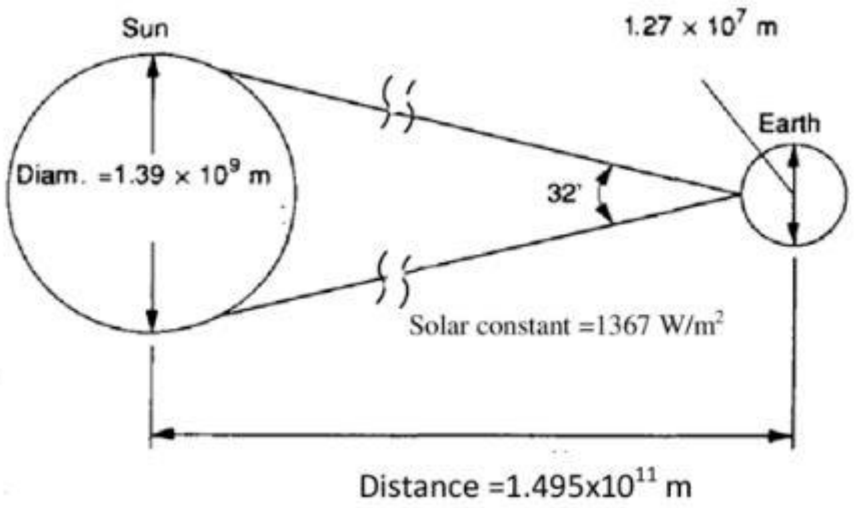
UNIT I - INTRODUCTION TO SOLAR ENERGY
Introduction - Sun-Earth relationships- solar constant- solar radiation at the earth surface-depletion of solar radiation- measurement of solar radiation- solar radiation data- solar time-solar radiation geometry- solar radiation on tilted surfaces-Sun as the source of energy- sun angles - overview of applications

1. Sun-Earth Relationships

Introduction

The relationship between the Sun and Earth plays a crucial role in determining the amount of solar energy received at different locations. The Sun is the primary source of energy for Earth, influencing climate, weather, and renewable energy applications. Understanding these relationships helps in designing efficient solar energy systems.



1.1 Earth's Motions and Their Effects on Solar Energy

The Earth has two main motions that affect how it receives solar radiation:

1. **Rotation** – Earth spins on its axis once every 24 hours.
2. **Revolution** – Earth orbits around the Sun once every 365.25 days.

Motion	Definition	Effect on Solar Energy
Rotation	Earth spins on its axis once in 24 hours	Causes day and night cycles
Revolution	Earth orbits the Sun in 365.25 days	Causes seasonal variations

1.2 Earth's Orbit and Seasons

Elliptical Orbit

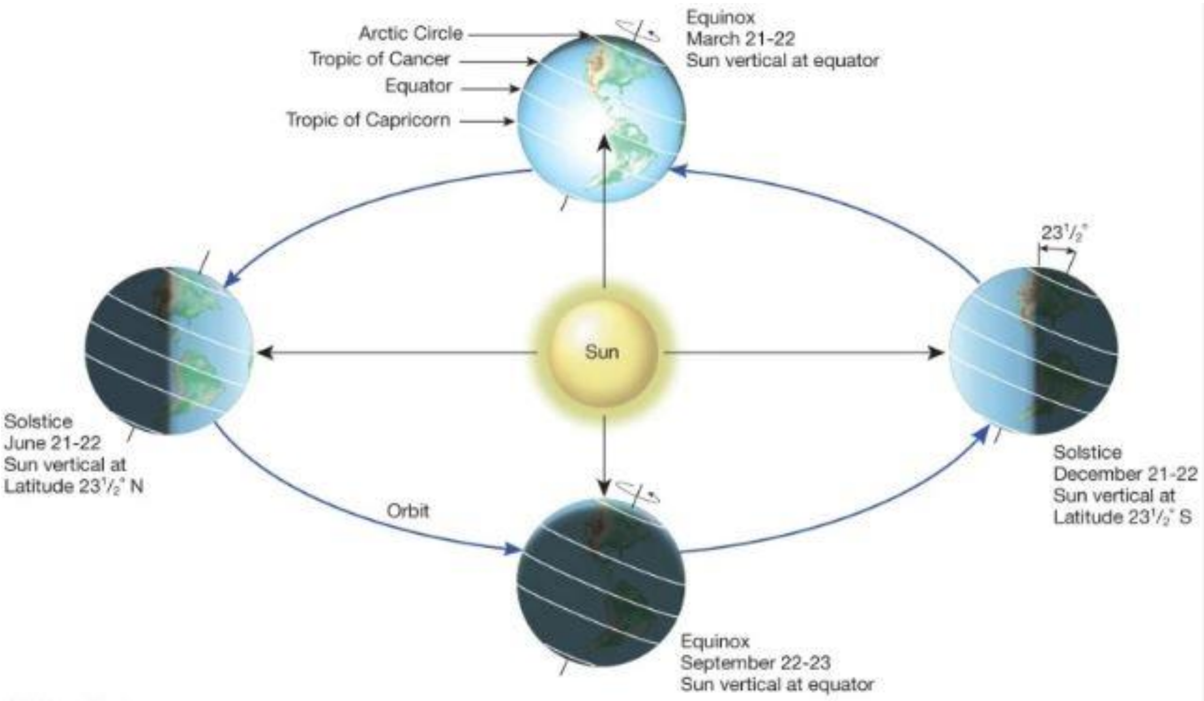
The Earth follows an **elliptical orbit** around the Sun, meaning the distance between the Earth and the Sun varies throughout the year.

- **Perihelion (closest to Sun):** ~147 million km (January 3rd)
- **Aphelion (farthest from Sun):** ~152 million km (July 4th)

Effect: The difference in distance causes small variations in solar energy received but does not significantly impact seasons.

Axial Tilt and Seasons

Earth's axis is tilted at **23.5°** relative to its orbit. This tilt causes different parts of the Earth to receive varying amounts of solar radiation throughout the year, leading to **seasons**.



Date	Solar Declination Angle	Season in Northern Hemisphere	Season in Southern Hemisphere
March 21 (Equinox)	0°	Spring Begins	Autumn Begins
June 21 (Solstice)	+23.5°	Summer Begins	Winter Begins
September 23 (Equinox)	0°	Autumn Begins	Spring Begins
December 21 (Solstice)	-23.5°	Winter Begins	Summer Begins

Explanation of Seasons:

- During **summer**, the hemisphere tilted towards the Sun receives more direct sunlight, resulting in **longer days and higher temperatures**.
- During **winter**, the hemisphere tilted away from the Sun receives less direct sunlight, leading to **shorter days and colder temperatures**.

Example:

In **India (Northern Hemisphere)**, June is the hottest month because the Sun is directly overhead (close to the Tropic of Cancer). In contrast, December is colder as the Sun is lower in the sky.

1.3 Day Length and Solar Time

The duration of sunlight varies with **latitude and season**.

- **Equator:** Day and night are always 12 hours.
- **Poles:** In summer, the Sun does not set for months (Midnight Sun). In winter, it does not rise (Polar Night).

Equation of Time (EOT)

Corrects for variations in the Earth's orbit, adjusting solar time.

Example:

On January 1st, the EOT is **-3 minutes**, meaning the solar noon occurs 3 minutes earlier than clock time.

1.4 Insolation and Solar Radiation

The amount of solar energy received per unit area is called **insolation**. It depends on:

- **Latitude** (closer to the equator receives more energy).
- **Season** (summer receives more energy).
- **Time of Day** (noon has the highest solar intensity).

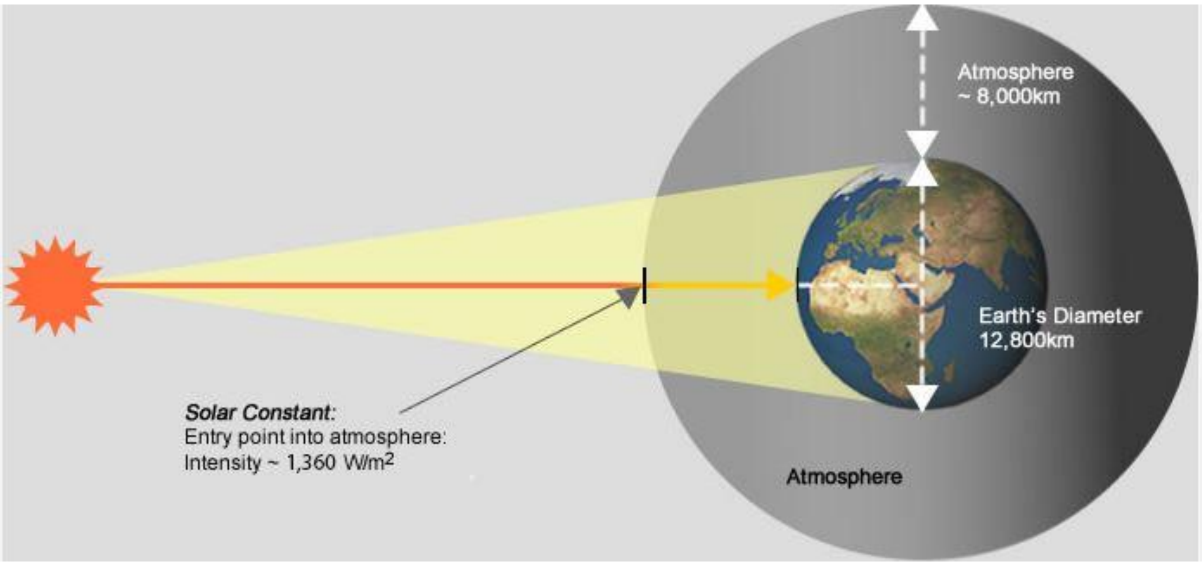
Location	Insolation ($kWh/m^2/day$)
Sahara Desert	6.0 - 7.5
India	5.0 - 6.5
Europe	3.0 - 4.5

Example:

A solar panel in Rajasthan (high insolation) produces **more energy** than the same panel in London (lower insolation).

2. Solar Constant

Definition: The solar constant is the amount of solar energy received per unit area on a surface perpendicular to the Sun's rays outside Earth's atmosphere.



- **Value:** 1361 W/m² (approx.)
- **Factors Affecting Solar Constant:**
    - Distance between Earth and Sun (varies due to elliptical orbit)
    - Sun's activity (solar flares, sunspots)

Example:

If a spacecraft with a solar panel of 1 m² is outside Earth's atmosphere, it receives **1361 W** of solar power.

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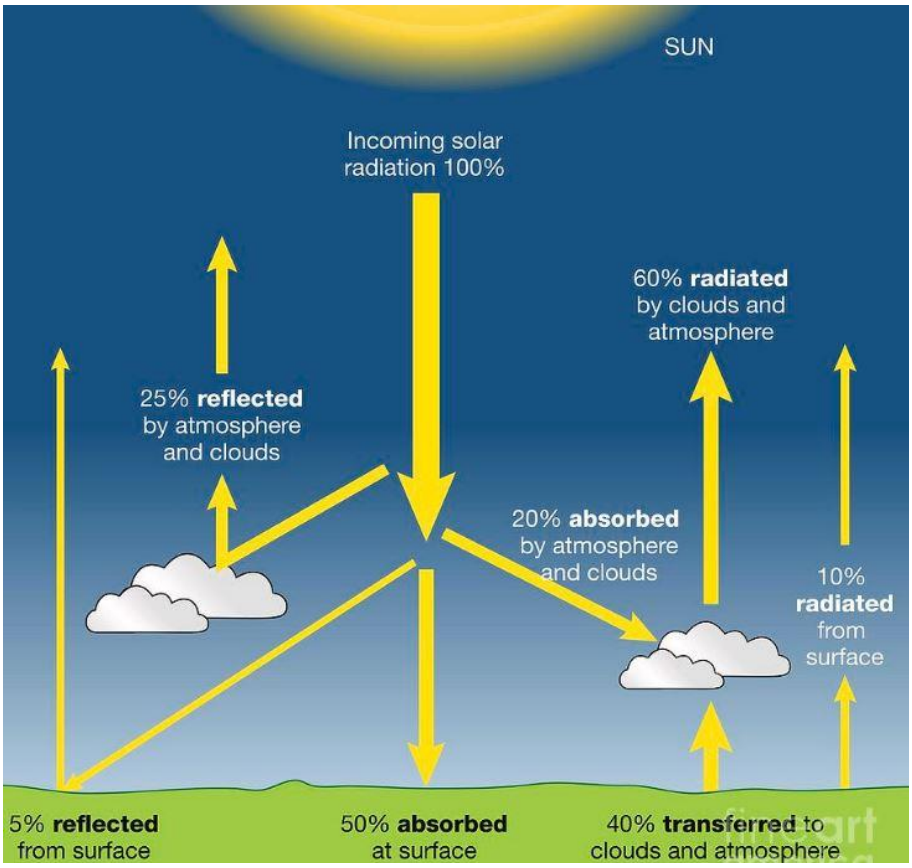
3. Solar Radiation at the Earth's Surface

Solar radiation reaching Earth is divided into:

- **Direct Radiation:** Comes straight from the Sun.
- **Diffuse Radiation:** Scattered by atmospheric particles and clouds.
- **Global Radiation:** Sum of direct and diffuse radiation.

Example:

On a clear day, **80-90%** of radiation reaches the ground as direct radiation. On a cloudy day, most of it is diffuse.



Type of Radiation	Source	Effect
Direct	Sun's rays travel without deviation	Strong shadows
Diffuse	Scattered by clouds, dust	Soft shadows
Global	Direct + Diffuse	Total received

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4. Depletion of Solar Radiation

Solar radiation is **absorbed, reflected, and scattered** by the atmosphere before reaching the surface.

Causes of Depletion:

- **Absorption by Gases:** Ozone absorbs UV radiation.
- **Scattering:** Small particles scatter shorter wavelengths (blue sky effect).
- **Reflection by Clouds:** Clouds reflect sunlight back into space.

Example:

On a foggy day, solar radiation at ground level is **significantly reduced** due to high scattering and absorption.

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5. Measurement of Solar Radiation

Solar radiation is measured using specialized instruments:

- **Pyranometer:** Measures global radiation.
- **Pyrheliometer:** Measures direct radiation.
- **Sunshine Recorder:** Records the number of sunshine hours per day.

Example:

If a pyranometer records **800 W/m²** at noon in a particular location, it indicates a strong solar radiation potential.

Instrument	Measurement	Application
Pyranometer	Global radiation	Solar energy studies
Pyrheliometer	Direct radiation	PV panel efficiency
Sunshine Recorder	Sunshine duration	Weather analysis

PYRANOMETER:

A **pyranometer** is a device used to measure **global solar radiation** (both direct and diffuse radiation) on a flat surface. It plays a crucial role in meteorology, climatology, and solar energy applications.

Principle of Pyranometer

The working principle of a pyranometer is based on the **thermopile sensor** or **photodiode sensor**, which converts solar radiation into an electrical signal.

- When sunlight falls on the **black-coated sensing element**, it absorbs solar radiation and converts it into heat.
- The generated heat is then converted into an electrical voltage, which is proportional to the intensity of solar radiation.
- The measured output voltage is used to calculate the solar irradiance in **Watts per square meter (W/m²).**

Components of a Pyranometer

A pyranometer consists of the following main components:

A. Thermopile Sensor (or Photodiode Sensor)

The core sensing element that absorbs solar radiation.

Thermopile pyranometers use a **black-coated surface** to absorb radiation, while some modern pyranometers use **photodiodes** that generate a photocurrent based on light intensity.

B. Hemispherical Glass Dome

A transparent dome that covers the sensor to **protect it from dust, wind, and rain** while allowing sunlight to pass through.

Ensures that both direct and diffuse radiation are measured.

C. Black Absorbing Surface

Coated with a highly absorbent material to capture a broad spectrum of solar radiation.

Converts the absorbed radiation into heat.

D. Thermoelectric Junctions (Thermopile Type)

A series of thermocouples arranged in a thermopile to measure temperature differences between the black surface and a reference (cold junction).

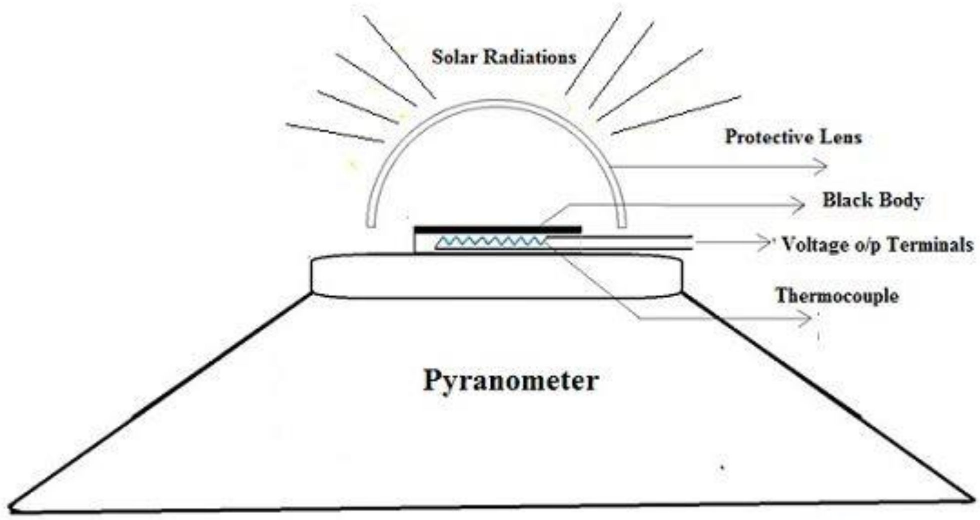
E. Signal Output System

Converts the thermopile or photodiode output into a measurable voltage signal.

The signal is sent to a **data logger** or **display unit** for analysis.

F. Leveling Device and Mounting Stand

Ensures accurate alignment of the pyranometer with the horizontal plane.



Working of a Pyranometer

Step 1: Absorption of Solar Radiation

The **black-coated sensor** absorbs the incoming global solar radiation (direct + diffuse radiation).

Step 2: Heat Generation

The absorbed radiation is converted into heat, leading to a temperature difference between the black sensor and the reference (cold) junction.

Step 3: Conversion to Electrical Signal

The **thermopile sensor** generates a voltage proportional to the temperature difference. If using a **photodiode**, it produces a photocurrent based on the light intensity.

Step 4: Signal Processing and Output

The generated electrical signal is processed, calibrated, and converted into **irradiance values (W/m²).**

Advantages of Pyranometers

✅ **Accurate Measurement**: Provides precise readings of global solar radiation.

✅ **Passive Instrument**: Does not require external power for operation (thermopile-based).

✅ **Durability**: Designed for long-term outdoor use with a protective glass dome.

✅ **Measures Both Direct and Diffuse Radiation**: Unlike pyrheliometers, which measure only direct radiation.

✅ **Can be Integrated with Data Loggers**: Useful for continuous solar monitoring.

Disadvantages of Pyranometers

❌ **Expensive**: High-quality pyranometers are costly compared to other radiation sensors.

❌ **Limited to Surface Measurements**: Cannot provide separate measurements of direct and diffuse radiation.

❌ **Requires Regular Calibration**: Sensor degradation over time affects accuracy.

❌ **Affected by Environmental Conditions**: Dirt, dust, or snow on the glass dome can reduce measurement accuracy.

Applications of Pyranometers

A. Solar Energy and Photovoltaics

- Used to measure **solar irradiance** for designing and evaluating **solar power plants**.
- Helps optimize the performance of **solar panels** and **concentrated solar power (CSP) systems**.

B. Meteorology and Climatology

- Essential for weather stations to monitor **solar radiation trends**.
- Helps in **climate change studies** by tracking long-term variations in solar radiation.

C. Agriculture and Greenhouse Monitoring

- Used in **precision farming** to determine optimal sunlight exposure for crops.
- Helps regulate light exposure in **greenhouses** for improved plant growth.

D. Building Energy Efficiency

- Used to measure **solar heat gain** in buildings for energy efficiency studies.
- Helps in designing passive solar buildings and **energy-efficient HVAC systems**.

E. Research and Environmental Studies

- Used in **atmospheric research** to study solar radiation effects on weather patterns.
- Helps in **renewable energy feasibility studies**.

A **pyranometer** is a vital instrument for measuring solar radiation, widely used in solar energy, meteorology, and environmental research. Despite some limitations like cost and maintenance needs, its **high accuracy** and **versatility** make it an essential tool for optimizing solar applications and understanding climate patterns.

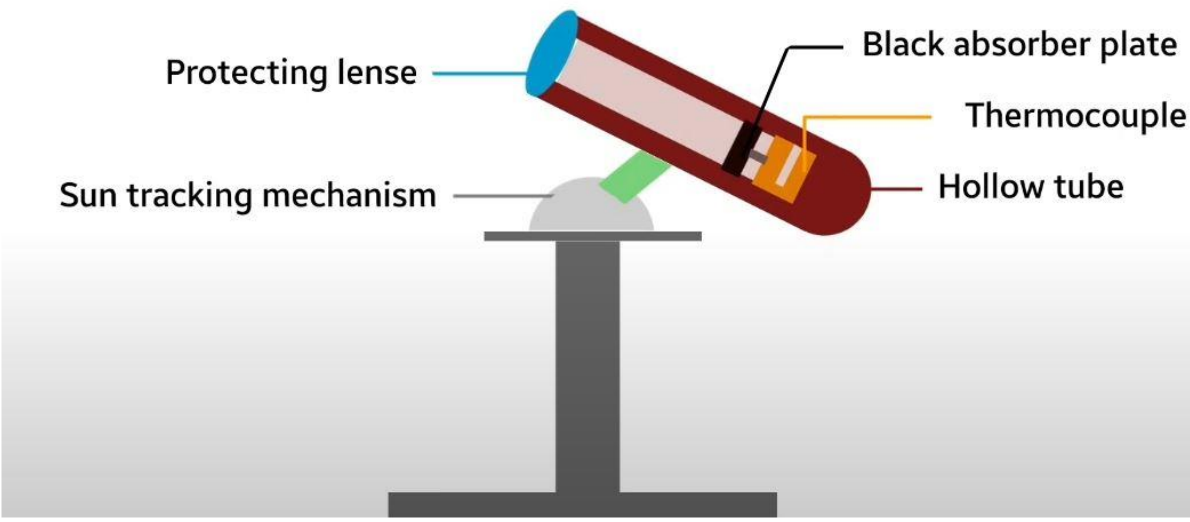
PYRHELIOMETER:

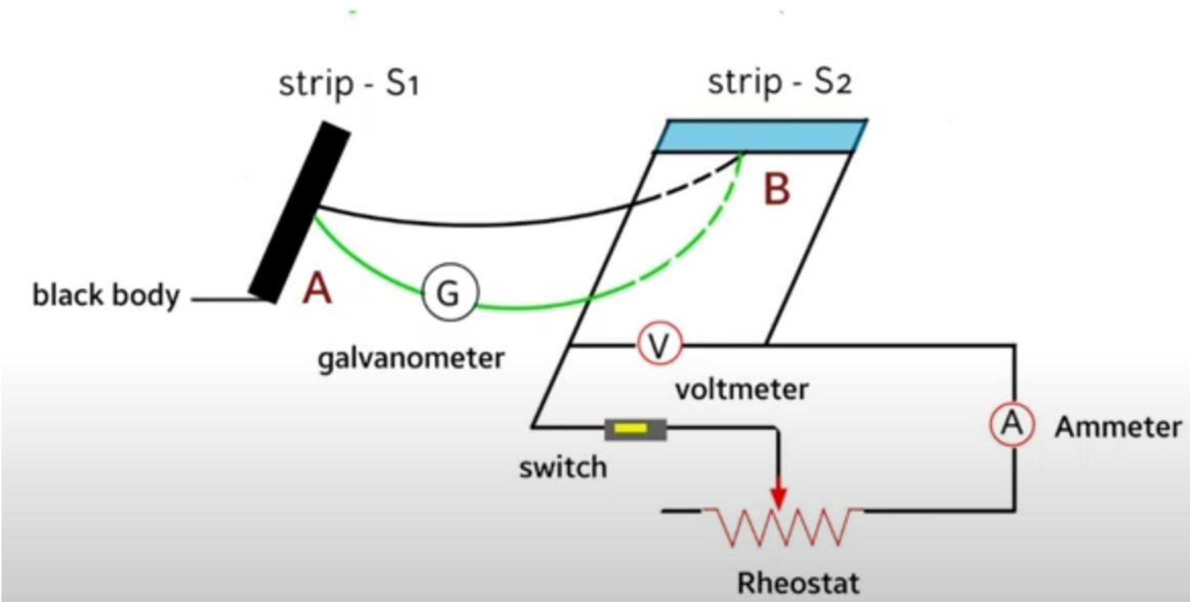
A **pyrheliometer** is an instrument used to measure **direct normal irradiance (DNI)** from the sun. Unlike a **pyranometer**, which measures global solar radiation, a pyrheliometer specifically measures the direct component of solar radiation, excluding diffuse radiation. It is widely used in solar energy research, weather monitoring, and photovoltaic (PV) system assessments.

Principle of Pyrheliometer

A pyrheliometer operates on the principle of **thermoelectric conversion**. It measures the direct solar radiation that falls perpendicular to its aperture using a **thermopile sensor** or **photodiode sensor**.

- The sunlight enters the instrument through a **collimating tube**, ensuring only direct radiation is measured.
- The absorbed radiation is converted into **heat**, creating a temperature difference between the **black-coated absorbing surface** and the surrounding environment.
- This temperature difference is converted into an **electrical voltage signal**, which is proportional to the intensity of direct solar radiation.
- The output is recorded in **Watts per square meter (W/m^2).**





Components of a Pyrheliometer

A typical pyrheliometer consists of the following key components:

A. Collimating Tube

A long, narrow tube that allows only the **direct** component of solar radiation to reach the sensor.

It blocks scattered or diffuse radiation from the sky.

B. Thermopile or Photodiode Sensor

A **thermopile sensor** consists of multiple thermocouples that generate a voltage proportional to the temperature difference caused by absorbed solar radiation.

Some modern pyrheliometers use **silicon photodiodes** for faster response time.

C. Black-Coated Absorber

A **highly absorptive surface** that captures solar radiation efficiently and minimizes reflection losses.

Converts solar radiation into heat.

D. Protective Quartz Window or Glass Cover

Allows sunlight to enter while preventing contamination by dust, dirt, and moisture.

Protects the sensitive sensor components.

E. Temperature Compensation System

Ensures accurate readings by adjusting for ambient temperature variations.

F. Signal Output System

Converts the electrical signal into a **readable voltage output**, which is later translated into **irradiance values (W/m^2).**

G. Sun-Tracking Mount

Since a pyrheliometer measures direct solar radiation, it is mounted on a **solar tracker** to follow the sun's movement across the sky for continuous measurements.

Working of a Pyrheliometer

Step 1: Sunlight Entry Through Collimating Tube

The instrument is aligned with the sun, and direct sunlight enters through the **collimating tube**, ensuring only direct normal irradiance (DNI) is measured.

Step 2: Absorption and Heat Generation

The sunlight falls on the **black-coated absorbing surface**, which absorbs radiation and converts it into heat.

Step 3: Temperature Difference Measurement

The thermopile sensor detects the **temperature difference** between the black absorbing surface and a reference (cold) junction.

Step 4: Electrical Signal Generation

The thermopile generates a small **voltage signal** proportional to the absorbed heat.

If using a **photodiode sensor**, it generates a photocurrent based on light intensity.

Step 5: Data Processing and Output

The voltage output is calibrated and converted into **irradiance values (W/m^2)** using a **data logger or computer interface.**

Advantages of Pyrheliometers

✅ **Highly Accurate Measurement of Direct Solar Radiation**

Provides precise **direct normal irradiance (DNI)** values, essential for solar energy applications.

✅ **Used for High-Temperature Solar Energy Applications**

Crucial for **concentrated solar power (CSP)** plants that rely on direct sunlight.

✅ **Resistant to Diffuse Light Interference**

The **collimating tube** blocks scattered or diffuse radiation, ensuring accurate measurements.

✅ **Can be Integrated with Automated Solar Trackers**

Continuous tracking of the sun improves data accuracy.

Disadvantages of Pyrheliometers

❌ **Requires Sun-Tracking Mechanism**

Since it measures only direct radiation, it must be aligned with the sun continuously, increasing complexity.

❌ **Expensive Compared to Pyranometers**

High-precision instruments with tracking mounts are costly.

❌ **Not Useful in Cloudy or Diffuse Conditions**

It cannot measure total solar radiation, making it unsuitable for overcast conditions.

❌ **Requires Regular Calibration**

Accuracy can drift over time, requiring periodic recalibration.

Applications of Pyrheliometers

A. Solar Energy and Photovoltaic Systems

- Used to measure **direct normal irradiance (DNI)** for solar power plant design and performance evaluation.
- Essential for assessing the feasibility of **concentrated solar power (CSP)** plants.

B. Meteorology and Climate Studies

- Helps in **weather forecasting** and **climate research** by monitoring solar radiation levels.
- Used in long-term solar radiation trend analysis.

C. Aerospace and Satellite Applications

- Used to measure solar radiation for satellite and space mission planning.
- Helps in determining the impact of solar radiation on spacecraft.

D. Agriculture and Environmental Research

- Assists in understanding **photosynthesis rates** and **crop growth patterns** based on solar radiation levels.
- Helps in **evapotranspiration studies** for water resource management.

E. Renewable Energy Research

- Used in **solar energy potential assessment** for various geographical locations.
- Helps in designing **solar thermal collectors** for industrial heating applications.

A **pyrheliometer** is an essential tool for measuring **direct normal irradiance (DNI)**, widely used in solar energy, meteorology, and climate research. While it offers **high accuracy** and is **crucial for CSP applications**, its dependence on sun-tracking systems and high cost can be limitations. Nevertheless, it remains an indispensable instrument for assessing solar potential and optimizing renewable energy projects.

DIFFERENCE BETWEEN PYRHELIOMETER AND PYRANOMETER

Feature	Pyranometer	Pyrheliometer
Measured Radiation	Global Solar Radiation (Direct + Diffuse)	Direct Normal Irradiance (DNI)
Collimating Tube	No	Yes (to block diffuse radiation)
Mounting	Fixed, placed horizontally	Requires solar tracker
Application	PV system analysis, meteorology	Concentrated Solar Power (CSP), DNI studies
Sun-Tracking	Not required	Required
Usage in Cloudy Weather	Useful	Not useful
Cost	Lower	Higher

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6. Solar Radiation Data

Solar radiation varies based on **latitude, altitude, and time of year.**

- Data is collected using satellite measurements and ground stations.
- **Solar maps** help identify high-potential locations for solar power.

Example:

India's Thar Desert receives **2000 kWh/m²/year**, making it ideal for solar farms.

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7. Solar Time

Solar time is based on the position of the Sun, different from local clock time.

- **Equation of Time (EOT):** Adjusts for variations due to Earth's orbit.
- **Solar Noon:** When the Sun is at its highest point in the sky.

Example:

If local noon is 12:15 PM but the Sun is at its highest at 12:05 PM, the solar time is 12:05 PM.

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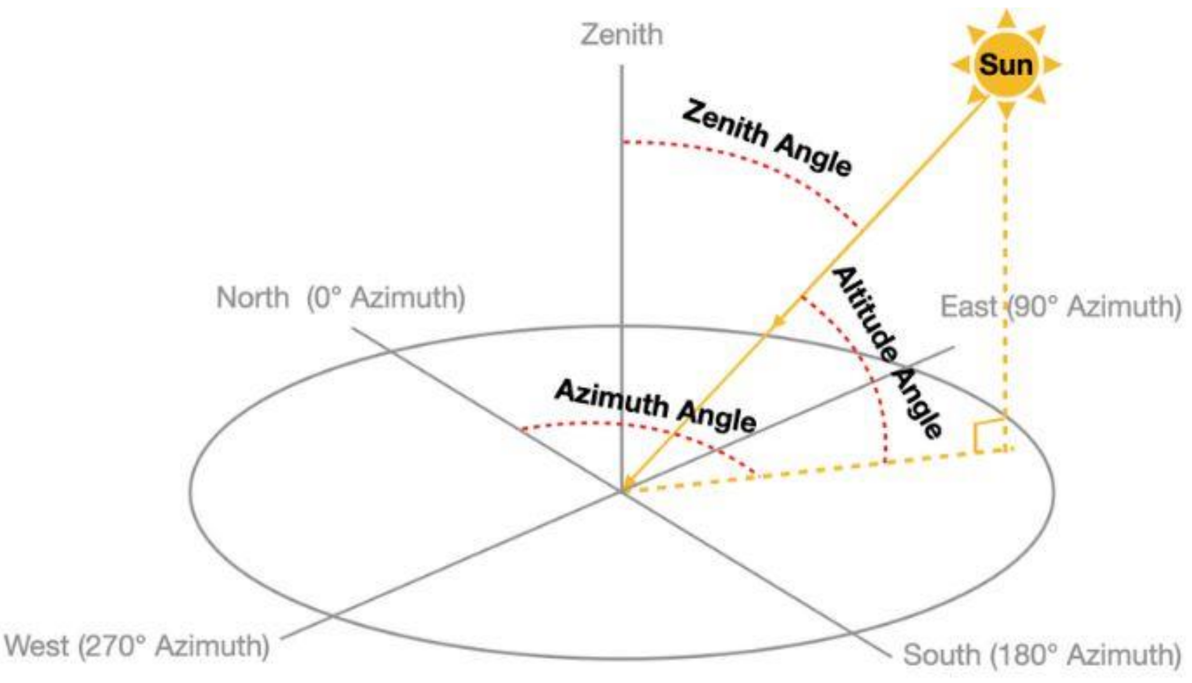
8. Solar Radiation Geometry



Determines how sunlight strikes a surface, affecting solar panel efficiency.

- **Zenith Angle:** Angle between Sun and vertical direction.
- **Altitude Angle:** Sun's height above the horizon.
- **Azimuth Angle:** Sun's direction from the north.

Example:

Solar panels in India are tilted at **25-30°** to maximize energy absorption.

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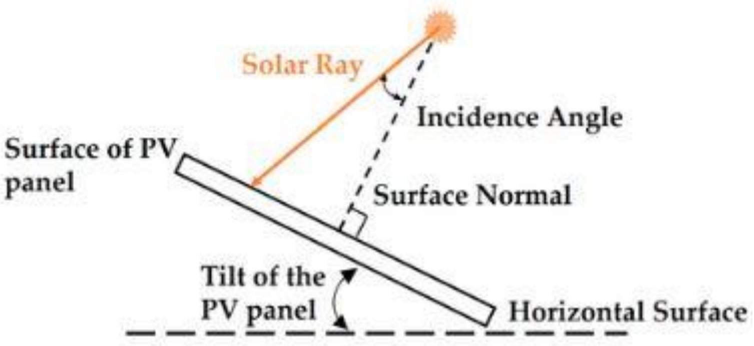
9. Solar Radiation on Tilted Surfaces

Solar panels work best when **tilted** towards the Sun's rays.



- **Optimum Tilt Angle:** Equal to the **latitude** of the location.
- **Seasonal Adjustments:**
  - **Winter:** Tilt is increased.
  - **Summer:** Tilt is reduced.

Example:

For a location at **30° latitude**, the ideal panel tilt is **30°**.

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10. Sun as the Source of Energy

- The Sun generates energy through **nuclear fusion**.
- Every second, it converts **600 million tons of hydrogen into helium**.
- It will continue to shine for **another 5 billion years**.

Example:

The energy received from the Sun in **one hour** is enough to power the Earth for **a year**.

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11. Sun Angles

- **Solar Declination Angle:** Varies from -23.5° to +23.5° throughout the year.
- **Hour Angle:** Indicates the Sun's movement across the sky.
- **Incident Angle:** Affects how much sunlight reaches a surface.

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12. Overview of Applications

Solar energy is used in various applications, including:

Application	Example
Solar PV Systems	Rooftop panels, solar farms
Solar Heating	Water heaters, space heating
Solar Cooking	Solar cookers, food dehydration
Solar Power Plants	CSP plants, solar towers
Solar Vehicles	Solar-powered cars, boats

Overview:

Unit 1 covered the fundamentals of solar energy, including how it reaches Earth, how it is measured, and its applications. This knowledge is crucial for designing and optimizing solar energy systems.

End Semester Questions

PART A (2 Marks Questions)

1. Outline the sun-earth relationship along with its dimensions. **(April / May 2022)**
2. Recall the terms hour angle and azimuth angle. **(April / May 2022)**
3. Why is it necessary to develop non-conventional methods of generating electrical energy? **(April / May 2023)**
4. Infer a note on total solar energy received in India. **(April / May 2023)**
5. Infer the difference between renewable and non-renewable sources of energy. **(April / May 2024)**
6. How is the energy being continuously produced in the sun? **(April / May 2024)**

PART B

1. Contrast the measurement of the beam radiation with a suitable device and its advantages over other devices. **(April / May 2022)**
2. Examine the various types of solar radiation and the benefits of solar radiation on tilted surfaces. **(April / May 2022)**
3. Conclude the importance and need for solar energy depletion on the earth's surface with various types of solar energy depletion. **(April / May 2022)**

4. (i) What is solar power? Discuss the environmental impact of solar power. (8 Marks)
   (ii) Converse the instruments for measuring solar radiation. (8 Marks) **(April / May 2023)**
5. (i) What is solar constant? Explain its calculation. (8 Marks)
   (ii) List the applications of solar energy. (8 Marks) **(April / May 2023)**
6. (i) Discuss the sun-earth relationship with different aspects. (8 Marks)
   (ii) State and explain the depletion of solar radiation. (8 Marks) **(April / May 2024)**
7. Explain the various techniques to measure various components of solar radiation. **(April / May 2024)**