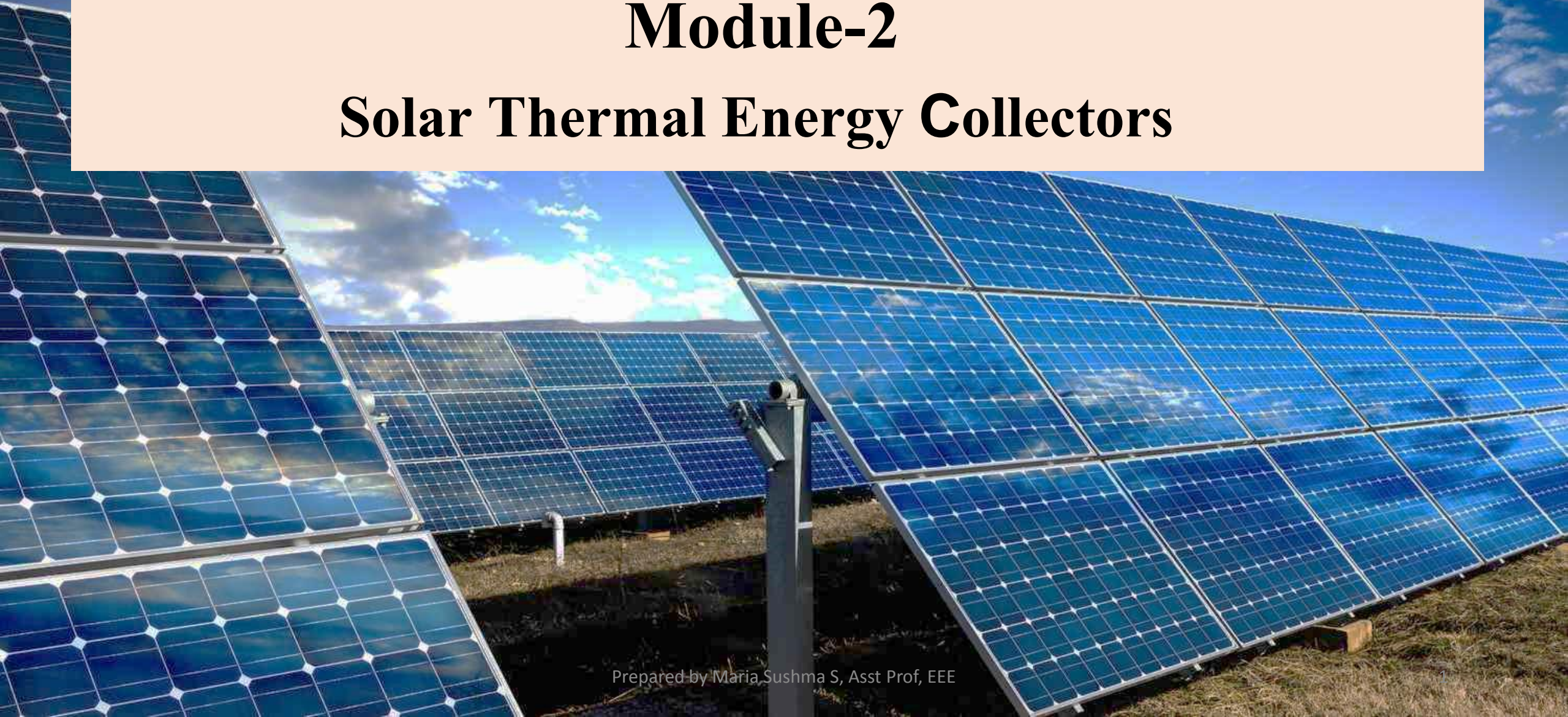


Module-2

Solar Thermal Energy Collectors



Syllabus

Solar Energy

- Fundamentals
- Solar Radiation
- Estimation of solar radiation on horizontal and inclined surfaces
- Solar radiation Measurements- Pyrheliometers, Pyrometer
- Sunshine Recorder.
- Solar Thermal systems: Flat plate collector
- Solar distillation
- Solar pond electric power plant.

Solar electric power generation:

- Principle of Solar cell
- Photovoltaic system for electric power generation
- Advantages, Disadvantages and applications of solar photovoltaic system.

Fundamentals: Introduction

Solar energy:

- The **sun's energy** that reaches the earth , received in the form of **radiation**.
- Can be **converted** directly or indirectly into other forms of energy, such as **heat and electricity**.
- It **inexhaustible source** of energy since the sun is expected to radiate for a few billion years.
- Energy is radiated by the sun as **electromagnetic waves** of which 99 per cent have wave lengths in the range of 0.2 to 4.0 micrometers (1 micrometer = 10^{-6} meter).
- Solar energy reaching the top of the earth's atmosphere consists of about **8% ultraviolet radiation** (short wavelength $< 0.39\text{mm}$), **46% visible light** (0.39 to 0.78mm wavelength) and **46% infrared radiation** (long wavelength $> 0.78\text{mm}$)
- The major **drawbacks** to the extensive application of solar energy are:
 1. The **intermittent and variable** manner in which it arrives at the earth's surface and
 2. The **large area** required to collect the energy at a useful rate.

Solar Constant

- The **diameter** of Sun is 1.39×10^6 km while that of the earth is 1.27×10^4 km.
- The mean distance between the two is 1.50×10^8 km.
- The radiation coming from the sun appears to be essentially equivalent to that coming from a black surface at 5762°K .
- **The rate at which solar energy arrives at the top of the atmosphere is called the solar constant I_{sc} .** This is the amount of energy received in unit time on a unit area perpendicular to the sun's direction at the mean distance of the earth from the sun.
- (NASA) standard value for the solar constant: 1.353 kilowatts per square metre
- The earth is closest to the sun in the 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.
- Surface temperature of the Sun can be calculated from solar constant.

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

$$\approx 1 + 0.033 \cos \frac{360 \times n}{365}$$

n is the day of the year.

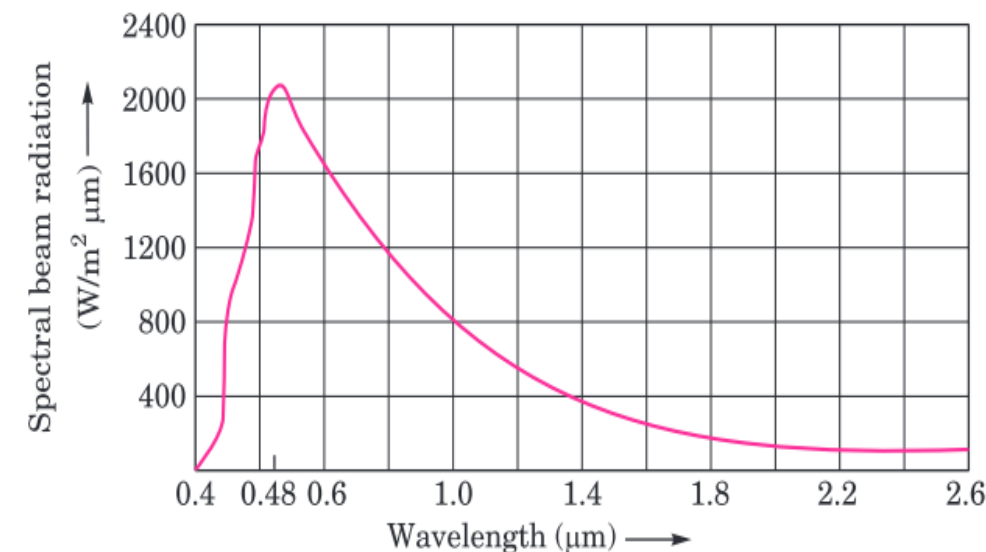
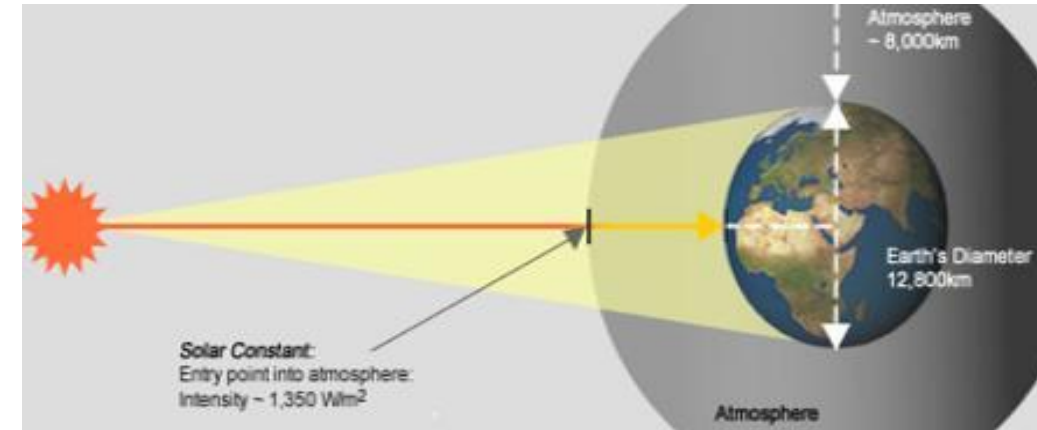


Fig. 2.1. Spectral distribution of solar radiation intensity.

Beam and Diffuse Solar Radiation:

The solar radiation that reaches the earth's atmosphere differs.

The radiation entering the atmosphere is partly **absorbed** by molecules in the air:

- Oxygen and ozone (O_3) formed from oxygen, absorb nearly all the ultraviolet radiation, and water vapour and carbon dioxide absorb some of the energy in the infrared range.
- In addition, part of the solar radiation is scattered by droplets in clouds by atmospheric molecules, and by dust particles.

Direct radiation: Solar radiation that has not been absorbed or scattered and reaches the ground directly from the sun is called "**direct radiation**" or **Beam radiation**.

Diffuse radiation: is that solar radiation received from the sun after its direction has been changed by reflection and scattering by the atmosphere.

The total solar radiation received at any point on the earth's surface is the sum of the **direct and diffuse radiation**. This is referred to as the **insolation** at that point.

Insolation is defined as the total solar radiation energy received on a horizontal surface of unit area on the ground in unit time. Ex: 1 sq. m in 1 day.

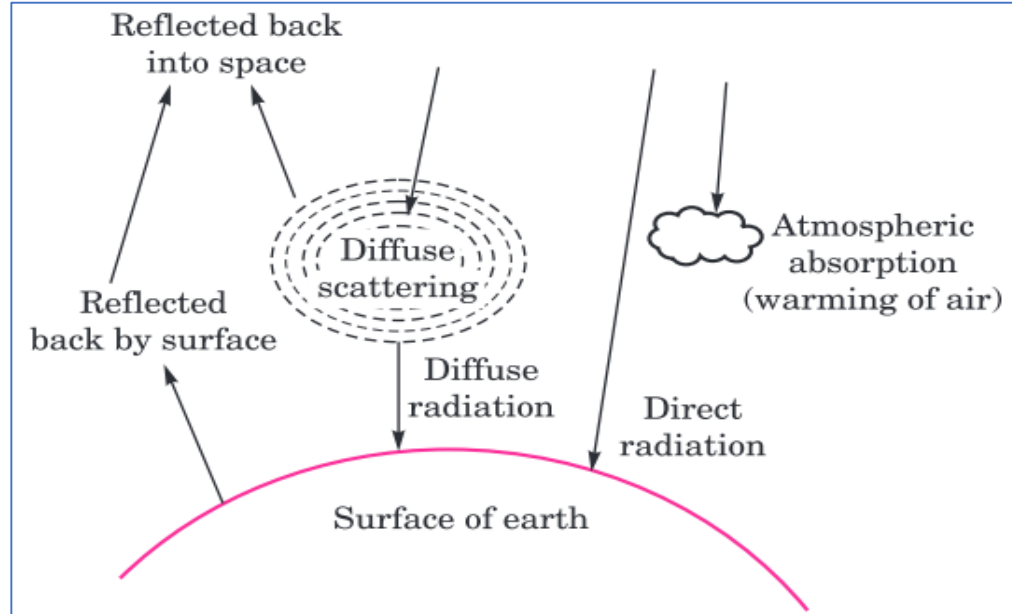
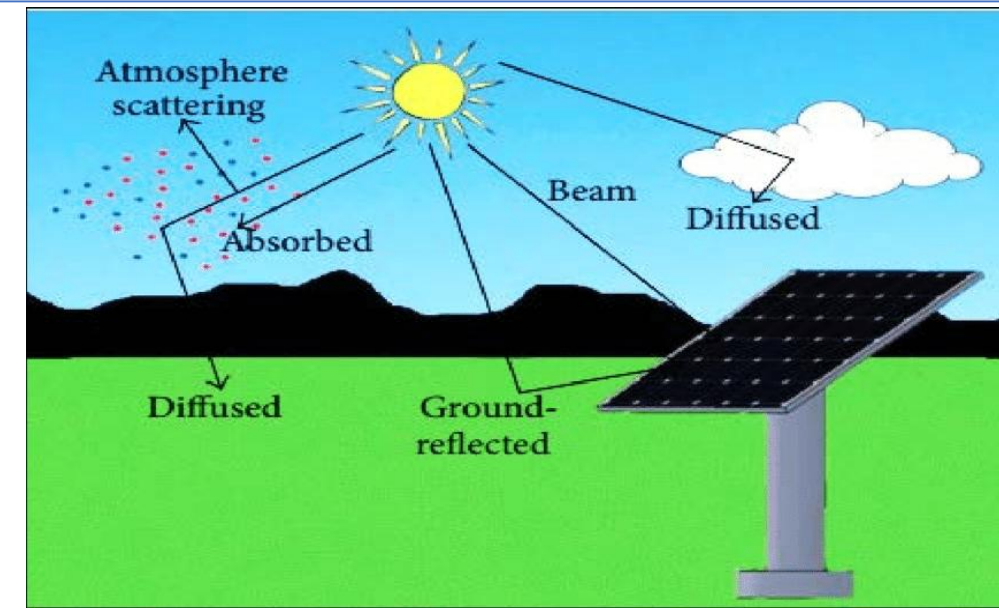


Fig. 2.2. Direct, diffuse and total radiation.



Attenuation of Beam Radiation

Variation in solar radiation reaching the earth than received at the outside of the atmosphere is due to absorption and scattering in atmosphere.

- (i) **Absorption-** As solar radiation passes through the earth's atmosphere the **short-wave ultraviolet rays** are absorbed by the **ozone** in the atmosphere and the **long wave infrared waves** are absorbed by the **carbon dioxide and moisture** in the atmosphere. This results in narrowing of the band width.
- (ii) **Scattering-** As solar radiation passes through the earth's atmosphere, the components of atmosphere such as water vapour and dust scatter a portion of the radiation. A portion of this scattered radiation always reaches the earth's surface as diffuse radiation.

Thus radiation finally received at the earth's surface consists of beam and diffuse radiation.

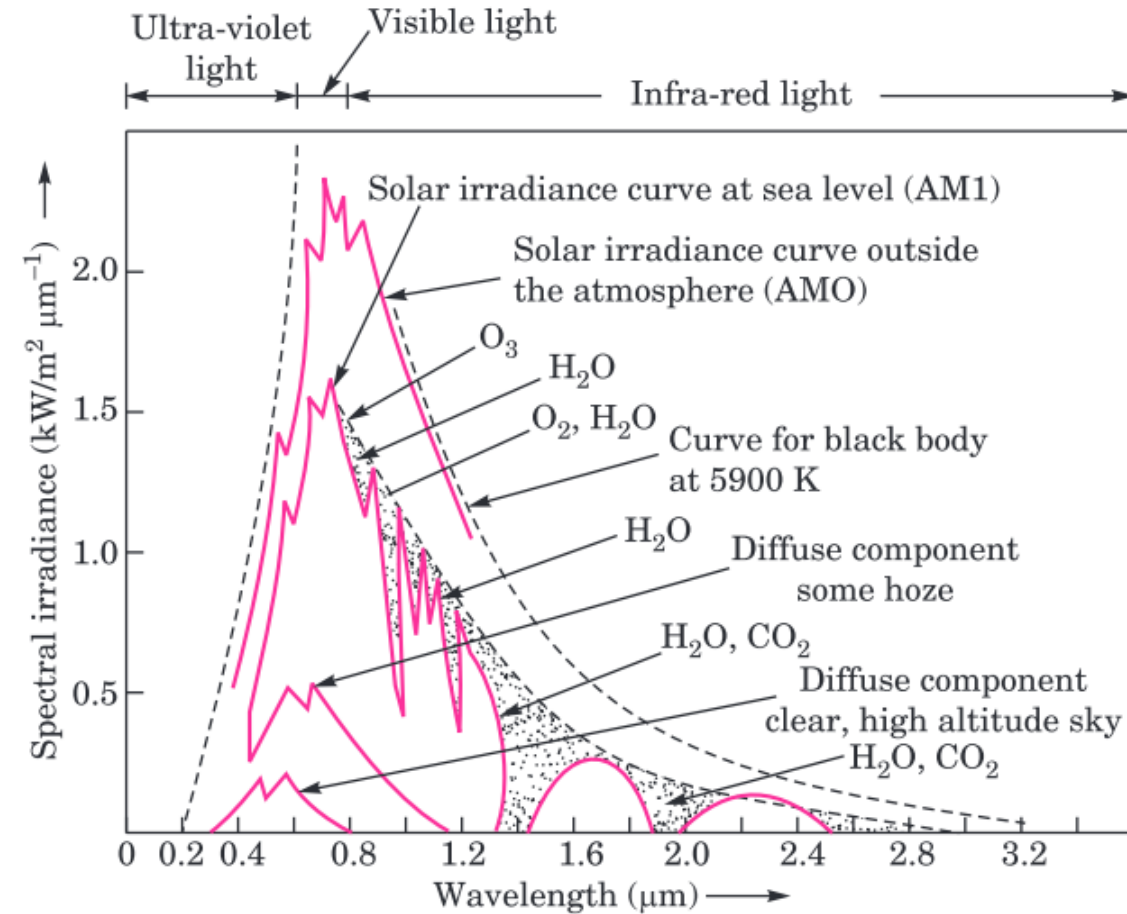


Fig. 2.3. The solar spectrum outside the atmosphere at a ground level.

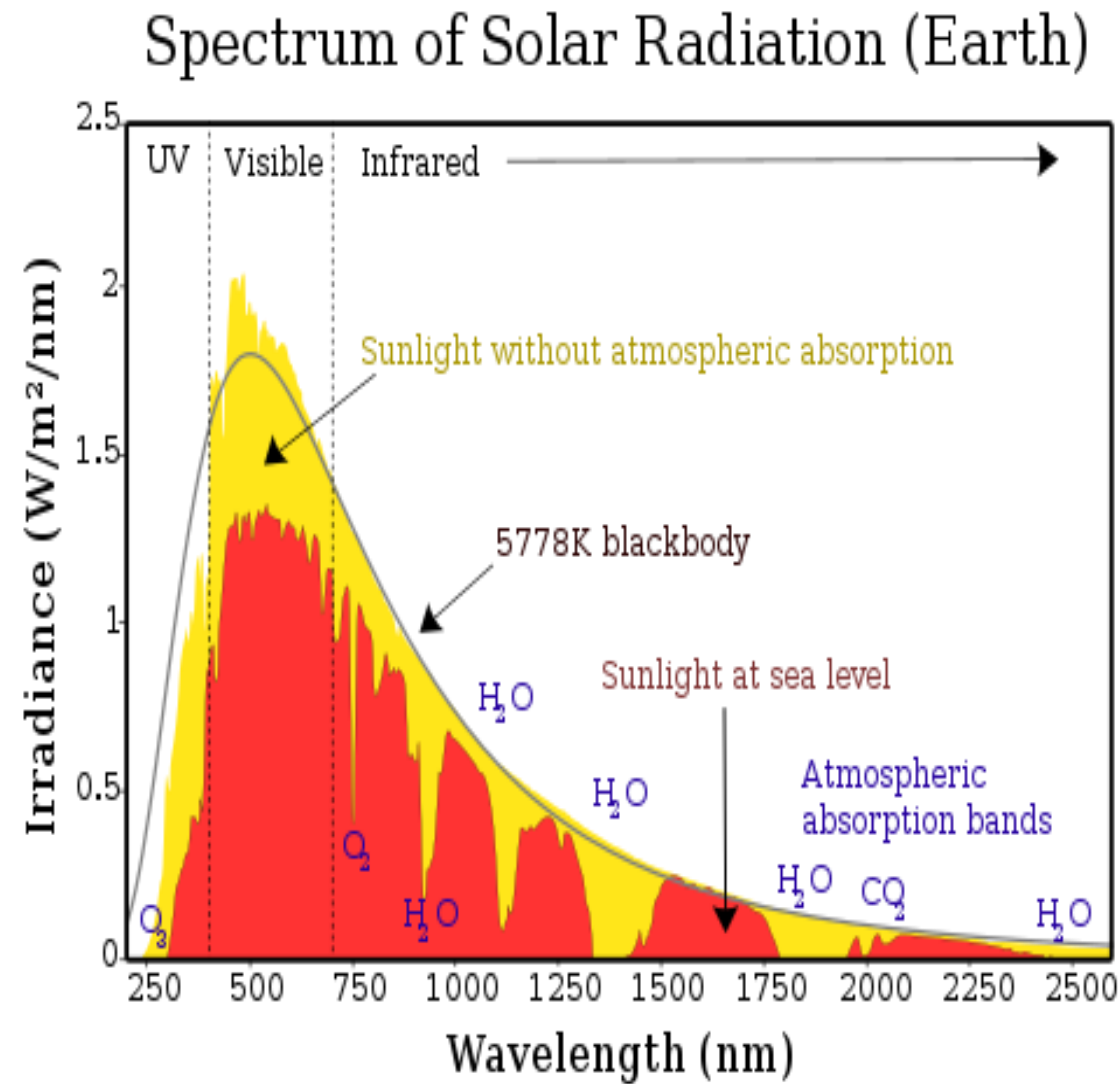
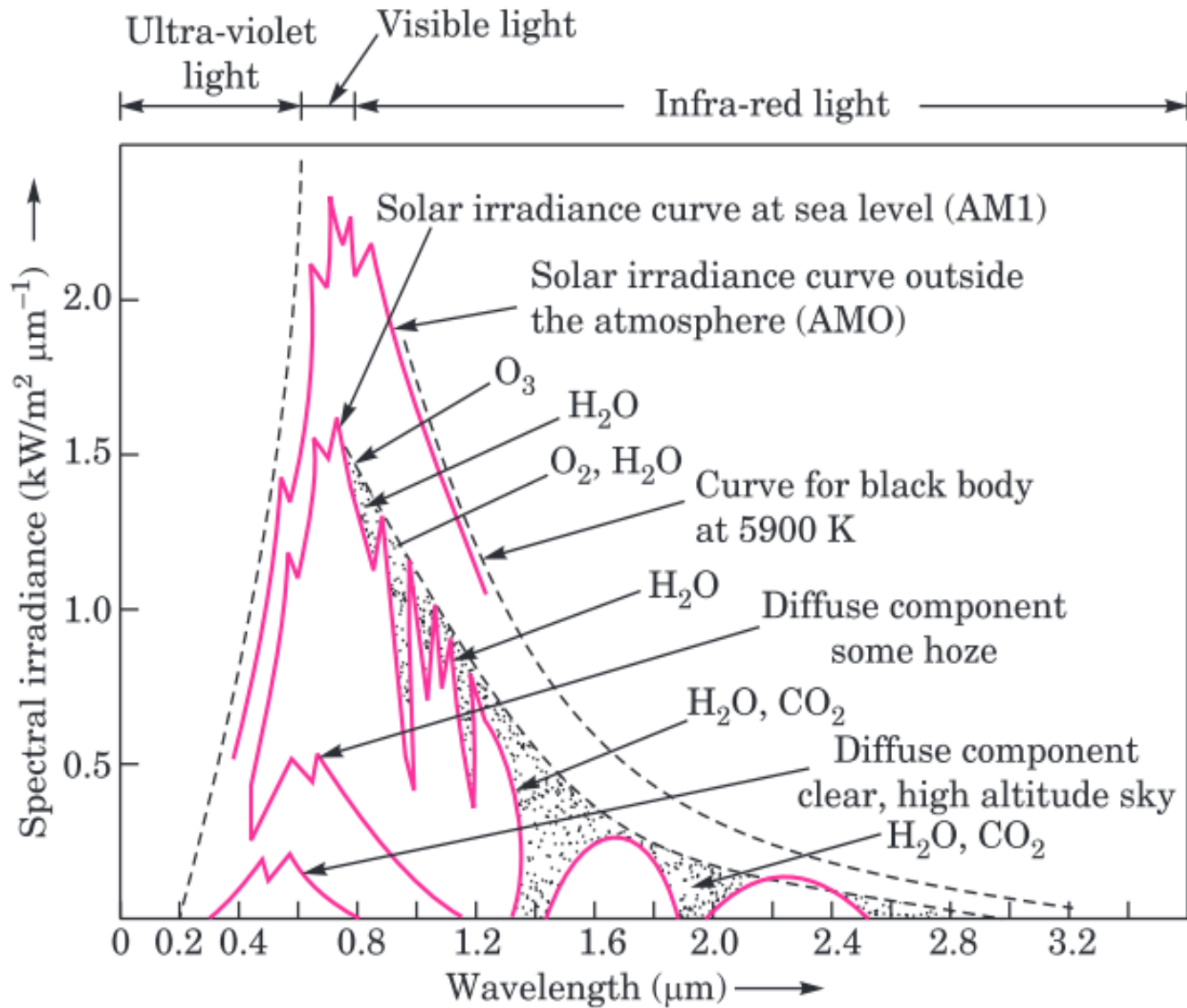


Fig. 2.3. The solar spectrum outside the atmosphere at a ground level.

Solar Radiation Geometry

In solar radiation analysis, the following angles are useful:

ϕ_l = latitude of location

ω = hour angle

s = slope

θ_z = zenith angle.

δ = declination

γ_s = solar Azimuth angle

α = altitude angle

1. Latitude of Location (ϕ_l)- of a point or location is the angle made by the radial line joining the location to the centre of the earth with the projection of the line on the equatorial plane.

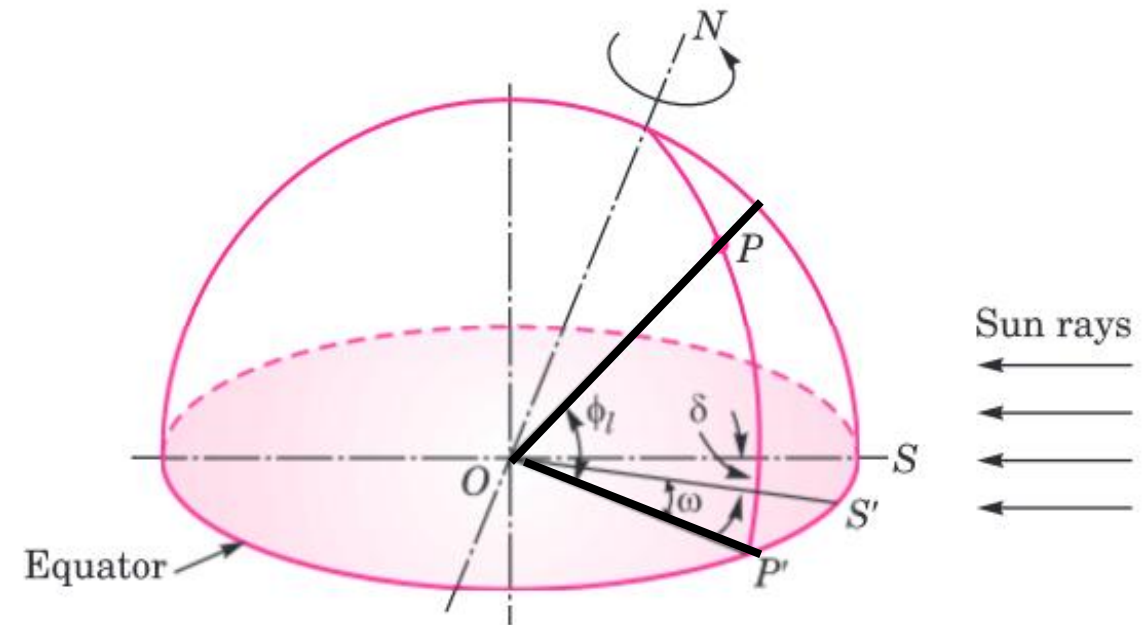


Fig. 2.4. Latitude ϕ_l , hour angle ω , and sun's declination δ .

Sun at Zenith: Position of the sun directly over head.

2. Air mass (m): It is the path length of radiation through the atmosphere, considering the vertical path at sea level as unity. The air mass m 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.

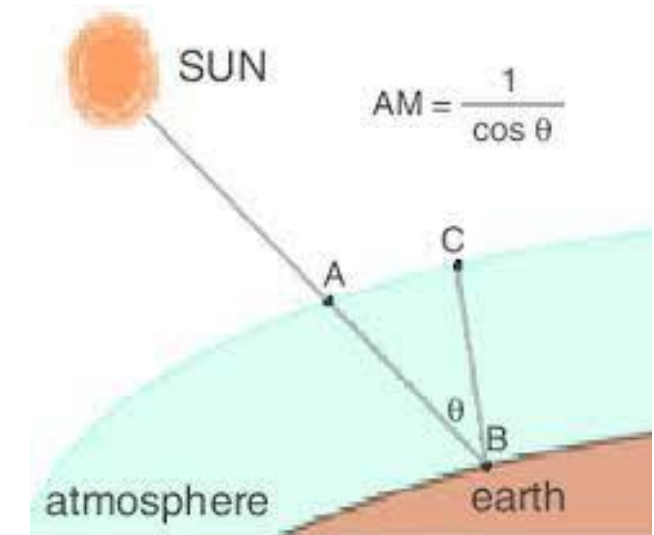
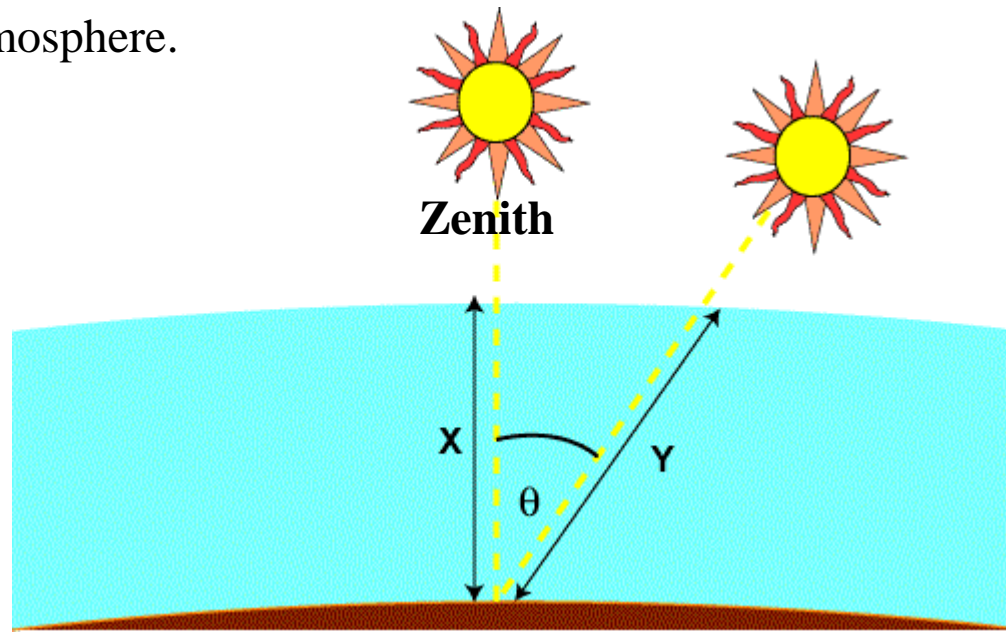
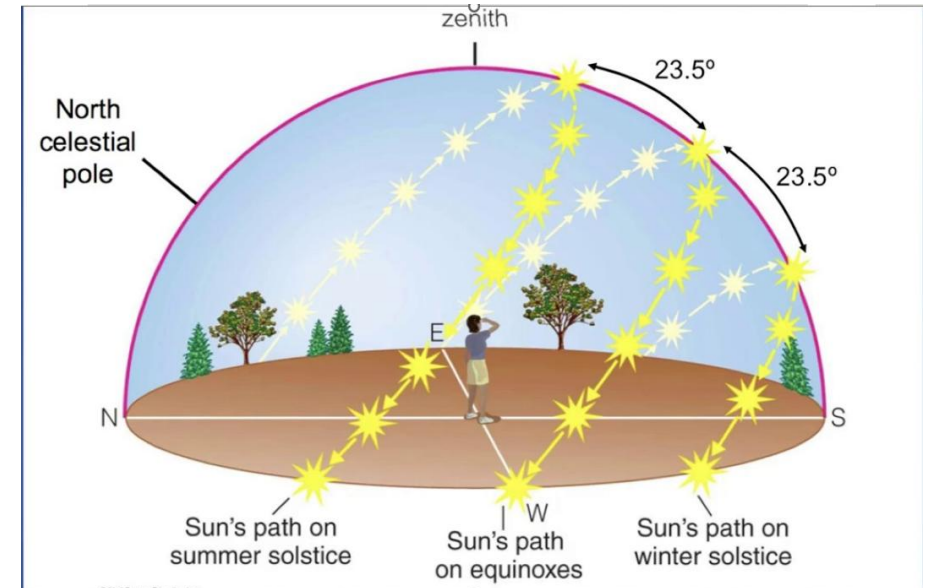
At sea level $m = 1$.

$m = 1$ when the sun is at zenith, i.e., directly over head.

$m = 2$ when zenith angle is 60° (Θ_z , the angle subtended by the zenith and the line of sight to the sun).

$m = \sec \Theta_z$, when $m > 3$.

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



3. Declination angle δ :

- The declination of the sun is the angle between the equator and a line drawn from the centre of the Earth to the centre of the sun.
- The solar declination changes mainly due to the rotation of Earth about an axis.
- The declination reaches a maximum of 23.45° on June 21 (**summer solstice** in the northern hemisphere) and a minimum of -23.45° on December 22 (**winter solstice** in the northern hemisphere).
- The declination is zero at the **equinoxes** (March 22 and September 22), positive during the northern hemisphere summer and negative during the northern hemisphere winter.

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

where n is the day of the year, [e.g., 21 June, 1988 is the 173th (31 + 29 + 31 + 30 + 31 + 21) day of 1988 i.e., $n = 173$].

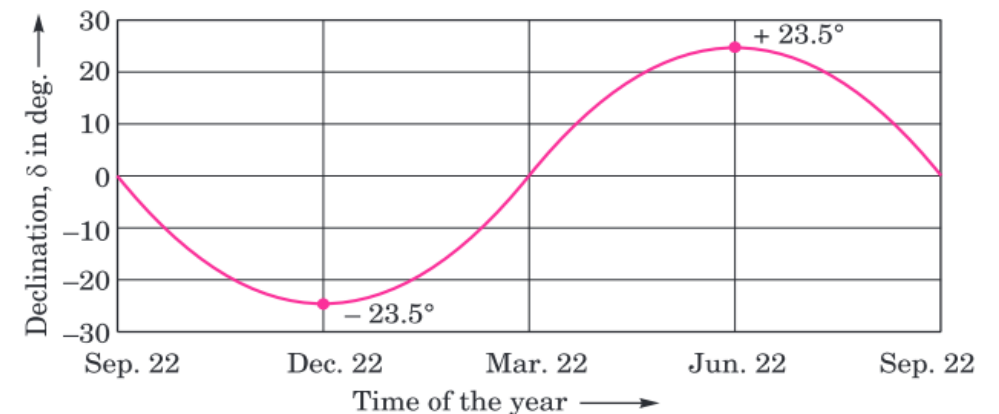
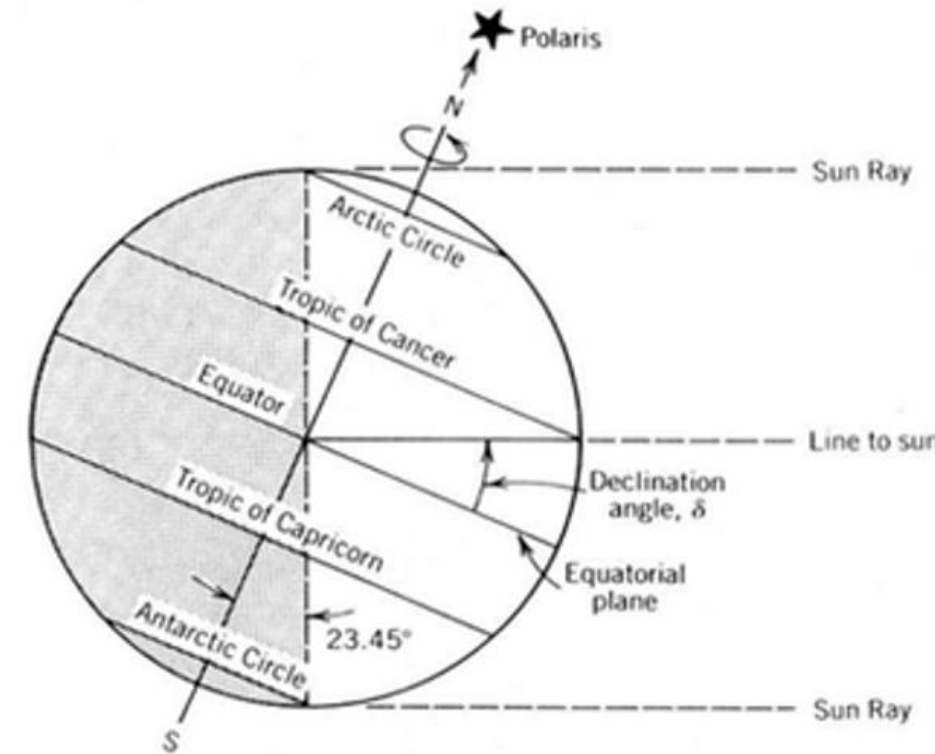
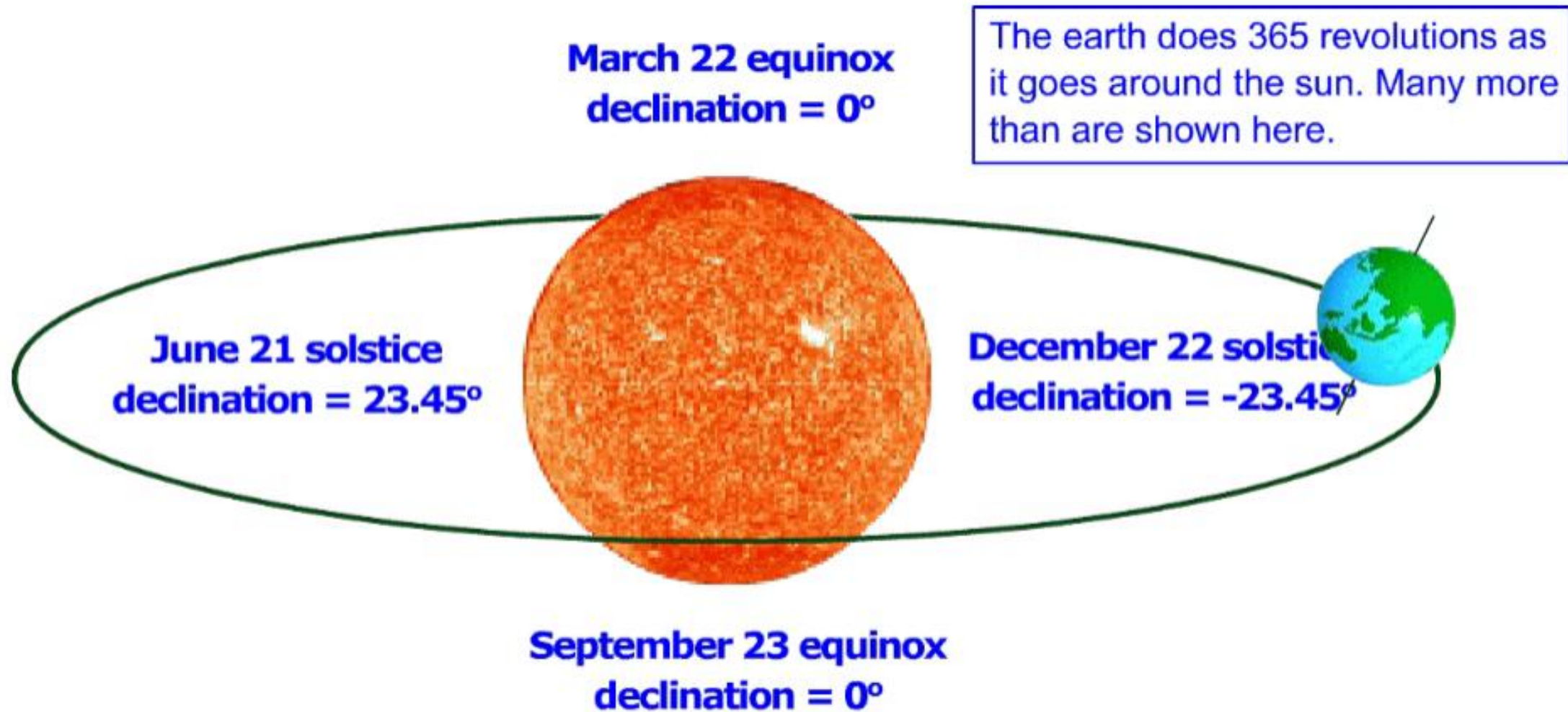
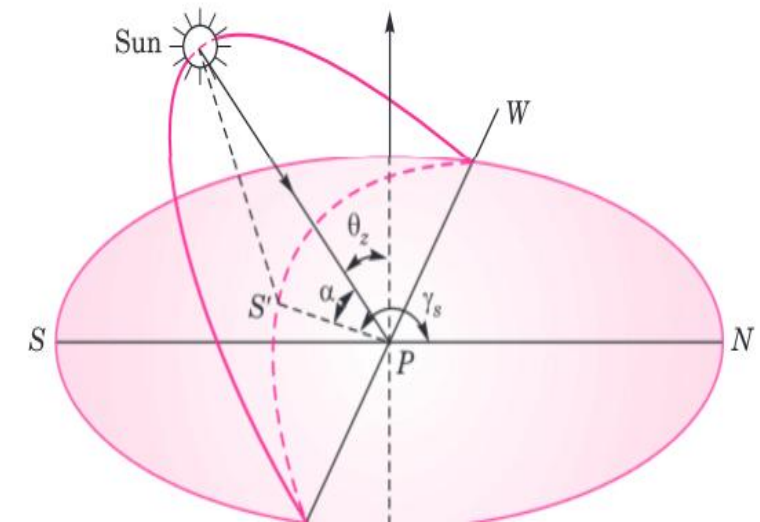
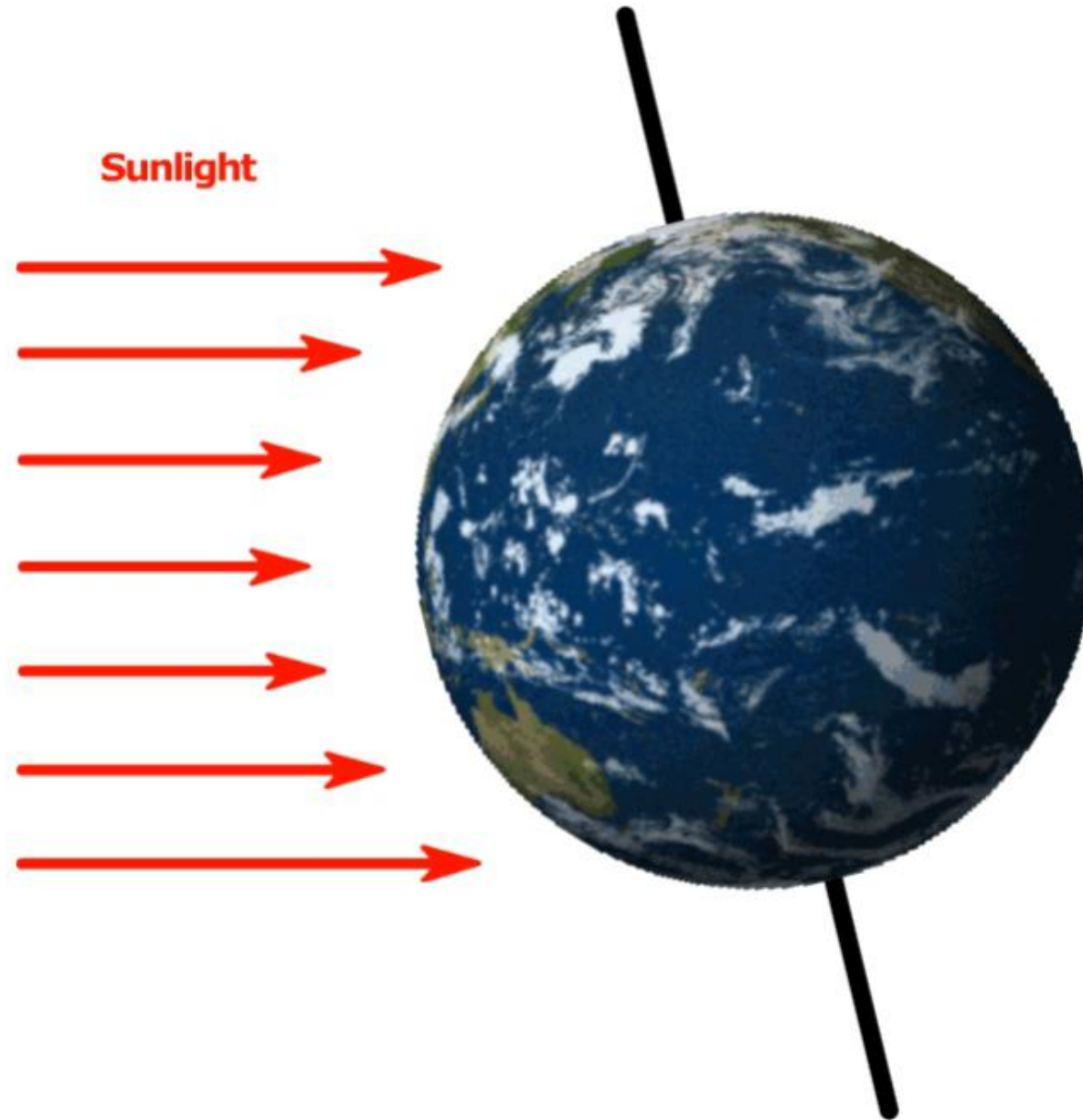


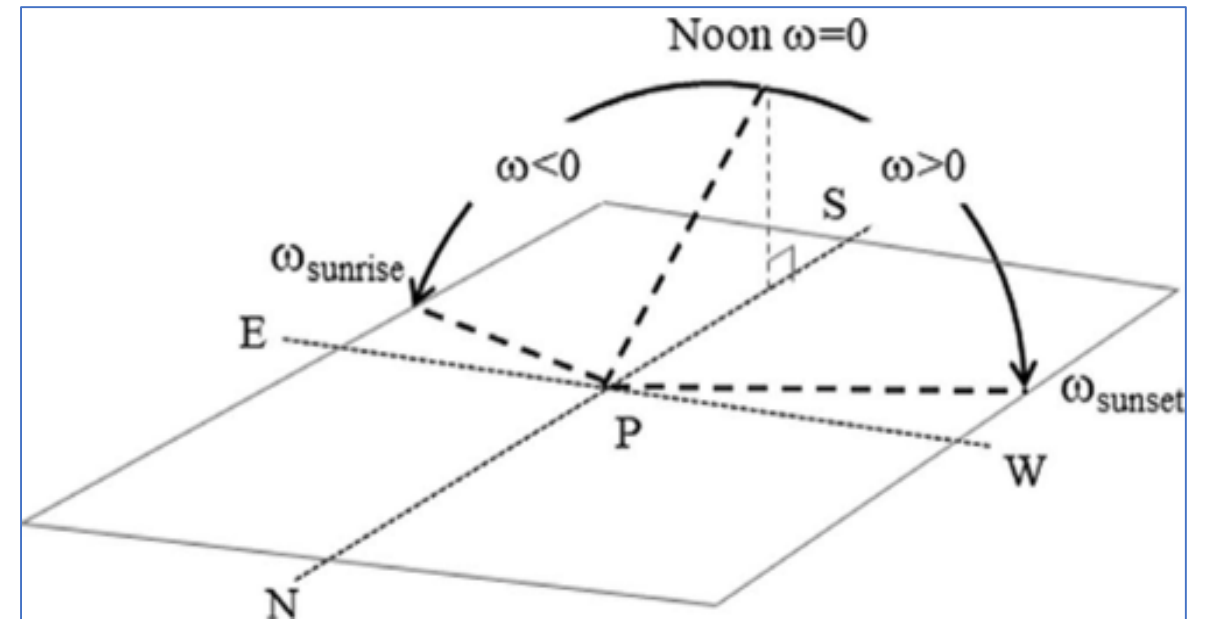
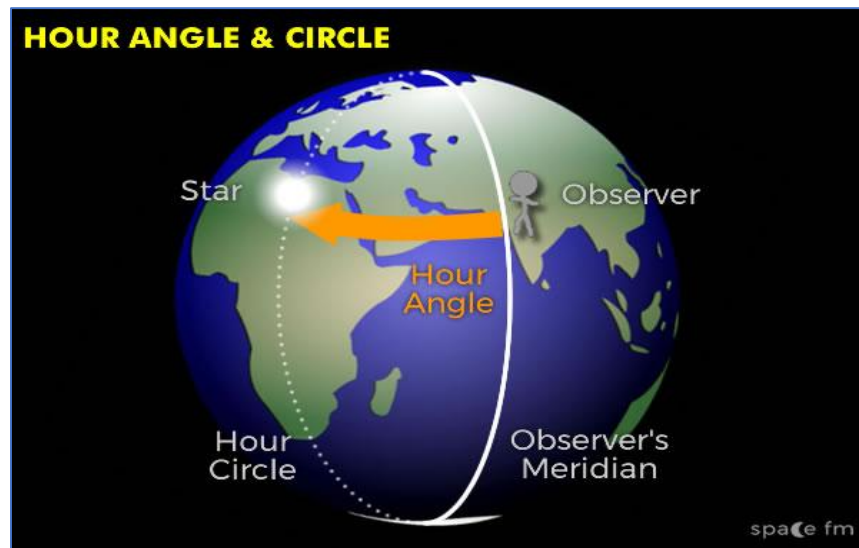
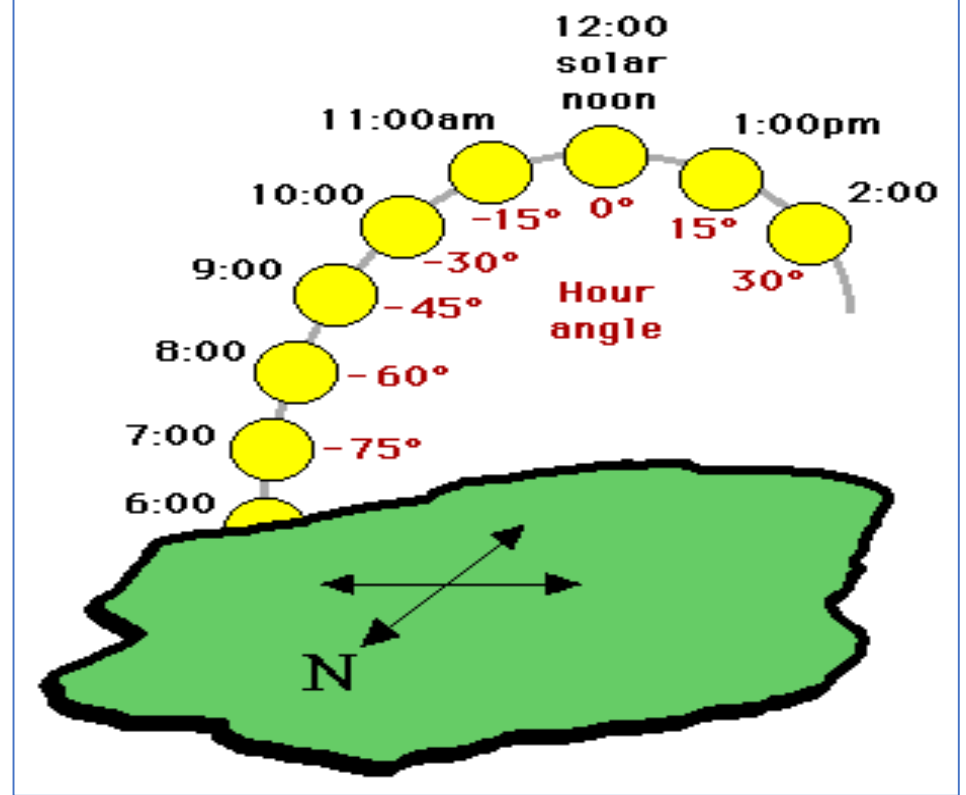
Fig. 2.5. Variation of sun's declination.





4. Hour angle ω :

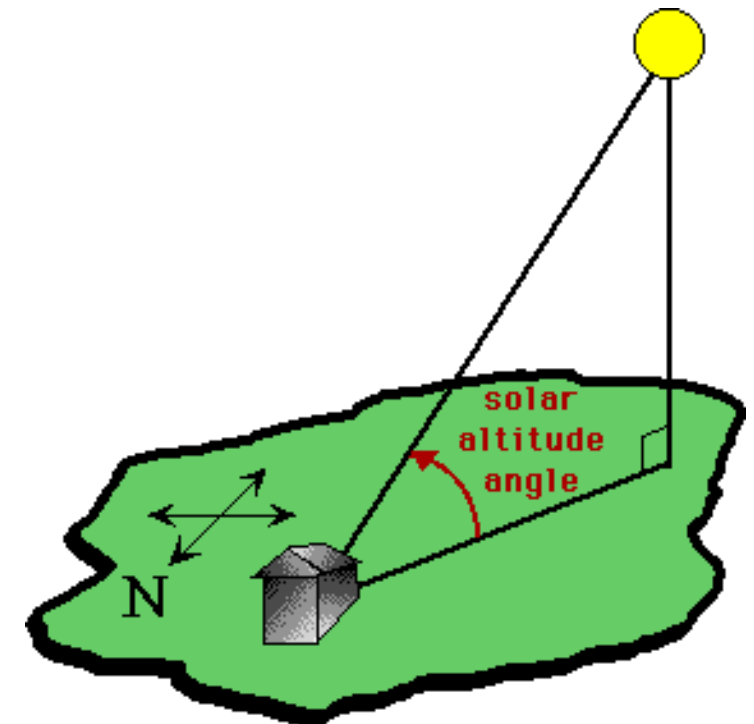
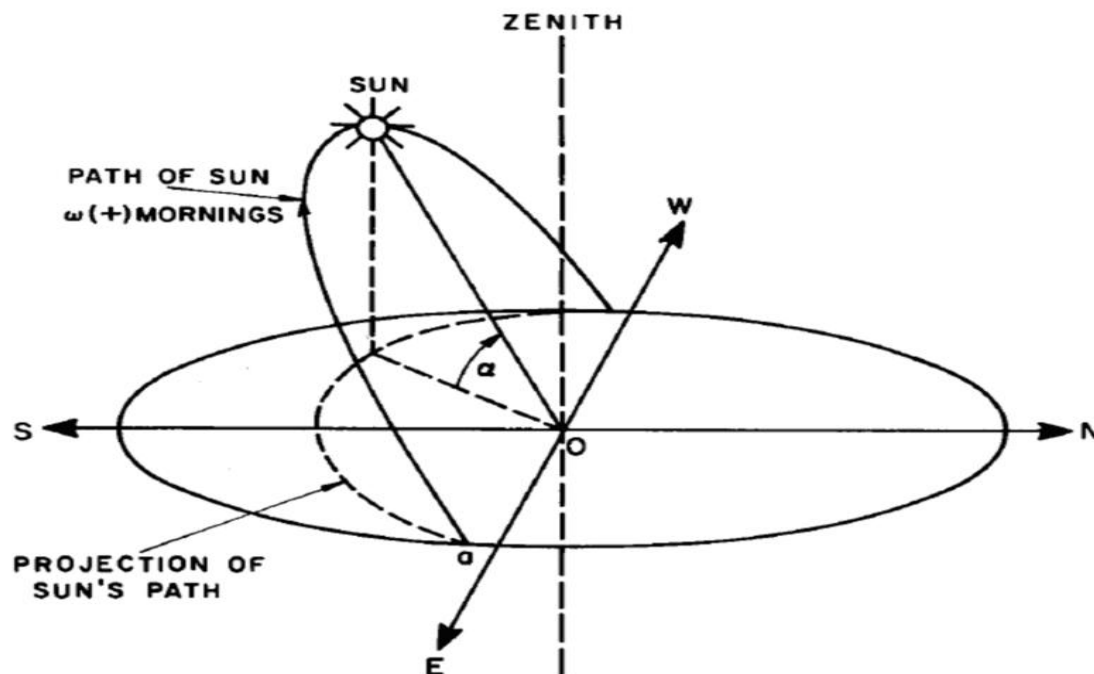
- It measures the angular distance between a celestial object and the observer's meridian at a given time. The hour angle ω is equivalent to 15° per hour. It is measured from noon based on the local solar time (LST) or local apparent time
- or
- The solar hour angle is a measure of the angular distance between the sun at the local solar time and the sun at solar noon. It is expressed in degrees or radians.
- It is negative in the morning and positive in the afternoon



5. Altitude angle (solar altitude) α : It is a vertical angle between the projection of the sun's rays on the horizontal plane and the direction of sun's rays.

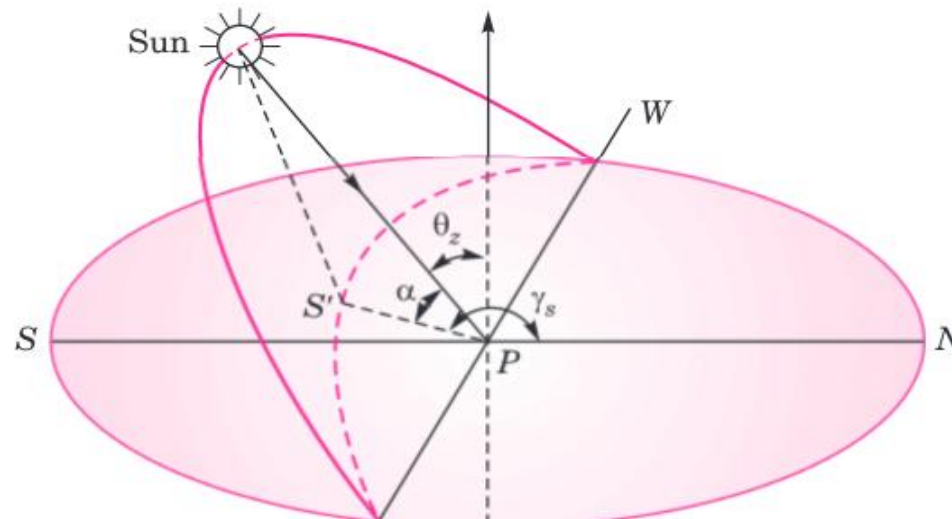
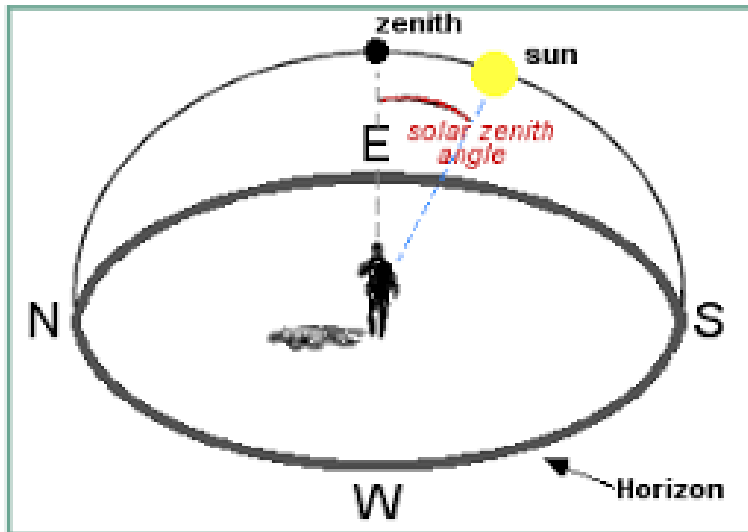
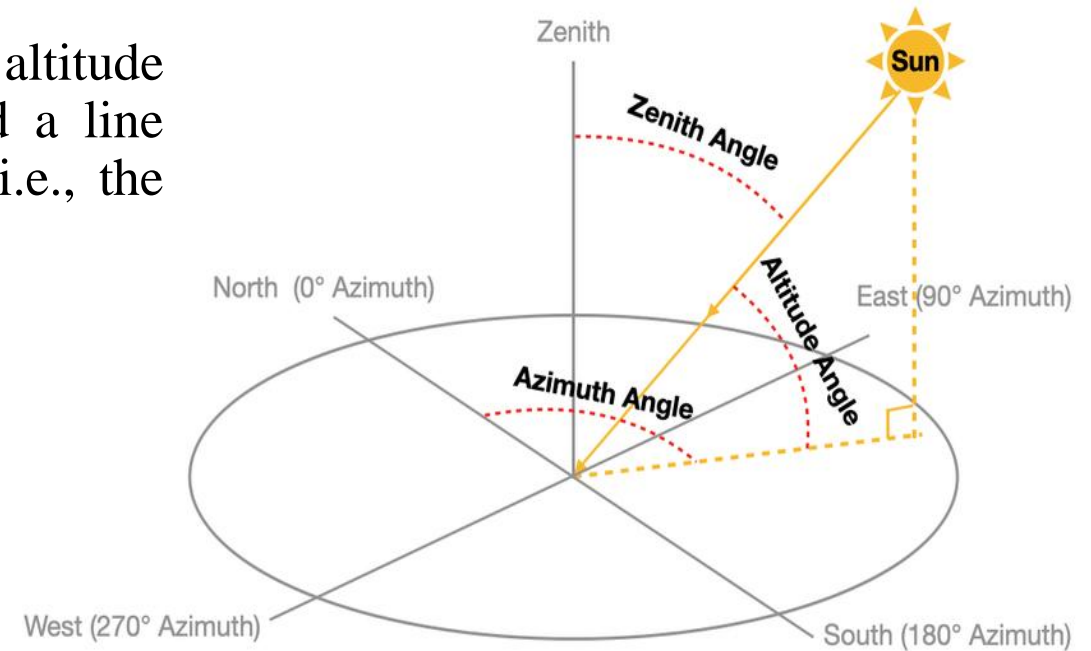
or

The **altitude angle** (sometimes referred to as the "solar elevation angle") describes how high the sun appears in the sky. The angle is measured between an imaginary line between the observer and the sun and the horizontal plane the observer is standing on.



5. Zenith angle θ_z : It is complimentary angle of sun's altitude angle. 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

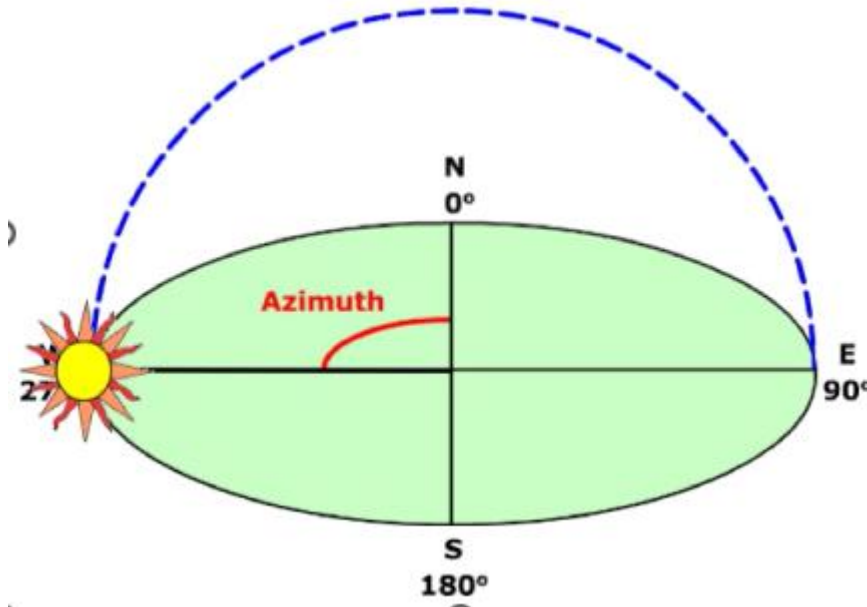
$$\theta_z = \frac{\pi}{2} - \alpha.$$



6. Solar Azimuth angle γ_s :

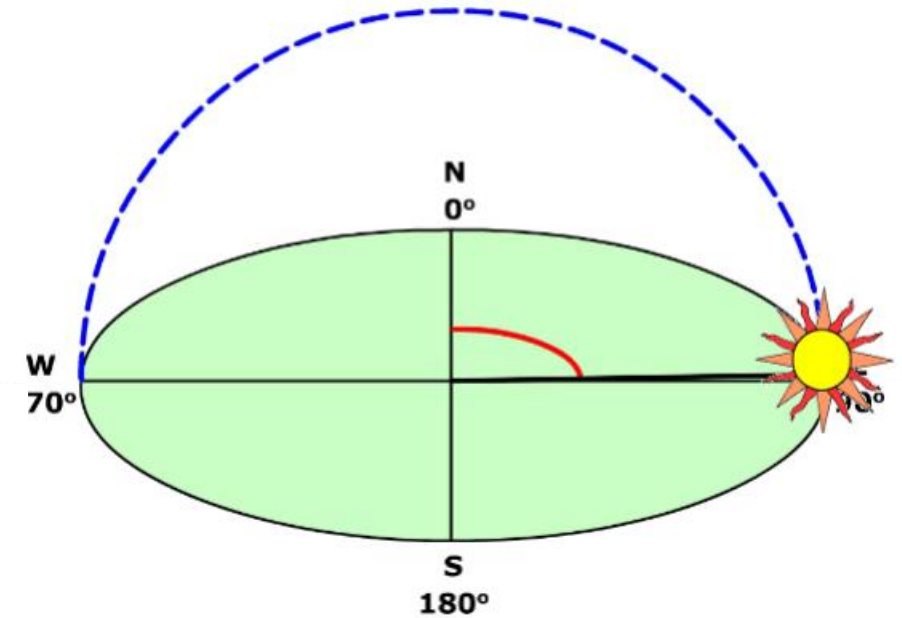
- Solar azimuth angle is defined as the angle between the projection of sun's centre onto the horizontal plane and due south direction.
- At solar noon, the sun is always directly south in the northern hemisphere and directly north in the southern hemisphere. The azimuth angle varies throughout the day as shown

<https://www.pveducation.org/pvc/drom/properties-of-sunlight/azimuth-angle>



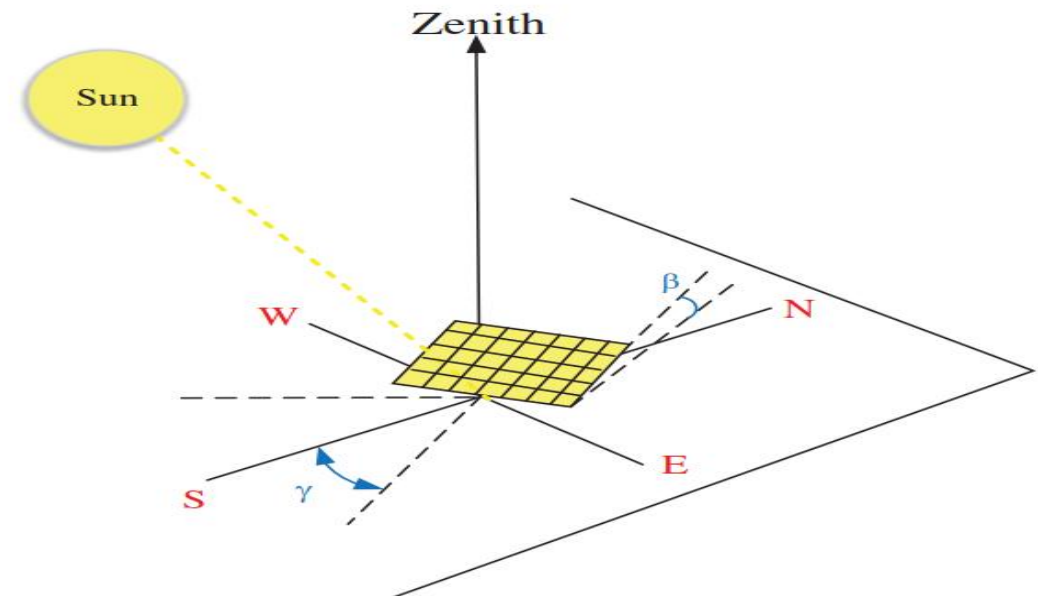
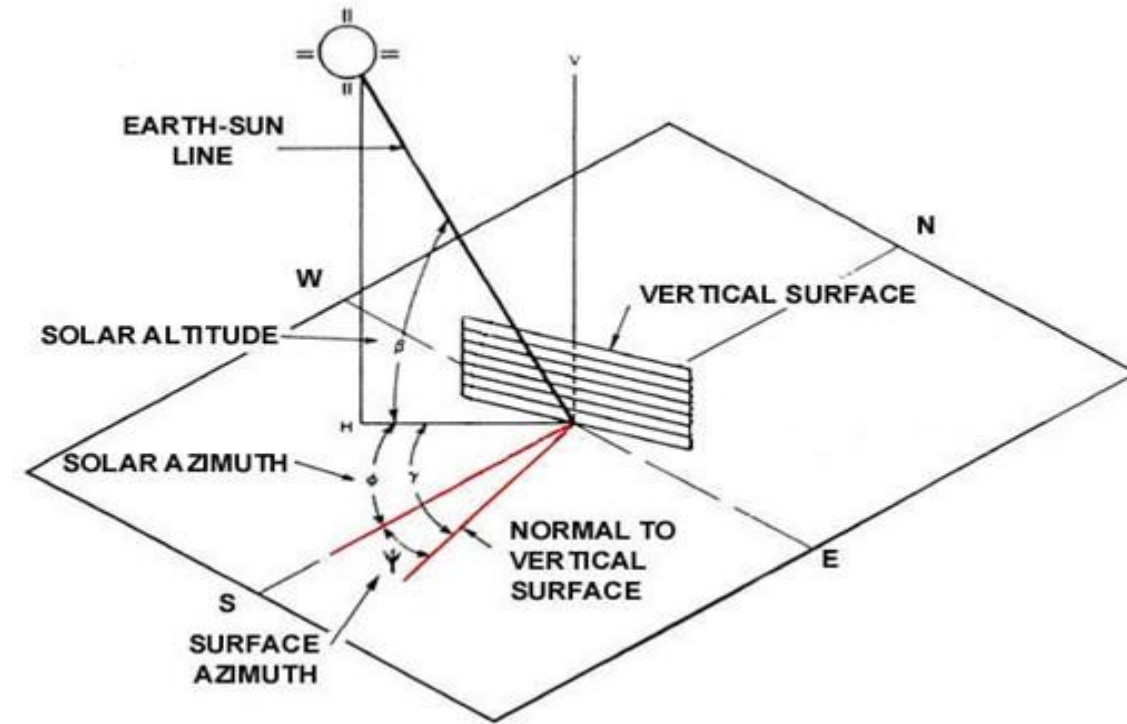
At sunrise on the spring and fall equinox, the azimuth angle is 90°.

[Click to Start](#)



8. Surface Azimuth angle (γ):

- Surface azimuth angle is the angle between line due south and the projection of normal to the surface on horizontal plane.
- $-180^\circ \leq \gamma \leq 180^\circ$



7. Slope (s): Is the angle made by the plane surface with the horizontal. It is taken to be positive for surfaces slopping towards the south and negative for surface slopping towards the north.

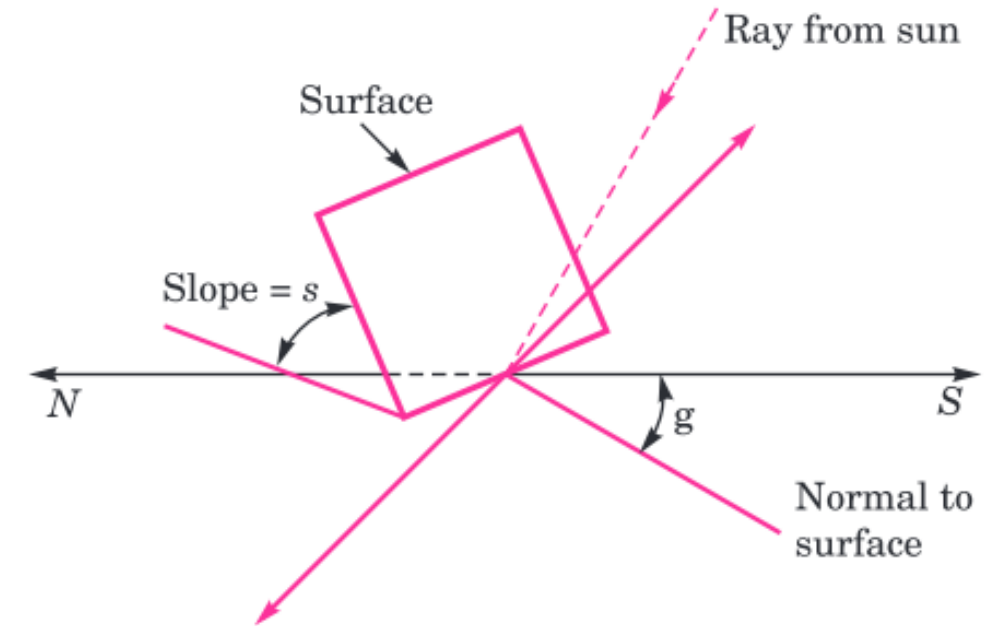
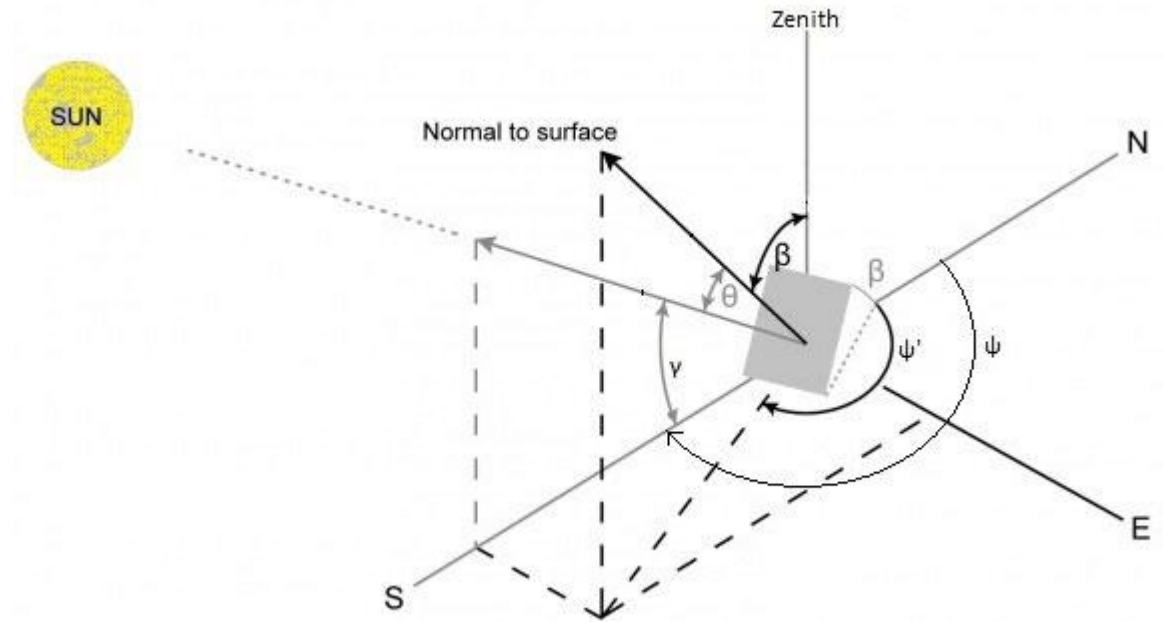


Fig. 2.7. Surface azimuth angle and slope defined.

9. Incident angle (θ). It is the angle being measured between the beam of rays and normal to the plane.

10. Local Solar Time (LST): Local Solar Time (LST) refers to the time of day based on the position of the Sun in the sky at a specific location.

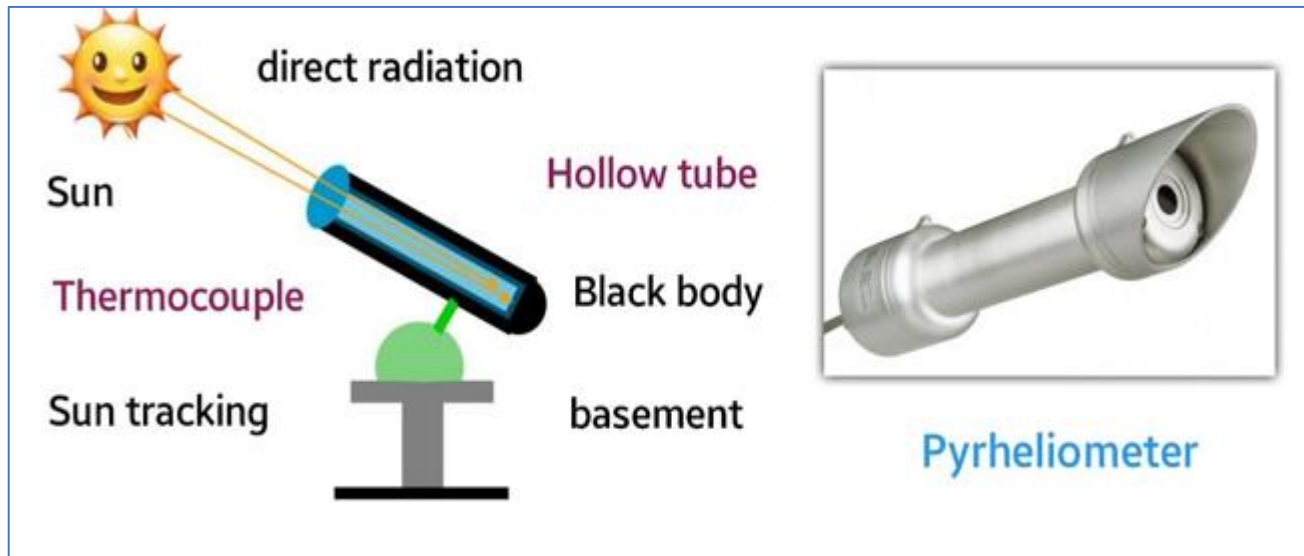


$$\text{LST} = \text{Standard Time} \pm 4(\text{Standard time longitude} - \text{longitude of location}) + (\text{Equation of time correction})$$

Solar Radiation Measurements.

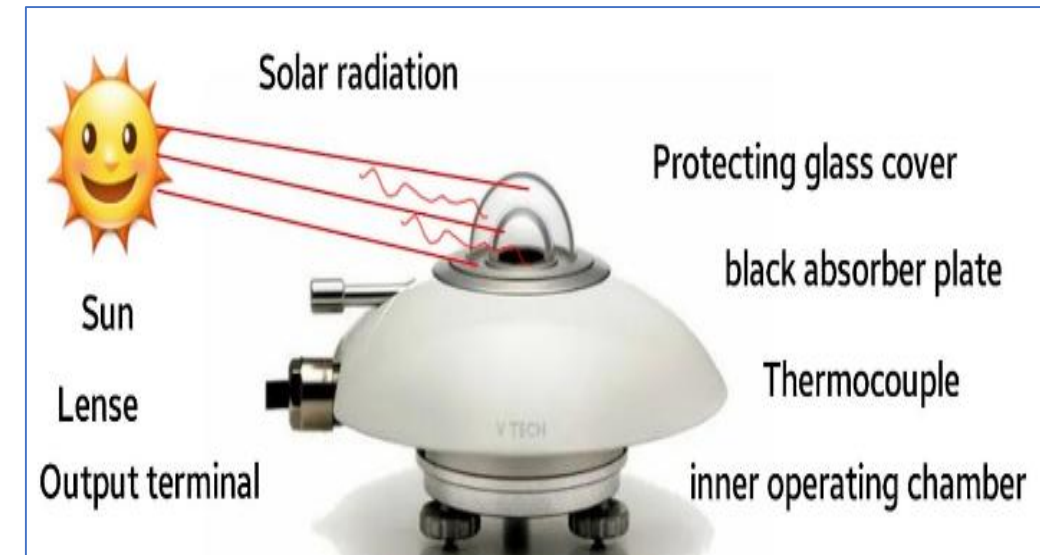
Two types of instruments are used for solar radiation measurement:

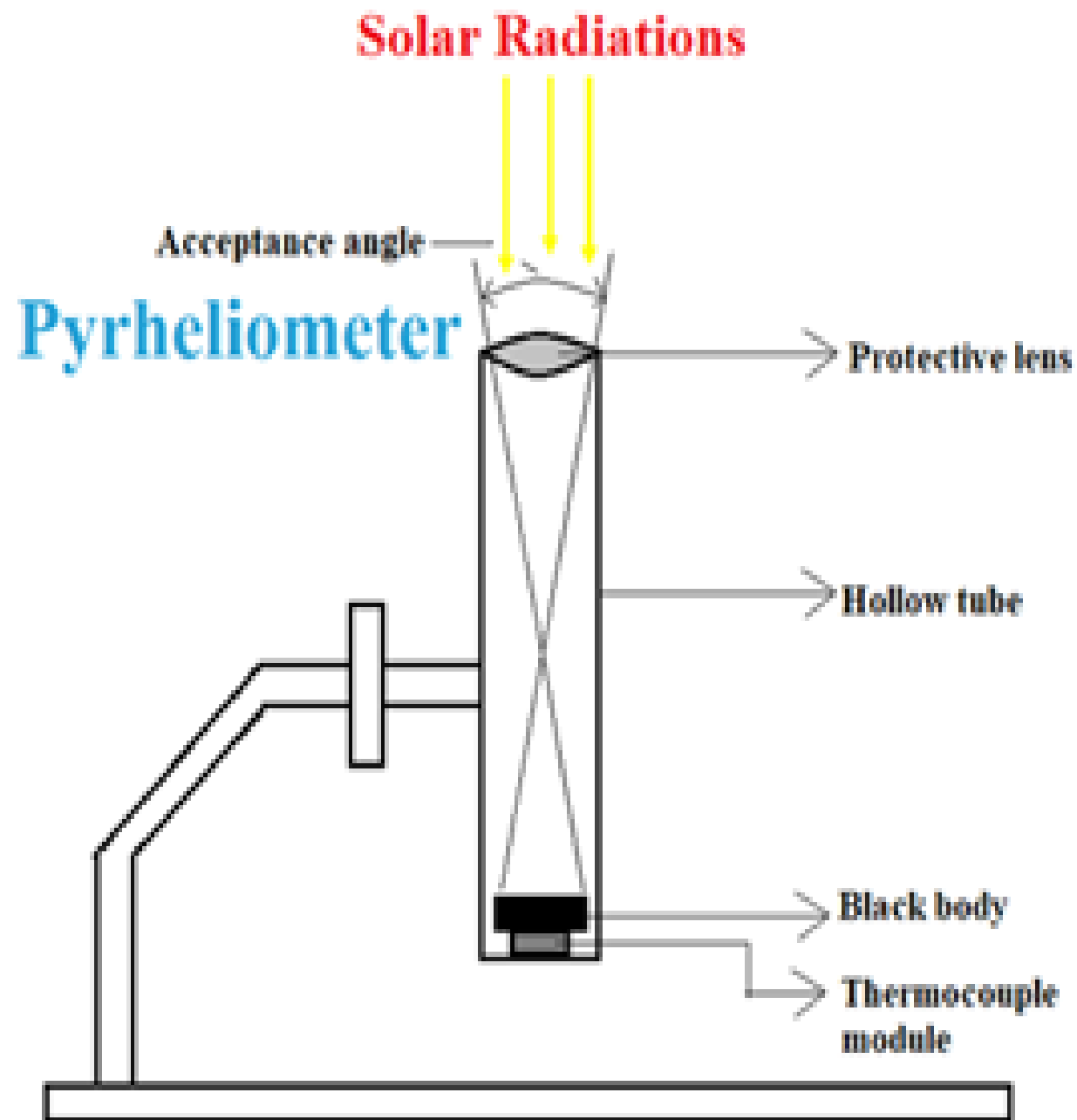
(1) **Pyrheliometer**-which collimates (aligns/place parallel to something) the radiation to determine the beam intensity as a function of incident angle.

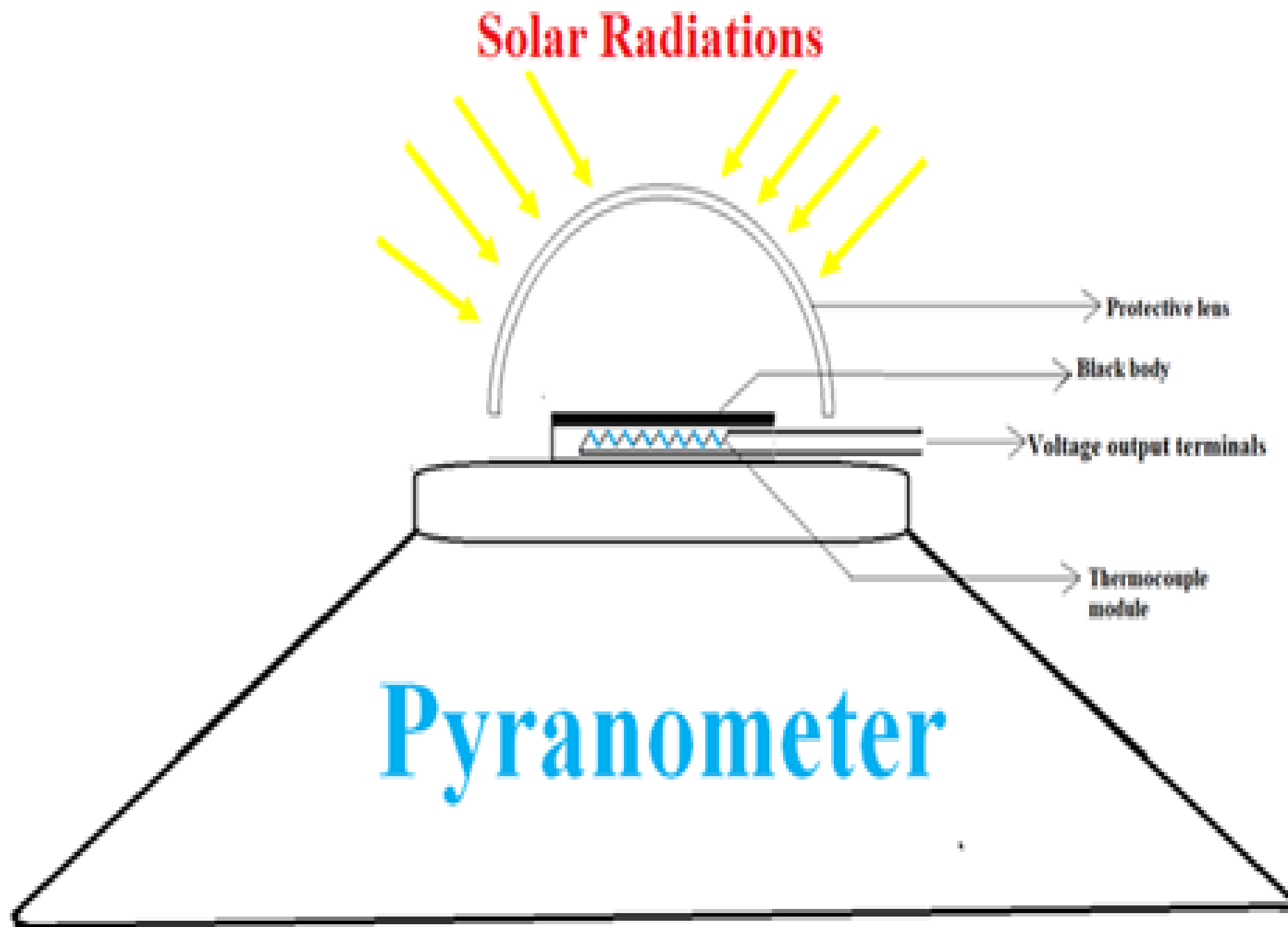


Collimates- to bring into line; make parallel.

(2) **Pyranometer**- which measures the total hemispherical solar radiation. The pyranometer measurements are the most common.

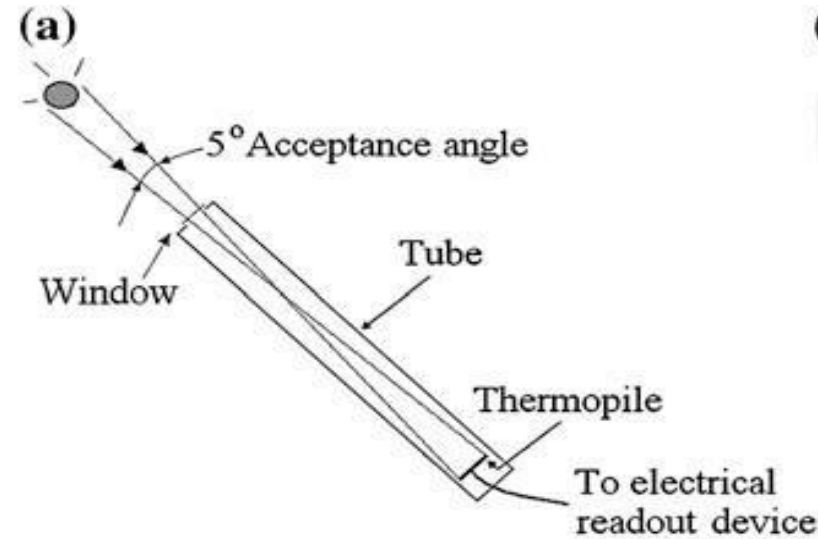






1. Pyrheliometers.

- An instrument which **measures beam radiation**.
- The **sensor disc** is located at the base of a tube, where **axis is aligned** with the direction of the sun's rays. Thereby **blocking the diffuse radiation** from the sensor surface.



- Commonly used type is the **thermopile pyrheliometer**. It consists of a blackened receiver plate that absorbs solar radiation and **converts it into heat**. This heat is then transferred to a **thermopile**, which is a **device that generates an electric voltage in response to temperature differences**. The **generated voltage is proportional to the solar irradiance**, allowing for the measurement of solar radiation.
- The **direct solar** component on a horizontal surface may also be obtained **using a shading ring**, this is done by subtracting the shaded (diffuse) from the unshaded (global) reading, normal to direct solar rays, i.e., a line joining the sun and receiver.

Types of Pyrheliometers

Three pyrheliometers have been in wide-spread use to measure normal incident beam radiation:

- (i) the Angstrom pyrheliometer
- (ii) the Abbot silver disc pyrheliometer
- (iii) Eppley pyrheliometer.

i. Angstrom compensation Pyrheliometer:



- In this pyrheliometer, a thin blackened shaded manganin strip (Size 20 x 2 x 0.1 mm) is heated electrically until it is at the same temperature as a similar strip which is exposed to solar radiation.
- Under steady state conditions (both strips at identical temperature) the energy used for heating is equal to the absorbed solar energy.
- The thermocouples on the back of each strip, connected in opposition through a sensitive galvanometer (or other null detector), are used to test for the equality of temperature.

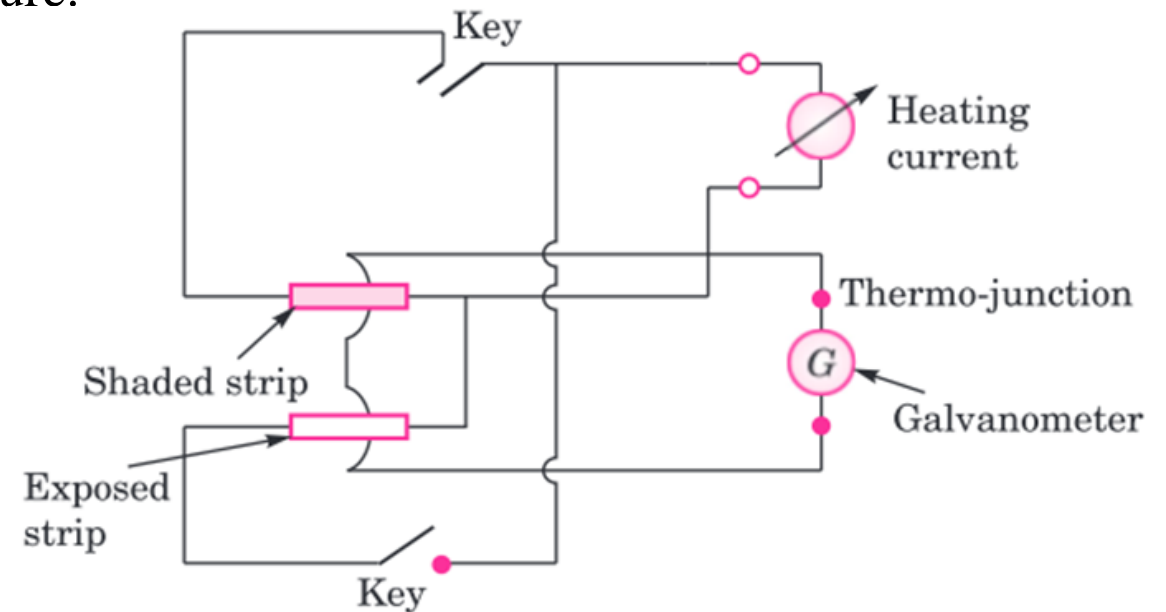


Fig. 2.9. Electric circuit for Angstrom Pyrheliometer.

(ii) Abbot silver disk Pyrheliometer:

- It consists a blackened silver disk positioned at the lower end of a tube with diaphragms to limit the whole aperture to 5.7° .
- A mercury in glass thermometer is used to measure the temperature at the disk.
- A shutter made of three polished metal leaves is provided at the upper end of the tube to allow solar radiation to fall on the disk at regular intervals and the corresponding changes in temperature of the disk are measured.

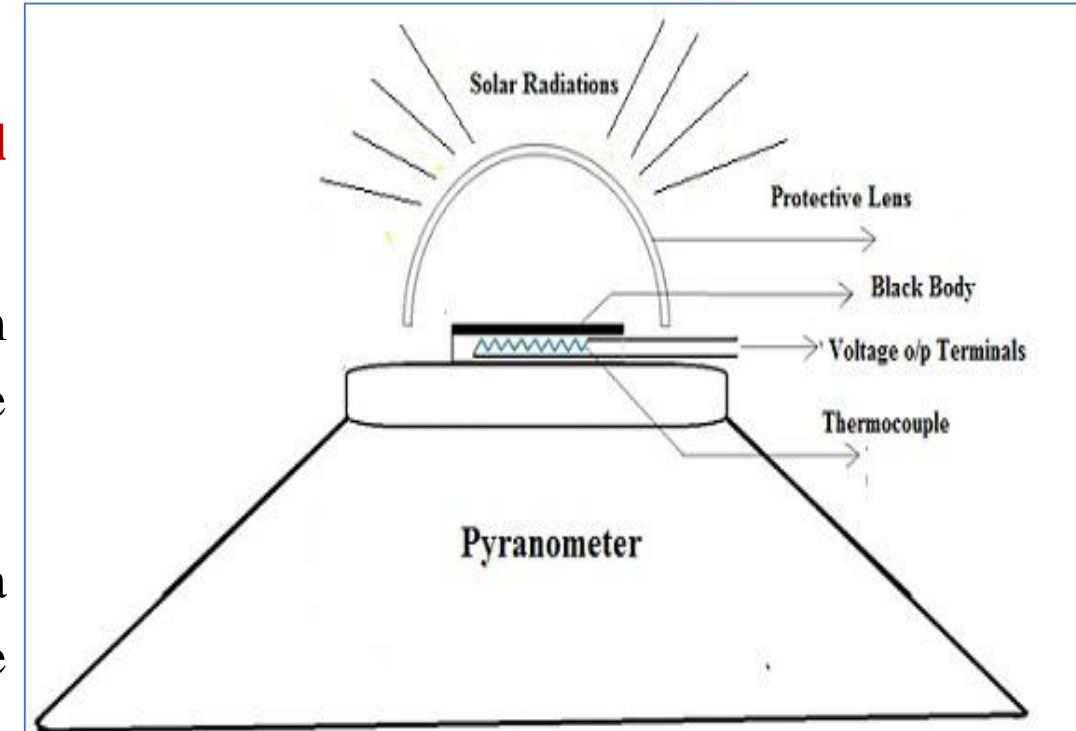


(iii) Eppley Pyrheliometer.

- The sensitive element in an Eppley pyrheliometer is a temperature compensated 15 junction bismuth silver thermopile mounted at the base of a brass tube, the limiting diaphragms of which subtend an angle of 5.7° .
- A thermopile is basically a series arrangement of thermocouples used to develop a much greater voltage than is possible using only one.
- The tube is filled with dry air and is sealed with a crystal quartz window which is removable. A filter wheel is standard.

2. Pyranometers:

- A pyranometer is an instrument which measures **total or global radiation** over a hemispherical field of view.
- If a shading ring is attached, the beam radiation is prevented from falling on the instrument sensor and it then measures only the diffuse component of the radiation.
- In most pyranometers, the sun's radiation is allowed to fall on a black surface to which the hot junctions of a thermopile are attached.



- The cold junctions of the thermopile are located in such a way that they do not receive the radiation.
- As a result, an e.m.f. proportional to the solar radiation is generated.
- This e.m.f. which is usually in the range of 0 to 10 mV can be read, recorded or integrated over a period of time with regular calibration of about ± 2 percent can be obtained.

2. Pyranometers Types

There are following types of pyranometers:

- (i) Eppley pyranometer,
- (ii) Yellot solarimeter (photovoltaic solar cell),
- (iii) Moll-Gorczyheski solarimeter,
- (iv) Bimetallic Actiono-graphs of the Rabitzsch type,
- (v) Velochme pyranometer,
- (vi) Thermoelectric pyranometer etc.

Eppley pyranometer:

- It is based on the principle that there is a difference between the temperature of black surfaces (which absorb most solar radiation) and white surfaces (which reflect most solar radiation).
- The detection of temperature difference is achieved by thermopile.
- It uses concentric silver rings 0.25 mm thick, appropriate coated black and white, with either 10 or 50 thermocouple junctions to detect temperature differences between coated rings.
- Later models use wedges arranged in a circular pattern, with alternate black and white coatings.
- The disks or wedges are enclosed in a hemispherical glass cover.

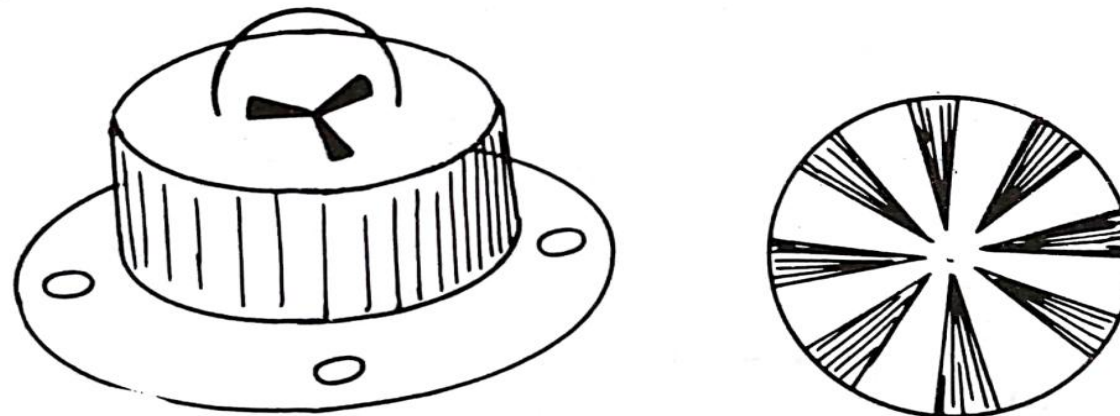


Fig. 2.3.2. Pyranometer with alternate black and white sensor segments.

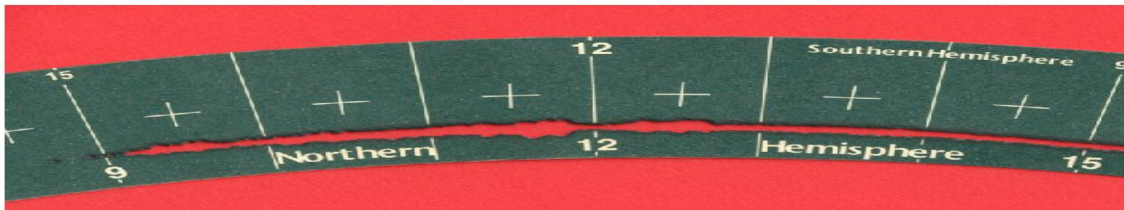
(ii) Yellot Solarimeter (Photovoltaic solar cell):

- Pyranometers have also been used on photovoltaic (solar cell) detectors.
- Silicon cells are the most common for solar energy.
- Silicon solar cells have the property that their light current (approximately equal to the short circuit current at normal radiation levels) in a linear function of the incident solar radiation.
- They have the disadvantages that the spectral response is not linear, so instrument calibration is a function of the spectral distribution of the incident radiation.

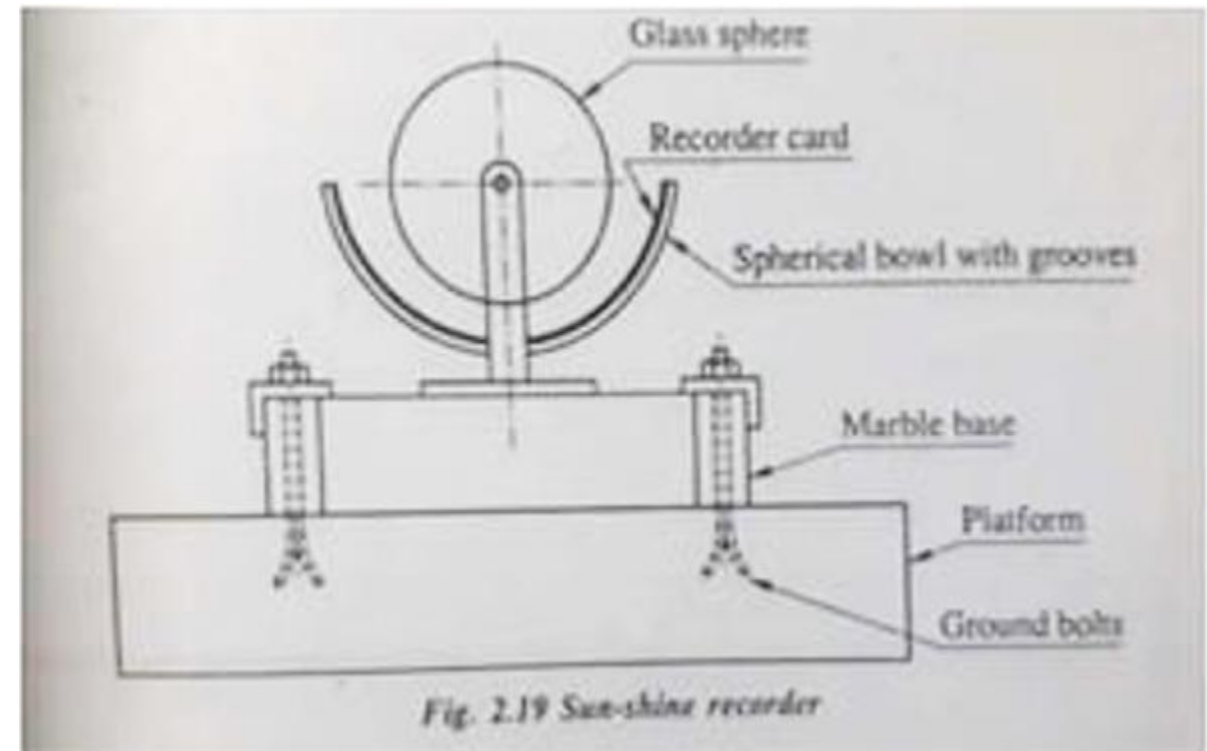


2.6. Sunshine Recorder

- The duration of bright sunshine in a day is measured by means of a sunshine recorder.
- The sun's rays are focussed by a glass-sphere to point on a card strip held in a groove in a spherical bowl mounted concentrically with the sphere.
- Whenever there is a bright sunshine, the image formed is intense enough to burn a spot on the card strip.
- Through the days the sun moves across the sky, the image moves along the strip. Thus a burnt space whose length is proportional to the duration of sun shine is obtained on the strip.



<https://www.youtube.com/watch?v=tBMnWs3ngkQ>



Solar Energy Collectors

A solar collector is a device for collecting solar radiation and transfer the energy to a fluid passing in contact with it. Utilization of solar energy requires solar collectors. These are general of two types:

- (i) Non concentrating or flat plate type solar collector.
- (ii) Concentrating (focusing) type solar collector.

(i) Flat-Plate Collectors

- Non-concentrating type collectors relatively simple to construct and erect
- **Temperatures below 90°C** are adequate, for space heating in buildings and service water heating.
- It **consists** of a flat, rectangular or square-shaped box from about 1.7 to 2.9 sq. m, in area with a transparent cover (usually glass or plastic) and an absorber plate.
- Flat plates can collect and **absorb both direct and diffuse solar radiation**, they are consequently partially effective even on cloudy days when there is no direct radiation



Flat-Plate Collectors cntd.

Flat-plate solar collectors may be divided into **two main classifications** based on the type of heat transfer fluid used: **Liquid/water heater , Air heater**

- i. Liquid heating collectors* - are used for heating water and non-freezing aqueous solutions and occasionally for non-aqueous heat transfer fluids.
- ii. Solar air heaters*- Air or gas heating collectors are used.

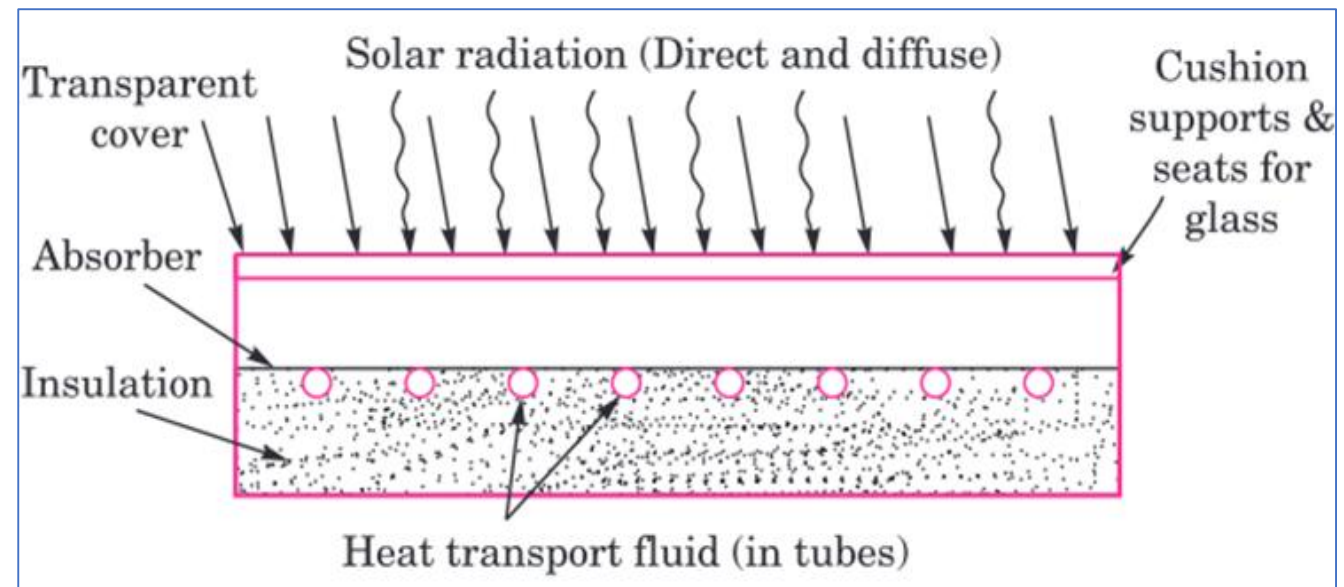
The principal difference between the two types is the design of the passages for the heat for the transfer fluid.

The majority of the flat-plate collector have **five main components as follows:**

- (i) A transparent cover*- which may be one or more sheets of glass or radiation transmitting plastic film or sheet.
- (ii) Tubes, fins, passages or channels*- are integral with the collector absorber plate or connected to it, which carry the water, air or other fluid.
- (iii) The absorber plate*- normally metallic or with a black, surface, although a wide variety of other materials can be used with air heaters.
- (iv) Insulation*- which should be provided at the back and sides to minimise the heat losses. Standard insulating materials such as fibre glass or styro-foam are used for this purpose.
- (v) The casing or container* -which enclose the other components and protects them from the weather.

Typical Liquid Collector

- It is the plate and tube type collector.
- It basically consists of a **flat surface** with high absorptivity for solar radiation, called the **absorbing surface**. Typically a **metal plate**, usually of copper, steel or aluminium material with **tubing of copper in thermal contact with the plates**, are the most commonly used materials.
- The absorber plate is usually made from a metal sheet 1 to 2 mm in **thickness**, while the tubes, which are also of metal, range in **diameter** from 1 to 1.5 cm.
- They are soldered, brazed or clamped to the bottom (in some cases, to the top) of the absorber plate with the pitch ranging from 5 to 15 cm.
- In some designs, the tubes are also in line and integral with the absorber plate.



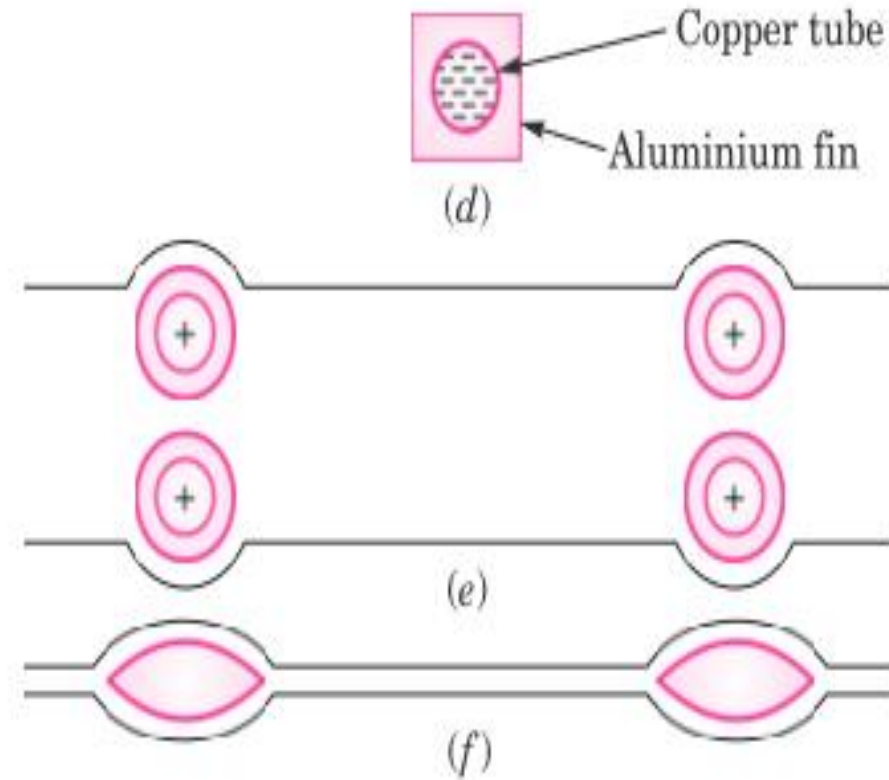
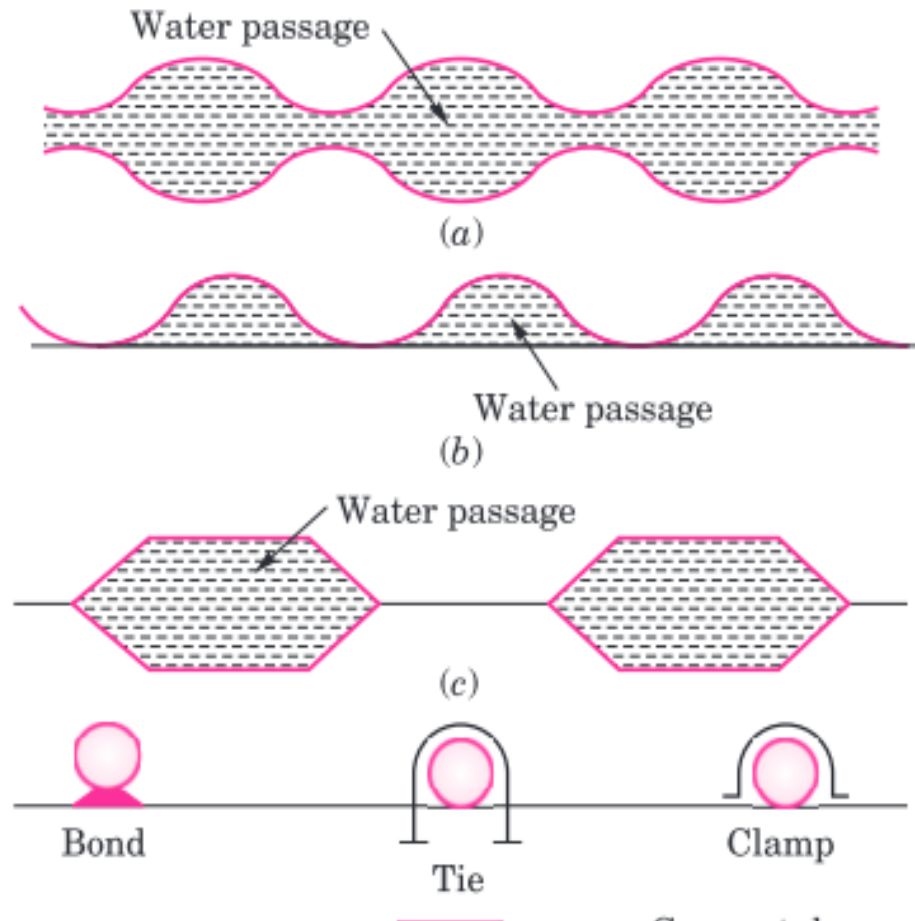


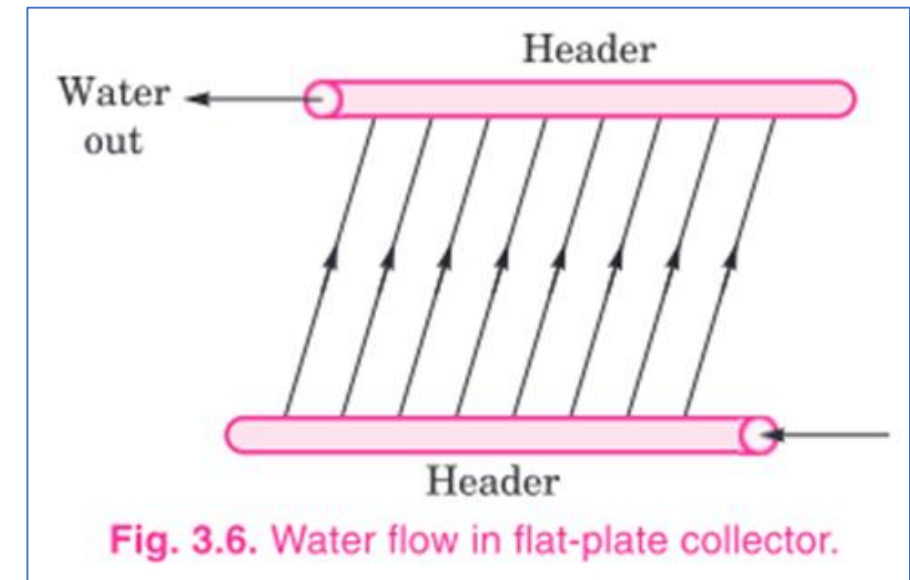
Fig: Cross Section through collector plates

Heat Transport System:

- The heat generated in the absorber is removed by continuous flow of a **heat-transport medium**, either **water or air**.
- When water is used, it is most commonly passed through **metal tubes**, either **circular or rectangular cross-section**.
- In order to maximise the exposure to solar radiation, collectors are almost invariably **sloped**.
- Cooler water then enters at the bottom header, flows upward through the tubes where it is warmed by the absorber, and leaves by way of the top header.

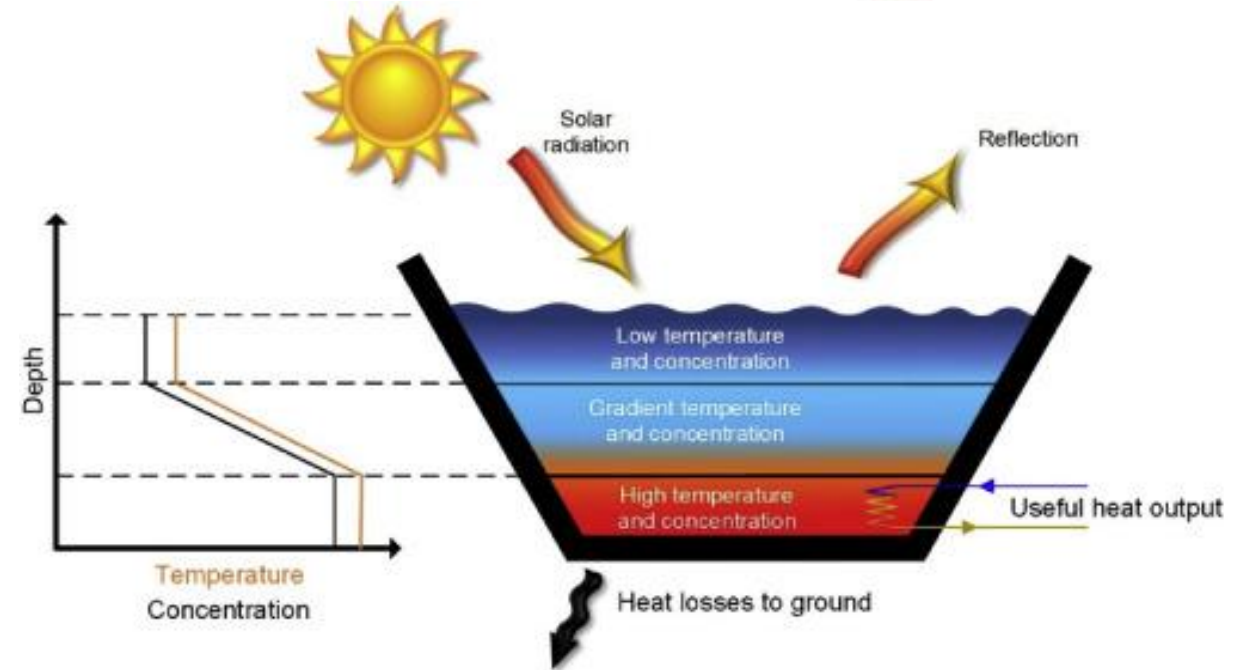
Advantages of Flat-plate Collectors

- They have the advantages of using both beam and diffuse solar radiation.
- They do not require orientation towards the sun.
- They require little maintenance.
- They are mechanically simpler than the concentrating reflectors, absorbing surfaces and orientation devices of focusing collectors.



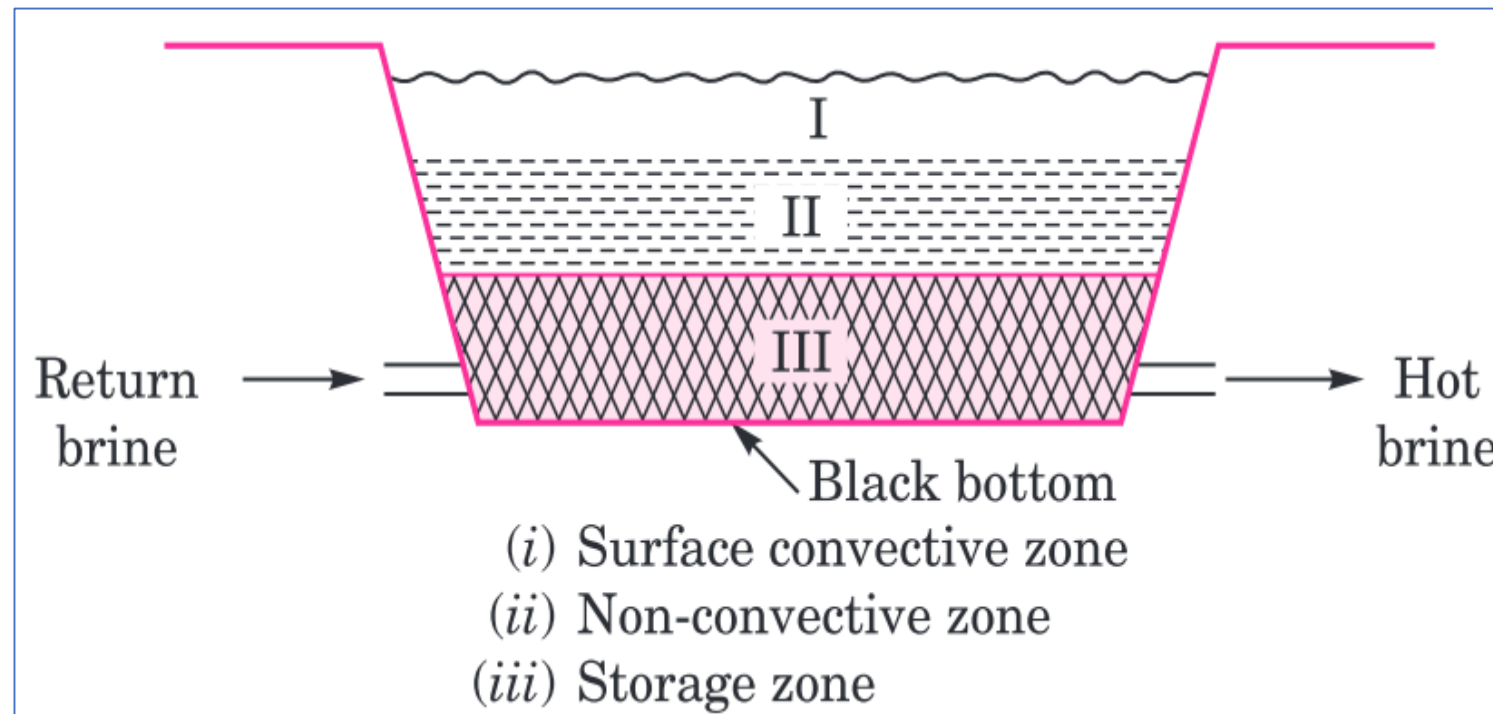
Solar pond

- It is a solar energy collector, large in size, that looks like a pond.
- This type of solar energy collector uses a large, **salty lake** as a **kind of a flat plate collector** that absorbs and stores energy from the Sun in the warm, lower layers of the pond.
- A solar pond is a **mass of shallow water about 1 or 2 metres deep** with a large collection area, which acts as a heat trap. It contains dissolved salts to generate a stable density gradient.
- Part** of the incident solar radiation entering the pond surface is **absorbed** throughout the **depth** and the **remainder** which penetrates the pond is absorbed at the **black bottom**.
- If the pond were initially filled with fresh water, the lower layers would heat up, expand and rise to the surface.
- Because of the convective mixing and heat loss at the surface, only a small temperature rise in the pond could be realized



The solar pond has three zones with following salinity with depth:

- (i) Surface convective zone or upper convective zone: (0.3—0.5 m), salinity $< 5\%$.
- (ii) Non-convective zone 1 to 1.5 m, salinity increases with depth.
- (iii) Storage zone or lower convective zone: 1.5 to 2 m, salinity 20%

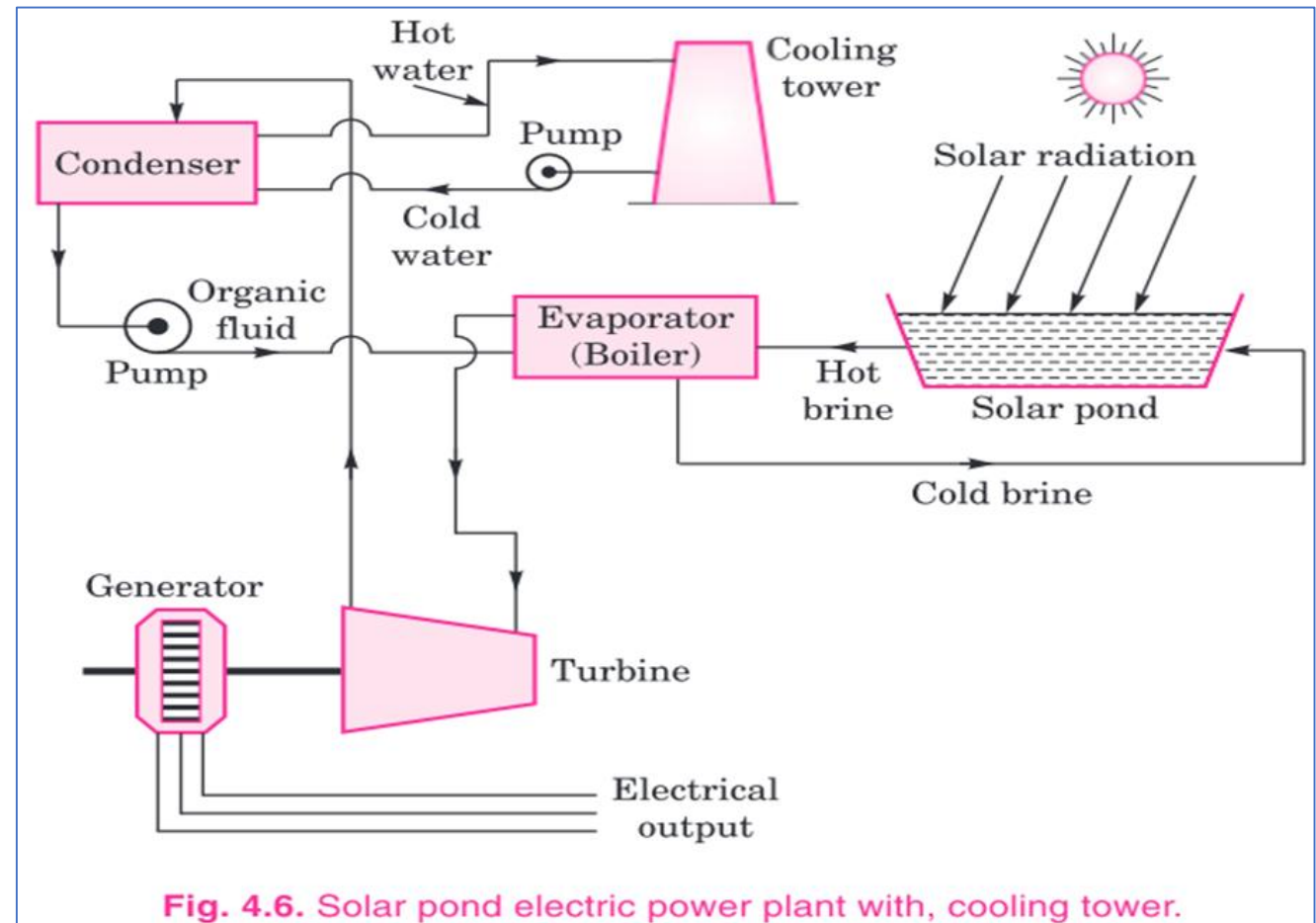


Solar Pond Electric power plant with cooling tower

- A solar pond electric power plant with a cooling tower is a type of power generation facility that combines the concept of a solar pond with conventional power generation methods to produce electricity

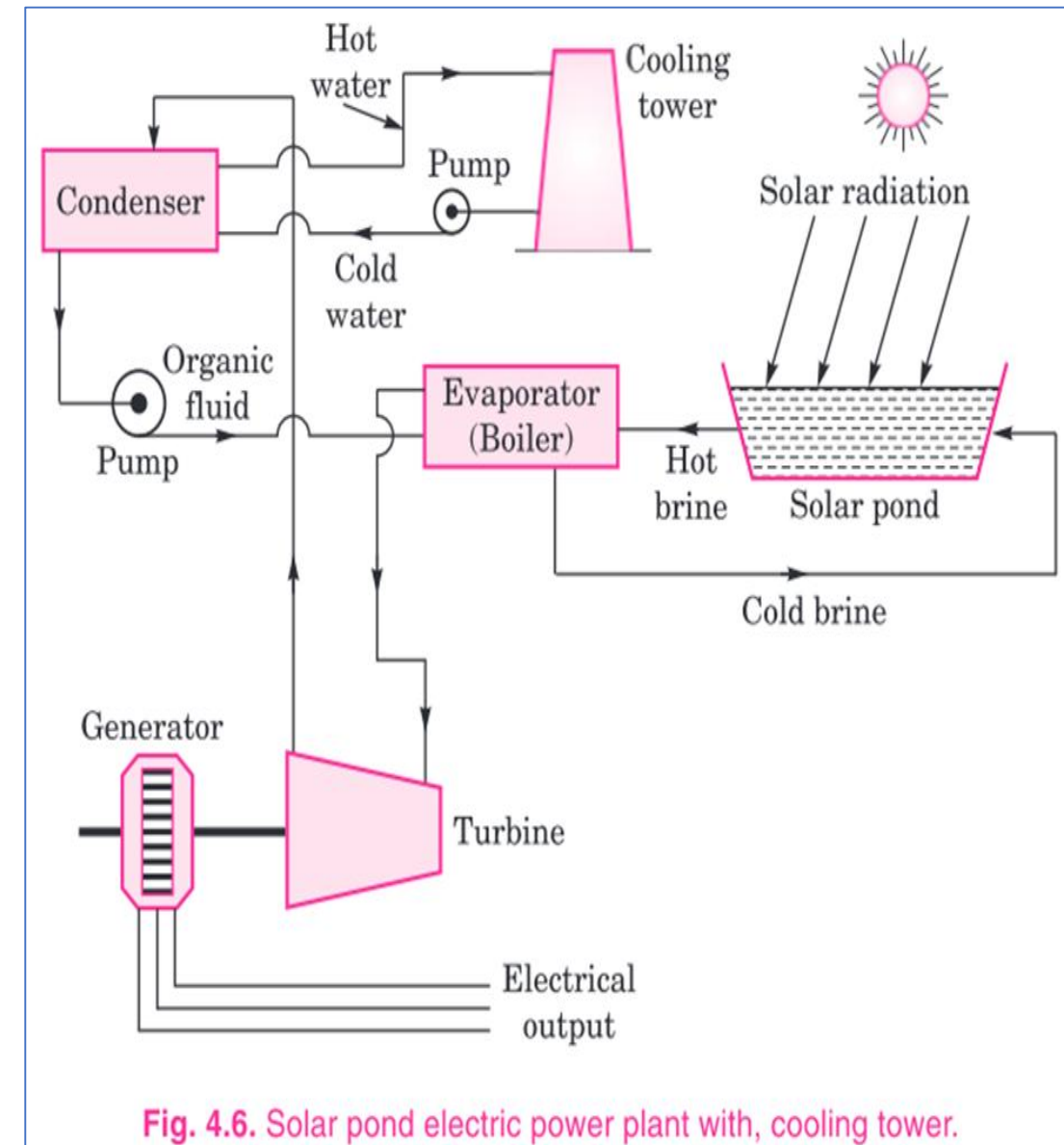
Working:

- Solar Pond
- Heat Extraction
- Steam Generation
- Power Generation
- Cooling Tower
- Condensation and Recirculation



Working:

- **Solar Pond:** Solar pond is designed to collect and store solar energy. The solar pond operates based on the salinity gradient principle. It traps and stores solar heat effectively.
- **Heat Extraction:** The heat from the solar pond is transferred to a heat transfer fluid(such as water or a specialized heat transfer fluid) circulating through a heat exchanger submerged in the lower layers of the solar pond.
- **Steam Generation:** The heated heat transfer fluid is then sent to a steam generator or boiler, where it produces high-pressure steam
- **Power Generation:** The high-pressure steam drives a turbine connected to a generator. As the steam expands through the turbine blades, electricity is generated through the attached generator.
- **Cooling Tower:** The excess heat from the steam turbine's exhaust is extracted using a cooling tower, helping to maintain the efficiency of the power generation process.
- **Condensation and Recirculation:** After passing through the turbine, the steam is condensed back into water using a condenser. The condensed water is then recirculated back to the solar pond or the heat transfer fluid system, completing the cycle.



Applications of Solar pond:

- (1) Heating and Cooling of Buildings:** Because of the large heat storage capability in the lower convective zone of the solar pond, it has ideal use for heating even at high latitude stations and for several cloudy days.
- (2) Production of Power:** A solar pond can be used to generate electricity by driving a thermo-electric device or an organic Rankine cycle engine—a turbine powered by evaporating an organic fluid with a low boiling point.
- (3) Industrial Process Heat:** the solar pond can play a significant role in supplying the process heat to industries thereby saving oil, natural gas, electricity, and coal.
- (4) Desalination:** The low cost thermal energy can used to desalt or otherwise purify water for drinking or irrigation.
- (5) Heat for biomass conversion:** solar ponds could provide heat to convert biomass to alcohol or methane.

Solar Distillation

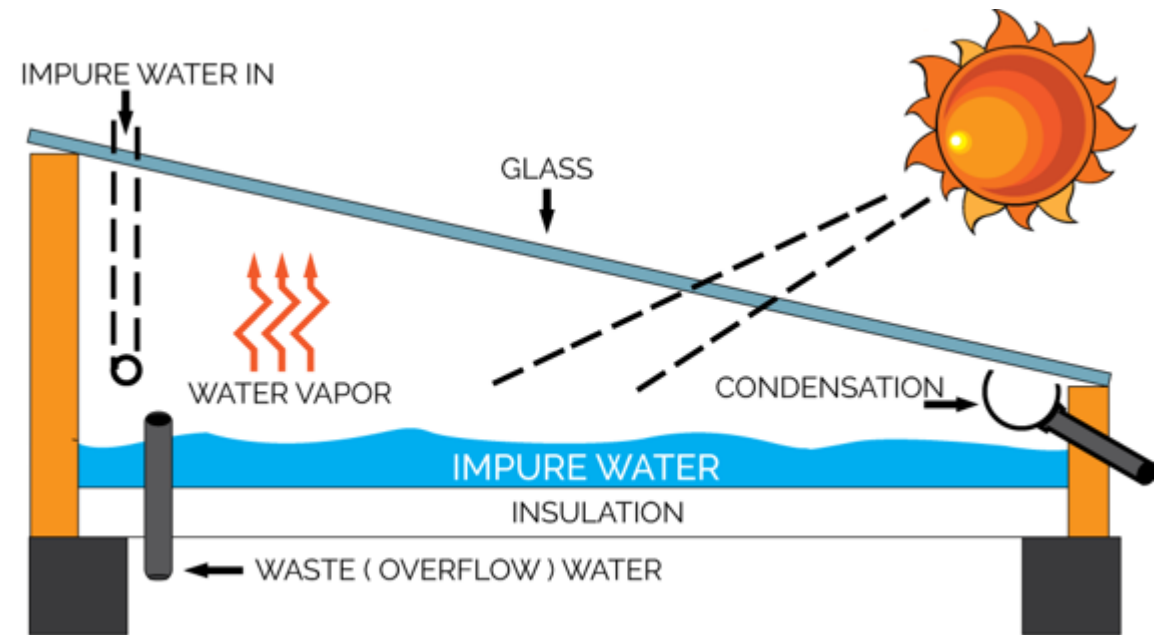
- Solar energy is plentiful and can be used for converting saline water into distilled water.
- The pure water can be obtained by distillation in the simplest **solar still**, generally known as “**Basin Solar Still**”
- It consists of a **blackened basin** containing **saline water at a shallow depth**, over which there is a **transparent air tight cover** that encloses completely the space above the basin.

It has a **roof-like** shape. The cover, which is usually **glass**, may be of plastic, is **sloped** towards a collection trough. **Solar radiation** passes through the cover and is **absorbed** and converted into heat in the black surface.

Impure water in the basin or tray is **heated** and the **vapour** produced is **condensed to purified water** on the cooler **interior** of the roof.

The **condensed water flows down** the sloping roof and is collected in troughs at the bottom. Saline water can be replaced in the operation by either continuous operation or by batches.

Operating efficiencies of 35 to 50% for basin type still have been achieved in practical units, as compared with a theoretical maximum of slightly more than 60%.



Solar Electric Power Generation: Solar Photovoltaics

Introduction.

- ***solar cells or Photovoltaic cell-*** A single converter cell is called a solar cell. Energy conversion devices, used to convert sunlight to electricity by the use of the photovoltaic effect. Photovoltaic cells are made of semiconductors that generate electricity when they absorb light.
- ***Solar module or solar array-***combination of such cells; designed to increase the electric power output
- These devices have theoretical efficiencies of the order of 25 percent. Actual operating efficiencies are less than half this value

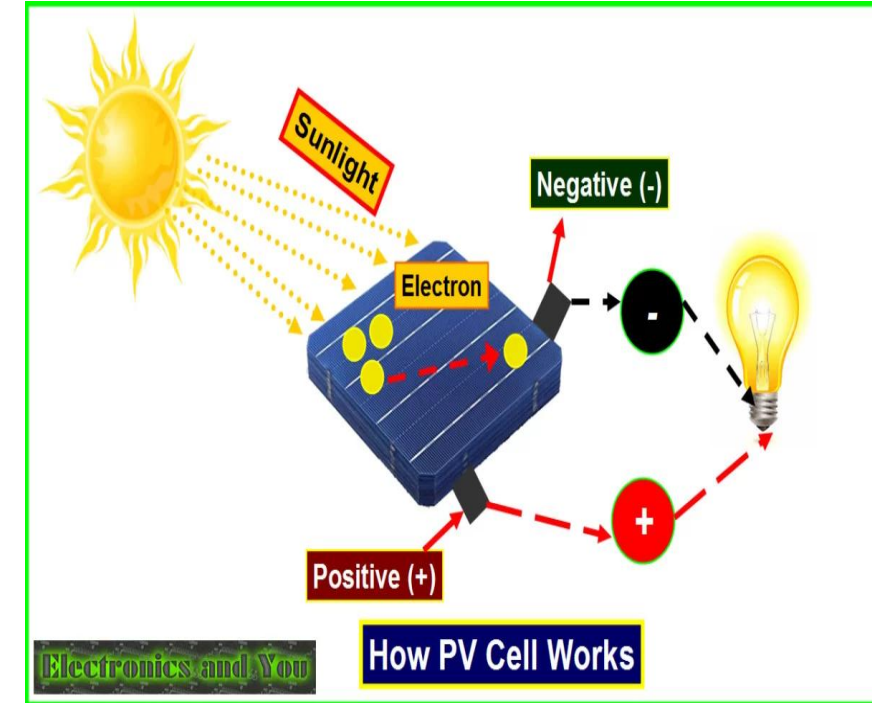
Solar Cell Principles

- When photons from the sun are absorbed in a semiconductor, they **create free electrons** with higher energies.
- Once these electrons are created, there must be an electric field to induce these **higher energy electrons to flow out of the semiconductor to do useful work.**
- The **electric field** in most solar cells is **provided by a junction of materials** which have different electrical properties.
- To obtain a useful power output from photon interaction in a semiconductor, three processes are required.

1. The **photons have to be absorbed** in the active part of the material and result in **electrons being excited to a higher energy potential.**

2. The **electron hole charge carrier** created by the absorption must be physically separated and moved to the edge of the cell.

3. The **charge carriers must be removed** from the cell and **delivered to a useful load** before they lose their extra potential.



PHOTOVOLTAIC SOLAR PANEL

Solar Energy

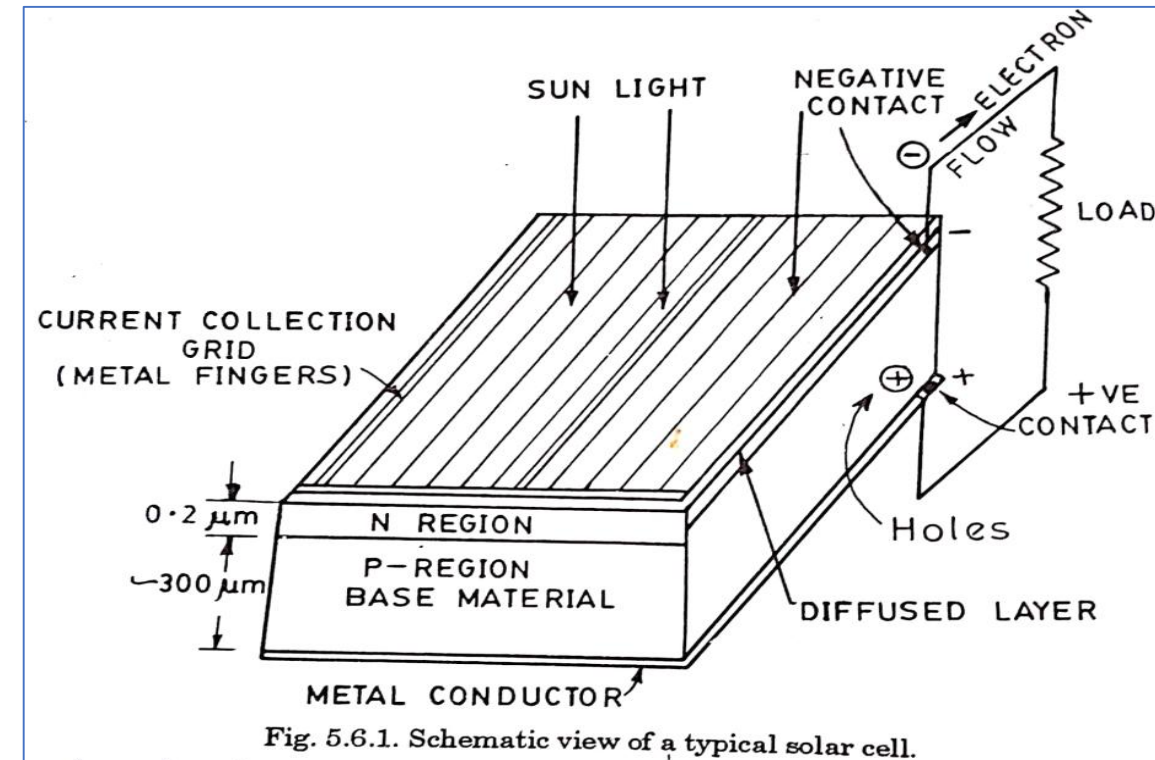
Play (k)



Solar Cell Principles cntd.

- The **flow of electrons through the external conductor constitutes an electric current** which will continue as long as more free electrons and holes are being formed by the solar radiation.
- This is the basis of photovoltaic conversion, that is, the conversion of solar energy into electrical energy.
- The combination of n-type and p-type semiconductors thus constitutes a photovoltaic (P V) cell or solar cell.
- All such cell, generate direct current which can be converted into alternating current if desired.
- The most **normal configuration** for a solar cell to make a **p-n junction semiconductor** is shown.
- The back is completely covered by a **metallic contact** to remove the charges to the electric load.
- The collection of charges from the **front of the cell is aided by a fine grid of narrow metallic fingers**.
- An **anti-reflective coating** is applied on the top of the cell.

<https://www.youtube.com/watch?v=X0OZ6tpZ3Mc>



A Basic Photovoltaic System for Power Generation

It consists of:

- (i) **Solar Array**: converts the insolation to useful DC electrical power.
- (ii) **A Blocking Diode**: which lets the array-generated power flow only toward the battery or grid. Without a blocking diode the battery would discharge back through the solar array during times of no insolation
- (iii) **Battery Storage**: solar generated electric energy may be stored.

(iv) **Inverter/converter**: converts the battery bus voltage to AC of frequency and phase to match that needed to integrate with the utility grid. Thus it is typically a DC, AC inverter. It may also contain a suitable output step up transformer, filtering and power factor correction circuits, power conditioning, i.e., circuitry to initiate battery charging and to prevent over charging.

(v) **Appropriate switches and circuit breakers**: to permit isolating parts of the system as the battery and breakers protect PV system and grid

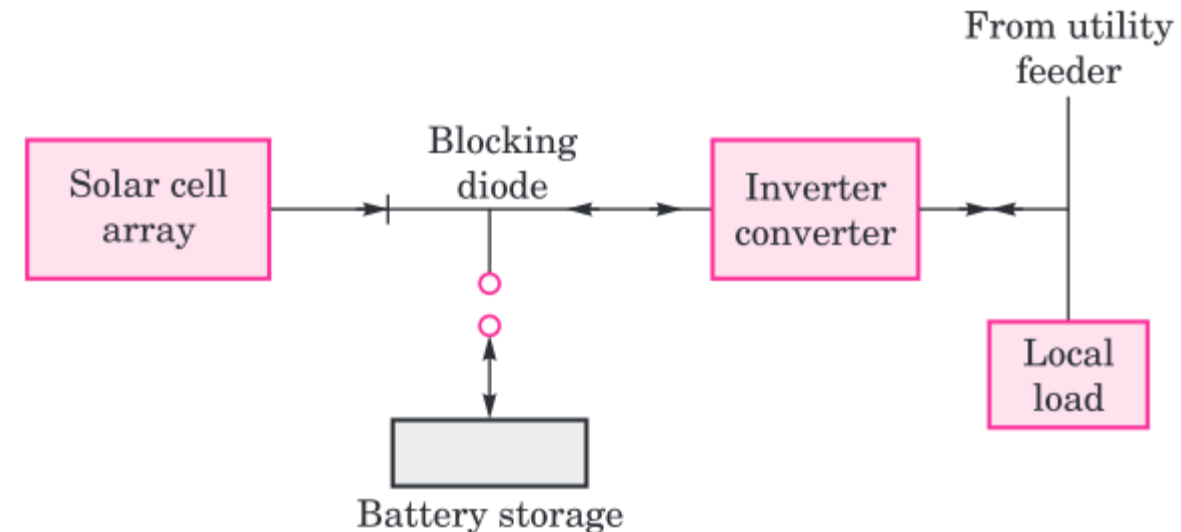


Fig. 5.25. Basic photovoltaic system integrated with power grid.

Applications of Solar Photovoltaic System

The terrestrial applications of these include provision of power supply to:

- (i) water pumping sets for micro irrigation and drinking water supply,
- (ii) radio beacons for ship navigation at ports,
- (iii) community radio and television sets,
- (iv) cathodic protection of oil pipe lines,
- (v) weather monitoring,
- (vii) battery charging,
- (vi) railway signalling equipment,
- (viii) street lighting.

The major application of photovoltaic systems lies in water pumping for drinking water supply and irrigation in rural areas.

The photovoltaic water pumping system essentially consists of:

- (a) a photovoltaic (P V) array,
- (c) power control equipment,
- (b) storage battery,
- (d) motor pump sets, and
- (e) water storage tank.

Advantages and Disadvantages of Photovoltaic Solar Energy Conversion

Advantages:

- Direct room temperature conversion of light to electricity through a simple solid state device.
- Absence Of moving parts.
- Ability to function unattended for long periods as evidence in space programme.
- Modular nature in which desired currents, voltages and power levels can be achieved by mere integration.
- Maintenance cost is low as they are easy to operate.
- They do not create pollution.
- They have a long effective life.
- They are highly reliable.

Advantages:

- They consume no fuel to operate as the sun's energy is free.
- They have rapid response in output to input radiation changes; no long- time constant is involved, as on thermal systems, before steady state is reached.
- They have wide power handling capabilities from microwatts to kilowatts or even megawatts when modules are combined into large area arrays. Solar cells can be used in combination with power conditioning circuitry to feed power into utility grid.
- They are easy to fabricate, being one of the simplest of semi conductor devices.
- They have high power to weight ratio, this characteristic is more important for space applications than terrestrial, may be favourable for some terrestrial applications,
- Amenable to on site installation- decentralised power
- They can be used with or without sun tracking for wide range of applications

Disadvantages:

- High cost
- Energy storage is required because of no insolation at night.
- Efforts are being made world-wide to reduce costs through various technological
- innovations.

Example 2.1. Determine the Local Solar time and declination at a location latitude $23^{\circ} 15' N$, longitude $77^{\circ} 30' E$ at 12.30 IST on June 19. Equation of time correction is given from standard table or chart = $(1' 01'')$.

Solution. \therefore The local solar time

$$\begin{aligned} &= \text{IST} - (\text{Standard time longitude} - \text{longitude of location}) \\ &\quad + \text{Equation of time correction} \\ &= 12^h 30^1 - 4 (82^{\circ} 30' - 77^{\circ} 30') - 1' 01'' \end{aligned}$$

Indian Standard Time (IST) is the local civil time corresponding to $82.5^{\circ} E$ longitude

$$\begin{aligned} &= 12^h 30' - 4 \times 5 - 1' 01'' \\ &= 12^h 8' 59''. \text{ Ans.} \end{aligned}$$

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

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

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

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

$$= 23.45 \sin 86^{\circ}$$

$$= \underline{23.43^{\circ}}. \text{ Ans.}$$

or

$$= 23^{\circ} 25' 56''.$$

Example 2.2. 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 $28^{\circ} 35' N$. 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, $n = 335$.

$$\begin{aligned}\delta &= 23.45 \sin \left[\frac{360}{365} (284 + n) \right] \\ &= 23.45 \sin \left[\frac{360 \times (284 + 335)}{365} \right] = -22.11^{\circ}.\end{aligned}$$

Hour angle ω corresponding to 9.00 hour = 45°

Hence, $\cos \theta_T = \cos (28.58^{\circ} - 38.58^{\circ}) \cos (-22.11^{\circ})$

$$\begin{aligned}&\cos 45^{\circ} + \sin (-22.11^{\circ}) \sin (28.58^{\circ} - 38.58^{\circ}) \\ &= \cos 10^{\circ} \cos 22.11^{\circ} \cos 45^{\circ} + \sin 22.11^{\circ} \sin 10^{\circ} \\ &= 0.6451 + 0.0653 = 0.7104\end{aligned}$$

or,

$$\theta_T = 44.72^{\circ}. \text{ Ans.}$$