varies during the day.

At *sunrise*, as the sun light is *parallel* to the ground surface, therefore, angle of incidence $\theta = 90°$, $\cos\theta = 0$

Inserting this value in Eqn. (2.13), we get,

$$\cos 90° = \sin\phi\sin\delta + \cos\phi\cos\delta\cos\omega_s$$

or, $$\sin\phi\sin\delta = -\cos\phi\cos\delta\cos\omega_s \qquad (\because \cos 90° = 0)$$

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

$$= -\tan\phi\tan\delta$$

i.e., $$\omega_s = \cos^{-1}(-\tan\phi\tan\delta) \qquad ...(2.16)$$

Day-length (t_{day}) in hours:

$$\text{Total day-length} = \omega_s + \omega_s$$
$$= 2\,\omega_s$$
$$= 2\cos^{-1}(-\tan\phi\tan\delta)$$

Since 15° of the hour angle is equivalent to 1 hour, hence $2\cos^{-1}(-\tan\phi\tan\delta)°$ corresponds to $\left[\dfrac{2\cos^{-1}(-\tan\phi\tan\delta)}{15}\right]$ hours.

$$\therefore \textit{Day-length (in hours)}, t_{day} = \frac{2}{15}\left[\cos^{-1}(-\tan\phi\tan\delta\right] \text{ hours} \quad ...(2.17)$$

Thus, the length of the day (t_{day}) is a *function of latitude and solar declination.* The angle hour at sunrise or sunset on an '*inclined surface*' (ω_{si}) will be *lesser* than the value obtained by Eqn. (2.15), if the corresponding angle of incidence (θ) comes out to be more than 90°. Thus for an *inclined surface facing south*, substituting θ = 90° in Eqn. (2.11), we get:

$$\omega_{si} = \cos^{-1}[-\tan(\phi-\beta)\tan\delta] \quad ...(2.18)$$

The corresponding day-length (in hours) is then given as:

$$t_{day} = \frac{2}{15}\cos^{-1}[-\tan(\phi-\beta)\tan\delta] \quad ...(2.19)$$

2.2.6. Local Solar Time (LST) or Local Apparent Time (LAT)

It is the time used for calculating the hour angle. LST can be obtained from the standard time observed on a clock by applying the following *two corrections*:

(*i*) The correction which arises due to the *difference in longitude between a location and the meridian on which standard time is based*.

This correction has a magnitude of 4 *minutes* for *every degree difference in longitude*.

(*ii*) This correction called the *equation of time correction* is due to the fact that earth's orbit and rate of rotation are subjected *to small perturbations*. This correction is *based on experimental observations*.

Hence,

Local Solar Time (LST) = Standard time ± 4 (Standard time longitude – longitude of location) + (Equation of time correction). ...(2.20)

The + **ve** *sign is used for 'Western hemisphere'* and – **ve** *sign for 'Eastern hemisphere'*.

- In **India** *standard time is based on* "**82.5° E longitude**".

2.2.7. Apparent Motion of Sun

The *"apparent motion of sun", caused by the rotation of the earth about its axis, changes the angle at which the direct component of light will strike the earth*. From a fixed location on earth, the sun *appears* to move throughout the sky. The position of the sun depends on the location of a point on earth, the time of day and the time of year.

This *apparent motion of the sun has a major impact on the amount of power received by a solar collector*. When the sun's rays are perpendicular to the absorbing surface, the power density of the surface is equal to the inside power density. However, as the angle between the sun and the absorbing surface *changes*, the intensity on the surface is *reduced*.

The angle between the sun and a fixed location on earth depends on the particular location (the longitude of the location), the time of year and the time of day. In addition, the time at which the sun rises and sets depends on the longitude of the location. Therefore, the complete modelling of the sun's angle to a fixed position on Earth requires the latitude, longitude, day of the year, and time of day.

2.3. MEASUREMENT OF SOLAR RADIATION

It is important to measure solar radiation, owing to the increasing number of solar heating and cooling applications, and the necessity for *accurate solar radiation data to predict performance.*

The following *three* devices are used for measuring the solar radiations.

1. Pyranometer;
2. Pyrheliometers;
3. Sunshine recorders.

2.3.1. Pyranometer

A **pyranometer** is *a device used to measure the "total hemispherical solar radiation"*. The total solar radiation arriving at the outer edge of the atmosphere is called the '*solar constant*'.

The *working principle* of this instrument is that sensitive surface is exposed to total (beam, diffuse and reflected from the earth and surrounding) radiations.

The description of a pyranometer is given below:

Construction. It consists of a "black surface" which receives the beam as well diffuse radiations which rises heat. A "*glass dome*" prevents the loss of radiation received by the black surface. A "*thermopile*" is a temperature sensor, and consists of a number of thermocouples connected in series to increase the sensitivity. The "*supporting stand*" keeps the black surface in a proper position.

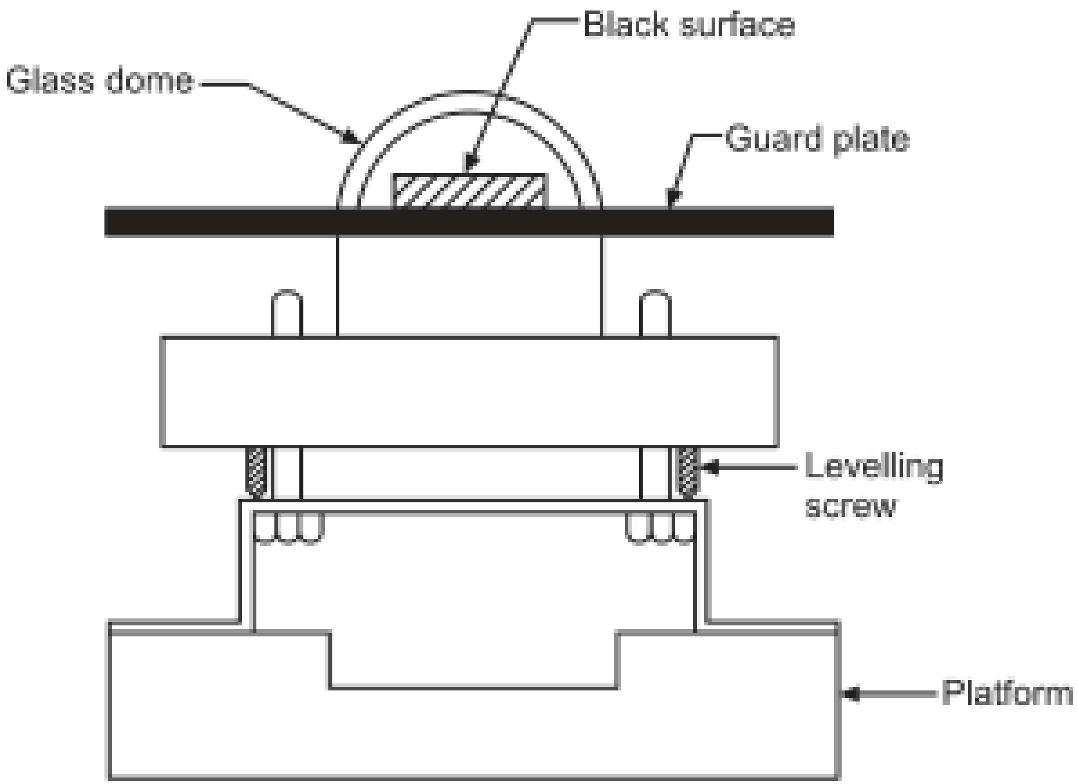


Fig. 2.9. Pyranometer.

Working: When the pyranometer is exposed to sun, it starts receiving the radiations. As a result, the surface temperature starts rising due to absorption of the radiation. The increase in the temperature of the absorbing surface is detected by the *thermopile*. The thermopile generates a *thermo emf* which is *proportional to the radiations absorbed;* this thermo emf is *calibrated in terms of the received radiations*. This will measure the global solar radiations.

2.3.2. Pyrheliometer

A **pyrheliometer** *is a device used to measure "beam or direct radiations"*. It collimates the radiation to determine the beam intensity as a function of incident angle.

This instrument uses a collimated detector for measuring solar radiation from the sun and from a small portion of the sky around the sun at normal incidence.

The description of a thermoelectric type pyrheliometer is given below:

Construction: In this instrument, two identical blackened manganin strips A and B are arranged in such a way that either can be exposed to radiation at the base of *collimating tubes* by moving a *reversible shutter*.

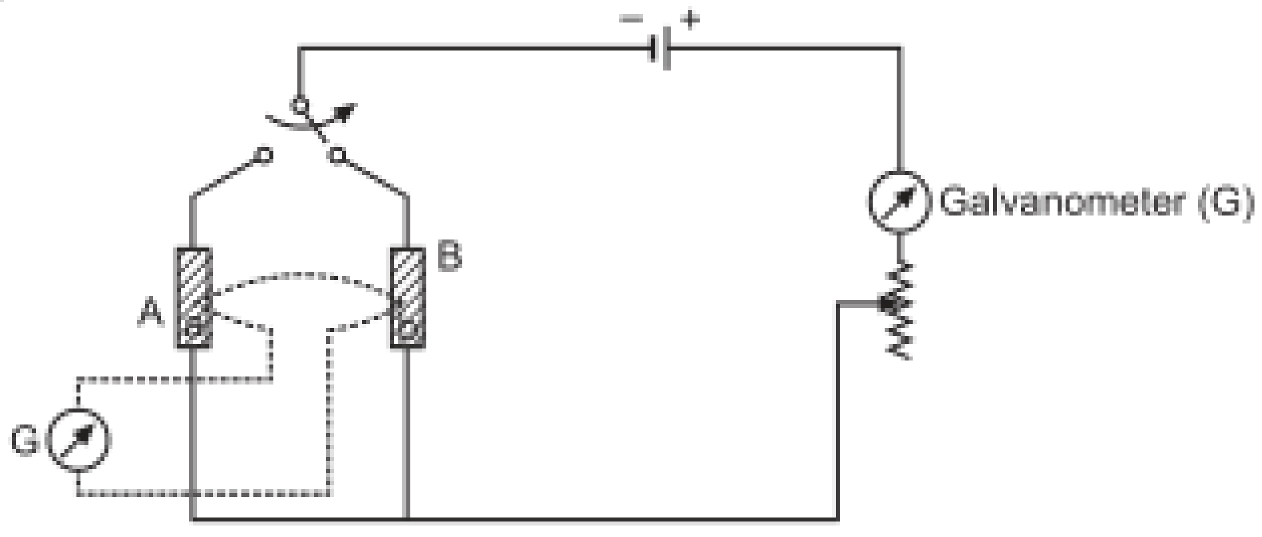


Fig. 2.10. Circuit diagram for the thermoelectric type pyrheliometer.

Working: One strip is placed in radiation and a current is passed through the *shaded strip* to heat it to the same temperature as the *exposed strip*. When there is *no difference in temperature*, the electrical energy supplied to shaded strip *must equal the solar radiation absorbed by the exposed strip*. Solar radiation is then determined by *equating the electrical energy to the product of incident solar radiation, strip area and absorptance.*

2.3.3. Sunshine Recorder

A **sunshine recorder** *is a device used to measure the "hours of bright sunshine in a day"*.

The description of a sunshine recorder is given below:

Refer to Fig. 2.11.

Construction: It consist of a *"glass-sphere"* installed in a section of *"spherical metal bowl"* having grooves for holding a *recorder card strip"* and the glass sphere.

Working. The glass-sphere, which acts as a convex lens, focusses the sun's rays/beams to a point on the card strip held in a groove in the spherical bowl mounted concentrically with the sphere.

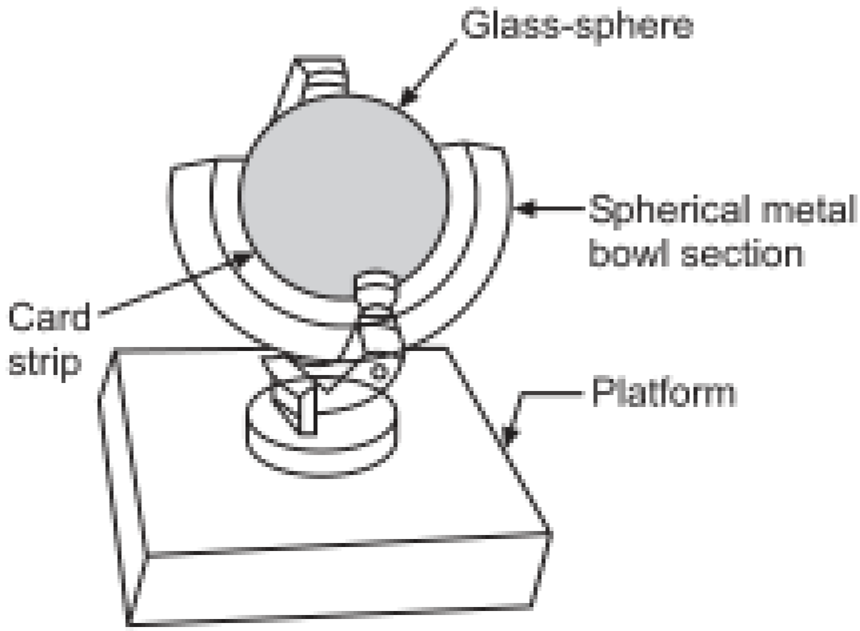


Fig. 2.11. Sunshine recorder.

Whenever there is a *bright sunshine, the image formed is intense enough to burn a spot on the card strip*. Through the day, the sun moves across the sky, the image moves along the strip. Thus a burnt space whose *length is proportional to the duration of sunshine* is obtained on the strip.

2.4. SOLAR RADIATION DATA

2.4.1. General Aspects

Solar radiation data should include the following informations:

(*i*) Whether they are *instantaneous* measurements or values *integrated* over some period of time (usually hour or days,) (*ii*) The *time* or *time period* of the measurements; (*iii*) Whether the measurements are of *beam, diffuse* or *total radiation* and the *instrument used;* (*iv*) The receiving surface *orientation* (usually horizontal, it may be inclined at a fixed slope or normal); (*v*) If averaged, the *period* over which they are averaged.

- When data are *not* available, '**Maps**' can be used as a source of average radiation.

  Charts are also available for *clear day horizontal radiation for any period for any latitude*. **Tables** are also available for *hours of sunshine for various locations*.
- The solar radiation data is collected for various locations in the world on the basis of:

1. Solar power calculations with reference to the movement of the sun, latitude of the location etc.
2. Hourly measurements of solar radiation at the location and calculation of:
   (*i*) *"Daily average"* global radiation (H_{dg}) at the location for the month (*kJ/m².day*); (*ii*) *"Monthly average"* global radiation (H_{mg}) at the location for various months (*kJ/m². month*); (*iii*) *"Yearly average"* global radiation (H_{yg}) at the location for a few years (*kJ/m². year*).

The data in terms of kJ/m^2. day or kWh/m^2. day for various days/months/an year can be readily used for calculating:

(*i*) Available solar energy at the location;

(*ii*) Determining the surface area of the solar collectors;

(*iii*) Determining rating of solar plant.

2.4.2. Solar Radiation Data for India

- India is in the *"northern hemisphere"* within latitudes of 7° and 37.5° N.
- The average solar radiation values for India are between 12.5 and 22.7 $MJ/m.^2$ day.
- The *peak solar radiation in India* occurs in some parts of Rajasthan and Gujrat and is equal to *25* MJ/m^2.
- The solar radiation *reduces to about 60 percent* during monsoon months.

2.4.3. Solar Insolation

The **solar insolation** *is the solar radiation received on a flat horizontal surface at a particular location on earth at a particular instant of time.*

The *unit of solar radiation is* **W/m²**.

The *parameters of the solar insolation for a given flat horizontal surface are:*

(*i*) Daily variation (hour angle); (*ii*) Seasonal variation and geographical location of the particular surface; (*iii*) Atmospheric clarity; (*iv*) Shadows of trees, tall structures, adjacent solar panels etc.; (*v*) Degree of latitude for location; (*vi*) Surface area m^2; (*vii*) Tilt angle.

2.5. ESTIMATION OF AVERAGE SOLAR RADIATION

"Angstrom's equation" for average daily global radiation:

The *expression* for the average radiation on a horizontal surface in terms of constants a and b and observed values of average length of solar days, as suggested by **Angstrom** (1924) is given by:

$$\frac{H_g}{H_c} = a + b\left(\frac{L_a}{L_m}\right) \quad \text{...(2.21)}$$

where, H_g = Monthly average of the daily global radiation on a horizontal surface at the location (kJ/m^2 day),

H_c = Monthly average of the daily global radiation on the same horizontal surface at the same location but on *clear* sky day (kJ/m^2. day),

a, b = Constants determined from various cities in the world by measurements,

L_a = Average length of *solar day* for a particular month calculated/observed (hours), and

L_m = Length of the *longest solar day* in the month (hours).

2.6. SOLAR RADIATION ON AN INCLINED SURFACE

The following three types of solar radiation constitute the total solar radiation on a surface:

(*i*) Beams solar radiation (I_b);

(*ii*) Diffuse solar radiation (I_d);

(*iii*) Solar radiation reflected from the ground and the surroundings.

Usually, I_b and I_d on a horizontal surface are recorded. In case of *non-availability of data* for beam and diffuse radiation, the following *expression* for beam and diffuse radiation on the horizontal surface may be used:

$$I_b = I_N \cos \theta_z \qquad ...(2.27)$$

and,

$$I_d = \frac{1}{3}(I_{ext.} - I_N)\cos\theta_z \qquad ...(2.28)$$

Li and Jordon (1962) suggested the following *formula* to evaluate *total radiation on a surface of "arbitrary orientation"*:

$$I_T = I_b R_b + I_d R_d + \rho R_r (I_b + I_d) \qquad ...(2.29)$$

where, R_b, R_d *and* R_r = *"Conversion factors"* for *beam, diffuse* and *reflected components respectively;*

ρ = The reflection coefficient of the ground

= 0.2 and 0.7 for ordinary and snow covered ground respectively.

Expressions for Conversion factors:

Refer to Fig. 2.12.

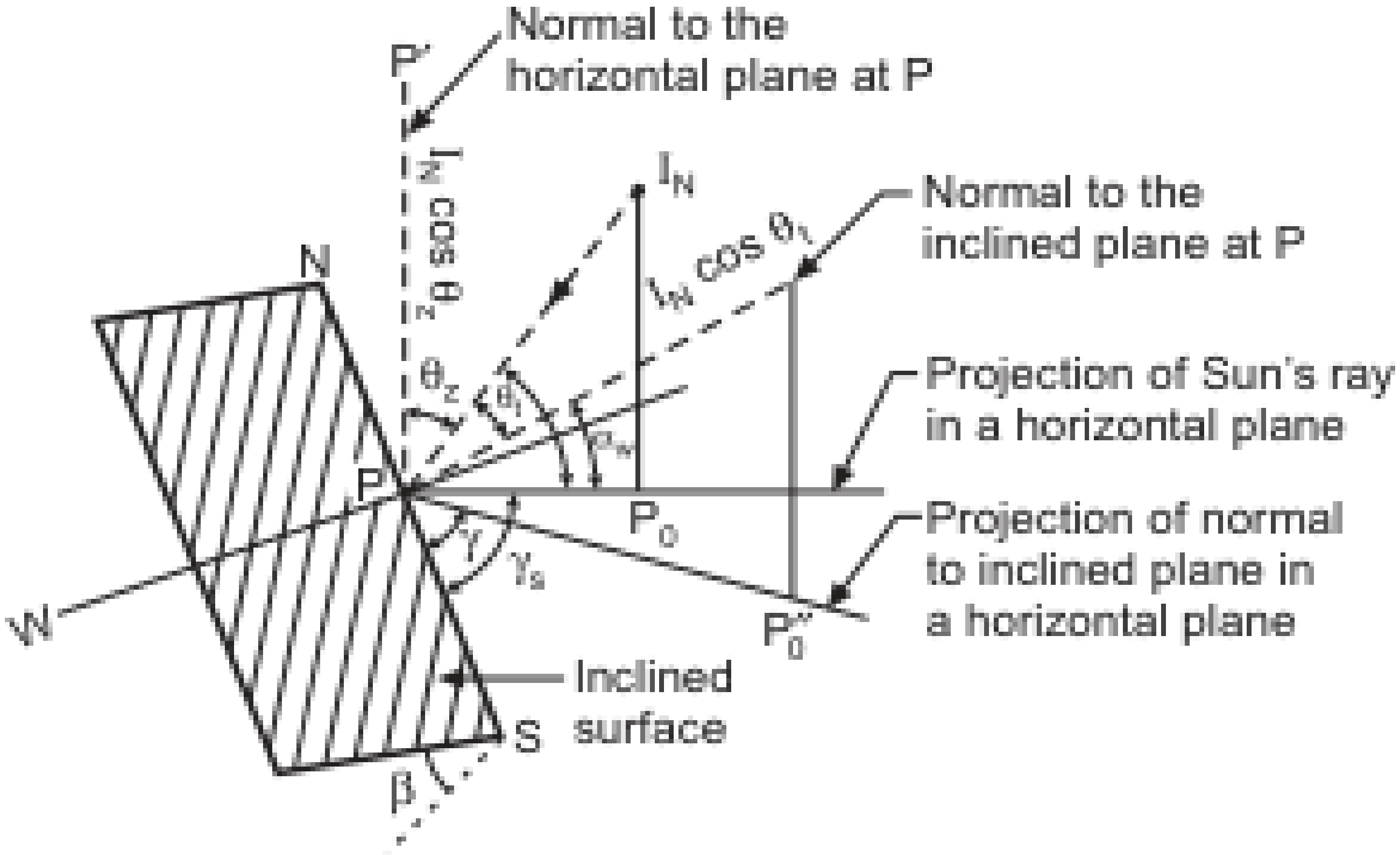


Fig. 2.12

(*i*) **R_b**: It *is defined as the ratio of flux of beam radiation (I_b) incident on an inclined surface (I_{bt})to that on a horizontal surface*. It is called *tilt factor* for beam radiation.

$$I_b = I_N \cos \phi_z \quad \text{...on } \textit{horizontal surface}$$

and, $$I_{bt} = I_N \cos \phi_t \quad \text{...on tilted/inclined surface}$$

Mathematically, $$R_b = \frac{I_b}{I_{bt}} = \frac{I_N \cos \theta_t}{I_N \cos z} = \frac{\cos \theta_t}{\cos z} \quad \text{...(2.30)}$$

where, I_N = Intensity of beam radiation,

θ_t = Angle of incidence on the inclined surface (it depends on several variables associated with the location and orientation of the surface and the direction of sun rays), and

θ_z = Angle of incidence on the horizontal surface.

For beam radiation, in most cases, the *tilted surface* faces due south *i.e.*,

$$\gamma = 0, \text{ for this case,}$$

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

For *horizontal force* ($\theta = \theta_z$),

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

Hence,

$$R_b = \frac{\cos\theta_t}{\cos\theta_z} = \frac{\sin\delta\sin(\phi-\beta)+\cos\delta\cos\omega\cos(\phi-\beta)}{\sin\phi\sin\delta+\cos\phi\cos\delta\cos\omega} \quad ...[2.30(a)]$$

(*ii*) $\boldsymbol{R_d}$: *It is the ratio of the flux of diffuse radiation falling on the tilted surface to that on the horizontal surface.*

If one *"radiation shape factor"* for the tilted surface with respect to sky, is $\frac{1+\cos\beta}{2}$, then

$$R_d = \frac{1+\cos\beta}{2} \quad ...(2.31)$$

(*iii*) $\boldsymbol{R_r}$: The reflected component comes *mainly from the ground and other surrounding objects*. If the considered reflected radiation is *diffuse and isotropic*, then the situation is opposite to that in the above case, and

$$R_r = (1-\cos\beta)\frac{\rho}{2}$$

where ρ = Reflection coefficient of the ground (0.2 for ordinary and 0.7 for snow covered ground).

Hence combining all the three terms, we get:

$$I_T = I_b R_b + I_d\left(\frac{1+\cos\beta}{2}\right) + (I_b + I_d)\left(\frac{1-\cos\beta}{2}\right)\rho \quad ...(2.32)$$

THANKS