RENEWABLE ENERGY POWER PLANTS: MODULE 1

Chapter 1: INTRODUCTION

- The word 'energy' itself is derived from the Greek word 'en-ergon', which means 'in-work' or 'work content'. The work output depends on the energy input. Energy can be defined as the ability to do work.
- Energy is the most basic infra-structure input required for economic growth & development of a country. Thus, with an increase in the living standard of human beings, the energy consumption also accelerated.
- Energy consumption of a nation broadly divided into following sectors
  - Domestic sector
  - Transportation sector
  - Agriculture sector
  - Industry sector
- A systemic study of various forms of energy & energy transformations is called energy science. While fossil fuels will be the main fuel for thermal power, there is a fear that they will get exhausted eventually in the next century. Therefore other systems based on non- conventional & renewable sources are being tried by many countries. These are solar, wind, sea, geothermal & bio-mass.
- Energy crisis is mainly due to two reasons
  - Population of the world has increased rapidly
  - Standard of living of human being has increased

Energy Sources: Classification

Energy can be classified into several types based on the following criteria:

- Primary and Secondary energy
- Primary energy sources are those that are either found or stored in nature.
- Primary energy sources are costly converted in industrial utilities into secondary energy sources.

Commercial and Non-commercial energy

Electricity, lignite, coal, oil, natural gas etc. (Commercial)

Firewood, cattle dung , agricultural wastes etc. (Non-commercial)

Renewable and Non-Renewable energy

Renewable energy

- Solar, Wind, Hydro, Biomass, Thermal Wave, Ocean Tidal energy

Non-Renewable energy

- Fossil fuels (Coal, Oil, Natural gas), Nuclear, oil shales and tar sands

Conventional and Non-conventional energy

Conventional Energy Sources:

- Fossil Fuels: Coal, oil, natural gas.
- Nuclear Energy: Uses uranium or thorium.

Non-Conventional Energy Sources:

- Renewable Energy: Solar, wind, hydro, biomass, geothermal.
- Emerging Technologies: Hydrogen fuel cells, tidal energy.

Based on Traditional use

- Conventional energy sources – Traditionally used
  Eg: Fossil fuels, Nuclear and Hydro resources
- Non conventional energy sources – Reused in nature
  Eg: Solar, wind, biomass

Based on Long term availability

- Non renewable resources – Finite an donot get replenished
  Eg: Fossil fuels, Nuclear and Hydro resources
- Renewable resources –Renewed by nature again and again
  Eg: Solar, wind, biomass

Based on commercial application

- Commercial energy resource– secondary usable energy depends on countries economy Ex: Electricity, petrol, diesel, gas
- Non-commercial energy resource - Energy derived from nature
  Ex: wood, Animal dung cake, crop residue etc.

Based on origin

Fossil fuel energy, Nuclear energy, Hydro energy, Solar energy, Wind energy, Tidal energy, Biomass energy. Geothermal energy, Ocean thermal energy, Ocean wave energy

Primary energy sources

1. Coal: Coal is the most common source of energy. World switched over from coal to oil as a major source of energy, Modern steam boilers burn coal as a primary fuel. Coal burnt to produce CO_2 and CO. Commissioning of 500 MW thermal power station plant at Korba, Bilaspur district, MP
NTPC - expanded from 500 MW to 2100 MW

2. Oil: Almost 40% of energy needs of the world are fed by oil. Refining of crude oil produce usable fuel oils. The potential oil bearing areas in India are Assam, Tripura, Manipur, West bengal, Ganga valley, Punjab

3. Gas: Gaseous fuels are Acetylene, ethylene, methane etc. Industrial gases like CO (Producer gas). The main drawback of these fuels are transportation cost is high compared to oil.

4. Agricultural and organic wastes: These include Garbage, cow dung, saw dust, bagasse

- Waste can be utilized near source and reduce transportation cost.
- Appropriate equipment's for burning or extracting energy from material to suite local conditions and meet the requirements

5. Water power: 20th century there is beginning of large scale power production. It started with <100KW plants. Large potential energy is converted to mechanical energy from prime movers of Hydraulic turbines
Dehar power house – Sutlej river – 6 units of 165MW
Rate of hydro power is low. Micro hydroelectric projects are developed based on availability of river flow.

6. Nuclear power:
Modern theory of atomic structure, Matter consists of minute particles known as atoms. These consist of enormous binding energy. The heavier fission of U235, Th232, and Pu 239 liberate large amount of energy.
a. Nuclear power plant – 400 MW- Tarapura-Maharastra
b. Nuclear power plant – 440 MW- Kalpakkam-TN- (1969)
c. Nuclear power plant – 940 MW- Kakrapar-GJ

India's Production and Reserves of Commercial Energy Sources

Coal: Major source of energy, with significant reserves in Jharkhand, Odisha, Chhattisgarh, West Bengal, and Madhya Pradesh. Coal India Limited (CIL) is the largest producer.

Oil and Natural Gas: Reserves in Assam, Gujarat, Mumbai High, Rajasthan, and the Krishna-Godavari Basin. Major producers include ONGC, Reliance Industries, and Cairn India.

Nuclear Energy: Limited but strategic reserves of uranium in Jharkhand and Andhra Pradesh. Heavy reliance on imports for uranium, with plans to utilize thorium reserves in future.

Hydropower: Significant potential in the Himalayan region and North-Eastern states. Major projects include Bhakra Nangal, Tehri, and Sardar Sarovar dams.

Need for Non-Conventional Energy Sources

Environmental Concerns: Reducing carbon emissions and mitigating climate change. Minimizing air and water pollution associated with fossil fuels.
Energy Security: Diversifying energy sources to reduce dependence on imports. Ensuring long-term sustainability of energy supply.
Economic Benefits: Creating jobs in the renewable energy sector. Reducing health costs associated with pollution.
Rural Electrification: Providing decentralized energy solutions for remote and rural areas. Enhancing energy access and improving quality of life.

Energy Alternatives

Solar Energy: Abundant and widely available, with decreasing costs of photovoltaic technology. Potential for rooftop installations and large solar farms.

Wind Energy: High potential in coastal regions and certain inland areas. Development of onshore and offshore wind farms.

Hydropower: Sustainable if managed well, with potential for small-scale projects in addition to large dams. Environmental and social concerns related to large dam projects.

Biomass Energy: Utilization of agricultural waste, animal dung, and municipal solid waste. Provides energy while managing waste and reducing landfill use.

Geothermal Energy: Limited potential in India, but promising in certain areas like the Himalayas. Stable and reliable energy source with minimal environmental impact.

Tidal and Wave Energy: Emerging technology with potential along India's extensive coastline. High initial costs but offers a predictable energy source.

Indian and Global Energy Scenario

India's Energy Scenario:

- Rapidly increasing energy demand due to economic growth and urbanization.
- Government initiatives like the National Solar Mission and Ujjwala Scheme to boost renewable energy and access to clean cooking fuels.
- Challenges include energy poverty, infrastructure deficits, and balancing development with environmental sustainability.

Global Energy Scenario:

- Shift towards renewable energy driven by climate policies and technological advancements.
- Major players like China, the USA, and the EU investing heavily in renewable energy.
- Global agreements like the Paris Agreement influencing national energy policies.

Trends and Challenges:

- Declining costs of renewable energy technologies making them more competitive.
- Integration of renewable energy into existing grids and the need for energy storage solutions.
- Geopolitical factors influencing global energy markets, especially oil and gas.
- Increasing role of digital technologies and smart grids in energy management.

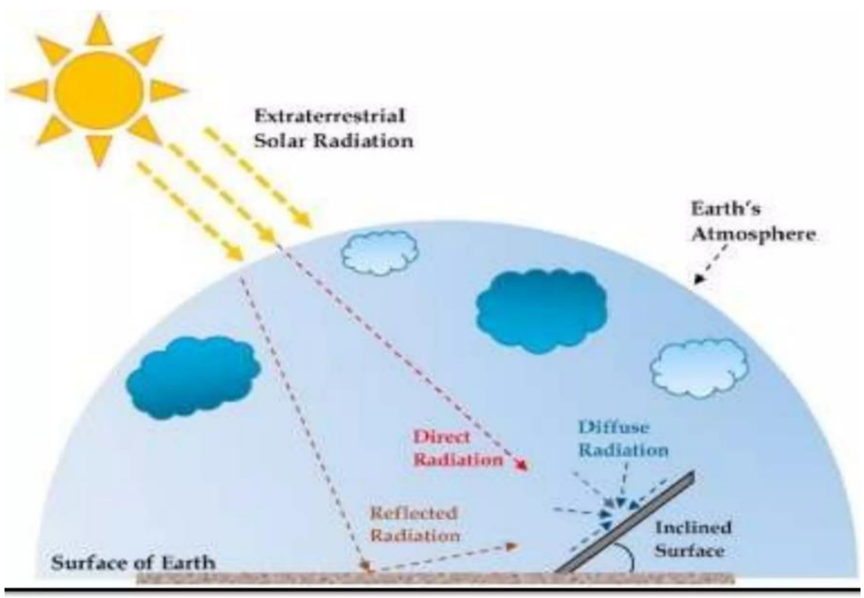
Solar Radiation

- Intensity of solar radiation incident on a surface is important in the design of solar collectors, photovoltaic cells, solar heating and cooling systems, and thermal management of building.
- This effect depends on both the location of the sun in the sky and ***the clearness of the atmosphere*** as well as on the **nature and orientation of the building.**
- We need to know

  - *Characteristics of sun's energy* outside the earth's atmosphere, its intensity and its spectral distribution

  - *Variation with sun's location in the sky* during the day and with seasons for various locations on the earth's surface.

Extra-Terrestrial Radiation



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Definition: Extra-terrestrial radiation refers to solar radiation received outside the Earth's atmosphere. It is the energy from the sun before it is filtered by the atmosphere.

Importance: It serves as the baseline for understanding the solar energy potential and the effects of atmospheric attenuation on solar radiation reaching the Earth's surface.

Characteristics: Consists primarily of visible light, ultraviolet (UV), and infrared (IR) radiation. The intensity of extra-terrestrial radiation varies slightly due to the elliptical orbit of the Earth.

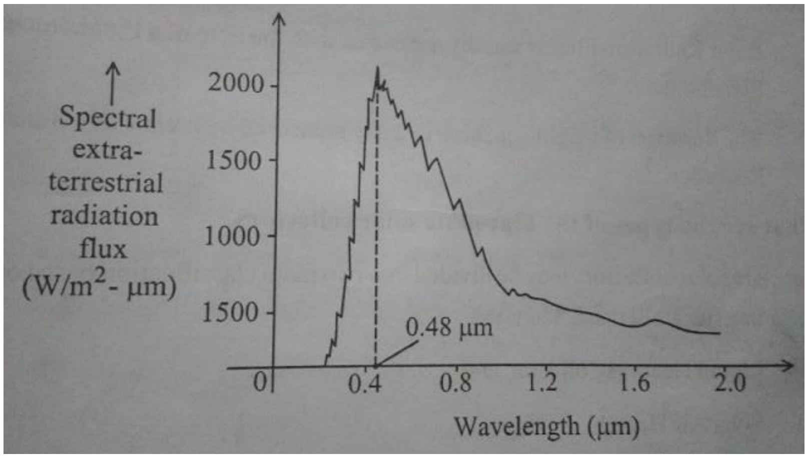
Spectral Distribution of Extra-Terrestrial Radiation

Solar Spectrum: The solar spectrum includes all wavelengths of electromagnetic radiation emitted by the sun. It ranges from gamma rays to radio waves, with the majority of energy in the visible, UV, and IR regions.

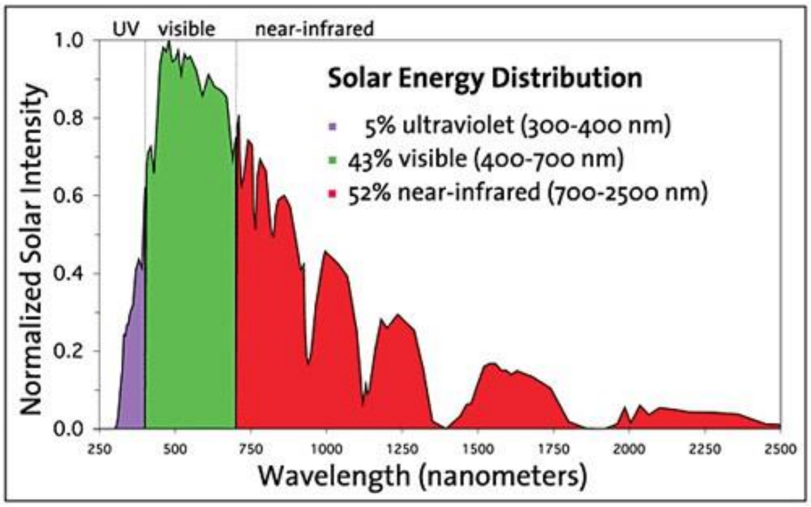
Wavelength Distribution:

- Ultraviolet (UV): 0.1 to 0.4 micrometers (μm).
- Visible Light: 0.4 to 0.7 μm (accounts for about 43% of the total energy).
- Infrared (IR): 0.7 to 3 μm.

Planck's Law: Describes the spectral density of radiation emitted by a black body in thermal equilibrium, which approximates the sun's radiation spectrum.



Spectral distribution of extra-terrestrial radiation



Solar Radiation Spectrum

Solar Constant

Definition: The solar constant is the average amount of solar radiation received per unit area at the top of the Earth's atmosphere, on a plane perpendicular to the rays, at a mean Earth-Sun distance.

Value: Approximately 1361 watts per square meter (W/m²).

Significance: It is a crucial parameter for climate studies and solar energy applications.

Variability: The solar constant can vary slightly due to solar activity and changes in the Earth-Sun distance.

Variation of Extraterrestrial Radiation

Solar radiation varies with the day of the year as the sun-earth distance varies. An empirical fit of the measured radiation data is given by

$$I_{ext} = I_{sc}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right]$$

where, I_{ext} = Extraterrestrial radiation (W/m^2)

I_{sc} = Solar constant

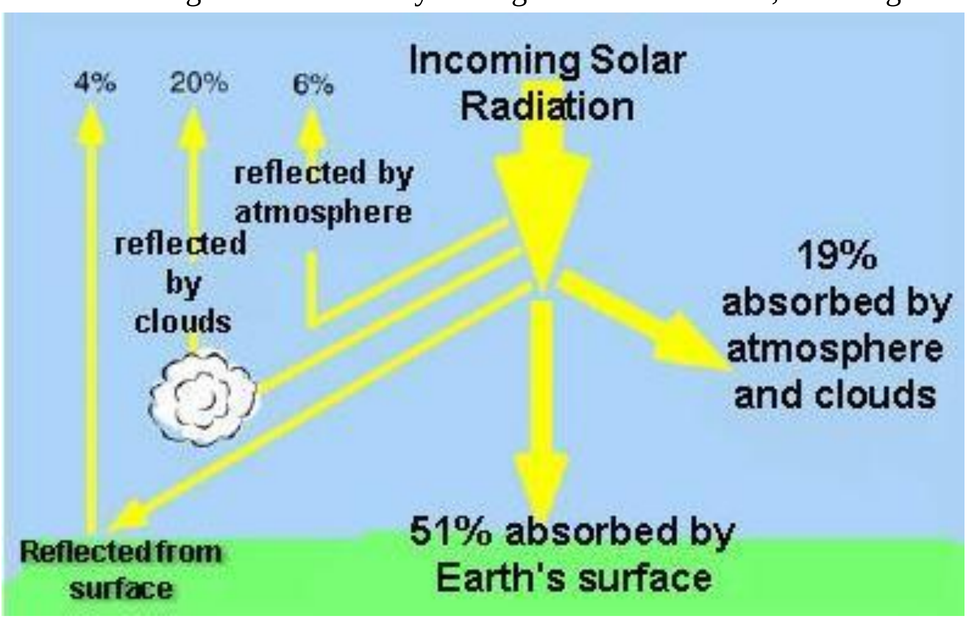
n = days of the year

Since cosine function varies from +1 to -1, the extra-terrestrial radiation flux varies by 3.3%.

Solar Radiation at the Earth's Surface

Factors Influencing Radiation:

- Atmospheric Composition: Gases, dust, and pollutants absorb and scatter sunlight.
- Cloud Cover: Clouds reflect and absorb solar radiation.
- Latitude: Solar radiation is more intense near the equator and diminishes towards the poles.
- Time of Year: The angle of the sun's rays changes with the seasons, affecting intensity.



Solar radiation at the earth's surface

Types of Solar Radiation:

Direct (Beam) Radiation: Solar radiation received directly from the sun without scattering.

Diffuse Radiation: Scattered sunlight reaching the ground from all parts of the sky.

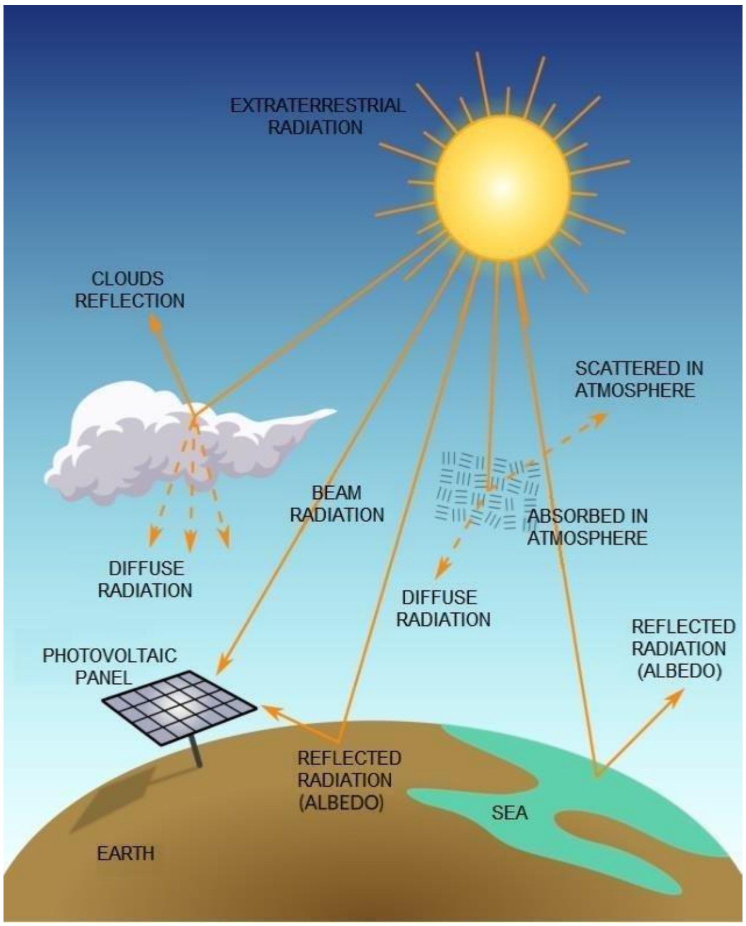
Global Radiation: The sum of direct and diffuse radiation on a horizontal surface.

Beam, Diffuse, and Global Radiation

Beam (Direct) Radiation:
- Measured on a surface perpendicular to the sun's rays.
- Intensity is highest on clear, sunny days.

Diffuse Radiation:
- Results from scattering by molecules, aerosols, and clouds.
- Present even on overcast days and in shaded areas.

Global Radiation:
- Total solar radiation received by a horizontal surface.
- Combination of both direct and diffuse radiation.



Types of Solar Radiation

Solar Radiation Data

Measurement:
- Pyranometer: Measures global solar radiation.
- Pyrheliometer: Measures direct beam solar radiation.
- Diffuse Radiometer: Measures diffuse sky radiation.

Data Collection:
- Meteorological Stations: Collect solar radiation data over time.

- Satellites: Provide comprehensive data on a global scale.

Applications:

- Solar Energy Systems: Designing and optimizing solar panels and solar power plants.
- Climate Studies: Understanding the Earth's energy balance and climate dynamics.
- Agriculture: Planning crop cycles based on sunlight availability.

Data Sources:

- National Renewable Energy Laboratory (NREL): Provides solar radiation data and resources.
- Solar and Meteorological Surface Observation Network (SAMSON): Offers extensive solar radiation and weather data.
- NASA: Satellite-based solar radiation data and tools.

Pyranometer

A pyranometer is an instrument used to measure solar irradiance on a planar surface, typically expressed in watts per square meter (W/m^2). It measures both direct and diffuse solar radiation from the entire hemisphere above the instrument.

Components of a Pyranometer

Thermopile Sensor:

- The core component that converts thermal energy into electrical energy.
- Consists of a series of thermocouples connected in series or parallel.

Glass Dome:

- Protects the sensor from environmental elements (rain, dust, etc.).
- Allows the transmission of solar radiation while minimizing spectral changes.

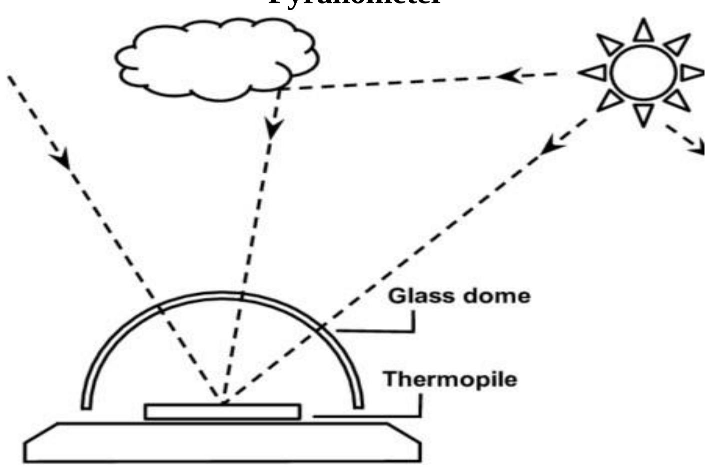
Black Coating:

- Applied to the surface of the thermopile to absorb solar radiation efficiently.
- Ensures that the absorbed radiation is converted to heat.

Housing: Provides structural support and houses electronic components for signal processing and data transmission.

Desiccant: Prevents moisture accumulation inside the pyranometer, which can affect accuracy.

Pyranometer



Working Principle

Absorption of Solar Radiation: Solar radiation passes through the glass dome and strikes the black-coated surface of the thermopile. The black coating absorbs the radiation, converting it into heat.

Generation of Temperature Gradient: The absorbed radiation heats up the junctions of the thermopile. This creates a temperature difference between the hot junctions (exposed to radiation) and the cold junctions (shielded).

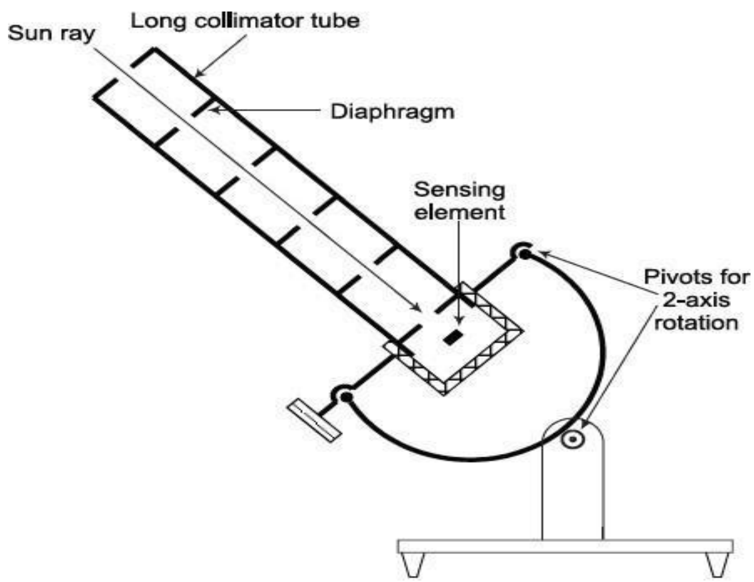
Thermoelectric Effect: The temperature gradient across the thermopile generates a voltage due to the Seebeck effect. The voltage is proportional to the amount of solar radiation absorbed.

Signal Processing: The generated voltage is low and needs amplification. Electronic circuits within the pyranometer amplify and convert the voltage into a readable signal, typically in W/m².

Calibration: Pyranometers are calibrated against a standard reference to ensure accurate readings. Calibration factors are applied to the measured voltage to convert it into the correct irradiance value.

Shading ring Pyrheliometer

A pyrheliometer is an instrument designed to measure direct beam solar irradiance. It is used to quantify the amount of solar energy received per unit area at a surface perpendicular to the sun's rays, typically expressed in watts per square meter (W/m²).



Pyrheliometer

Components of a Pyrheliometer

Collimating Tube: A long, narrow tube that ensures only direct sunlight enters the instrument. Minimizes the influence of diffuse solar radiation.

Entrance Aperture: Located at the end of the collimating tube, it defines the solid angle of acceptance. Ensures a precise measurement area.

Shutter Mechanism: Can open and close to control the exposure of the sensor to sunlight. Helps in taking zero measurements for calibration purposes.

Thermopile Sensor: Converts the absorbed solar radiation into an electrical signal. Typically consists of multiple thermocouples connected in series or parallel.

Protective Housing: Encloses and protects the sensitive components from environmental damage.

Sun Tracking System: Ensures the pyrheliometer continuously points directly at the sun. Uses a motorized mount or manual adjustment to follow the sun's path.

Working Principle

Direct Solar Radiation Collection: The pyrheliometer is aligned so that the collimating tube is pointed directly at the sun. Only the direct beam radiation passes through the entrance aperture, while diffuse and reflected radiation are blocked by the tube.

Absorption and Heating: Solar radiation entering the collimating tube strikes the thermopile sensor. The sensor is coated with a black material that efficiently absorbs solar radiation, converting it into heat.

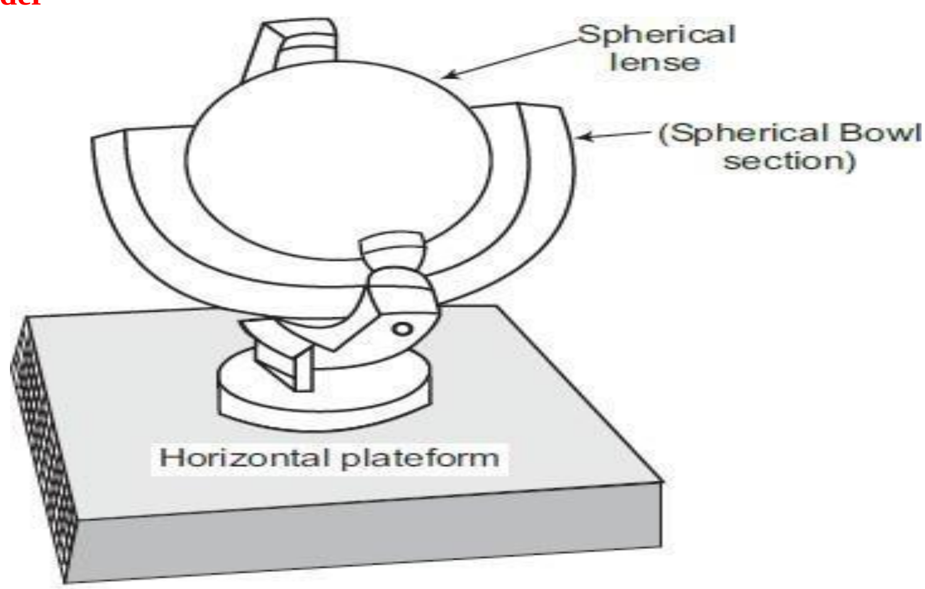
Temperature Difference Creation: The absorbed solar energy heats the thermopile junctions that are exposed to the sunlight. This creates a temperature gradient between the hot (exposed) and cold (unexposed) junctions.

Thermoelectric Effect: Due to the Seebeck effect, the temperature difference across the thermopile generates a voltage. The magnitude of this voltage is proportional to the intensity of the direct solar radiation.

Signal Processing: The generated voltage is typically low and needs to be amplified. Electronic circuits within the pyrheliometer amplify the signal and convert it into a measurable output, often in W/m².

Calibration: Pyrheliometers are calibrated against standard reference instruments to ensure accurate measurements. Calibration factors are used to convert the measured voltage into the correct irradiance value.

Sunshine recorder



Sunshine recorder

A sunshine recorder is an instrument used to measure the duration of sunshine at a particular location. The most commonly used type is the Campbell-Stokes sunshine recorder, which records the amount of direct sunlight by burning a trace on a specially designed card.

Components of a Sunshine Recorder

Spherical Glass Lens: A solid glass sphere that acts as a lens to focus sunlight onto a specific point.

Metal Frame: Holds the glass sphere in place and provides stability.

Recording Card Holder: A curved metal or plastic support that holds the recording card in the correct position. The holder is usually adjustable to account for different seasons.

Recording Cards: Specially designed cards placed in the card holder to record the sunshine duration. The cards are usually marked with hourly lines to indicate the time of day.

Base and Mounting: A sturdy base to mount the instrument, often equipped with a leveling mechanism. The mount allows the recorder to be oriented correctly according to geographical location and the Earth's tilt.

Working Principle

Sunlight Focusing: The spherical glass lens focuses direct sunlight onto a single point. As the sun moves across the sky, the focused point of light moves along the recording card.

Recording Sunshine Duration: When the sun is shining, the concentrated light from the glass sphere heats a small spot on the recording card. This heat causes a burn trace to form on the card. The length and continuity of the burn trace correspond to the duration and intensity of sunshine.

Seasonal Adjustment: The recording card holder is adjusted according to the season to ensure accurate measurements. Different cards are used for different times of the year (summer, winter, and equinox) to accommodate the changing path of the sun.

Daily Operation: Each day, a new recording card is placed in the holder before sunrise. At the end of the day, the card is removed, and the burn trace is measured to determine the total hours of sunshine.

Actinometer

An actinometer is a device used to measure the intensity of solar radiation. It is often used in meteorology and climatology to study the amount of sunlight reaching the Earth's surface. There are several types of actinometers, including:

Chemical Actinometers: These use a chemical reaction that occurs at a known rate under sunlight to measure the intensity of radiation. The amount of chemical change can be measured to determine the radiation intensity.

Physical Actinometers: These might use a photoelectric cell to convert light into an electrical current, which can then be measured.

Bolometer

A bolometer is a device for measuring the power of incident electromagnetic radiation via the heating of a material with a temperature-dependent electrical resistance. It is highly sensitive and can be used to measure very low levels of radiation. Bolometers are used in various fields, including:

Astronomy: To measure the radiation from stars and other celestial objects.

Thermal imaging: To detect infrared radiation and convert it into an image.

Scientific Research: In laboratories to measure radiation in experiments.

Key Differences

	Actinometer	**Bolometer**
Purpose	Measures the intensity of solar radiation, primarily in the ultraviolet and visible spectra.	Measures the power of incident electromagnetic radiation over a wide range of wavelengths, including infrared.
Principle	Can use chemical or physical processes to measure radiation.	Measures the heating effect of radiation on a material with a temperature-dependent resistance.
Sensitivity	Generally used for higher levels of solar radiation.	Can detect very low levels of radiation and is used for precise measurements.