Renewable-Energy-Systems-Module-1-Important-Topics-PYQs

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- 15. With a neat labelled diagram explain the construction and working of a Flat plate solar collector
  - Components of a Flat Plate Solar Collector:
  - Working of the Flat Plate Solar Collector:
  - Advantages:
  - Disadvantages:
- 16. Compare the features (4 points) of non-concentrating and non-concentrating type solar collectors
  - Key Differences:
- 17. Explain the principle and working of the following solar radiation measuring instruments:
  - Pyranometer
    - Principle:
    - Working:
  - Pyrheliometer
    - How it Works:
  - Sunshine Recorder
    - How it Works:
    - Summary:
- 18. Explain various factors contributing to losses in solar cell. How is the efficiency reduced due to these factors.
  - 1. Reflection Losses
  - 2. Incomplete Absorption
  - 3. Partial Utilization of Photon Energy
  - 4. Collection Losses
  - 5. Open Circuit Voltage (Voc) Losses
  - 6. Curve Factor Losses
  - 7. Series Resistance Losses
  - 8. Thickness of the Cell
- 19. Explain the construction of a solar cell with the help of a neat diagram.
  - 1. P-Type Silicon Layer
  - 2. N-Type Silicon Layer
  - 3. Front Metallic Grid
  - 4. Opaque Back Metal Contact
    - How the Solar Cell Works:

Important Topics & PYQs

1. Explain about the role of non-conventional energy sources on the basis of current energy demands of the world

- The world's energy needs have been rising rapidly, with traditional sources like coal, oil, and natural gas depleting over time.
- Non-conventional energy sources are becoming increasingly important to meet these growing demands sustainably. These energy sources include solar, wind, tidal, and geothermal power, which offer long-term, cleaner alternatives to fossil fuels.

Why Non-Conventional Energy Is Important:

1. **Depletion of Conventional Resources**: Traditional energy sources such as coal and oil are finite and will likely run out in the next 50–60 years. Non-conventional sources, like solar and wind, are renewable and can be harnessed for the long term.
2. **Environmental Impact**: Conventional energy generation often results in pollution and contributes to climate change. Non-conventional sources are cleaner and produce little to no emissions, helping reduce the environmental footprint.
3. **Sustainability**: Non-conventional energy sources are renewable, meaning they are naturally replenished and won't run out in the foreseeable future. This makes them vital for a sustainable energy future.
4. **Energy Security**: As fossil fuels become scarcer and more expensive, renewable sources can help countries reduce dependence on imported energy, ensuring a more secure and stable energy supply.

Non-conventional energy sources are essential for addressing the growing global demand for energy. They offer sustainable, cleaner alternatives to fossil fuels but come with challenges like intermittency and high upfront costs. As technology advances and investment increases, these sources will play a key role in securing the world's energy future.

2. Explain the principle of solar energy conversion into heat energy.

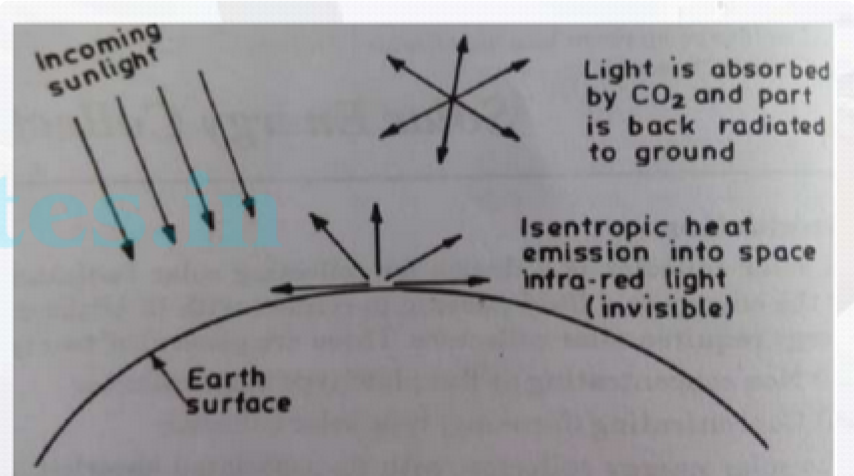

Fig. 3.2.1. The green house effect radiated to the CO_2 content of the atmosphere.

The principle of converting solar energy into heat is based on how sunlight, which is a form of energy, interacts with materials.

1. **Solar Radiation**: The energy from the sun travels to Earth in the form of **light** (shortwave radiation). This is the sunlight that we see.
2. **Absorption and Conversion**: When sunlight strikes a solid or liquid object (like a solar collector or a surface), the material **absorbs** this light energy. The energy is then **transformed into heat**. This makes the material warm.
3. **Storage and Transfer of Heat**: Once the material absorbs the sunlight, it **stores the heat**. It can also **conduct** the heat to nearby materials, like air or water, or **reradiate** the heat to cooler surroundings. This is similar to how a greenhouse works, where sunlight enters and heats up the space, but the heat cannot easily escape, trapping it inside.

3. List any three advantages and disadvantages of solar PV systems.

Advantages:

1. **No Moving Parts**: Solar PV systems directly convert solar energy into electricity without the need for moving parts, making them more reliable and less prone to wear and tear.

2. **Low Maintenance**: These systems are durable and require minimal maintenance, which reduces long-term operational costs.
3. **Environmentally Friendly**: Solar PV systems are non-polluting, contributing to clean energy production with no harmful emissions.

Disadvantages:

1. **High Initial Cost**: The installation of solar PV systems can be expensive, particularly for large-scale systems, which can deter some consumers.
2. **Low Efficiency**: Solar PV systems generally have lower efficiency compared to other energy sources, meaning they need more space to generate the same amount of power.
3. **Intermittent Energy Source**: Solar energy is dependent on sunlight, which means the system's output is variable and energy storage or backup systems are needed for periods of low or no sunlight.

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4. Compare concentrating and non-concentrating collectors.

Concentrating Collectors:

- **How they work**: Use mirrors or lenses to focus sunlight onto a small area (the receiver).
- **Radiation**: Only work well with **direct sunlight** (beam radiation).
- **Temperature**: Can reach **high temperatures**, good for industrial uses.
- **Tracking**: Need **trackers** to follow the sun, so they can be a bit more complex.
- **Maintenance**: Require more **maintenance** because of moving parts.
- **Best for**: **Commercial or large-scale** applications where high temperatures are needed.

Non-Concentrating Collectors (Flat Plate Collectors):

- **How they work**: Simply absorb sunlight using a flat plate, no focusing needed.
- **Radiation**: Can absorb both **direct and scattered sunlight** (diffuse radiation), making them more reliable.
- **Temperature**: Reach **lower temperatures** compared to concentrating collectors.
- **Tracking**: **No tracking** needed, they work well even when not directly facing the sun.
- **Maintenance**: **Low maintenance**, no moving parts.
- **Best for**: **Residential or small-scale** applications like heating water or homes.

5. Differentiate between Conventional and Non-conventional sources of energy

Aspect	Conventional Sources of Energy	Non-Conventional Sources of Energy
Definition	Traditional energy sources that have been used for a long time.	Newer and renewable energy sources, not widely used before.
Examples	Coal, oil, natural gas, and nuclear energy.	Solar, wind, biomass, hydro, geothermal, tidal, and wave energy.
Availability	Limited, non-renewable (will eventually deplete).	Renewable, can be replenished naturally (infinite supply).
Environmental Impact	Polluting, causes environmental damage (e.g., global warming, air pollution).	Clean, eco-friendly, minimal or no pollution.
Cost	Generally cheaper to extract and use in the short term.	Initially expensive, but becoming cheaper with technology advancements.
Energy Production	Large-scale energy production, often centralized.	Can be small-scale or decentralized (e.g., rooftop solar).
Sustainability	Not sustainable in the long term due to limited resources.	Sustainable, as they depend on natural processes like sunlight or wind.
Efficiency	High efficiency in converting to energy (e.g., coal, nuclear).	Can be less efficient but improving with technology (e.g., solar panels).
Examples of Usage	Power plants, transportation, industries.	Homes, small businesses, remote locations, and some industries.

Key Differences:

1. **Source**: Conventional energy comes from finite resources (coal, oil), while non-conventional energy comes from renewable sources (wind, solar).
2. **Impact**: Conventional energy sources contribute to environmental issues, while non-conventional sources are cleaner and have less environmental impact.

3. **Sustainability**: Conventional energy is not sustainable in the long term, whereas non-conventional energy is renewable and sustainable.

6. Explain 3 applications of stand-alone solar PV systems

1. **Powering Remote Areas or Villages**:
    1. Stand-alone solar PV systems are ideal for providing electricity to areas that are not connected to the main power grid.
    2. These systems are set up in remote villages, farmlands, or isolated installations. They generate electricity during sunny hours and store excess energy in batteries, ensuring a reliable power supply even when the sun isn't shining.
2. **Solar-Powered Water Pumps**:
    1. Stand-alone solar PV systems are used to run water pumps for agricultural or drinking water purposes in remote locations.
    2. These systems can power the pump during the day, and the stored energy can be used to continue pumping water during the night or cloudy days. This is particularly useful in rural areas where water sources are far and grid power is unavailable.
3. **Off-Grid Homes or Small Businesses**:
    1. Stand-alone solar PV systems are used to provide electricity to off-grid homes, cabins, or small businesses that are far from the main electrical grid.
    2. These systems generate power from sunlight, store energy in batteries, and supply it to appliances or equipment. They are highly beneficial in places like countryside homes, mountain cabins, or eco-friendly buildings that want to be self-sufficient.

7. Discuss primary and secondary energy sources. Describe future of non-conventional energy resources in India.

Primary and Secondary Energy Resources

1. **Primary Energy Resources**
   These are natural resources found in their raw form in nature and can be used directly or after extraction and processing. Examples include:
    - **Fossil Fuels**: Coal, oil, and natural gas

- **Uranium**: For nuclear energy
- **Hydropower**: Energy derived from the flow of water

  Primary resources need to be processed or converted into usable forms before they can be used by consumers.

2. **Secondary Energy Resources**

   These are energy forms that are derived from primary resources through processing or conversion. Secondary energy sources are typically more useful in daily life. Examples include:

   - **Electricity**: Generated from various primary sources like coal, wind, or solar
   - **Petrol, Diesel, CNG**: Fuels refined from crude oil
   - **Steam, Hot Water**: Produced from primary energy sources like coal or geothermal

Conventional and Non-Conventional Energy Resources

1. **Conventional Energy Resources**

   These are traditional energy sources that have been used for many years. They are widely available and typically have established technologies for their use. However, they are limited and likely to be depleted in the future. Examples:

   - **Coal**
   - **Petrol and Diesel**
   - **Natural Gas**
   - **Nuclear Fuels**

   Characteristics:

   - Traditionally used for a long time
   - Readily converted into mechanical energy
   - Limited and non-renewable

2. **Non-Conventional Energy Resources**

   These are emerging energy sources that are not traditionally used but are being developed as alternatives to conventional energy sources. They are often renewable and have the potential to be available in vast quantities. Examples:

   - **Solar Energy**
   - **Wind Energy**
   - **Geothermal Energy**

- **Biogas**

Characteristics:

- Not widely used yet
- Often require advanced or costly technology for conversion
- Renewable or abundant, potentially inexhaustible

Future of Non-Conventional Energy Resources in India

India is making significant strides towards adopting non-conventional (renewable) energy resources due to the growing demand for sustainable and clean energy. The future of non-conventional energy resources in India looks promising for several reasons:

1. **Government Support and Policies**
   India has set ambitious targets to increase the share of renewable energy in its energy mix. The government is actively promoting solar, wind, and other renewable energy sources through policies, subsidies, and incentives.
2. **Reduction of Dependence on Fossil Fuels**
   With the depletion of fossil fuels and the adverse environmental effects of burning coal and oil, India is investing in renewable sources like solar and wind, which are inexhaustible and environmentally friendly.
3. **Technological Advancements**
   Advancements in solar photovoltaic technology, wind turbines, and energy storage solutions are making renewable energy more cost-effective and efficient. This encourages large-scale adoption, especially in rural and remote areas.
4. **Energy Security and Rural Electrification**
   Non-conventional energy sources can provide decentralized energy solutions for remote areas, reducing India's dependence on fossil fuel imports and enhancing energy security.
5. **Job Creation and Economic Growth**
   The renewable energy sector is generating jobs in manufacturing, installation, and maintenance, contributing to India's economic growth and employment opportunities.

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8. What are the different types of solar cells? Write about any three types of solar cells.

1. **Single Crystal Silicon Solar Cells**
    - **How made**: Made from pure silicon, shaped into a single crystal and cut into thin slices.
    - **Efficiency**: Very good (~22%).
    - **Pros**: Works really well and lasts a long time.
    - **Cons**: Expensive and needs strong sunlight.
2. **Polycrystalline Silicon Solar Cells**
    - **How made**: Made from silicon that is melted and cooled to form many crystals.
    - **Efficiency**: Good (~15-18%).
    - **Pros**: Cheaper than single crystal ones.
    - **Cons**: Not as efficient as single crystal cells.
3. **Amorphous Silicon Solar Cells**
    - **How made**: Made from silicon that is not in crystal form, using a thin-film process.
    - **Efficiency**: Low (~4-8%).
    - **Pros**: Very cheap and light.
    - **Cons**: Doesn’t work well in sunlight for long periods.
4. **Cadmium Telluride Solar Cells (CdTe)**
    - **How made**: Made with a thin film of cadmium telluride material.
    - **Efficiency**: Medium (~10%).
    - **Pros**: Uses less material, works well in sunlight.
    - **Cons**: Cadmium can be harmful to the environment.
5. **Copper Indium Gallium Selenide (CIGS) Solar Cells**
    - **How made**: Made from a thin film of copper, indium, gallium, and selenium.
    - **Efficiency**: Good (~14%).
    - **Pros**: Flexible and stable.
    - **Cons**: A little more expensive.
6. **Gallium Arsenide (GaAs) Solar Cells**
    - **How made**: Made from gallium arsenide, a very strong material.
    - **Efficiency**: Very good (~20%).
    - **Pros**: Great for special uses like space, very efficient.
    - **Cons**: Very expensive.

9. What are solar collectors? Give their classification and compare them based on construction and area of applications.

- Solar collector is a device for collecting solar radiation and then transferring the absorbed energy to a fluid passing through it.
- A solar collector absorbs solar energy in the form of heat and simultaneously transfers this heat to a fluid so that heat can be transported by the fluid.

Classification of solar collectors

- There are mainly 2 types of solar collectors
  - Non concentrating or flat plate solar collector
  - Concentrating type solar collector

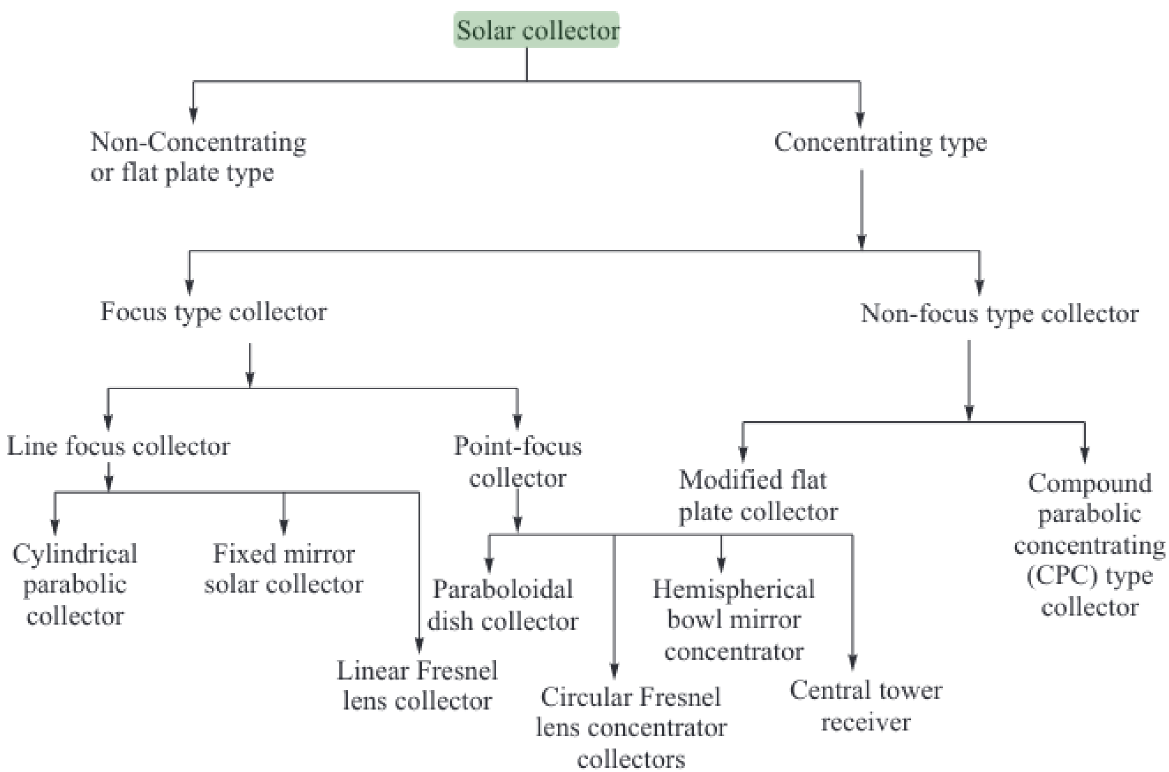

Figure 3.1 Classification of collectors.

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1. Flat plate collector

- A flat plate collector consists of the following components
  - Absorber plate
    - Intercept and absorb incident solar radiation

    - Blackened heat absorbing plate
- Transparent Cover
    - Placed above absorber plate, allows radiation to reach absorber
- Fluid tubes or channels
    - Heat is transferred from absorber to fluid in tubes or channels
- Thermal insulation
    - Provided under absorber plate and fluid tubes to minimise heat loss
- Tight container or box
    - Above components are protected by tight container

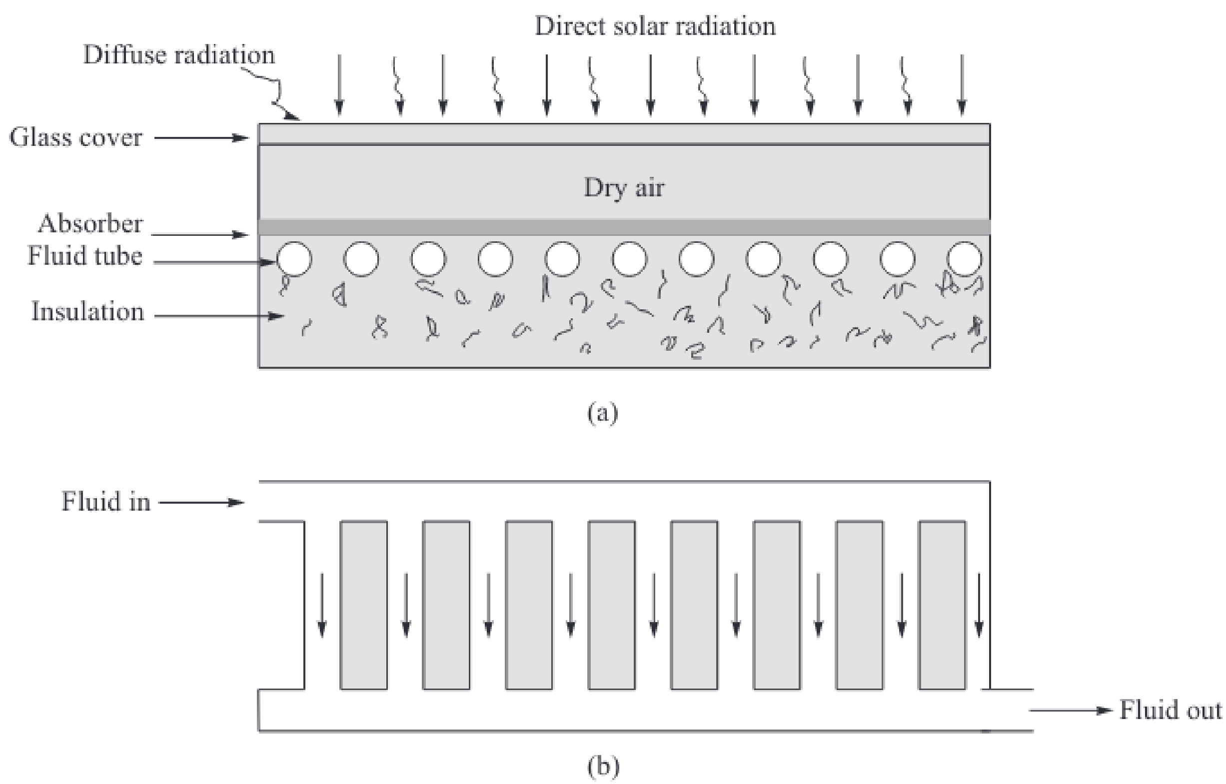


Figure 3.3 Flat plate solar collector. (a) Layout of transparent cover, absorber and fluid tubes. (b) Fluid tube connection and fluid flow.

2. Modified Flat plate collector

- Modified form of flat plate collector, as it has plain reflectors at edges to reflect additional radiation to the absorber or receiver and so there is some concentratiion of solar radiation at the receiver
- Concentration ratio 1->4

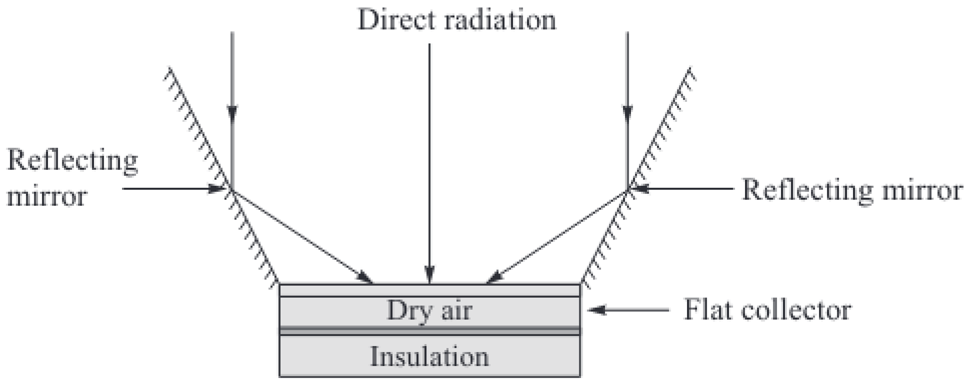
- 

Figure 3.4 Modified flat plate collector.

3. Compound parabolic concentrator

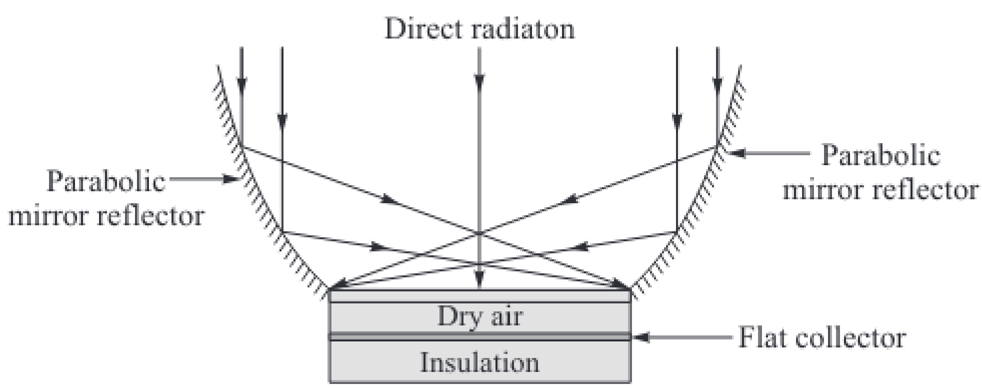
- Compound parabolic concentrator is a flat collector having 2 parabolic mirrors attached at the edge of flat plate collector
- 

Figure 3.5 Compound parabolic concentrator.
- The parabolic mirrors are adjusted such that focus of one mirror is located at bottom end of the other mirror in contact with the receiver. The arrangement helps in increasing acceptance angle
- Concentration ratio: 3 -> 7

4. Cylindrical parabolic concentrator

- Consists of a cylindrical parabolic trough reflector with a metallic fluid tube or receiver tube containing fluid at its focal line
- Fluid tube is blackened for better absorption of solar radiation
- The concentrated fluid tube heats up the transport fluid flowing through it.
- Concentration ratio 5 - 30

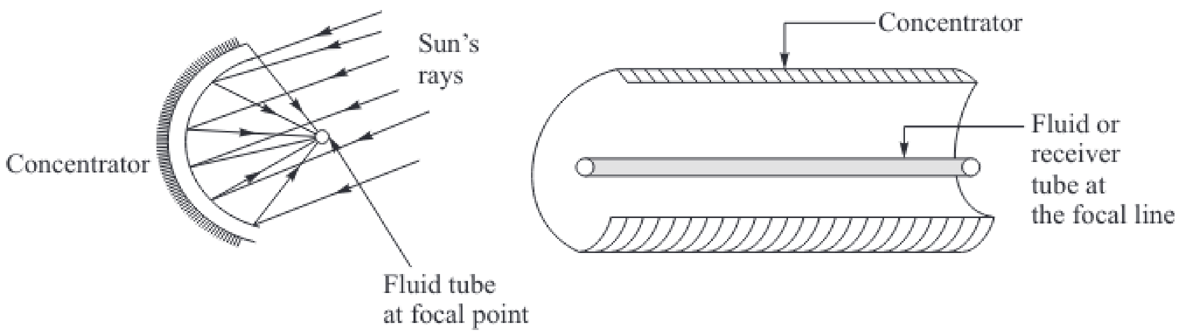


Figure 3.6 Cylindrical parabolic concentrator. (a) Focussing of sun's rays. (b) Arrangement of cylindrical concentrator and fluid tube.

5. Linear Fresnel Lens Collector

- Concentrator in the form of Fresnel lens is used.
- Fresnel lens consist of fine and linear grooves formed on one of the surfaces of some refracting materials, while other surface is flat.
- The grooves are designed in sucha way that it behaves similar to spherical lens, so it converges to focal line of lens where fluid tube is provided.
- The heat is transferred to transport fluid flowing in the fluid tube.
- Concentration ratio of 10 to 30
- Temperature range: 150 -> 300

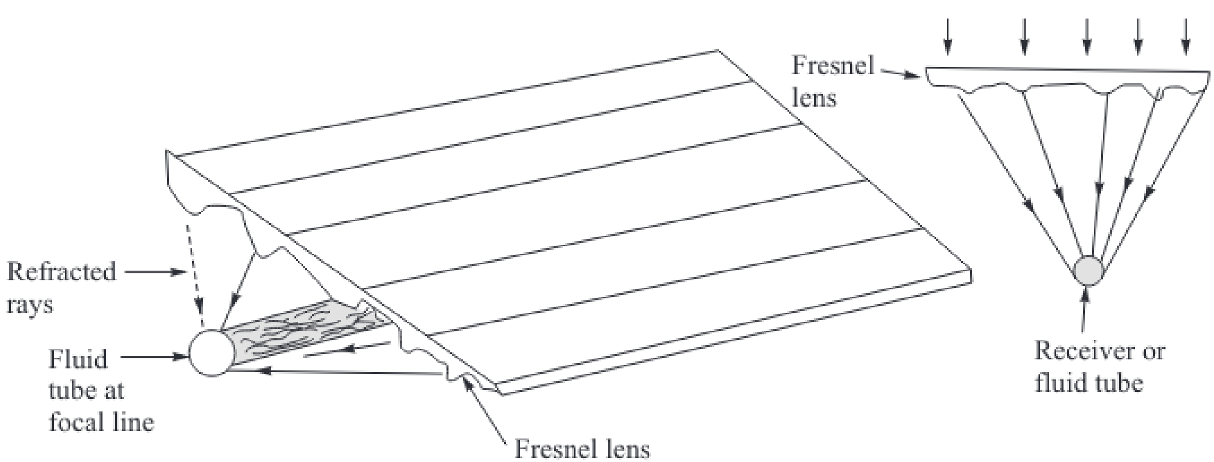


Figure 3.7 Linear Fresnel lens collectors.

6. Fixed Mirror Solar Concentrator

- The concentrator consists of a number of long narrow mirror strips fixed on circumference of a certain reference cylinder with a fluid tube moving at the same circular circumference or focal circle

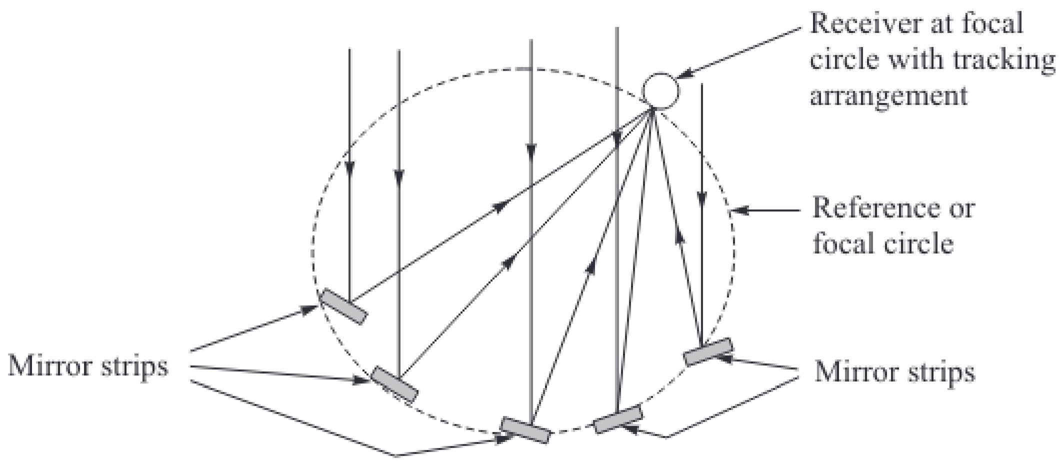


Figure 3.8 Fixed mirror solar concentrator.

- The mirrors are arranged in such a manner that incident radiation on them is focused on the receiver tube on their common focal circle
- The receiver tube can move along focal circle as per the movement of sun in the sky
- Concentration ratio = number of mirrors used

7. Paraboloidal dish collector

- A point focus collector has a dish in the shape of a paraboloidal.
- It concentrates all radiation parallel to its axis to a point where receiver tube is positioned

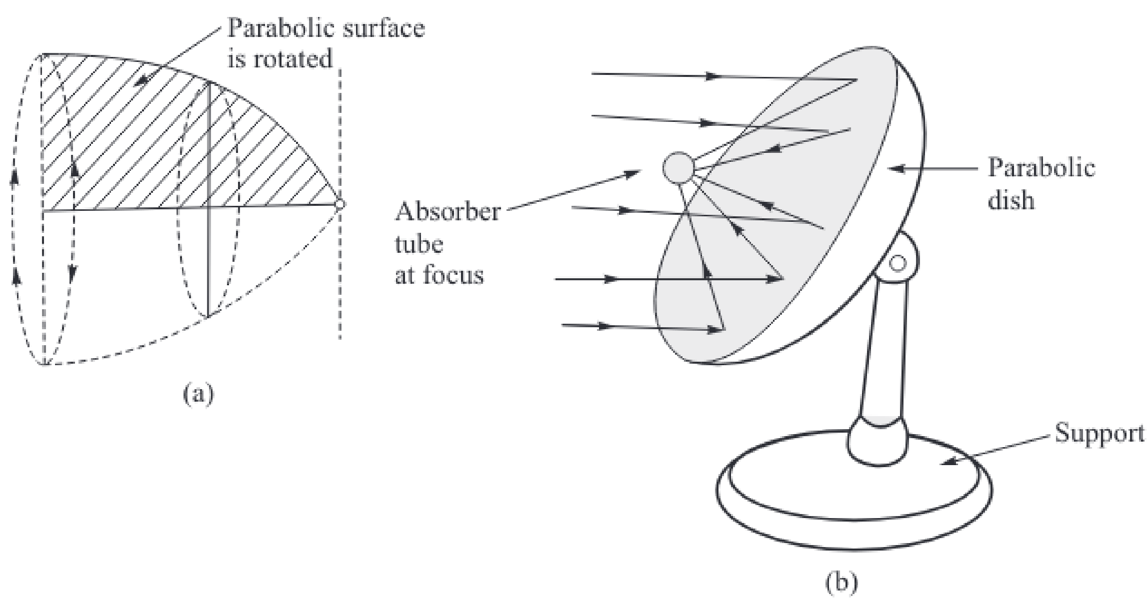


Figure 3.9 Paraboloid point focus solar collector. (a) Generation of paraboloid surface. (b) Parabolic surface concentrating radiation.

- Concentration Ratio ranging from 10 to 1000
- Produces temperature upto 3000C

8. Hemispherical Bowl Mirror Concentrator

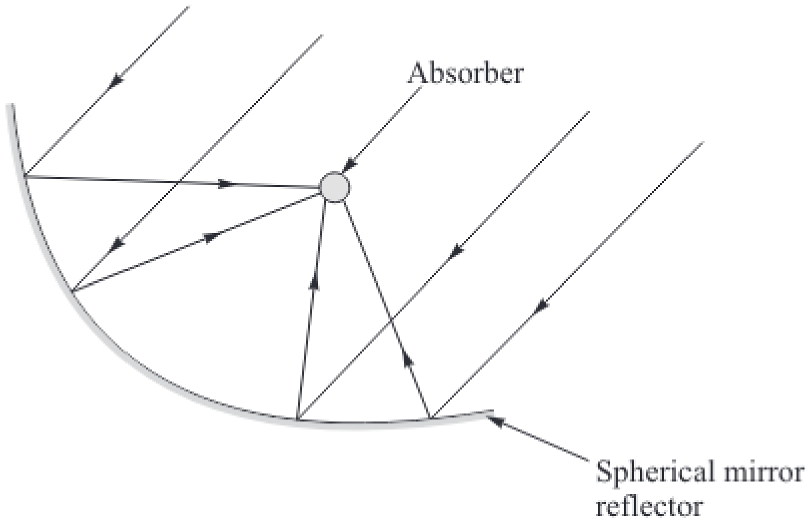
- Hemispherical Bowl Mirror Concentrator is a point focus concentrator in which reflector remains stationary
- Receiver is made to track 2 axes per movement of sun in the sky.
- All sun rays after reflection are concentrated at focal point
- 

Figure 3.10 Hemispherical bowl mirror concentrator.

9. Circular Fresnel Lens Concentrator

- Principle of working is similar to linear fresnel collector
- This type of collector is designed to concentrate the radiation at one focal point instead of line focus.
- Concentration ratio = 2000

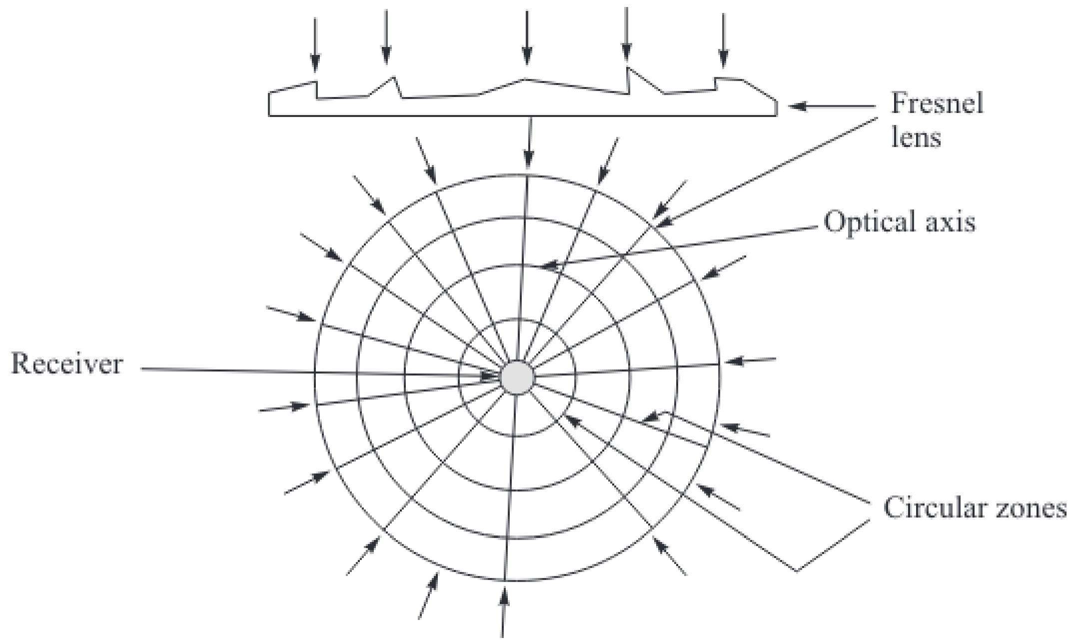


Figure 3.11 Circular Fresnel lens concentrator.

10. Central Tower Receiver Collector

- In this type of collector, the receiver is located at the top of a tower and solar radiation is reflected on it from a large number of independently controlled flat mirrors called heliostats
- Heliostats are spread over a large area on ground surrounding the absorber mounted on the tower
- Number of heliostats can be high as thousands, they track the sun to reflect the radiation
- Concentration ratio = 3000

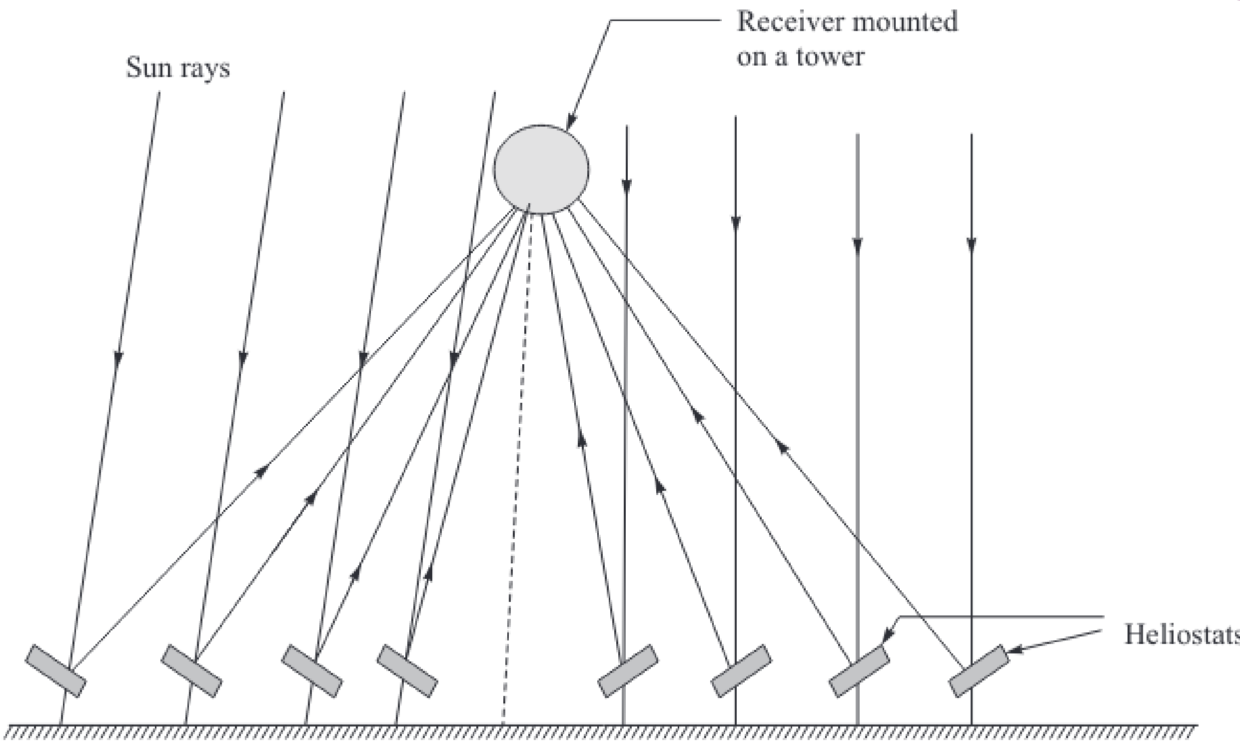


Figure 3.12 Heliostats and the receiver in a central tower receiver collectors.

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10. Explain about stand alone and grid connected solar photo voltaic systems

Stand-Alone System

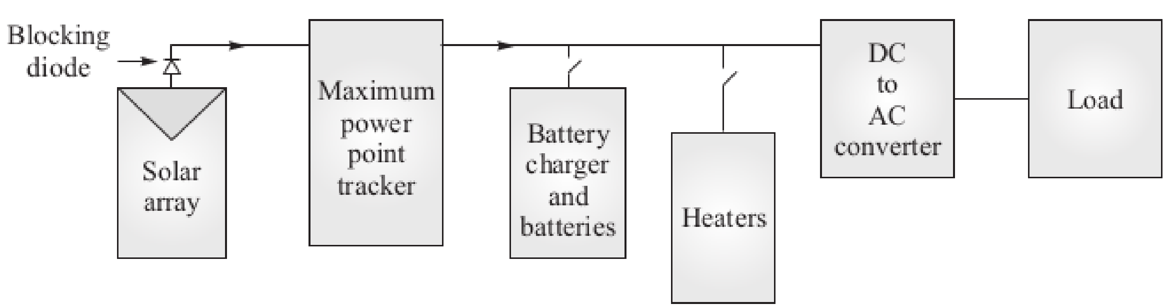
A stand-alone solar photovoltaic (PV) system is an independent power station designed to generate electricity from sunlight. It's particularly useful in remote areas where connection to the main power grid is not feasible.

Key Components and Functions:

1. **Solar PV Power Station:**
   - **Location:** The solar panels are installed at the load center, meaning close to where the electricity is needed, such as in a remote village, isolated area, or a specific installation.
   - **Purpose:** The entire system is designed to meet the electrical needs of the area without relying on external power sources.
2. **Maximum Power Point Tracker (MPPT):**

- **Function:** The MPPT is a crucial component that optimizes the efficiency of the solar panels. It continuously monitors the voltage and current output from the solar array (the group of solar panels) and adjusts the operating point to ensure the panels are generating the maximum possible power under current conditions.

3. **Power Conversion:**
   - **DC to AC Conversion:** The electricity generated by the solar panels is in direct current (DC) form. Since most household appliances and electrical systems operate on alternating current (AC), an inverter is used to convert the DC output to AC. This AC electricity is then used to power the electrical loads (like lights, fans, and other devices).
4. **Energy Storage:**
   - **Battery Storage:** Excess electricity generated by the solar panels, which isn't immediately needed, is stored in batteries. These batteries are charged during the day when solar radiation is available.
   - **Backup Supply:** When sunlight isn't available (e.g., at night or during cloudy weather), the stored energy in the batteries is used to power the electrical load, ensuring a continuous power supply.
5. **Excess Power Management:**
   - **Electric Heaters:** If the batteries are fully charged and there's still excess power being generated, this surplus energy can be diverted to electric heaters or other devices that can safely consume the extra power, preventing waste and ensuring the system runs efficiently.

- 

Grid Interactive Solar PV System

- The system first meets the requirement of house, village, and all excess power is fed into electric grid
- During absence of insufficient sunshine, the supply of electricity is maintained from the

electric grid, so no need of battery

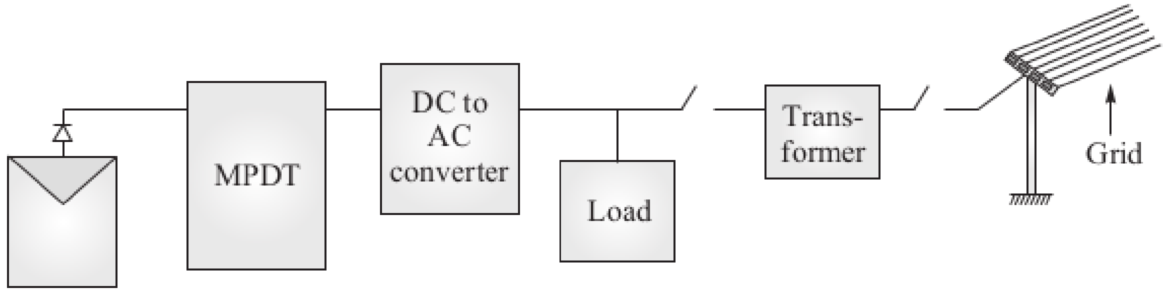


Figure 4.18 Grid interactive solar PV system.

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11. Explain the voltage- current characteristics of a solar cell with neat sketch

Voltage-Current Characteristics of a Solar Cell

A **solar cell** is essentially a **p-n junction** that converts light energy into electrical energy. The relationship between the **voltage (V)** and **current (I)** of a solar cell is known as its **I-V characteristic**.

1. Key Points of the I-V Characteristics:

- The **current** produced by the solar cell depends on the **incident light** (solar radiation), and the **voltage** depends on the external load connected to the cell.
- The **I-V curve** is typically **non-linear**, showing a decreasing current as the voltage increases.

2. I-V Curve Explanation:

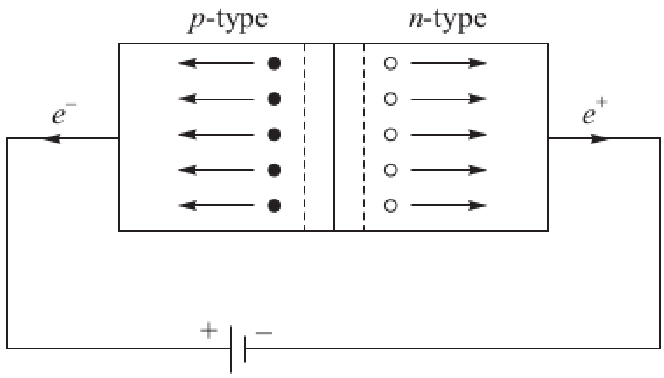

Figure 4.12 The *p-n* junction forward biased.

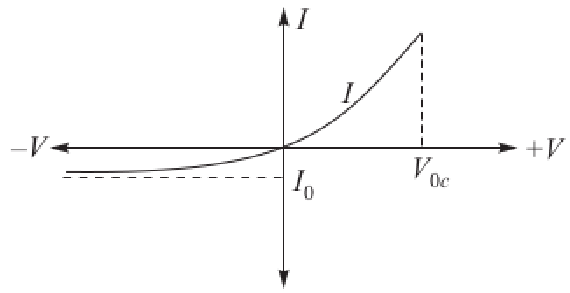

Figure 4.13 Current–Voltage characteristic of *p-n* junction when forward and backward biased.

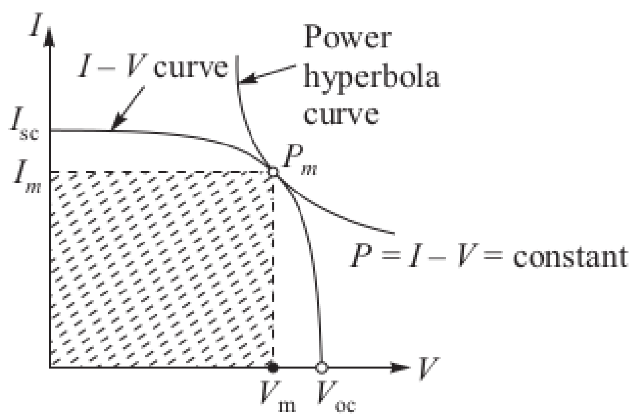

Figure 4.15 Current–voltage characteristics of solar cell and maximum power point (P_m).

- At **zero voltage (V = 0)**, the current is at its **maximum value**, called the **short-circuit current (I_{sc})**. This happens because there is no resistance to the current flow, so all the light energy gets converted into current.
- As the voltage increases, the **current decreases** because some of the generated current is used to overcome the voltage drop (opposing the flow of current).
- At the **open-circuit voltage (V_{oc})**, the current drops to **zero**. This is when the solar cell is not connected to any load, and no current can flow.
- The **maximum power point (Pm)** is where the product of **current (I)** and **voltage (V)** (P = I × V) is maximized. This is a point of interest because it represents the **optimal operating point** for the solar cell.

3. Power Curve:

- The **power curve** is a **hyperbola** (P = I × V) that shows the variation of power with respect to current and voltage.

- The area of the rectangle drawn under the curve with sides **Vm** (voltage) and **Im** (current) represents the maximum power that can be produced by the solar cell.
- The **maximum power point (Pm)** is the point where the hyperbola is tangent to the I-V curve, and this corresponds to **Vm** and **Im** values.

4. Fill Factor (FF):

- The **fill factor (FF)** indicates the **quality** of the solar cell. It shows how effectively the solar cell can convert sunlight into power.
- The **FF** is the ratio of the maximum power (Vm × Im) to the product of the open-circuit voltage (Voc) and the short-circuit current (I_sc). Mathematically:
    - A higher fill factor means the solar cell is better at utilizing the available area and generating more power.
- **Ideal FF**: The fill factor is **1 (unity)** in an ideal solar cell, meaning the cell uses the entire available area between the characteristic curve and the axes.
- **Typical FF values**: These range from **0.5 to 0.83**, depending on the quality of the solar cell.

5. Improving Fill Factor:

To improve the fill factor and make the solar cell more efficient:

- **Increase photocurrent**: Enhance the amount of current generated by the sunlight.
- **Decrease reverse saturation current**: Reduce the unwanted current that flows in the opposite direction.
- **Minimize series resistance**: Reduce internal resistance that opposes the current flow.
- **Maximize shunt resistance**: Prevent leakage current that bypasses the junction.

6. Effect of Illumination and Temperature:

- **Illumination (Solar Radiation)**: The intensity of sunlight directly affects the **short-circuit current (I_sc)**. More light means more current. However, the **open-circuit voltage (Voc)** remains mostly unchanged.
- **Temperature**: As the temperature increases, the **open-circuit voltage (Voc)** decreases slightly, but the **short-circuit current (I_sc)** increases. This results in a slight reduction in the overall efficiency of the solar cell at higher temperatures.

12. Describe the classification of energy sources with suitable examples.

1. Primary Energy Resources:

These are energy resources found naturally in their raw form. They are directly available for use but usually require some processing or conversion into a usable form. Primary energy resources include:

- **Fossil Fuels**:
  - **Coal**: A solid fossil fuel used for electricity generation and industrial processes.
  - **Oil**: A liquid fossil fuel used for transportation, heating, and electricity generation.
  - **Natural Gas**: A gaseous fossil fuel used for heating, electricity generation, and as a raw material in industries.
- **Nuclear Energy**:
  - **Uranium**: A mineral used in nuclear power plants to generate electricity through nuclear fission.
- **Renewable Resources**:
  - **Hydropower**: Energy harnessed from flowing water (like rivers and dams) to generate electricity.
  - **Wind Energy**: Energy obtained from wind using turbines.
  - **Solar Energy**: Energy obtained from sunlight using solar panels.

These resources must be **extracted**, **processed**, or **converted** into usable forms (e.g., coal into electricity, sunlight into electricity).

2. Secondary Energy Resources:

Secondary energy resources are derived from primary energy sources after they undergo processing or conversion. These are the usable forms of energy delivered to consumers. Some examples include:

- **Electricity**: Produced by converting primary energy sources (such as coal, natural gas, or nuclear) into electrical energy.
- **Steam**: Often produced in power plants from heating water with fossil fuels or other primary energy sources.
- **Petrol and Diesel**: Derived from crude oil after refining. Used mainly as fuels in transportation.

- **Liquefied Natural Gas (LNG)**: Natural gas that has been cooled into a liquid form for easier transport and storage.
- **Compressed Natural Gas (CNG)**: Natural gas stored at high pressure and used as an alternative fuel for vehicles.
- **Hot Water**: Sometimes used directly in heating systems, and can be produced from geothermal sources or fossil fuels.

13. With a neat sketch, explain how the solar energy is harvested using a central tower collector. List any two advantages.

The **Central Tower Receiver Collector** is a type of **Concentrated Solar Power (CSP)** system. This system uses **heliostats** (mirrors) to concentrate sunlight onto a receiver located at the top of a tall tower.

- In this type of collector, the receiver is located at the top of a tower and solar radiation is reflected on it from a large number of independently controlled flat mirrors called heliostats
- Heliostats are spread over a large area on ground surrounding the absorber mounted on the tower
- Number of heliostats can be high as thousands, they track the sun to reflect the radiation

Advantages of Central Tower Collector:

1. **High Efficiency**: The **concentration ratio** of around **3000** allows for very efficient use of solar energy, as the sunlight is focused onto a small area, making it possible to generate high temperatures for electricity generation.
2. **Scalability**: This system can be scaled up easily by adding more heliostats. The system can also be adapted to work with different types of heat transfer fluids, making it flexible for various applications and locations.

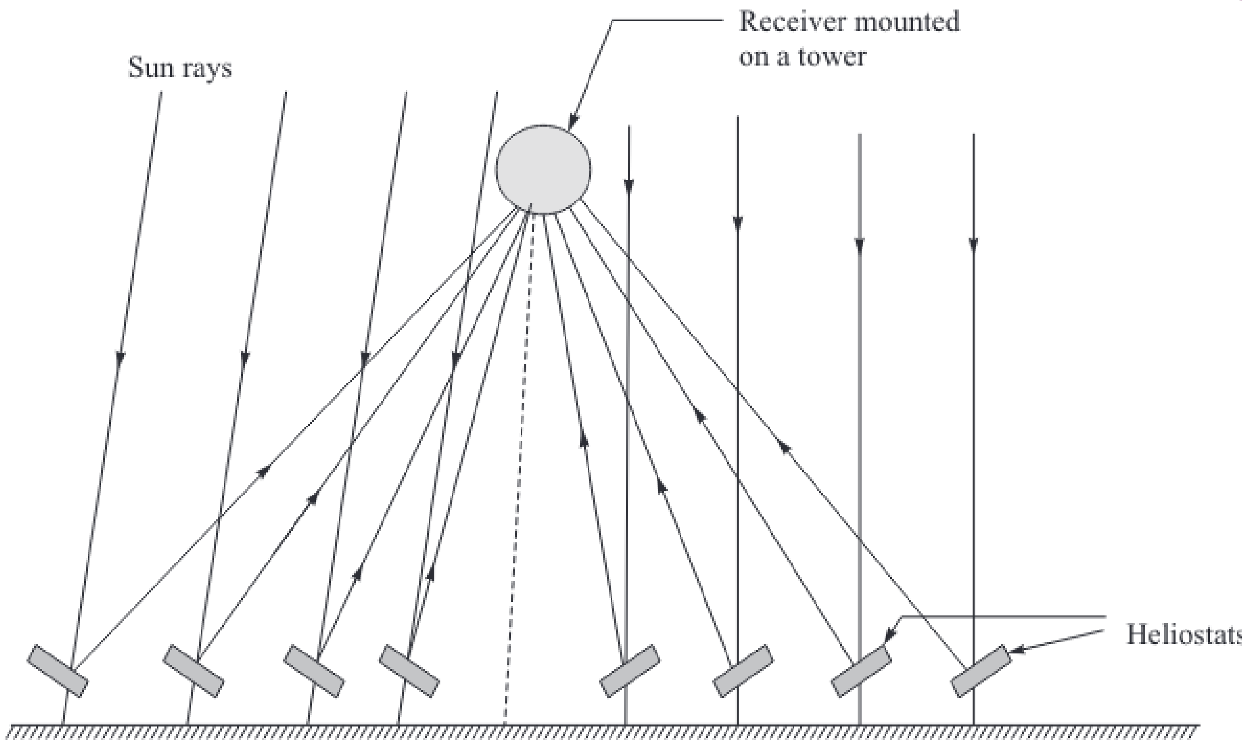

Figure 3.12 Heliostats and the receiver in a central tower receiver collectors.

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14. What are the important parameters to be considered while selecting a solar panel for its good performance? How is its performance affected by the variation in insolation?

Key Parameters for Selecting a Solar Panel:

1. **Efficiency**: Measures how much sunlight is converted into electricity. Higher efficiency means better performance in limited space.
2. **Power Output (Wattage)**: Indicates the electricity a panel produces. Higher wattage means more power generation.
3. **Temperature Coefficient**: Shows how much efficiency drops as temperature rises. Lower coefficient is better for hot climates.
4. **Durability and Warranty**: Solar panels should last 20-25 years. Check for a good warranty to ensure reliability.
5. **Size and Weight**: Important for installation, especially on roofs with limited space.
6. **Cost**: Consider both upfront and long-term costs, including installation and maintenance.

Effect of Insolation on Solar Panel Performance:

- **Higher Insolation**: More sunlight = more electricity. Best performance occurs with direct sunlight, especially midday.
- **Lower Insolation**: Less sunlight (cloudy days or early/late hours) reduces power output.
- **Angle of Incidence**: Panels facing the sun at the right angle get more sunlight, improving performance.
- **Temperature Impact**: Higher sunlight can increase temperature, reducing efficiency unless the panel is designed for high heat.

In summary, more insolation leads to higher power output, but temperature and panel orientation also play a role in the overall performance.

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15. With a neat labelled diagram explain the construction and working of a Flat plate solar collector

A flat plate solar collector is a simple, stationary system designed to absorb solar energy and convert it into heat. It is commonly used for water heating and other low-temperature applications. The main components and their function are as follows:

Components of a Flat Plate Solar Collector:

1. **Absorber Plate:**
   - This is a flat, blackened surface, often made of copper, aluminum, or steel. It absorbs the solar radiation and converts it into heat. The dark color helps in better absorption, and coatings can be applied to minimize heat loss through radiation.
2. **Transparent Cover:**
   - Typically made of glass or clear plastic, this cover is placed above the absorber plate. It allows sunlight to reach the absorber plate but reduces heat loss by preventing re-radiation and convection.
3. **Fluid Tubes or Channels:**
   - These are arranged in contact with the absorber plate. The heat absorbed by the plate is transferred to a fluid (such as water or air) circulating through the tubes. The heated fluid then moves to where the heat is needed.
4. **Thermal Insulation:**

- Positioned beneath the absorber plate and tubes, insulation minimizes heat loss from the system by reducing transmission or convection of heat to the environment.

5. **Tight Container or Box:**
   - All these components are housed in a box that helps protect them from environmental elements like rain or wind. The box also serves to retain heat, further improving the collector's efficiency.

Working of the Flat Plate Solar Collector:

- **Solar radiation** strikes the **transparent cover** and passes through it, reaching the **absorber plate**. The absorber plate absorbs the radiation and gets heated.
- The **fluid tubes** in contact with the absorber plate then transfer the heat to the fluid circulating inside them.
- The **heated fluid** is sent to storage or directly used for applications like water heating.
- The **insulation** reduces heat loss, ensuring that most of the heat stays within the system.

Advantages:

1. **Simple Construction**: Does not require any complex parts like tracking systems.
2. **Durability**: Can withstand harsh weather conditions with minimal maintenance.
3. **No Tracking Required**: Mechanical strength is higher as it does not need to follow the sun’s movement.

Disadvantages:

1. **Heat Loss**: Since there is no optical concentration, the surface area is large, leading to more heat loss.
2. **Limited Temperature**: Cannot achieve very high temperatures as efficiently as other types of collectors like evacuated tube collectors.

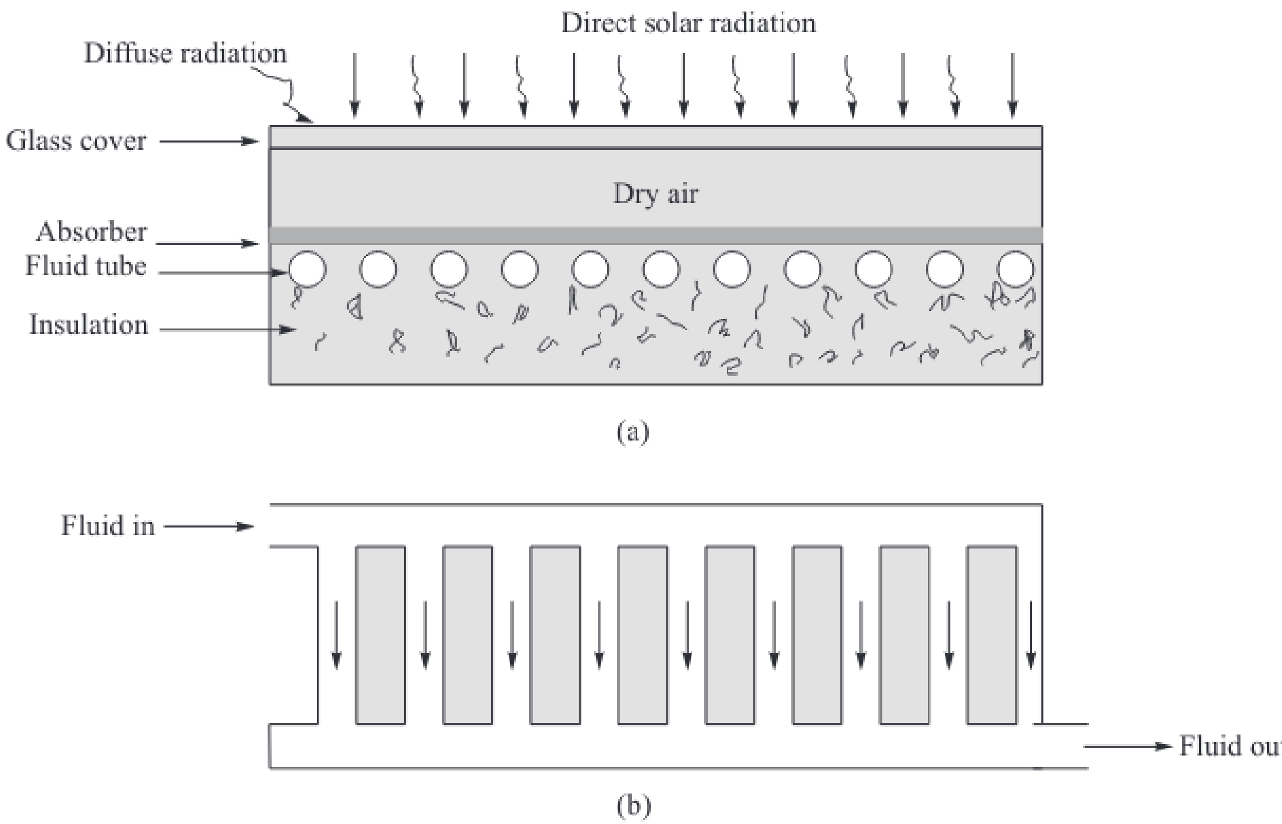

Figure 3.3 Flat plate solar collector. (a) Layout of transparent cover, absorber and fluid tubes. (b) Fluid tube connection and fluid flow.

16. Compare the features (4 points) of non-concentrating and non-concentrating type solar collectors

Feature	Concentrating Solar Collectors	Non-Concentrating Solar Collectors
Principle	Uses mirrors or lenses to focus sunlight onto a small area to increase heat.	Uses a large flat surface to directly absorb sunlight without concentration.
Efficiency	Higher efficiency as they focus more sunlight onto a smaller area, increasing heat.	Lower efficiency as the entire surface area is used to collect sunlight directly.
Complexity	More complex in design due to the need for tracking systems (to follow the sun) and focusing elements.	Simpler design, usually stationary and requires less maintenance.
Applications	Suitable for high-temperature applications (like electricity generation in concentrated solar power plants).	Typically used for low-temperature applications such as water heating.

Key Differences:

1. **Efficiency**: Concentrating collectors tend to be more efficient because they focus sunlight onto a smaller area, whereas non-concentrating collectors capture solar radiation over a larger area but without focusing it.
2. **Design Complexity**: Concentrating collectors require mechanisms like sun-tracking devices and reflective surfaces, making them more complex, while non-concentrating collectors have simpler stationary designs.
3. **Temperature and Applications**: Concentrating collectors are used in high-temperature applications, such as generating electricity, while non-concentrating collectors are used for applications like heating water at lower temperatures.
4. **Maintenance**: Non-concentrating collectors usually have fewer moving parts and require less maintenance than concentrating ones due to their simpler design.

17. Explain the principle and working of the following solar radiation measuring instruments:

(i) Pyranometer (ii) Pyrheliometer and (iii) Sunshine recorder

Pyranometer

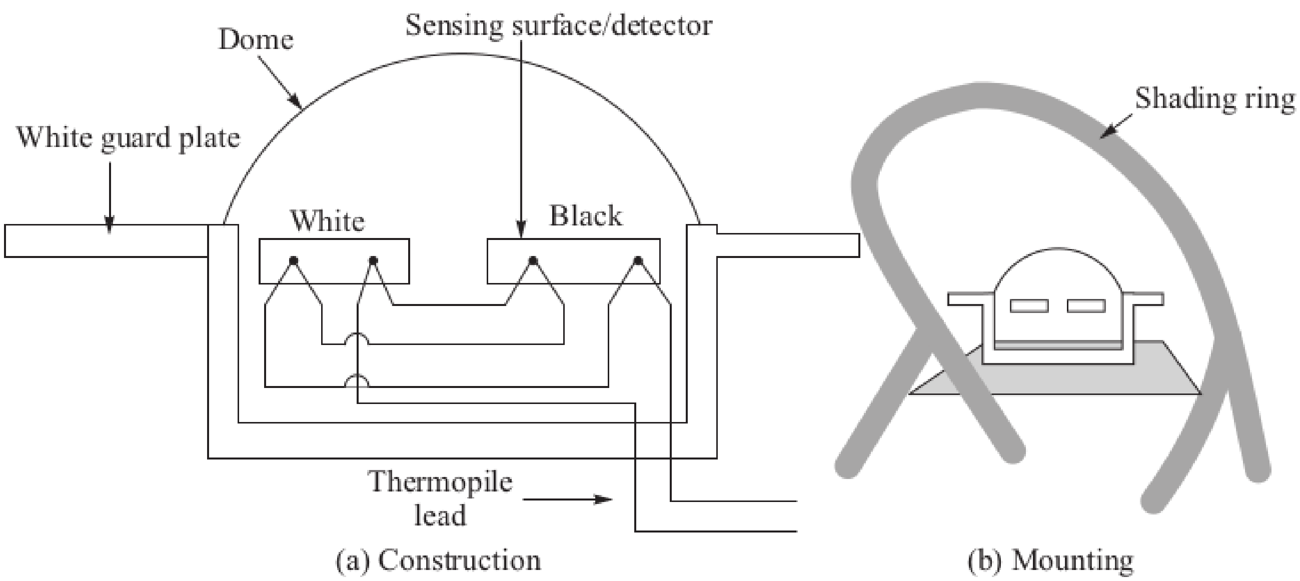

Figure 2.19 Construction of the pyranometer.

A **Pyranometer** is an instrument used to measure **global solar radiation**, which includes both **direct and diffuse sunlight** falling on a surface, usually on a horizontal plane.

Principle:

- The **pyranometer** works based on the principle of **heat absorption**. It uses a device called a **thermopile**, which converts heat from solar radiation into a measurable electrical signal.
- When solar radiation hits the **blackened surface** of the thermopile (also called the hot junction), it heats up, creating a temperature difference between the **hot junction** (exposed to the sun) and the **cold junction** (shaded and protected).
- This temperature difference generates a small voltage, which can be measured and is proportional to the amount of solar radiation.

Working:

1. **Thermopile**: The pyranometer contains a **thermopile** at its core. The thermopile's sensitive surface (the hot junction) is **blackened** to absorb all types of radiation (visible, infrared, etc.). This surface heats up as it absorbs solar radiation.
2. **Temperature Difference**: The **cold junction** of the thermopile is kept in the shade, so it doesn't absorb radiation and stays cooler than the hot junction. The difference in temperature between the two junctions causes an electrical voltage to be produced, which is proportional to the amount of radiation falling on the hot junction.
3. **Protective Elements**:
   - The **hot junction** is protected from environmental factors like wind and rain by two **hemispherical glass domes.**
   - A **white-painted guard plate** around the pyranometer prevents direct sunlight from reaching the thermopile's cold junction, which could affect the readings.
   - A **shadow band** can be used to block direct sunlight and measure only **diffuse radiation** (when the pyranometer is shaded).
4. **Output**: The thermopile produces a small **voltage output** (around 9 μV per watt per square meter), which is then recorded by a **chart recorder** over time. The readings show how much solar radiation is incident at different hours of the day, creating a **pyranogram** (a graph showing radiation over time).
5. **Drying and Leveling**: Inside the pyranometer, there's a **silica gel** tube to prevent moisture buildup. The instrument is leveled using three leveling screens to ensure accurate readings.

Pyrheliometer

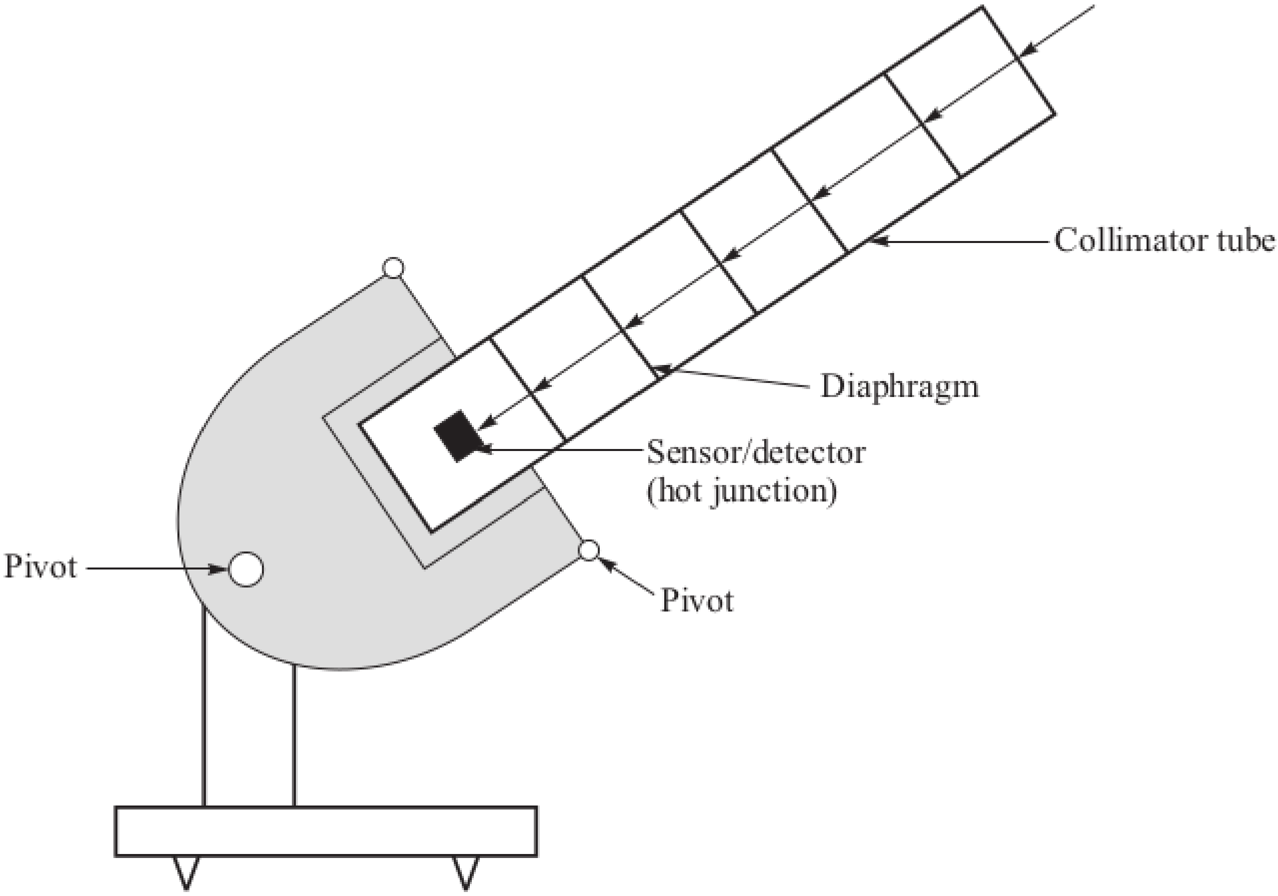

Figure 2.20 Construction of a pyrheliometer.

A **Pyrheliometer** is a device used to measure **beam radiation**, which is the direct sunlight that comes in a straight line from the sun (as opposed to diffuse radiation scattered in all directions).

How it Works:

1. **Collimator Tube**: The pyrheliometer has a **long, narrow tube** called the **collimator tube**. This tube is designed to only collect sunlight that is coming directly from the sun. It does this by limiting the angle of sunlight that can enter (about **5.5°**), ensuring only **direct beam radiation** is measured.
2. **Blackened Inside**: The inside of the collimator tube is **blackened** to absorb any unwanted radiation. This helps ensure that only the sunlight entering at the right angle is detected.
3. **Thermopile Detector**: At the end of the collimator tube, there is a **thermopile**, which is a device that converts heat into an electrical signal. The thermopile detects the amount of radiation by measuring the temperature increase caused by the sunlight hitting its surface. The sensitivity of the thermopile is around **8 μV per watt per square meter**.

4. **Dry Air**: The inside of the collimator tube is sealed with **dry air** (using **silica gel**) to prevent moisture from affecting the readings, which could absorb some of the radiation.
5. **Tracker**: The pyrheliometer has a **tracker** that continuously moves the instrument to keep the collimator tube directly facing the sun as it moves across the sky. This ensures that only the direct sunlight is measured throughout the day.

Sunshine Recorder

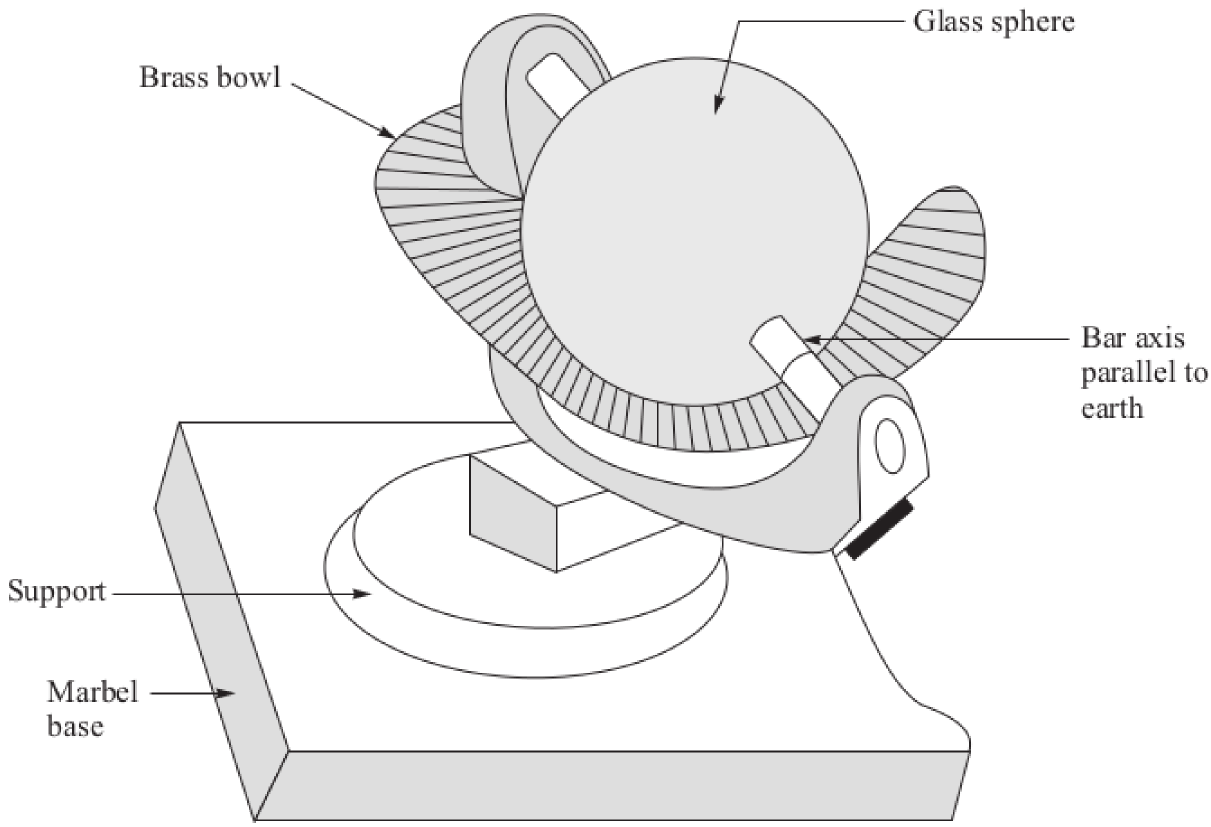

Figure 2.22 Sunshine recorder.

A **Sunshine Recorder** is an instrument used to measure the duration of **bright sunshine hours** in a day, or how long the sun shines brightly.

How it Works:

1. **Glass Sphere**: The recorder has a **10 cm diameter glass sphere**. This sphere acts like a lens, focusing sunlight onto a piece of paper.
2. **Bowl Structure**: The glass sphere is mounted inside a **bowl** that holds a **special paper card**. The bowl and sphere are arranged in a way that the sun's rays are focused sharply onto the paper.

3. **Paper Card**: The card inside the bowl has a **time scale printed on it** and is coated with special material. When sunlight hits the paper, it **burns a small spot** on the card. The paper **burns** wherever sunlight falls, leaving a trace.
4. **Sun's Movement**: As the sun moves across the sky, the **focused sunlight** creates a **continuous burn path** on the paper. The longer the sun shines, the longer the burn path.
5. **Measurement**: The **length of the burn trace** indicates how many hours of bright sunshine occurred. The trace is a measure of sunshine duration for the day.
6. **Seasonal Adjustment**: The instrument has **three sets of grooves** to place the paper card, allowing for seasonal adjustments as the sun's position changes throughout the year.

Summary:

- A **glass sphere** focuses sunlight onto a **paper card** inside a **bowl**.
- **Sunlight burns spots** on the card, forming a trace that shows how long the sun shone.
- The **length of the trace** indicates the **duration of sunshine** for the day.
- The recorder has grooves for **seasonal adjustments** to account for the sun's position changing throughout the year.

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18. Explain various factors contributing to losses in solar cell. How is the efficiency reduced due to these factors.

The **efficiency** of a solar cell is the ratio of the electrical power it generates to the total solar energy it receives. Unfortunately, solar cells cannot convert all the incident sunlight into electricity due to various **losses**. These losses limit the performance of the cell. Here are the main factors contributing to energy losses and how they reduce the efficiency of solar cells:

1. Reflection Losses

- **Cause**: Some of the sunlight that strikes the surface of the solar cell is **reflected** away.
- **Effect on Efficiency**: This reduces the amount of light entering the cell and lowers the energy available for conversion into electricity. To minimize this, **anti-reflective coatings** are often applied to the surface of solar cells.

2. Incomplete Absorption

- **Cause**: A solar cell material can only absorb photons with energy greater than or equal to its **band gap energy**. If the energy of a photon is lower than the band gap energy, it cannot be absorbed and contributes no useful energy. This is especially an issue for photons with longer wavelengths.

- **Effect on Efficiency**: Photons that have lower energy than the band gap energy are wasted, and the higher the band gap, the greater the waste. This is why materials like **silicon (1.1 eV)** are commonly used, as their band gap is well-suited to absorbing sunlight efficiently.

3. Partial Utilization of Photon Energy

- **Cause**: Some photons generate electron-hole pairs that have **excess energy**. This energy is not needed for generating current and is lost as heat.
- **Effect on Efficiency**: This excess energy is wasted, especially when using materials with a large band gap. A better band gap would help minimize this loss. Materials with a band gap between **0.9–1.1 eV** are typically ideal for solar cells.

4. Collection Losses

- **Cause**: The electron-hole pairs generated by sunlight must be **collected** efficiently to contribute to the output current. If the pairs recombine before being collected, they generate heat instead of electricity.
- **Effect on Efficiency**: The **collection efficiency** depends on factors like:
  - The **absorption characteristics** of the semiconductor,
  - **Recombination rates** (how often electrons and holes recombine),
  - The **distance** carriers need to travel, and
  - The **electric field** that accelerates carriers toward the electrodes. If these factors aren't optimized, collection losses occur, and efficiency decreases.

5. Open Circuit Voltage (Voc) Losses

- **Cause**: The **open circuit voltage (Voc)** is the maximum voltage a solar cell can generate when not connected to a load. It is always less than the **band gap energy** due to factors like **lower levels of illumination** and **doping** in the semiconductor.
- **Effect on Efficiency**: If the Voc is too low, the potential difference at the **p-n junction** reduces, limiting the voltage that can be used to power devices. There is an optimum Voc and short-circuit current (Isc) that maximizes power output.

6. Curve Factor Losses

- **Cause**: The current-voltage (I-V) characteristic curve of a solar cell doesn't have a **rectangular shape**; it is typically curved. This means that the actual maximum power output is always **less** than the product of Voc and Isc (theoretical maximum power).
- **Effect on Efficiency**: The **area under the I-V curve**, which represents the actual power output, is less than the product of Voc and Isc. This results in a loss of potential power.

7. Series Resistance Losses

- **Cause**: **Series resistance** is the resistance to the flow of current through the solar cell and the connections. This resistance causes a **voltage drop** and **power loss** as current flows.
- **Effect on Efficiency**: The I-V curves become **flattened**, and the output power decreases. Minimizing series resistance is crucial to improving efficiency.

8. Thickness of the Cell

- **Cause**: If the **cell material** is too thin, high-energy photons may pass through without being absorbed. To increase absorption, a **reflecting back contact** is often added to re-direct photons that pass through back into the cell.
- **Effect on Efficiency**: If the thickness of the cell is insufficient, the cell won't absorb as much sunlight, reducing its efficiency.

19. Explain the construction of a solar cell with the help of a neat diagram.

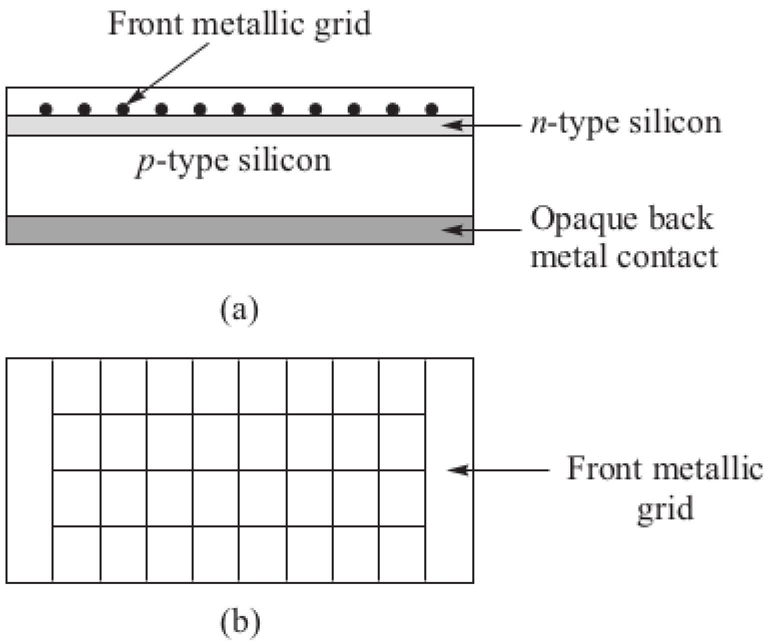

Figure 4.8 Construction of a solar cell. (a) Side view of the solar cell. (b) Top view of the solar cell.

A **solar cell** is a device that converts sunlight into electrical energy using the photovoltaic effect. The basic structure of a solar cell consists of several key components. Here's a simple explanation of the construction:

1. P-Type Silicon Layer

- **Material**: The main material used for the solar cell is **silicon**. The **p-type silicon** is created by doping silicon with elements like **boron** to give it an excess of **holes** (positive charge carriers).
- **Thickness**: The thickness of this p-type layer is typically around **100-350 micrometers (μm)**.

2. N-Type Silicon Layer

- **Material**: A thin layer of **n-type silicon** is placed on top of the p-type layer. This is achieved by doping silicon with elements like **phosphorus**, which introduces **extra electrons** (negative charge carriers).
- **Thickness**: This n-type layer is much thinner than the p-type layer, usually around **2 micrometers (μm)**.
- The combination of p-type and n-type materials forms a **p-n junction**, which is where the electricity is generated when sunlight hits the cell.

3. Front Metallic Grid

- **Material**: The **front metallic grid** is a network of fine metal lines that cover the surface of the solar cell. It's usually made of **silver** or other conductive metals.
- **Purpose**: The grid serves two purposes:
  - **Collects the electrical charge** generated by the solar cell when sunlight hits the p-n junction.
  - **Allows light to pass through** while minimizing any reflection. The grid's fine structure ensures that it doesn't block too much sunlight from reaching the cell.

4. Opaque Back Metal Contact

- **Material**: The **back metal contact** is an opaque metal layer (often made of **aluminum** or similar material) that covers the back of the p-type silicon.
- **Purpose**: This back contact serves as the **positive terminal** of the solar cell, completing the electrical circuit and allowing the current to flow out of the cell.

How the Solar Cell Works:

- When sunlight strikes the **solar cell**, it excites electrons in the **n-type silicon**, which causes the electrons to move toward the p-n junction.
- At the **p-n junction**, the electrons are separated, with electrons moving towards the **n-type layer** and holes (positive charges) moving toward the **p-type layer**.
- This movement of electrons creates an **electric current**, which can then flow through the external circuit, powering electrical devices.

20. Solar Pond

A solar pond is a special type of pond designed to collect and store solar energy in the form of heat, which can then be used for various purposes such as electricity generation or industrial processes.

Principle

- In ordinary pond, when water is heated by by sun rays, the heated water rises to top of the pond
- Hot water loses heat to the atmosphere, net temperature at the top of the pond remains nearly at atmospheric temperature

- Solar pond technology ensures that heated brine water remains at the bottom of the pond due to more brine concentration and density

What is a solar pond?

- Solar pond consist of a large size brine pond
- Most concentrated and dense part of the brine solution is at the bottom of the pond
- It has 3 zones, top zone, non convective zone, bottom zone
- **Top zone** is surface zone with least salt content
- **Bottom zone** is having maximum salt content and high temperature
- Solar energy is collected and stored in the **bottom zone.**

Working

- The hot brine solution from bottom of solar pond is taken out
- The solution is taken to the heat exchanger to remove heat from the brine solution
- These vapours are used to run a turbine which is coupled to a generator to generate power.

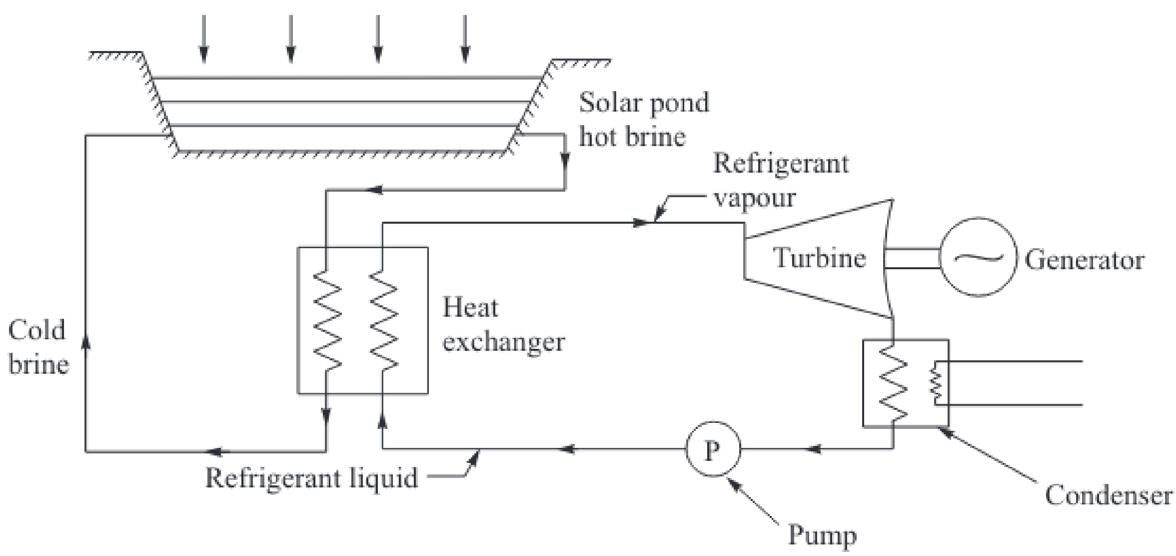

Figure 3.18 Layout of a solar pond electric power plant.

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