Module- 2

Solar Energy :

- Solar energy, recieved in the form of radiation can be converted directly & indirectly into other forms of energy such as heat and Electricity
- Since Solar energy is in-exhaustible source of usefull energy.
- The major drawbacks to the extensive application of solar energy are

1. The intermittent & Variable manner in which it arrives at the earth's surface
2. The large area required to collect the energy at a useful rate..

- Energy is radiated by the sun as electromagnetic waves of which 99% have wavelengths in the range of 0.2 to 4.0 micrometers.
- Solar energy reaching the top of the earth's atmosphere consists of about 8% Ultraviolet radiation [short wavelength less than 0.39 μm), 46% visible light (0.39 to 0.78 μm) & 46% Infrared radiation (long wavelength more than 0.78 μm).
- The sun is a large sphere of very hot gases, diameter is 1.39×10^6 km while that the earth is 1.27×10^4 km
- The mean distance between the two is 1.50×10^8 km.

Solar Constant.

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 recieved 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 the value for the Solar Constanst as $1.353\ kW/m^2$.

- The variation in distance produces a nearly sinusoidal variation in the intensity of solar radiation I that reaches the earth.

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

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

where n is the day of the year

Solar Radiation at the Earth's Surface

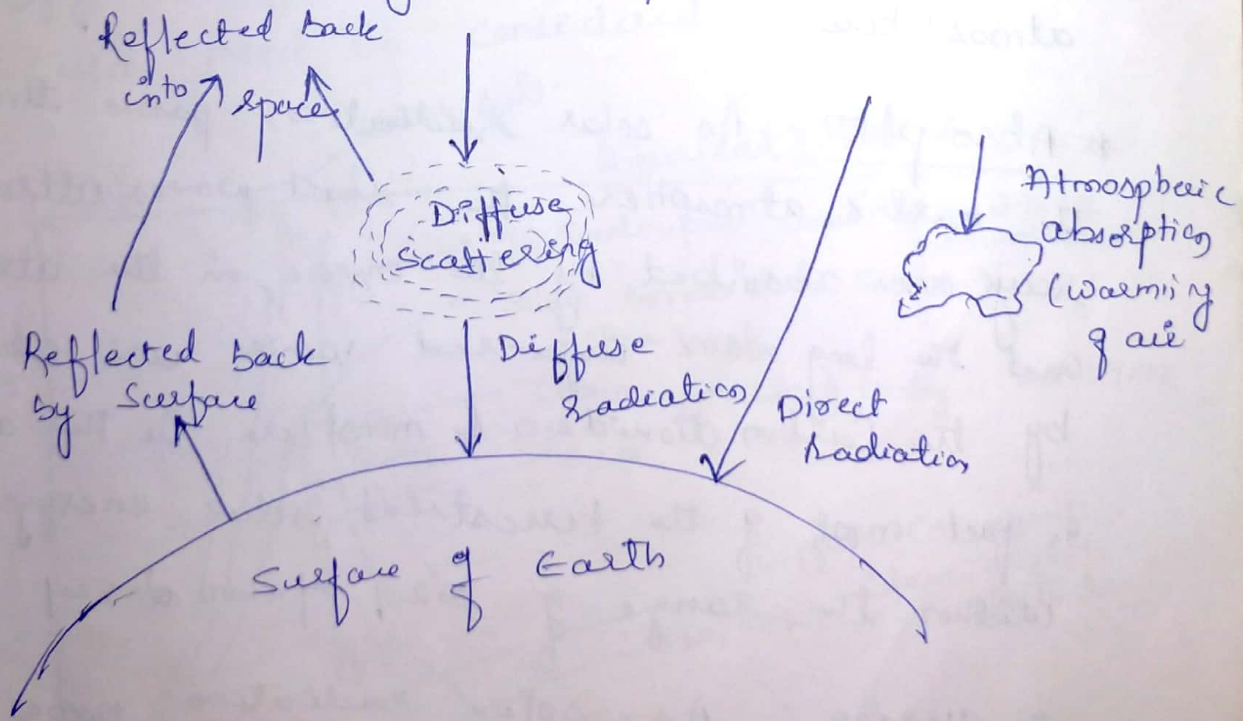
Beam and Diffuse Solar Radiation.

- The solar radiation that penetrates the Earth's atmosphere & reaches the surface differs in both amount & character from the radiation due to

→ part of the radiation is reflected back into the space by clouds.

→ part of it absorbed by molecules in the air.

→ part of solar radiation is scattered by droplets in clouds by atmospheric molecules & by dust particles.



- Solar radiation that has not been absorbed or scattered & reaches the ground directly from the sun is called "direct radiation" or "Beam radiation"
- It is the radiation which produces a shadow when interrupted by an opaque object
- Diffuse radiation is that solar radiation recieved & scattering by the atmosphere
- The total solar radiation recieved at any point on the earth's surface is the sum of the direct and diffuse radiation. (Insolation).

- Attenuation of Beam radiation.

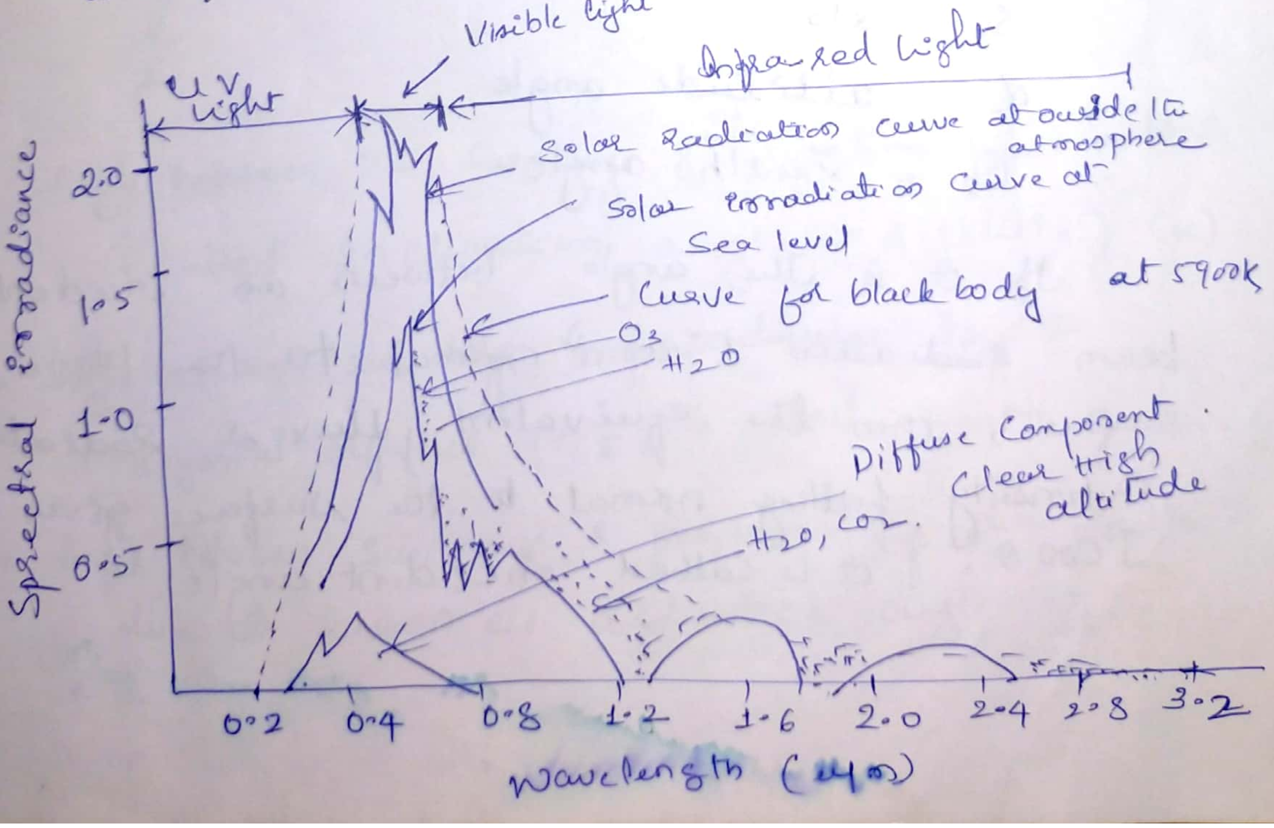
The variation in solar radiation reaching the earth than received at the outside of the atmosphere is due to absorption & scattering in atmosphere.

* 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 infra-red waves are absorbed by the carbon dioxide & moisture in the atmosphere. In fact most of the terrestrial solar energy lies within the range of 0.29 μm to 2.5 μ

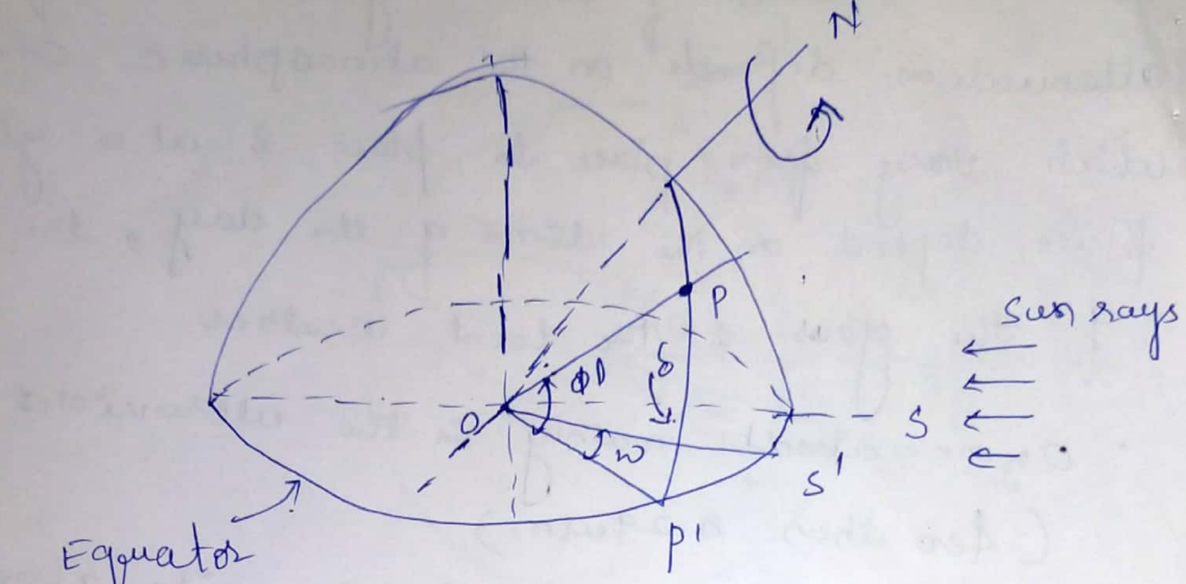
* Scattering: As solar radiation passes through the earth's atmosphere the components of the atmosphere, such as water vapour and dust

scatter a portion of the radiation.

- The exact amount of scattering and consequential attenuation depends on the atmospheric conditions which vary from place to place & at a given place depend on the time of the day, the month of the year & the local weather.
- Ozone absorbs mainly in the ultraviolet band. (less than 0.29 μm)
- it transmittance is almost unity above wavelengths of 0.35 μm.
- Water vapour absorbs mainly in the infrared bands (less th 2.3 μm)
- Hence for terrestrial application of solar energy, only wavelengths between 0.29 and 2.5 μm need be considered.



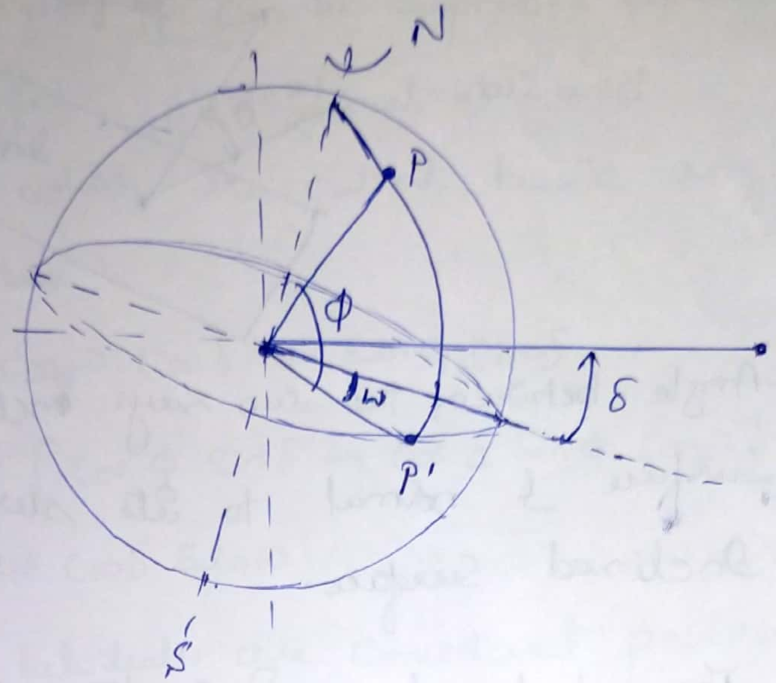
Solar Radiation Geometry.

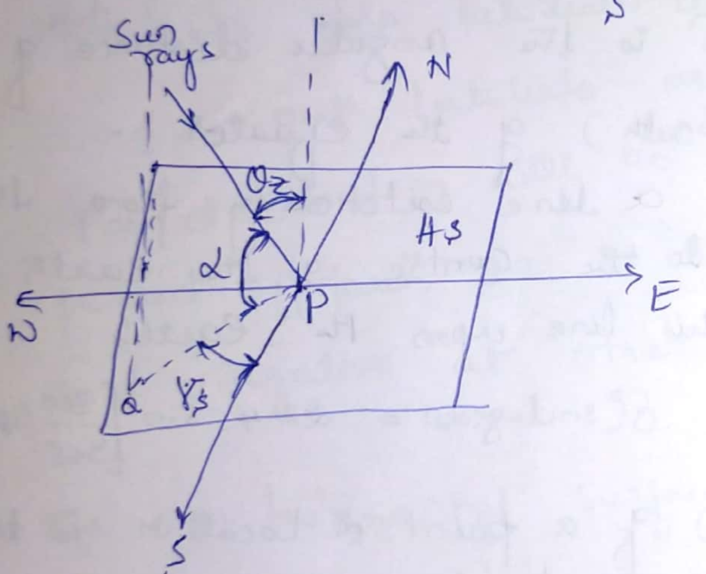


Latitude ϕl, hour angle ω, & sun's declination δ.

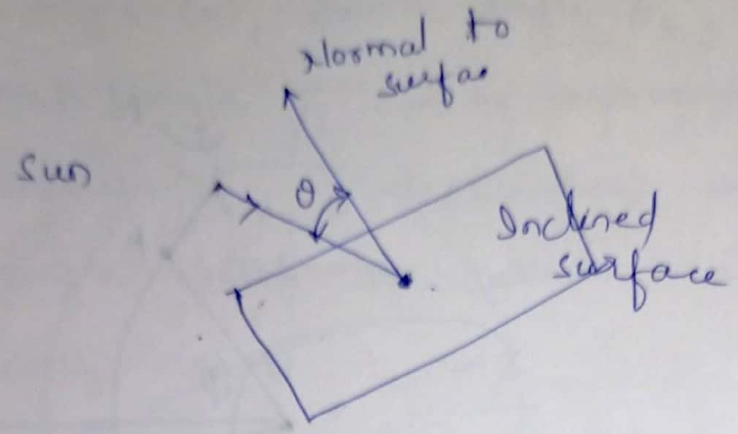
ϕl = latitude of location
δ = declination
ω = hour angle
γ_s = solar Azimuth angle
s = slope
α = altitude angle
θ_z = Zenith angle

If θ is the angle between an incident beam radiation I and normal to the plane surface, then the equivalent flux or radiation intensity falling normal to the surface given by $I \cos\theta$. θ is called incident angle.





- Angle between the sun rays & its projection point on Ht. S is called Inclination angle (Altitude) (α)
- Angle between sun rays & perpendicular to the Horizontal surface (θ_z) is called Zenith angle.
- Angle between sun rays & projection of due South line is known as azimuthal angle γ_s



- Angle between the sun rays incidence on the surface & normal to its surface is known as Inclined Surface.

- The declination δ is the angular distance of the sun's rays north (or South) of the equator.
  It is the angle between a line extending from the Centre of the sun to the centre of the earth and the projection of this line upon the earth's equatorial plane. $\delta(\text{in degrees}) = 23.45 \sin\left[\frac{360}{365}(284+n)\right]$

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

- The hour angle (ω) is 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 equal to 15° per hour

The Altitude angle (α), Zenith angle θ_z, and Solar azimuth angle γ_s can be expressed interms of ϕ_l (latitude angle), δ (declination) and ω (hour angle) which are called basic angle

The expressions are :-

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

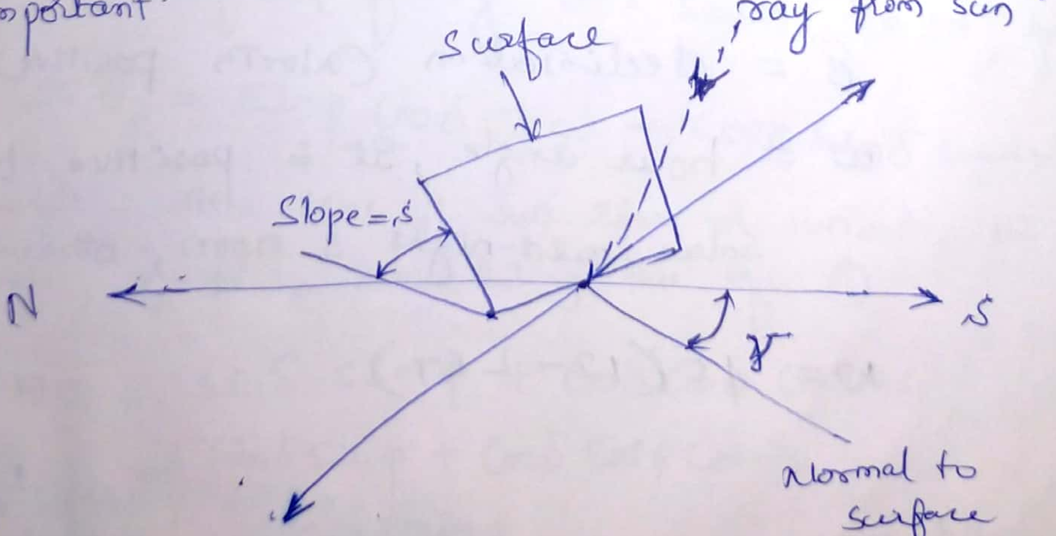
$$\cos\gamma_s = \sec\alpha \left[\cos\phi \sin\delta - \cos\delta \sin\phi \cos\omega \right]$$

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

Note :- If North latitudes are considered positive & South latitudes are negative

The declination will be positive for the summer period (March 22 to Sept 22 approximately) and negative at other times.

- For non-horizontal surfaces angles such as incident angle, slope angle, surface azimuth angle are important.



Surface azimuth angle & slope defined.

The slope (s): Is the angle made by the plane surface with the horizontal.
It is positive for surface sloping towards South & Negative for " " " 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 → +ve, west → -ve

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

From spherical geometry the relation between θ and other angles is given by the equation

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

Where ϕ_l = latitude (North positive)

δ = declination (North positive)

ω = hour angle, It is positive between Solar mid-night & noon, otherwise negative

$$w = 15(12 - LST)$$

For vertical surfaces, $s = 90^\circ$

$$\cos\theta = \sin\phi \cos\delta \cos\gamma \cos\omega - \cos\phi \sin\delta \cos\gamma + \cos\delta \sin\gamma \sin\omega \longrightarrow (2)$$

For horizontal surface. $s = 0^\circ$, $\theta = \theta_z$ zenith angle

$$\therefore \cos\theta_z = \sin\delta \sin\phi + \cos\delta \cos\phi \cos\omega$$
$$= \sin\alpha \longrightarrow (3)$$

i.e, $\cos\theta = \cos\theta_z = \sin\alpha \longrightarrow (4)$

For surface facing due south $\gamma = 0$

$$\cos\theta_T = \sin\phi \,(\sin\delta \cos s + \cos\delta \cos\omega \sin s)$$
$$= \cos\phi \,(\cos\delta \cos\omega \cos s - \sin\delta \sin s)$$

(Incident angle θ is expressed as θ_T, denoting the surface as tilted one)

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

• Vertical surfaces facing due south ($s = 90^\circ$, $\gamma = 0$)

$$\cos\theta_z = \sin\phi \cos\delta \cos\omega - \cos\phi \sin\delta \longrightarrow (6)$$

Day length: At the time of sun rise or sunset, the zenith angle, $\phi_z = 90^\circ$, substituting this eq. (3)

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

$$\frac{1}{} = \sin\delta \sin\phi + \cos\delta \cos\phi \cos\omega_s$$

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

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

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

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

- The hour angle at sunrise or sunset on an inclined surface w_{st} will be lesser than the value obtained by putting $\theta = 90^\circ$ in eqn 5

$$\cancel{\cos 90 = \sin\phi \cos\delta \cos\gamma}$$

$$\cos 90 = \sin\delta \sin(\phi - s) + \cos\delta \cos w \cos(\phi - s)$$

$$1 = \sin\delta \sin(\phi - s) + \cos\delta \cos(\phi - s) \cos w_{st}$$

$$\cos w_{st} = -\frac{\sin\delta \sin(\phi - s)}{\cos\delta \cos(\phi - s)} = -\tan\delta \tan(\phi - s)$$

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

The corresponding day length (in hours) is then given by

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

Local Solar Time (or Local Apparent Time).

The time used for calculating the hour angle in all the equation above, is the local solar time or local apparent time, which does not coincide with the local clock time.

The solar time can be obtained from the standard time observed on a clock by applying two corrections.

1.

(i) The first correction arises because of the difference in longitude between a location & the meridian on which the standard time is based.

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

(ii) Equation of time: correction is due to the fact that earth's orbit and rate of rotation are subject to small perturbations.

Thus

LST = Standard time ±4(Standard time Longitude − Longitude of location) + (Equation of time correction)

The negative sign is applicable for the eastern hemisphere.

Solar Radiation Measurements

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

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

(i) a pyrheliometer, which collimates the radiation to determine the beam intensity as a function of incident angle

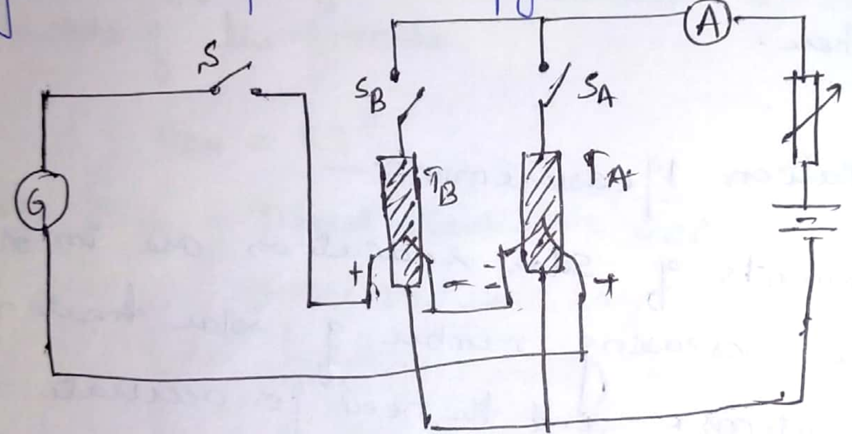
(ii) pyranometer, which measures the total hemispherical solar radiation. The pyranometer measurements are the most common.

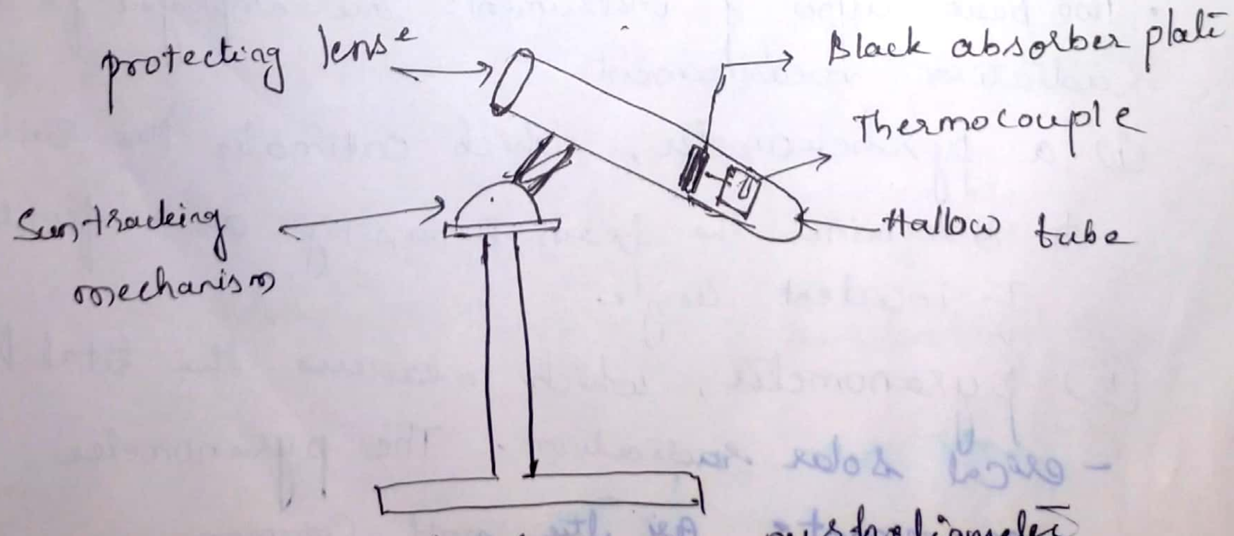
1. Pyrheliometers : pyrheliometer is an instrument which measures beam radiation. In Constrast to a pyranometer, the sensor disc is located at the base of a tube whose axis is aligned with the direction of the Sun's rays. Thus diffuse radiation is essentially blocked from the sensor surface.

There are 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) Epply pyrheliometer

i) Angstrom Compensation pyrheliometer :





General Construction of pyrheliometer

Explanation of Angstrom compensation pyrheliometer

- In this pyrheliometer, a thin blackened shaded magnanin strip (Size 20x2x0.1 mm) is heated electrically until it is at the same temperature as a similar strip which is exposed to solar radiation
- Under steady state condition (both strips at identical temp^r) 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).
- The energy H of direct radiation is calculated by means of the formula

$$H_{DN} = k i^2$$

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

i = heating current in amperes

K is a dimension of instrument constant

$$i = \frac{R}{W\alpha}$$

R is the resistance per unit length of the absorbing strip (Ω/cm).

W is the mean width of the absorbing strip

α is absorbing coefficient of the absorbing strip.

2) Abbot silver disk pyrheliometer :

- It consists essentially of 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 & corresponding changes in temperature of the disk are measured.
- these are widely used for calibrating pyranometers.

3) 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 ~~diagra~~ diaphragms of which subtend an angle of 5.7°

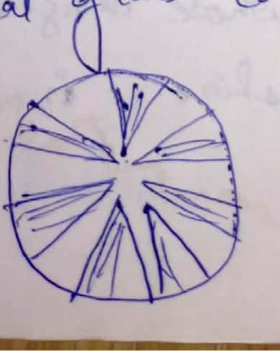
- A thermopile is basically a series arrangement of thermocouples used to develop a much greater voltage than is possible using only one
- The tube is filled with dry air & is sealed with a crystal quartz window which is removable

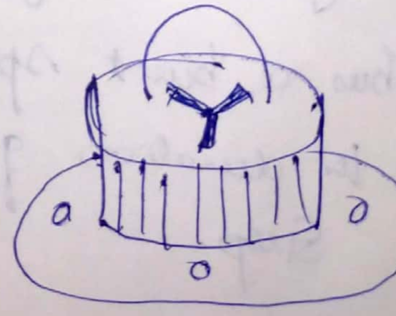
Pyranometer:

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 in then measures only the diffuse component of the radiation.

1) Eppely pyranometer: It is based on the principle as stated above that there is a difference between the temperature of black surface (which absorb most solar radiation) & white surface (which reflect most solar radiation)

- The detection in tempr difference is achieved by thermopile
- It uses concentric silver rings 0.25mm thick, appropriate coated black & white, with either 10 or 50 thermocouple junctions to detect temperature difference between coated rings
- These wedges arranged in a circular pattern with alternate black & white coatings.
- The disks or wedges are enclosed in a hemispherical glass cover.





d) Yellot Solarimeter (photovoltaic solar cell) :-

pyranometers have also been used on photovoltaic (solar cell) detectors.

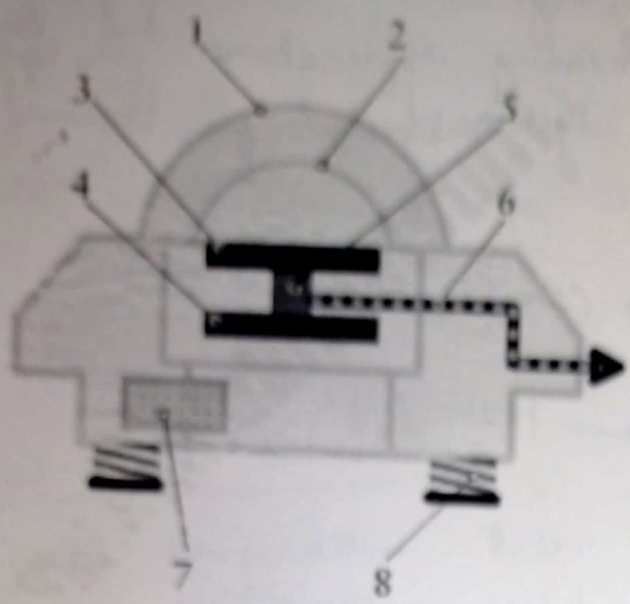
- Silicon cells have the property that their current (approximately equal to the short circuit current at normal radiation levels) is a linear function of the incident solar radiation.
- They have the disadvantage that the spectral response is not linear.

* Sunshine Recorder

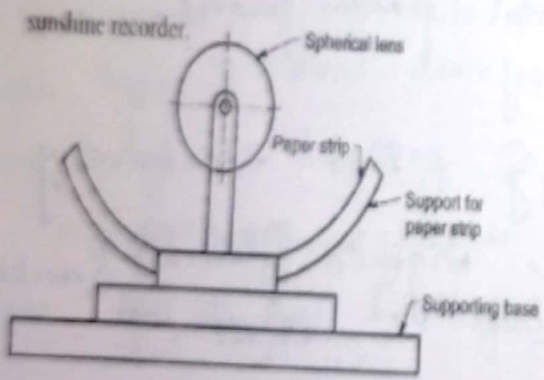
The duration of bright sunshine in a day is measured by means of a sunshine recorder. The sun's rays are focused by a glass-sphere to point on a card strip held in a groove in a spherical bowl mounted concentrically with the sphere.

- Whenever there is 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 sunshine is obtained on the strip.

pyranometer



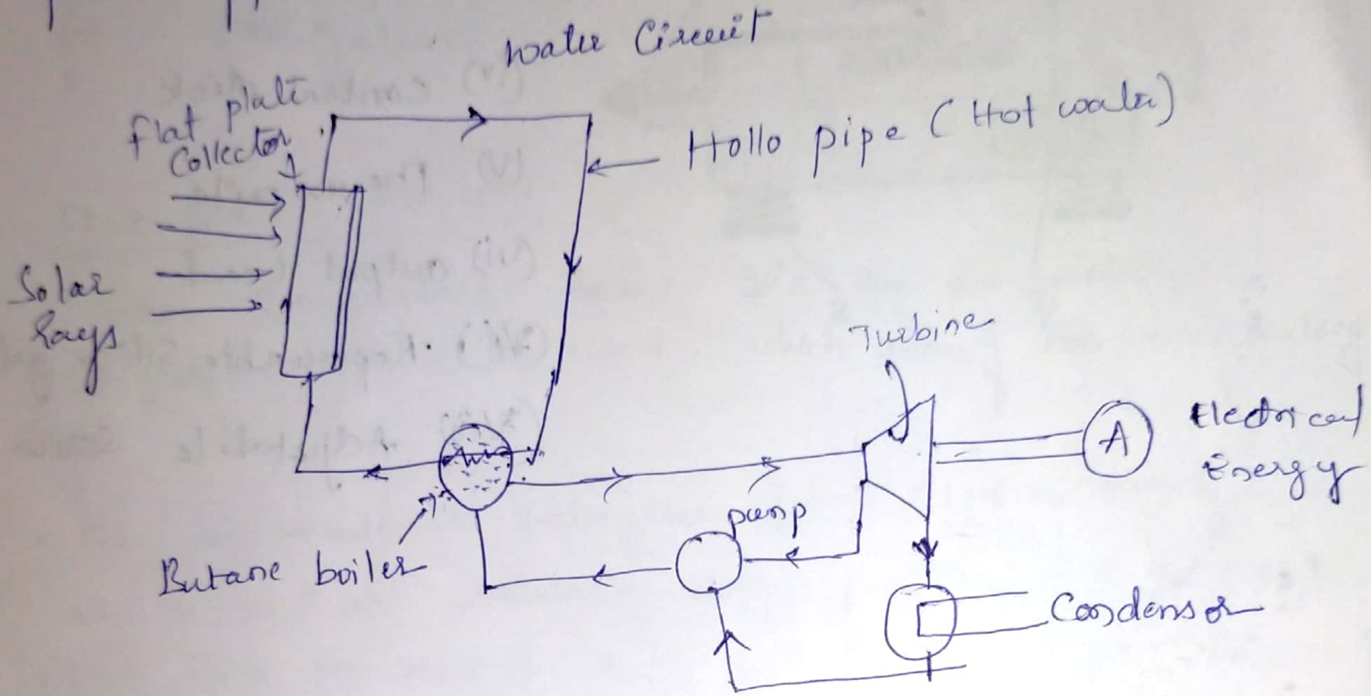
(i) outer dome glass
(ii) Inner dome
(iii) Black carbon disk
(iv) control disk
(v) Thermopile
(vi) output lead
(vii) ·Replaceable silica gel
(viii) Adjustable screw.



Sunshine recorder

Solar thermal system.

Thermal energy storage is essential for both domestic water and space heating applications and for the high temperature storage systems needed. for thermal power applications.



low temperature thermal power plant

To Convert solar energy into electricity through thermal conversion, organic fluid Rankine cycle has been extensively used in ~~its~~ it.

Low temperature solar engine, using heated water from flat plate collector & butane as working fluid as shown in figure (Developed in France for lift irrigation)

The system has array of flat plate collectors to heat water upto 70°C and in the heat exchanges the heat of water is used for boiling butane

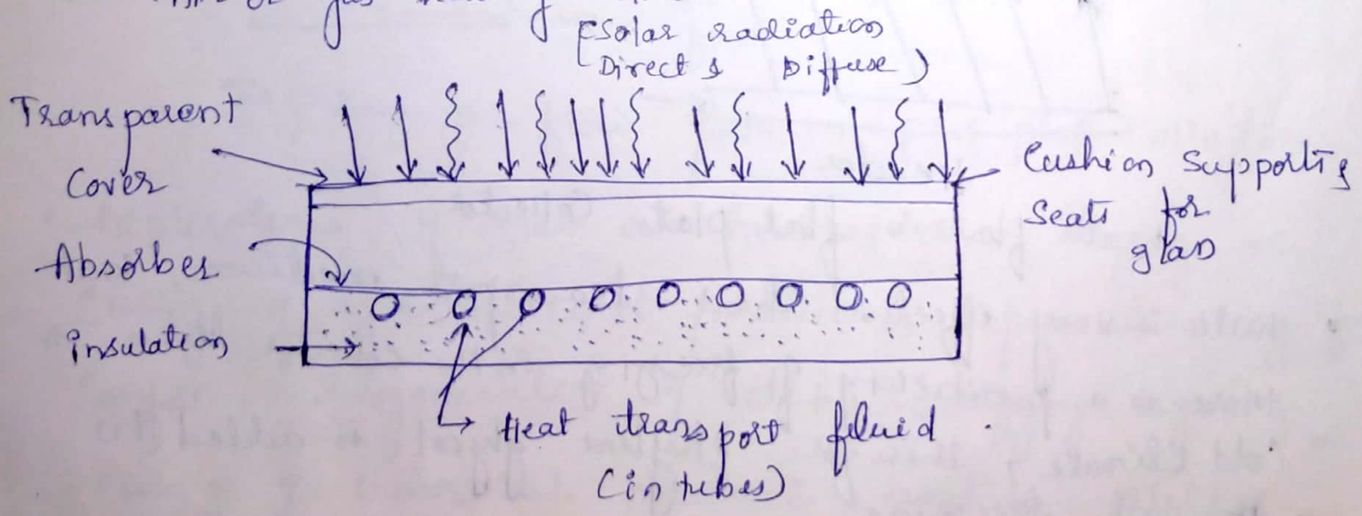
The high pressure butane vapour runs a butane turbine and coupled Alternator will generate the electricity.

This mechanism also used to operates a hydraulic pump which pumps the water from well & used for irrigation.

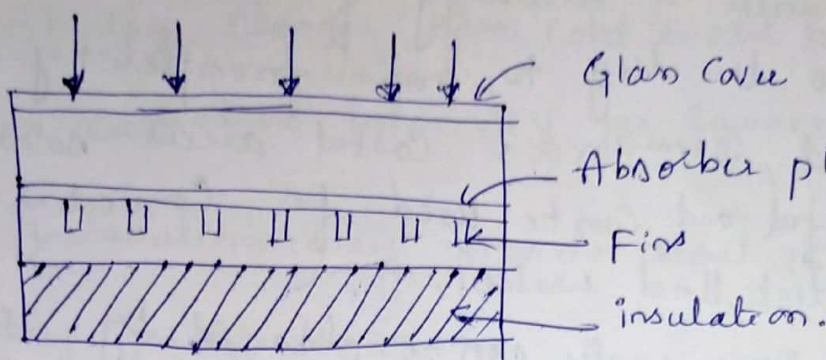
Flat-plate Collectors

Where temperature below 90°c are adequate, Flat-plate collectors are used which are of non-concentrating type.

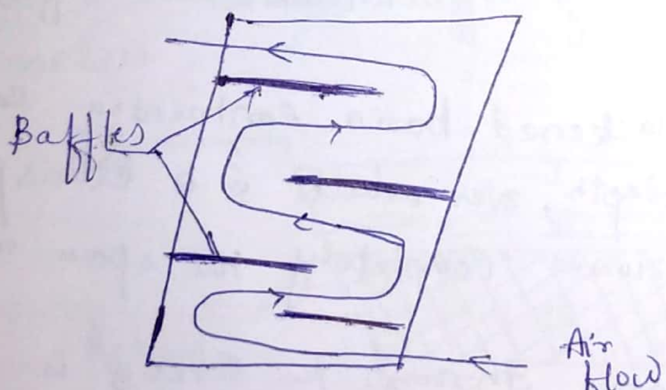
- They are made in rectangular panels (1.7 to 2.9 sq m in area), and are relatively simple to construct & erect.
- Flat plates can collect & absorb both direct & diffuse solar radiation.
- these are divided into two main classification based on the type of heat transfer fluid used.
  - → liquid heating collectors for heating water & non freezing aqueous solutions.
  - → Air or gas heating collectors.



2) Typical Air collectors & Solar Air Heaters.



- figure shows a schematic flat-plate collector where an air stream is heated by the back side of the collector plate. which is heavily insulated with mineral wool or some other material
- Fins attached to the plate increase the contact surface.
- Air passed through a space between the absorber plate & insulator with baffles arranged to provide a long (zig-zag) flow path.



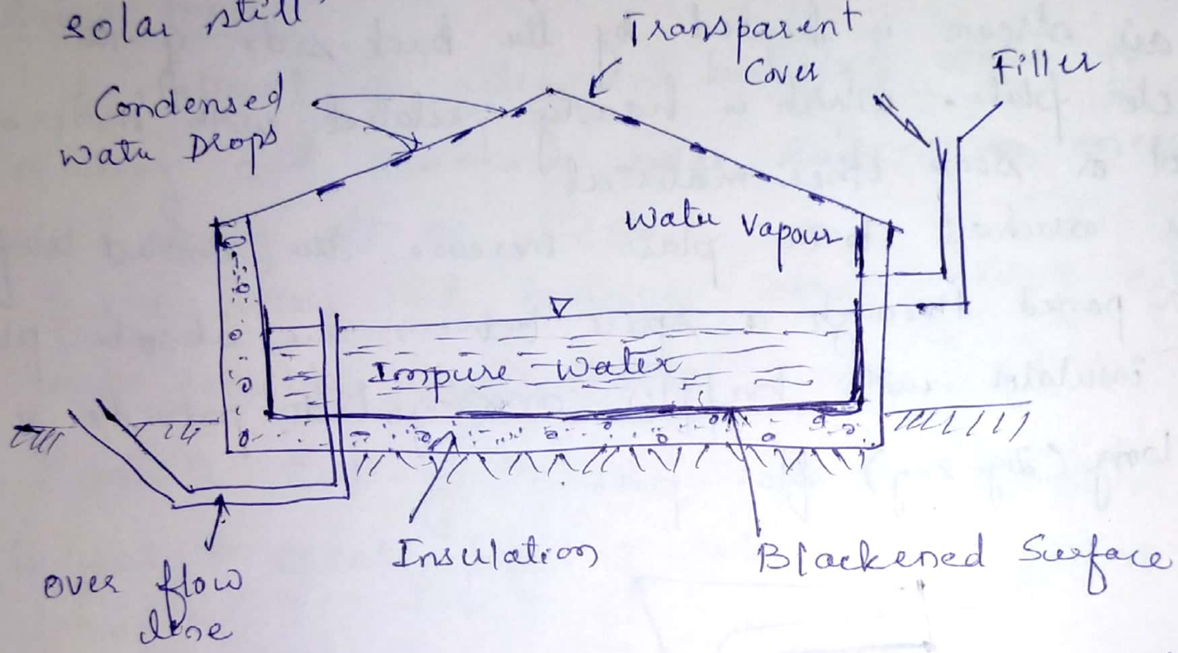
Zig-Zag air flow path in Flat-plate collectors.

- Applications of solar air heaters are drying or curing of agricultural products, space heating for comfort, regeneration of dehumidifying agents, curing of industrial products such as plastics.

Solar Distillation

Fresh water is necessity for the substenance of life and also the key to man's prosperity.

- In arid, semiarid & Costal areas solar energy is plentiful and can be used for converting saline water into distilled water.
- The pure water can be obtained by destillation in the simplest of solar still known as "basin type solar still"



- It consists of a blackened basin containing saline water at a shallow depth, over which is a transparent airtight Cover that encloses completely the space above the basin.
- Solar radiation passes through the Cover & is absorbed & converted into heat in the black surface
- Impure water in the basin or tray is heated & the vapour produced is condensed to purified water on the interior of the roof
- operating efficiency of 35 to 50% is estimated. is given by $\eta = \frac{w \Delta h}{H}$

where w = weight of distillate per square meter per day.

Δh = enthalpy change from cold water to vapour

H = Solar radiation intensity per square meter/day.

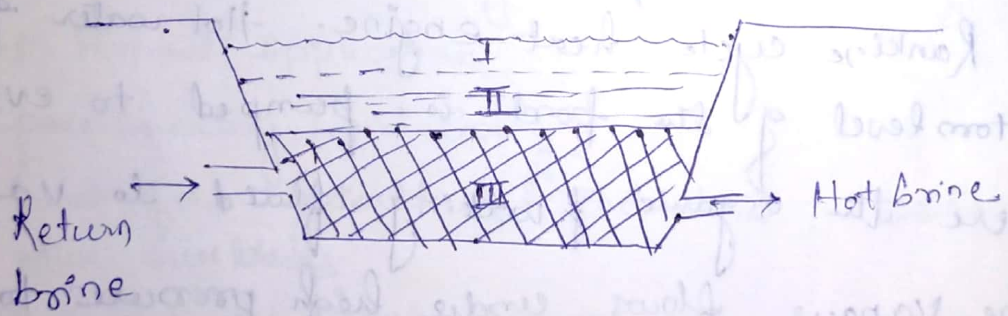
Solar still installations may provide about 15 to 50 liters per day per ~~sq~~. 10 sq.m.

Solar Pond :

A natural or artificial body of water for collecting and absorbing solar radiation energy and storing it as heat.

Thus a solar pond combines solar energy collection and sensible heat storage.

- In the salt-gradient solar ponds, dissolved salt is used to create layer of water with different densities.

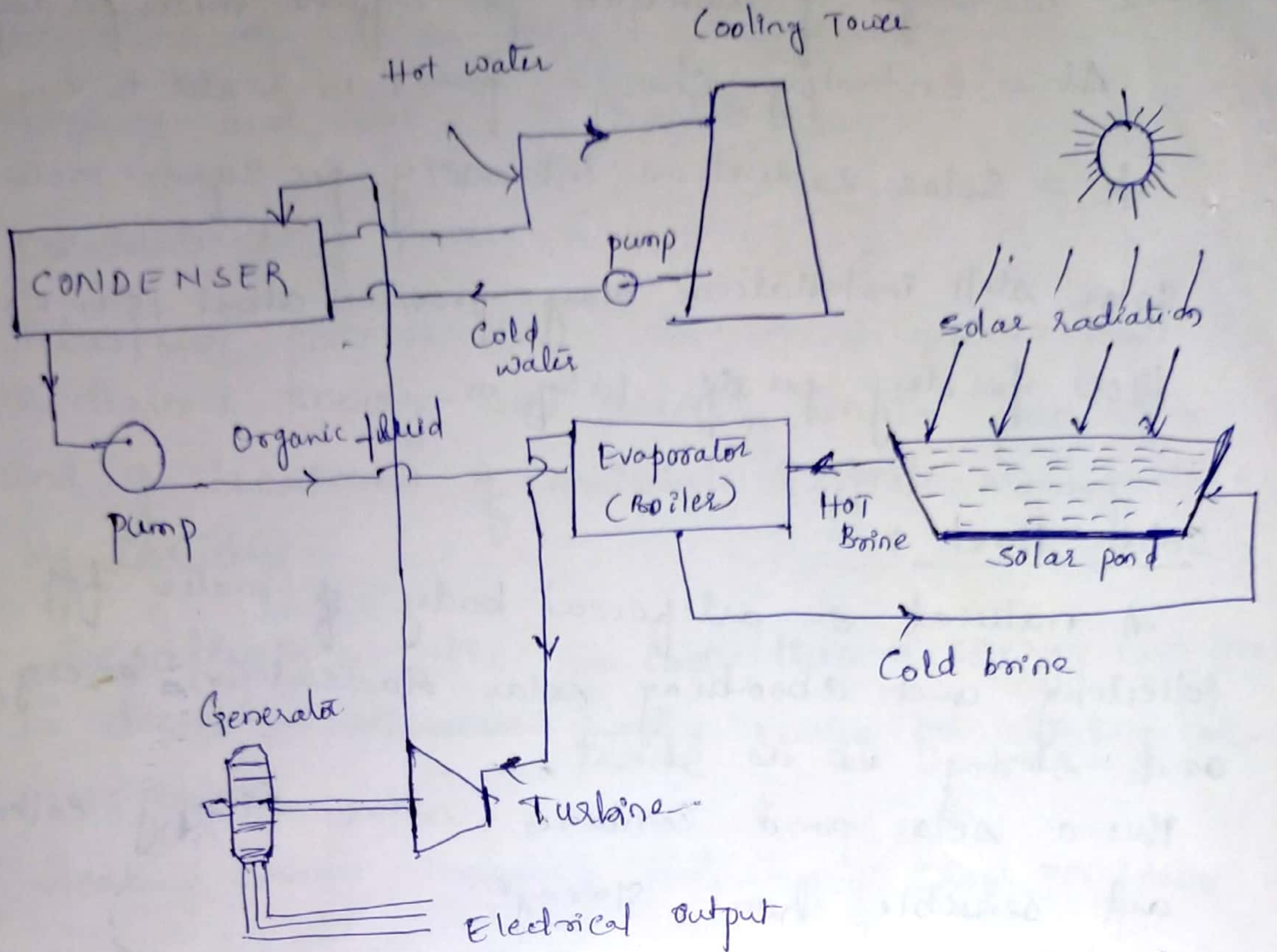


(i) Surface convective zone or upper convective zone (0.3 to 0.5m), salinity < 5%.

(ii) Non-convective zone 1 to 1.5m, salinity increases with depth

(iii) Storage zone or lower convective zone 1.5 to 2m, salinity ≈ 20%.

as shown in above figure



Solar pond electric power plant with Cooling tower

- Thermal energy from solar pond is used to drive a Rankine cycle heat engine. Hot water from the bottom level of the pond is pumped to evaporator where the organic of working fluid to vaporized
- the vapour flows under high pressure to the turbine & thereby expanding through the turbine wheel & the electric generator linked to it
- Output of the vapour travels to the Condenser where cold water from the cooling tower condenses the vapour back it to a liquid.
- the liquid is pumped back to the evaporator where the cycle is repeated. as shown in above figure

(27)

Applications of Solar Ponds.

1) Heating and Cooling of Buildings.

2) production of power

3) Industrial process Heat: Industrial process heat is the thermal energy used directly in the preparation and of treatment of materials & goods manufacture by industry.

4) Desalination: The low cost thermal energy can used to desalt or otherwise purify water for drinking or irrigation.

5) Heating animal housing and drying crops on farms.

6) Heat for bio mass Conversion.

Applications of Solar Energy

there are main three catagories of application of S.E

I. Direct thermal Application

→ Space heating (and Cooling)

→ heat for agricultural industrial, residences & other buildings

→ other processes that require only moderate temperature

II. Solar Electric Applications:

→ solar thermal electric conversion

→ Solar photovoltaic conversion

→ thermo electric conversion using thermo electric effect.

→ Wind energy [Indirect form of Solar)

→ Ocean thermal energy conversion.

Scanned with CamScanner

III. Energy from Biomass & Bio-gas :.
Energy related to product of organic matter derived directly or indirectly from plants which use solar energy to grow.

Direct Solar energy applications are as follows
(i) Solar water heating
(ii) Space heating & cooling
(iii) Thermal electric conversion
(iv) photovoltaic electric conversion
(v) Solar distillation
(vi) Solar pumping
(vii) Agriculture & industrial process heat
(viii) Solar furnance, Solar cooking
(ix) Solar production of hydrogen, and
(x) Solar green houses.

Solar Electric power Generation :

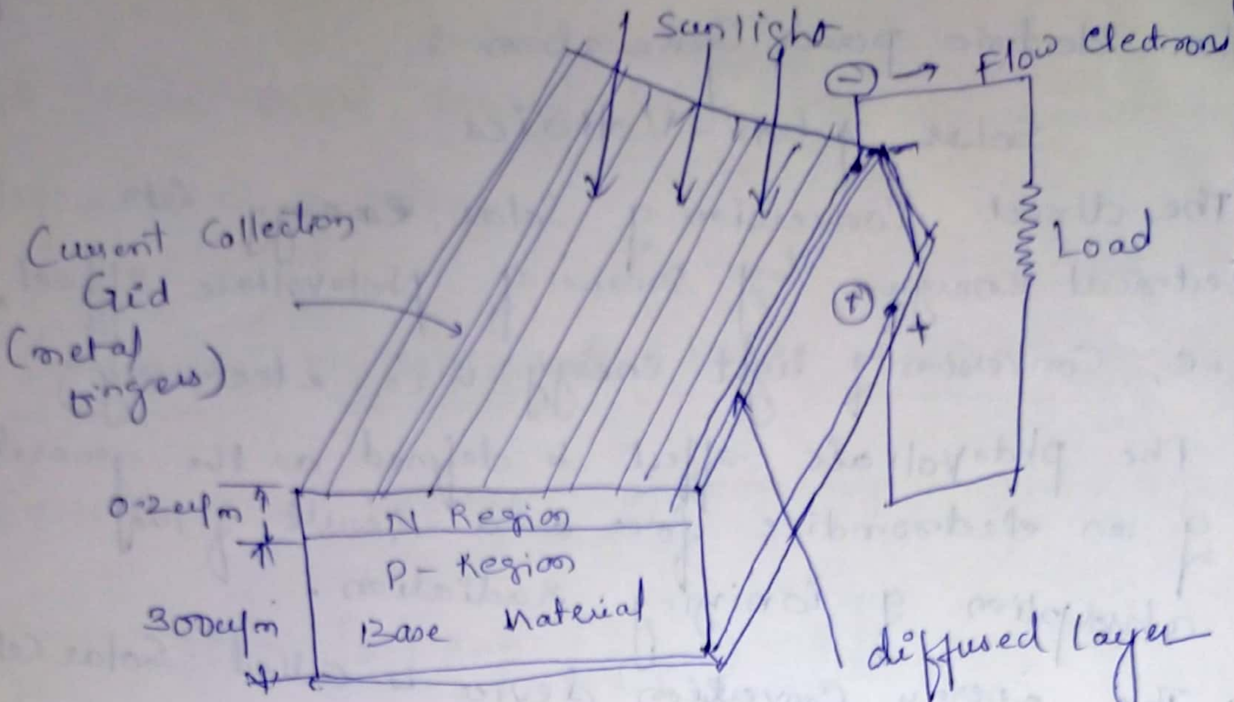
Solar photo-Voltaics.

- The direct Conversion of Solar energy into electrical energy by means of photovoltaic effect, (i.e, Conversion of light energy into electricity)
- The photovoltaic effect is defined as the generation of an electromotive force as a result of the absorption of ionizing radiation.
- The energy Conversion device is called Solar cell or Photovoltaic cell. The combination of such cells designed to increase the electric power output is called a solar module or Solar array.

- The photo voltaic effect can be described easily for p-n junction in a semi-conductor. In an intrinsic semi-conductor such as silicon, each one of the four valence electrons of the material atom is tied in a chemical bond. (no free electrons at absolute zero).

If a piece of such a material is doped on one side by five valence electron material such as arsenic & phosphorus, there will be excess electrons becomes 'n' type semiconductor, if three valence electron material such as Boron is doped there will be a deficiency of electrons forming p-type material.

- The combination of n-type & p-type Semiconductors thus Constitutes a photovoltaic cell or solar cell



Schematic view of a typical Solar Cell.

The junction is thus formed slightly below the planar surface of the cell & the light impinges perpendicular to the junction.

The positive & negative charges created by the absorption of photons are thus encouraged to drift to the front and back of the Solar Cell. as shown in figure above.

- each of the individual solar cells will produce power at about 0.5V with the current directly proportional to the cell's area
- The individual cells are connected in series-parallel combination to meet the voltage, power & reliability requirements of the particular applications.

Space cells are covered with transparent cover slips to absorb the high energy particles in space.

(contd)

that could cause damage in the cell and result in a degradation of output.

Conversion Efficiency & Power output

Current and Voltage relationship is given by

$$J_i = J_0 \left[\exp\left(\frac{Ve}{KT}\right) - 1 \right] \longrightarrow (1)$$

where J_0 is the saturation current also called the dark current and is obtained when a large negative voltage is applied across the diode.

V is the Voltage across junction

e is the electric charge

k is Boltzmann's Constant

T is the absolute temperature.

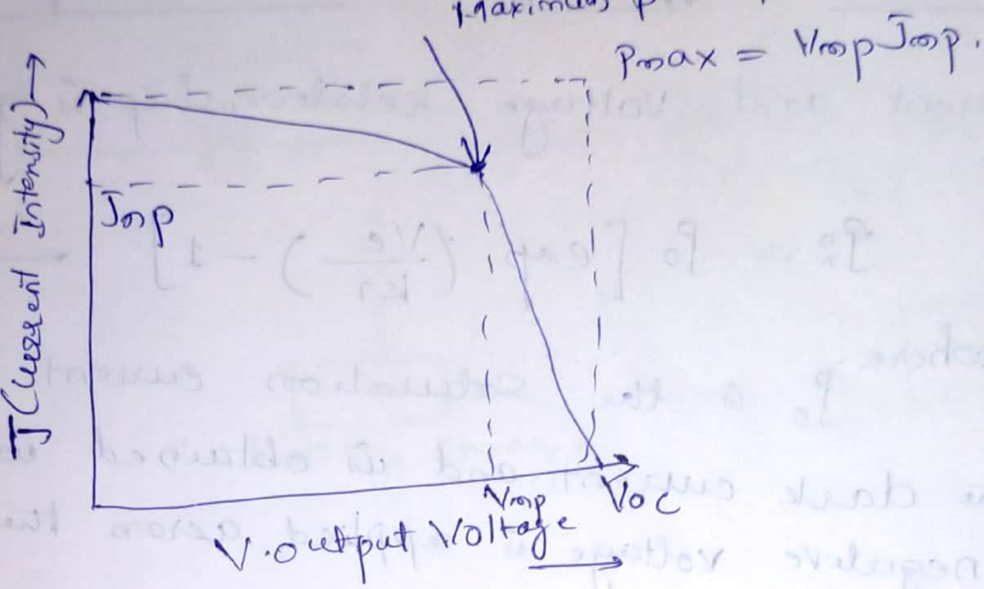
when light impinges on the junction, electron hole pairs are created at a constant rate providing an electrical current flow across the junction

- The net current is thus the difference between the normal diode current and light generated current J_L.

$$J = J_L - J_i = J_L - J_0 \left[\exp\left(\frac{Ve}{KT}\right) - 1 \right] \rightarrow (2)$$

Open circuit voltage Voc for the ideal cell is then given by

$$V_{oc} = \left(\frac{kT}{e}\right) \ln\left[\frac{J_L}{J_0} + 1\right] \rightarrow (3)$$



J – V plot for an ideal solar cell.

$\because J_{LL} >> J_0$, 1 in eq (3) can be neglected

$$\therefore V_{oc} = \frac{kT}{e} \ln \frac{J_L}{J_0}.$$

- The maximum power that can be derived from the device is given by

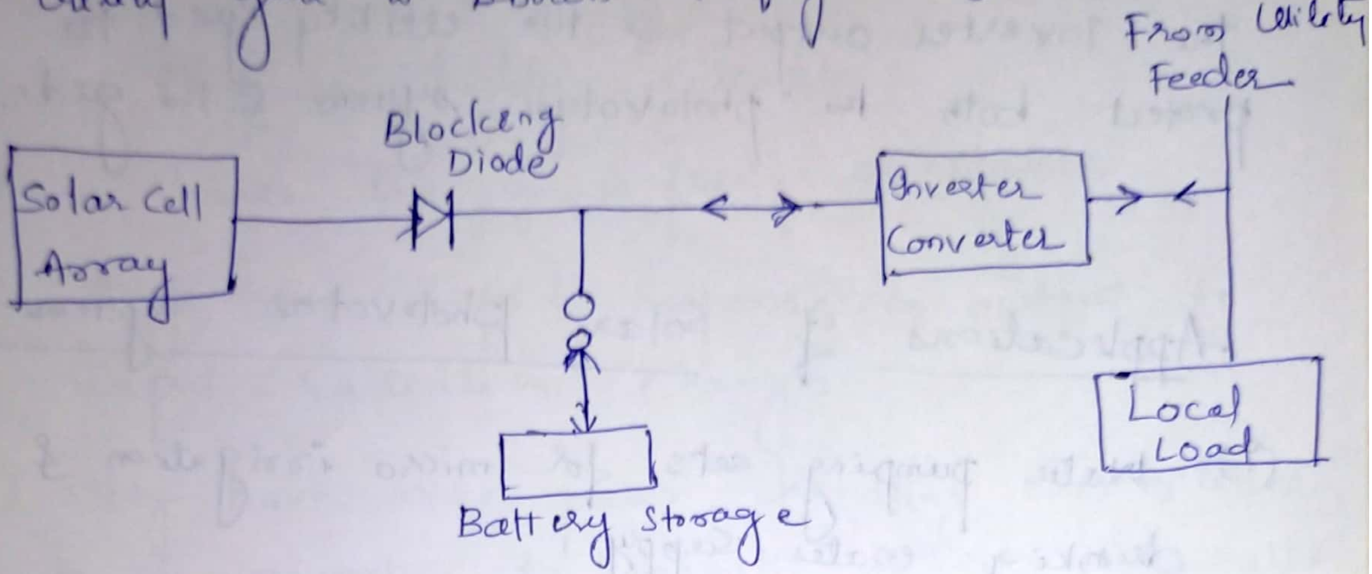
$$\boxed{P_{max} = V_{mp} \cdot J_{mp}}$$

where V_{mp} & J_{mp} are the voltage & current at maximum power point as shown in figure

efficiency is given by $\boxed{\eta = \frac{V_{mp} J_{mp}}{P_{sun}}}$

A Basic photovoltaic system for Power Generation.

A basic photovoltaic system integrated with the utility grid is shown in figure.



(i) Solar array : Large or small, which 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 : in which the solarly generated electric energy may be stored

(iv) Inverter / Converter : Usually solid state which converts the battery voltage to AC of frequency & phase to match that needed to integrate with utility grid.

(v) Appropriate switches & Circuit Breakers, to permit isolating parts of the system, includes breakers & fusing protection between the inverter output & the utility grid to protect both the photovoltaic system & the grid.

Applications of Solar photovoltaic systems.

(i) Water pumping sets for micro irrigation & drinking water supply.
(ii) Radio beacons for ship navigation at ports
(iii) Community radio & television sets.
(iv) Cathodic protection of oil pipe lines
(v) Weather monitoring
(vi) Railway signalling equipment.
(vii) battery charging
(viii) Street lighting

Advantages:

(i) Direct room temp^r conversion of light to electricity through simple solid state device
(ii) Absence of moving parts
(iii) Modular nature in which desired currents, Voltages & power levels can be achieved by mere integration.

(v) Maintenance Cost is low as they are easy to operate

(vi) They do not create pollution

(vii) They have a long effective life

(viii) They are highly reliable

(ix) Source energy is freely available

(x) They have rapid response in output to input radiation changes.

(xi) They have wide power handling capabilities from microwatts to kilowatts or even megawatts when modules are combined into large area arrays.

(xii) They are easy to fabricate, being one of the simplest of semiconductor devices

(xiii) Amenable to on site installation i.e., decentralized or dispersed power, thus the problem of power distribution by wires could be eliminated by the uses of Solar Cells at the site where the power is required.

(ix) They can be used with or without sun tracking, making possible a wide range of application possibilities.

The main disadvantage are their 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.