

## **MODULE-1**

### **INTRODUCTION**

#### **Energy Sources (including Fossil Fuels and Nuclear Energy)**

##### **What Is Energy?**

The classical description of energy is the ability of a system to perform work. Energy exists in many forms, making it challenging to define comprehensively. It is a property of an object that can be transferred from one object to another or converted into different forms but cannot be created or destroyed. Numerous sources of energy are available, and in the following sections, we will discuss these sources in detail.

##### **Sources of Energy**

Energy sources can be classified into:

- **Renewable Sources**
- **Non-renewable Sources**

##### **Renewable Sources of Energy**

Renewable sources of energy are abundantly available in nature and are sustainable. These energy resources can be naturally replenished and are environmentally friendly. Examples of renewable energy sources include:

- **Solar energy**
- **Geothermal energy**
- **Wind energy**
- **Biomass**
- **Hydropower**
- **Tidal energy**

##### **Non-renewable Sources of Energy**

Non-renewable resources are natural resources found beneath the earth's surface. These energy resources do not replenish at the same speed at which they are consumed, taking millions of years to form. Main examples of non-renewable resources are coal, oil, and natural gas. Examples include:

- **Natural gas**
- **Coal**

- **Petroleum**
- **Nuclear energy**
- **Hydrocarbon gas liquids**

#### **Difference between Renewable and Non-renewable Sources of Energy**

<b>Renewable</b>	<b>Non-renewable</b>
Resources that can be renewed once consumed	Resources that cannot be renewed once consumed
Environmentally friendly, no pollution	Cause environmental pollution
Inexhaustible	Exhaustible
Not affected by human activities	Affected by human activities
Examples: Air, water, solar energy	Examples: Natural gas, coal, nuclear energy

#### **Natural Sources of Energy**

Over time, the primary sources of energy have evolved:

- **Stone Age:** Wood
- **Iron Age:** Coal
- **Modern Age:** Fossil fuels like petroleum and natural gas

#### **Qualities of Good Energy Sources:**

- Optimum heat production per unit of volume/mass used
- Easy to transport
- Least polluting
- Economical

#### **Types of Natural Sources of Energy**

Energy sources are also classified based on their popularity and use into:

- **Conventional Sources of Energy**
- **Non-Conventional Sources of Energy**

#### **Detailed Notes on Specific Energy Sources**

**Fossil Fuels:** Fossil fuels are non-renewable energy sources that include coal, oil, and natural gas. These fuels are formed from the remains of ancient plants and animals over millions of years.

##### **1. Formation:**

- **Coal:** Formed from plant material in swampy areas that is subjected to heat and

pressure over time.

- **Oil and Natural Gas:** Derived from marine organisms that settle on the ocean floor, buried under sediment, and transformed by heat and pressure.

## 2. Extraction Methods:

- **Coal:**

**S** Surface mining (e.g., open-pit mining)

**S** Underground mining (e.g., room and pillar, longwall mining)

- **Oil and Gas:**

**S** Drilling (both onshore and offshore)

## 3. Usage and Environmental Impact:

- Fossil fuels are crucial for electricity generation, transportation, and industrial processes.
- Environmental impacts include air pollution and climate change due to CO<sub>2</sub> emissions, habitat destruction, and water pollution.

**Nuclear Energy:** Nuclear energy is produced through nuclear fission, where the nucleus of an atom splits into smaller parts, releasing a large amount of energy.

## 1. Nuclear Reactors:

- **Pressurized Water Reactors (PWR)**
- **Boiling Water Reactors (BWR)**
- The nuclear fuel cycle involves mining uranium, fuel fabrication, reactor use, and spent fuel management.

## 2. Safety Measures:

- Modern reactors have multiple safety systems, including containment structures, emergency cooling systems, and redundant control systems.
- International guidelines and safety drills ensure operational safety.

## 3. Usage and Environmental Impact:

- Provides significant electricity without emitting CO<sub>2</sub> during operation.
- Produces radioactive waste that requires long-term management.
- Rare but severe accidents (e.g., Chernobyl, Fukushima) highlight the need for stringent safety measures.

## India's Production and Reserves of Commercial Energy Sources

### Introduction

India has the third-highest total primary energy consumption in the world since 2013, following China and the United States. As of 2017, India is the second-top coal consumer and the third in oil consumption globally. India relies heavily on energy imports, meeting nearly 47% of its total primary energy needs in 2019.

### Energy Consumption Overview (2022-23):

- **Total Primary Energy Supply (TPES) per capita:** 25,745 MJ
- **Total Final Consumption per capita:** 16,699 MJ
- **Electricity consumption per capita:** 1,015 kWh
- **Energy intensity in agriculture vs. industry:** Agriculture's energy intensity is seven times less than that of industries.

### Year-wise Consumption of Energy Sources:

- **2013-14 to 2022-23:**

✓ Steady increase in coal, lignite, crude oil, natural gas, and electricity consumption.  
✓ Significant rise in CO<sub>2</sub> emissions from 2,087.5 million tonnes to 2,865.2 million tonnes.

### Primary Energy Use (2017):

- **Coal:** 56.26%
- **Petroleum & other liquids:** 29.47%
- **Natural gas:** 6.18%
- **Nuclear:** 1.13%
- **Hydroelectricity:** 4.07%
- **Other renewables:** 2.89%

### Energy in India:

#### 1. Coal:

- India is the second-largest producer and importer of coal.
- Major coal-fired electricity generation contributes to significant greenhouse gas emissions.
- Jharia is India's largest coal belt with environmental and pollution challenges.

- India imports coking coal for steel production due to the lack of high-quality domestic reserves.

## **2. Oil and Natural Gas:**

- India is the third top crude oil consumer globally.
- Significant crude oil refining capacity (4.972 million barrels per day) ranked 4th globally.

## **3. Liquefied Petroleum Gas (LPG):**

- Extensive use of LPG for cooking, with India being the second-largest consumer globally.
- Piped city gas supply is not yet developed on a major scale.

## **4. Biomass and Charcoal:**

- Biomass is a significant renewable energy source, with potential for biofuel and organic chemical production.
- Torrefaction and co-firing biomass with coal can reduce coal import dependency.
- Initiatives to use agro waste and biomass in rural areas to boost the economy and job potential.

## **5. Biofuel:**

- Target of 20% ethanol blending in petrol by 2025 to reduce import costs and promote renewable energy sources.

## **6. Electricity:**

- Nearly 100% of the population has access to power supply.
- India ranks 6th globally in hydropower generation.
- Significant investments in renewable energy, aiming for 190.573 GW installed capacity by 2024.
- Target of 175 GW of renewable energy capacity by 2022 was missed but expected to be achieved by the end of 2025.

India's energy sector is characterized by a heavy reliance on fossil fuels, significant coal consumption, and increasing investments in renewable energy sources to meet its growing energy demands and reduce environmental impact.

## Need for Non-Conventional Energy Sources

### Introduction

The reliance on conventional energy sources such as coal, oil, and natural gas has led to numerous environmental and economic challenges. Non-conventional energy sources, including solar, wind, geothermal, and biomass, offer sustainable and environmentally friendly alternatives.

### Key Reasons for the Need:

#### 1. Environmental Concerns:

- **Climate Change:** Burning fossil fuels releases greenhouse gases (GHGs) like carbon dioxide, contributing to global warming and climate change.
- **Air Pollution:** Fossil fuel combustion emits pollutants such as sulfur dioxide, nitrogen oxides, and particulate matter, leading to air quality deterioration and health issues.

#### 2. Resource Depletion:

- **Finite Reserves:** Conventional energy sources are finite and are being depleted rapidly. For example, oil and coal reserves are expected to last only a few more decades at current consumption rates.
- **Sustainability:** Non-conventional energy sources are renewable and inexhaustible, ensuring a continuous supply of energy.

#### 3. Energy Security:

- **Import Dependency:** Many countries, including India, rely heavily on importing fossil fuels, which exposes them to global market volatility and geopolitical tensions.
- **Self-Reliance:** Developing non-conventional energy sources reduces dependency on imports and enhances national energy security.

#### 4. Economic Benefits:

- **Job Creation:** The renewable energy sector creates numerous job opportunities in manufacturing, installation, and maintenance.
- **Cost Savings:** Although the initial investment may be high, renewable energy sources have lower operational and maintenance costs in the long run.

#### 5. Technological Advancements:

- **Innovation:** Advancements in technology have made non-conventional energy sources more efficient and cost-effective.

- **Energy Storage:** Improved energy storage solutions, such as batteries, help in managing the intermittent nature of renewable energy sources like solar and wind.

## 6. Rural Development:

- **Electrification:** Non-conventional energy sources can provide electricity to remote and rural areas that are not connected to the grid.
- **Local Solutions:** Small-scale renewable energy projects can be implemented locally, providing energy independence to rural communities.

## Examples of Non-Conventional Energy Sources:

- **Solar Energy:** Harnessing sunlight to generate electricity through photovoltaic cells or solar thermal systems.
- **Wind Energy:** Using wind turbines to convert kinetic energy from the wind into electrical power.
- **Geothermal Energy:** Utilizing heat from the Earth's interior for power generation and direct heating applications.
- **Biomass:** Converting organic materials like agricultural waste and wood into energy through combustion or biochemical processes.
- **Hydropower:** Small-scale hydroelectric plants that utilize the kinetic energy of flowing water to produce electricity.
- **Tidal Energy:** Capturing the energy from tidal movements to generate electricity.

## Energy Alternatives

### Introduction

Energy alternatives refer to the various sources of energy that serve as replacements or supplements to conventional fossil fuels. These alternatives are crucial for addressing the environmental, economic, and geopolitical challenges posed by traditional energy sources.

### Types of Energy Alternatives:

#### 1. Solar Energy:

- **Photovoltaic (PV) Systems:** Convert sunlight directly into electricity using semiconductor materials.
- **Solar Thermal Systems:** Use sunlight to generate heat, which can be used for electricity production, water heating, and space heating.

#### 2. Wind Energy:

- **Onshore Wind Farms:** Turbines located on land that convert wind kinetic

energy into electricity.

- **Offshore Wind Farms:** Turbines installed in bodies of water, where wind speeds are generally higher and more consistent.

### 3. Hydropower:

- **Large-scale Hydropower:** Utilizes large dams to store water and release it through turbines to generate electricity.
- **Small-scale Hydropower:** Includes micro and mini hydro projects that can supply electricity to local communities.

### 4. Biomass Energy:

- **Direct Combustion:** Burning organic materials like wood, agricultural residues, and animal waste to produce heat and electricity.
- **Biofuels:** Converting biomass into liquid fuels such as ethanol and biodiesel for use in transportation.

### 5. Geothermal Energy:

- **Geothermal Power Plants:** Extract heat from the Earth's interior to generate electricity.
- **Direct Use Applications:** Utilize geothermal heat directly for applications such as heating buildings, greenhouses, and industrial processes.

### 6. Tidal and Wave Energy:

- **Tidal Energy:** Harnessing energy from the rise and fall of tides using tidal turbines and barrages.
- **Wave Energy:** Capturing the energy from surface waves on the ocean to generate electricity.

### 7. Nuclear Energy:

- **Fission Reactors:** Splitting atomic nuclei (usually uranium or plutonium) to release energy for electricity generation.
- **Fusion Reactors (Future Potential):** Combining atomic nuclei to release energy, with research ongoing to make this a viable and sustainable energy source.

### 8. Hydrogen Energy:

- **Hydrogen Fuel Cells:** Produce electricity by combining hydrogen with oxygen, with water as the only by-product.
- **Hydrogen Production:** Can be produced from various sources, including natural



gas, water electrolysis, and biomass.

### **Advantages of Energy Alternatives:**

#### **1. Environmental Benefits:**

- **Reduced Emissions:** Most alternative energy sources produce little to no greenhouse gases or other pollutants.
- **Conservation:** Helps in conserving natural resources and reducing habitat destruction.

#### **2. Economic Benefits:**

- **Job Creation:** The renewable energy sector provides significant employment opportunities in manufacturing, installation, and maintenance.
- **Cost Savings:** Over time, the cost of renewable energy technologies has decreased, making them economically competitive with fossil fuels.

#### **3. Energy Security:**

- **Diversification:** Reduces dependence on imported fossil fuels, enhancing national energy security.
- **Reliability:** Distributed renewable energy systems can provide more reliable energy supplies to remote and rural areas.

### **Challenges and Considerations:**

- **Intermittency:** Some renewable energy sources, like solar and wind, are intermittent and require energy storage solutions or backup systems to ensure a reliable supply.
- **Initial Costs:** High initial investment costs can be a barrier, though long-term savings and government incentives can mitigate this issue.
- **Land and Resource Use:** Large-scale renewable energy projects can require significant land and resources, which can impact ecosystems and communities.

## **Indian and Global Energy Scenario**

### **Introduction**

The energy landscape is rapidly evolving due to technological advancements, policy changes, and increasing awareness of environmental impacts. Both India and the world are witnessing significant shifts in energy production and consumption patterns.

### **Indian Energy Scenario:**

### 1. Primary Energy Consumption:

- India is the third-largest energy consumer globally, following China and the United States.
- The country's energy consumption has been growing rapidly due to its expanding economy and population.

### 2. Energy Mix:

- **Coal:** Dominates India's energy mix, accounting for around 56% of total primary energy consumption. India is the second-largest producer and consumer of coal.
- **Oil and Natural Gas:** India is the third-largest oil consumer globally. It imports a significant portion of its oil and natural gas requirements.
- **Renewable Energy:** India has made substantial investments in renewable energy, with solar and wind power leading the way. The country aims to achieve 175 GW of renewable energy capacity by 2022, though this target has been extended to 2025.
- **Nuclear Energy:** Contributes a small but growing portion of India's energy mix.

### 3. Electricity Generation:

- India is the world's third-largest producer of electricity, with significant contributions from coal-fired power plants.
- Renewable energy sources, particularly solar and wind, are becoming increasingly important in the electricity sector.

### 4. Energy Policies:

- The Indian government has introduced several policies to promote energy efficiency and renewable energy, such as the National Solar Mission and the Ujwal DISCOM Assurance Yojana (UDAY).
- Initiatives like the Pradhan Mantri Sahaj Bijli Har Ghar Yojana (Saubhagya) aim to provide electricity access to all households.

### 5. Challenges:

- High dependence on coal leads to significant greenhouse gas emissions.
- Import dependence for oil and gas creates vulnerabilities in energy security.
- Integrating renewable energy into the grid and ensuring reliable supply remains a challenge.

### Global Energy Scenario:

### 1. Primary Energy Consumption:

- Global energy consumption is led by China, the United States, and India.
- There is a growing shift towards cleaner energy sources to combat climate change.

### 2. Energy Mix:

- **Fossil Fuels:** Still dominate the global energy mix, with coal, oil, and natural gas accounting for the majority of energy consumption.
- **Renewable Energy:** The fastest-growing energy sector, driven by declining costs and supportive policies. Solar and wind power are leading the transition.
- **Nuclear Energy:** Continues to be a significant source of low-carbon electricity in many countries, though growth is slower compared to renewables.

### 3. Electricity Generation:

- The global shift towards renewable energy is most evident in the electricity sector, where renewables are expected to account for nearly 50% of the global electricity supply by 2050.
- Investment in energy storage technologies and smart grids is crucial for managing the intermittency of renewable energy sources.

### 4. Energy Policies:

- Countries worldwide are implementing policies to reduce carbon emissions and promote sustainable energy. The Paris Agreement is a landmark international accord aimed at limiting global warming.
- Carbon pricing, renewable energy mandates, and subsidies for clean technologies are common policy tools.

### 5. Challenges:

- Balancing energy demand growth with environmental sustainability.
- Ensuring energy access and equity, particularly in developing regions.
- Managing the economic impacts of transitioning away from fossil fuels, especially in regions dependent on fossil fuel industries.

## SOLAR RADIATION & MEASUREMENT

### Planck's Law:

- Describes the wavelength distribution of radiation emitted by a black body.
- Formula:

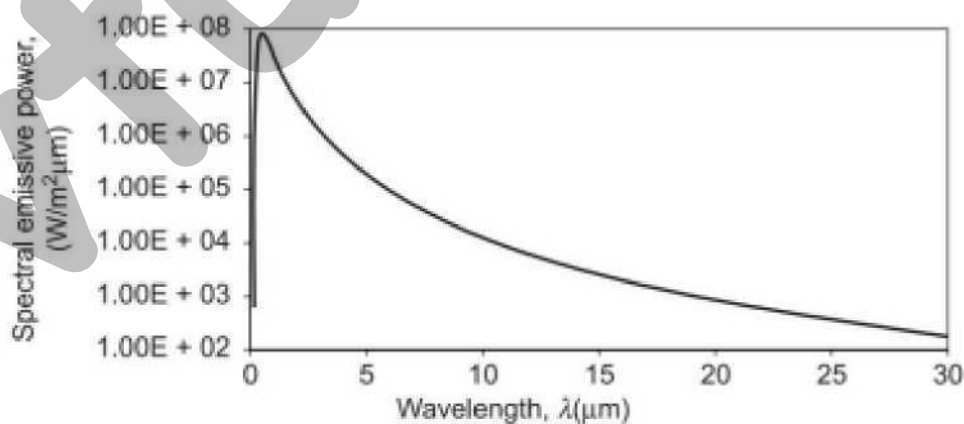
$$e_{\lambda} = \frac{C_1}{\lambda^5 (e^{C_2/\lambda T} - 1)} \quad (\text{W/m}^2\text{-unit wavelength})$$

where:

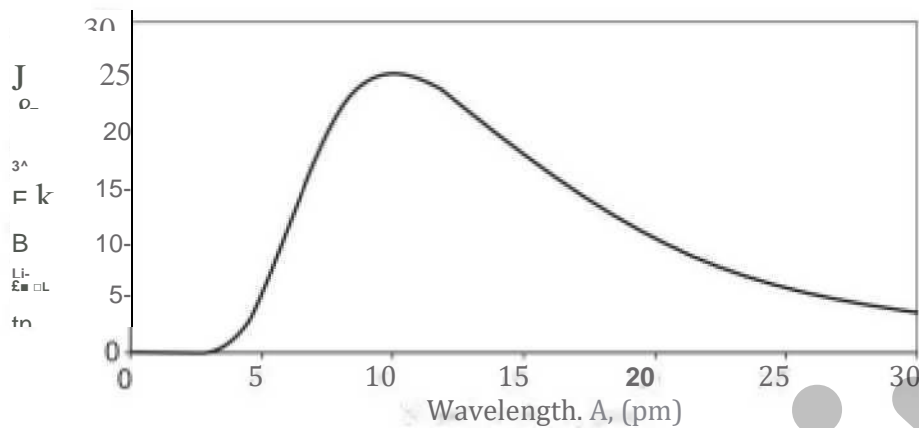
- $C_1 = 3.74 \times 10^{16} \text{ Wm}^3$
- $C_2 = 0.01439 \text{ mK}$
- $\lambda$  is the wavelength in meters.
- $T$  is the temperature in Kelvin.
- **Power Density Distribution:**
  - At the sun's surface (5760 K), radiation peaks around 0.48  $\mu\text{m}$ .
  - At the earth's surface (288 K), radiation peaks around 10  $\mu\text{m}$ .

### Solar Constant:

- Defined as the energy received from the sun per unit time on a unit area perpendicular to the radiation direction, at the earth's mean distance from the sun.
- Standard value:  $1367 \text{ W/m}^2$ .



(a) Blackbody emissive power at  $T = 5760 \text{ K}$  (surface of sun)



(b) Blackbody emissive power at  $T = 288 \text{ K}$  (surface of earth)

## Extraterrestrial and Terrestrial Radiations:

### 1. Extraterrestrial Radiation ( $I_{\text{ext}}$ ):

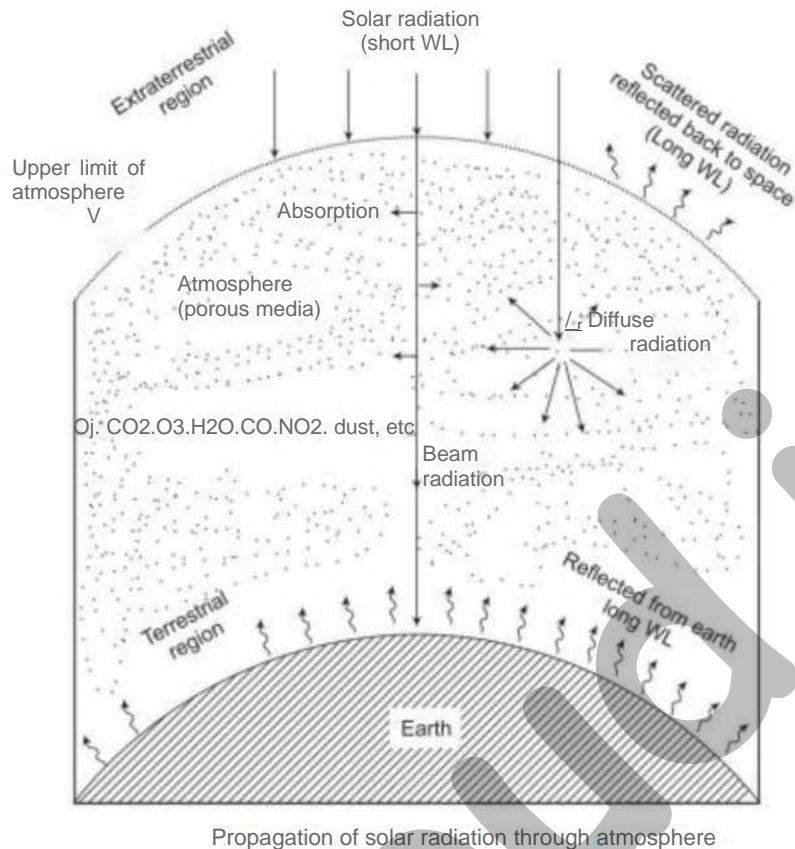
- Solar radiation incident on the outer atmosphere.
- Varies due to changes in solar emission ( $< \pm 1.5\%$ ) and earth-sun distance ( $\pm 3\%$ ).
- Formula:

$$I_{\text{ext}} = I_{\text{sc}} \left[ 1 + 0.033 \cos \left( \frac{360n}{365} \right) \right] \text{ W/m}^2$$

- Where  $n$  is the day of the year starting from January 1.

### 2. Terrestrial Radiation:

- Solar radiation that reaches the earth's surface after passing through the atmosphere.
- Affected by atmospheric absorption and scattering.
- Known as Solar Irradiation when expressed in  $\text{W/m}^2$ .
- Solar Insolation refers to the energy received on a given surface area over a specific time period (in  $\text{J/m}^2$  or  $\text{kWh/m}^2$ ).



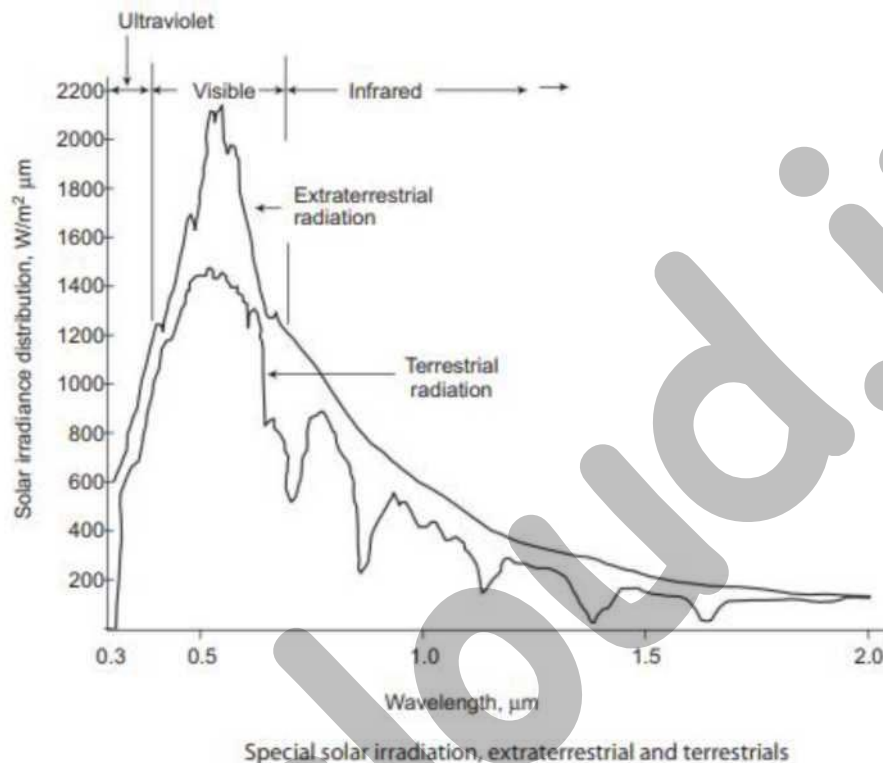
### Key Differences:

- **Extraterrestrial Radiation:** Unaffected by atmospheric conditions.
- **Terrestrial Radiation:** Modified by the atmosphere, leading to absorption, scattering, and reduced intensity.

### Solar Radiation Spectrum:

- **Frequency Range:** Solar radiation covers a broad spectrum of electromagnetic radiation.
- **Dominant Wavelengths:** About 99% of extraterrestrial radiation falls between 0.2 to 4  $\mu\text{m}$ , with maximum intensity at 0.48  $\mu\text{m}$  (green portion of visible light).
- **Energy Distribution:**
  - Ultraviolet Region ( $1 < 0.38 \mu\text{m}$ ): 6.4%
  - Visible Region ( $0.38 \mu\text{m} < 1 < 0.78 \mu\text{m}$ ): 48%
  - Infrared Region ( $1 > 0.78 \mu\text{m}$ ): 45.6%
- **Atmospheric Absorption:** Shortwave radiation ( $1 < 0.29 \mu\text{m}$ ) and infrared radiation ( $1 > 2.3 \mu\text{m}$ ) are mostly absorbed in the atmosphere.

- **Significant Range:** For terrestrial applications, radiation between 0.29 and 2.3  $\mu\text{m}$  is most relevant due to atmospheric transmission characteristics.
- **Solar Irradiation Distribution:** Extraterrestrial and terrestrial solar irradiation distributions are represented in Figure 4.4, with areas under these curves indicating total radiation intensities in  $\text{W/m}^2$  for both regions.



The solar constant is a crucial measure in understanding the amount of solar energy that Earth

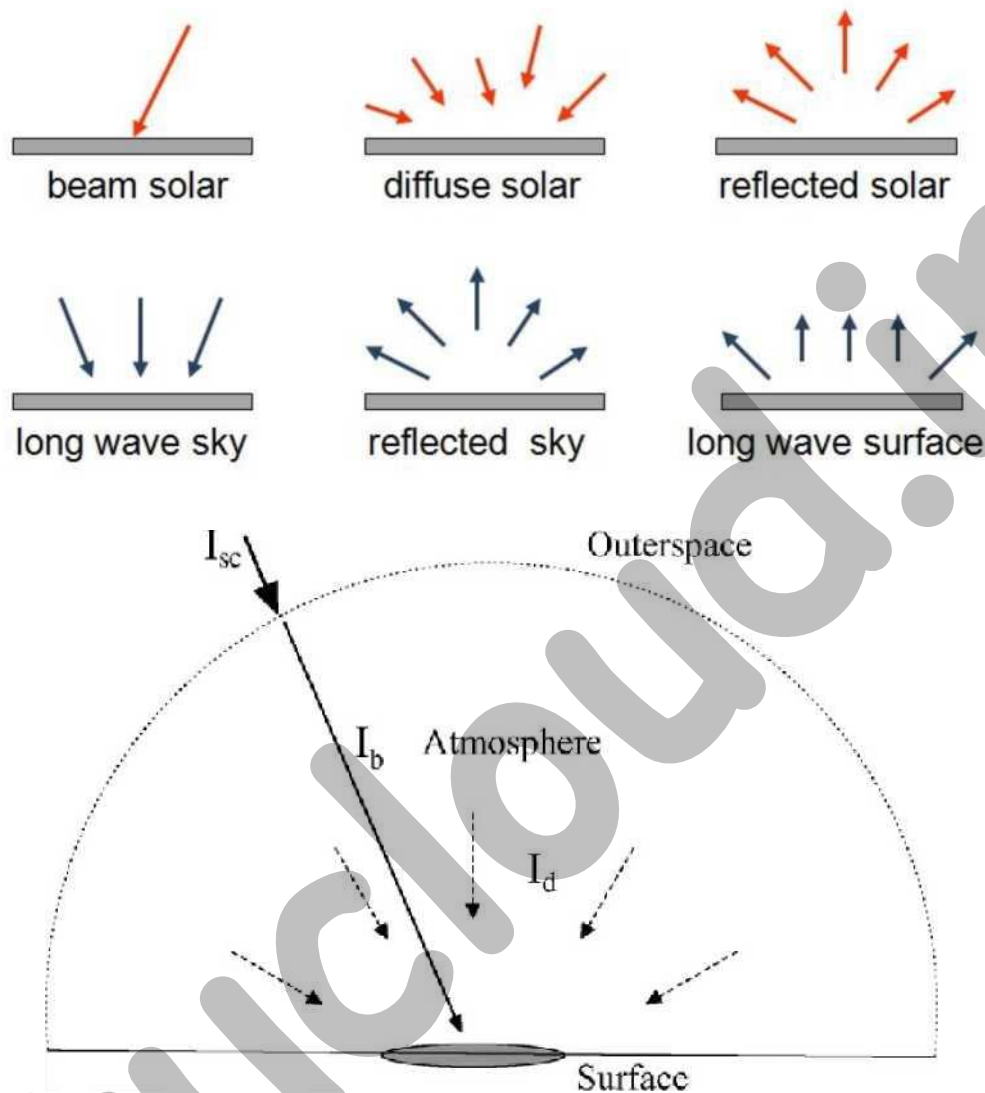
- 1 **Definition:** The solar constant is defined as the amount of solar radiation received per unit area at a distance of one astronomical unit (AU) from the Sun. One AU is approximately the average distance between Earth and the Sun, which is about 93 million miles (150 million kilometers).
- 2 **Measurement:** It is measured outside Earth's atmosphere, typically at a point where the Sun's rays are perpendicular to a surface. This measurement is crucial because it provides a baseline for understanding the total energy output of the Sun that reaches the outer limits of Earth's atmosphere.
- 3 **Value:** The solar constant is approximately 1,366 watts per square meter ( $\text{W/m}^2$ ). This value represents the power flux density of solar radiation that would be incident on a surface perpendicular to the Sun's rays at Earth's average distance from the Sun.
- 4 **Variation:** While 1,366  $\text{W/m}^2$  is the average value, the actual solar constant can vary slightly due to factors such as solar activity, Earth's varying distance from the Sun throughout its elliptical orbit, and changes in the Sun's output over its solar cycle.

receives from the Sun. Here's a more detailed explanation:

Vtucloud.in



Solar radiation at the Earth's surface can be categorized into three main components: beam (direct) radiation, diffuse radiation, and global radiation (total radiation).



### 1. Beam (Direct) Radiation:

**Definition:** Beam radiation refers to solar radiation that travels in a straight line from the direction of the Sun.

- **Formula:** The intensity  $I_b$  of beam radiation received at the Earth's surface depends on the solar constant  $S_0$ , the solar zenith angle  $\theta$ , and atmospheric attenuation effects:

$$I_b = S_0 \cdot e^{-k/\cos(\theta)}$$

- $S_0$ : Solar constant (approximately  $1366 \text{ W/m}^2$ ).

- 9: Solar zenith angle (angle between the vertical and the direction of the Sun's rays).
- k: Atmospheric extinction coefficient.
- e: Euler's number (approximately 2.718).

## 2. Diffuse Radiation:

**Definition:** Diffuse radiation is solar radiation that has been scattered and redirected by the atmosphere.

- **Formula:** The intensity  $I_d$  of diffuse radiation depends on the sky clearness index  $K_t$  and the extra-terrestrial radiation  $I_0$ :

$$I_d = I_0 (1 - K_t)$$

- $I_0$ : Extra-terrestrial radiation (solar constant adjusted for Earth-Sun distance and atmospheric effects).
- $K_t$ : Sky clearness index (ratio of global to extra-terrestrial radiation).
- $F_{beam}$ : Fraction of global radiation due to beam radiation.

## 3. Global Radiation (Total Radiation):

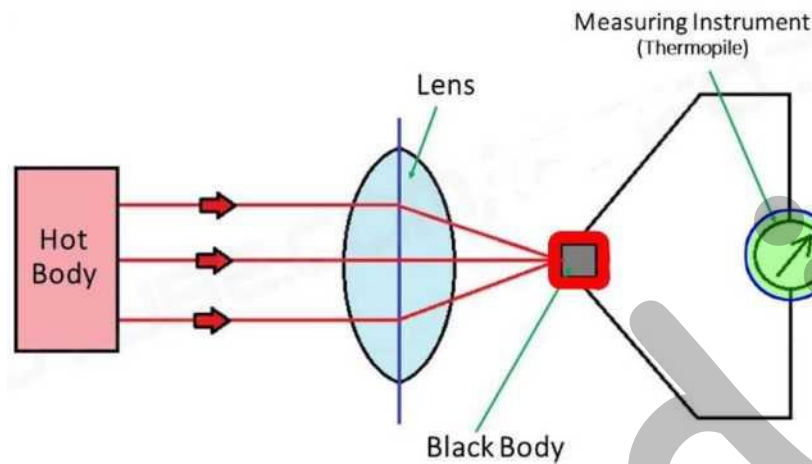
**Definition:** Global radiation is the total solar radiation received at the Earth's surface, which is the sum of beam and diffuse radiation.

- **Formula:** The total global radiation  $I_g$  is the sum of beam and diffuse radiation:

$$I_g = I_b + I_d$$

## PYROMETER

A pyrometer is an instrument used for measuring high temperatures, typically in industrial and scientific applications where direct contact with the object is impractical or impossible.



1. **Function:** Pyrometers measure the temperature of an object by detecting the amount of thermal radiation emitted by the object.

2. **Types:**

- **Optical Pyrometers:** Measure temperature based on the color or brightness of the thermal radiation emitted by the object. They compare the brightness of the object's thermal radiation to a calibrated filament or reference source.
- **Infrared Pyrometers:** Measure temperature based on the intensity of infrared radiation emitted by the object. They detect the infrared radiation using sensors sensitive to specific wavelengths.

3. **Working Principle:**

- Optical pyrometers utilize the principle that as an object gets hotter, it emits more visible light. The instrument compares the brightness of the object's emitted light with a known source, allowing it to determine the temperature.
- Infrared pyrometers detect the thermal radiation emitted by the object. They typically use a lens to focus the infrared radiation onto a detector, which converts the radiation into an electrical signal. The temperature is then calculated based on the intensity of the infrared radiation.

4. **Applications:**

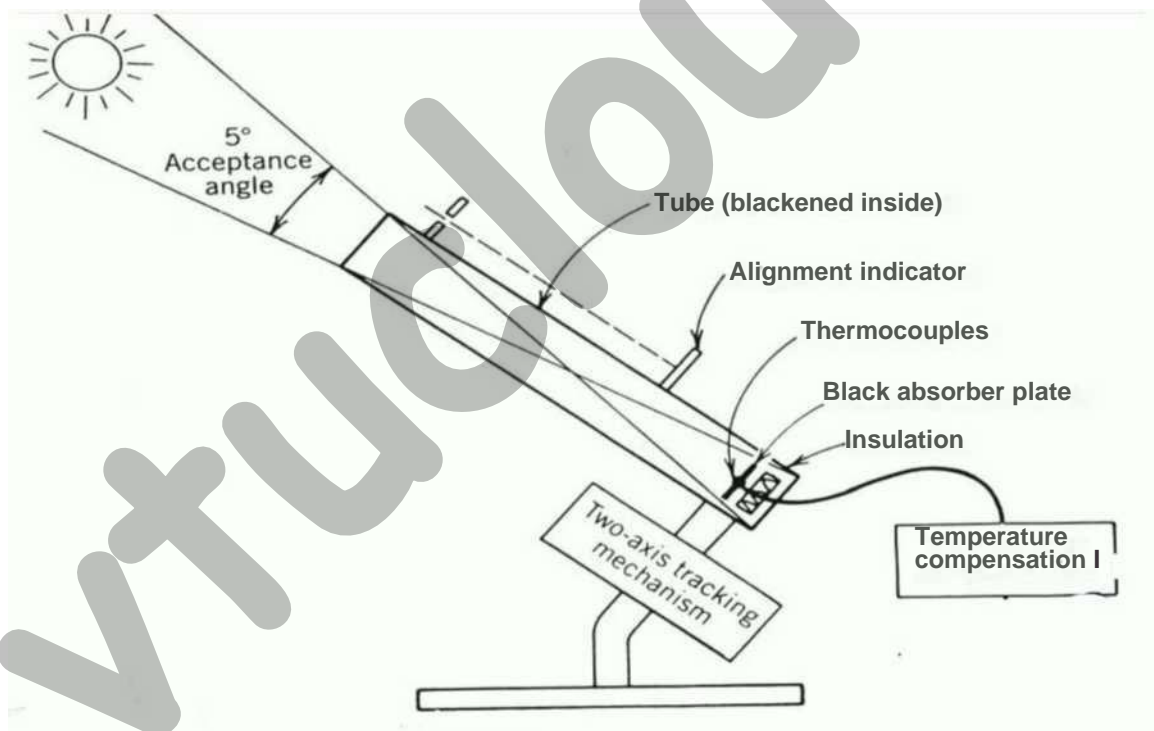
- **Industrial:** Used in steel manufacturing, metalworking, ceramics, and glass industries to monitor and control temperatures during processing.
- **Scientific:** Used in laboratories for high-temperature research, combustion studies, and materials testing.

- **Medical:** Used in medical diagnostics to measure body temperature at a distance.

## PYRHELIOMETER

A shading ring pyrheliometer is a specialized instrument used to measure direct solar irradiance, particularly in scientific and meteorological research contexts.

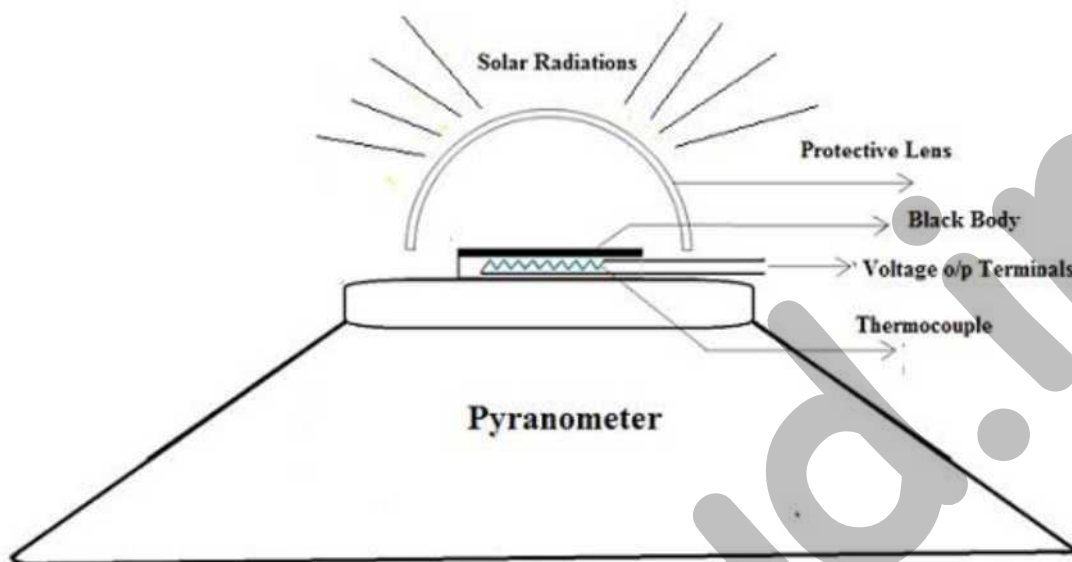
- **Function:** A shading ring pyrheliometer measures the direct solar irradiance, which is the amount of solar radiation received per unit area perpendicular to the Sun's rays at the Earth's surface.
- **Design:** It consists of a spherical receiver mounted on a horizontal axis. The receiver is shaded by a ring or disk, which casts a shadow on the receiver's surface. This shading ensures that only direct solar radiation, not diffuse or reflected radiation, is measured.
- **Operation:** The instrument is typically oriented to track the movement of the Sun throughout the day. As the Sun moves across the sky, the shading ring ensures that only the direct sunlight falls on the receiver. The irradiance is measured in watts per square meter ( $\text{W/m}^2$ ).



- **Applications:** Shading ring pyrheliometers are used in climate research, solar energy studies, and atmospheric science. They provide essential data for understanding solar radiation patterns, which influence weather, climate, and solar energy system design.
- **Accuracy:** Calibration and proper maintenance are crucial to ensure accurate measurements, as any deviation can affect the reliability of data collected.

## PYRANOMETER

A pyranometer is a scientific instrument used to measure the solar irradiance (the power of electromagnetic radiation from the Sun) incident on a surface.



**Function:** Pyranometers measure the total solar radiation flux density (Watts per square meter) from the entire hemisphere above the instrument. This includes direct solar radiation, diffuse sky radiation, and radiation reflected from the ground.

### 1. Design:

- Typically, a pyranometer consists of a thermopile sensor that absorbs incoming solar radiation.
- The sensor is covered by a glass dome or filter that allows sunlight to pass through while reducing thermal interference.

### 2. Working Principle:

- When sunlight strikes the sensor, it generates a small voltage proportional to the solar radiation received.
- This voltage is then converted into a measurement of solar irradiance, typically in units of Watts per square meter ( $\text{W/m}^2$ ).

### 3. Types:

- **Broadband Pyranometers:** Measure the total solar irradiance across a wide spectrum of wavelengths (typically from about 300 nm to 3000 nm).
- **Narrowband Pyranometers:** Measure solar irradiance in specific wavelength bands within the solar spectrum.

**4. Applications:**

- Used in meteorology, climatology, solar energy studies, and environmental monitoring.
- Essential for assessing the performance of solar energy systems, studying climate patterns, and calculating potential solar energy generation.

**5. Accuracy:**

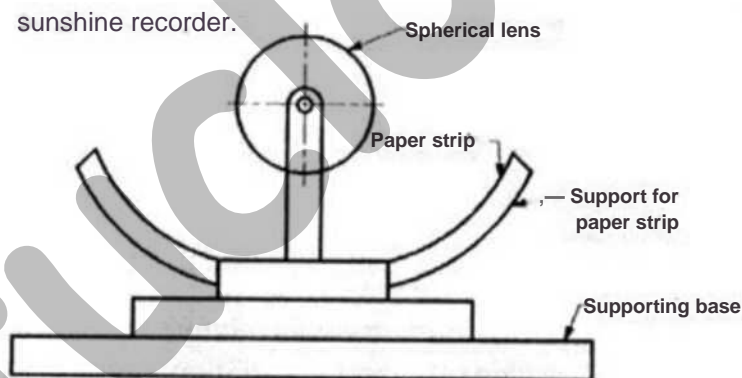
- Calibration is critical to ensure accuracy, considering factors like temperature variations and spectral response.

**6. Deployment:**

- Pyranometers are often mounted horizontally and require regular maintenance to ensure reliable data collection.

## SUNSHINE RECORDER

The Campbell-Stokes recorder, a type of sunshine recorder, is an important meteorological instrument used to measure the duration of sunlight received at a specific location throughout the day.



**1. Invention and Design:** Invented by John Francis Campbell in 1853 and later modified by Sir George Gabriel Stokes in 1879, the Campbell-Stokes recorder utilizes a spherical glass lens to focus sunlight onto a specially designed record card beneath it.

**2. Operation:**

- The recorder consists of a glass sphere that refracts and focuses sunlight onto a record card placed at its base.
- As the Sun moves across the sky, the focused sunlight burns or scorches the record card, leaving a trace or burn marks.
- The length of these burn marks correlates with the duration of direct sunshine received during that period.

**3. Measurement:**

- Observers can measure the duration of sunshine by assessing the length and number of burn marks on the record card.
- This instrument measures sunshine duration rather than the intensity of sunlight, which requires a solarimeter for measurement.

**4. Components:**

- The sphere is typically made from optical glass, ensuring precise refraction and focusing of sunlight.
- The record card is inserted into the base of the unit and is designed to capture and display the burn marks.

**5. Applications:**

- Provides crucial data for meteorology, climate studies, agriculture, and tourism, offering insights into local weather patterns and climate variability.
- Used to monitor and analyze sunshine hours, which influences plant growth, solar energy potential, and various environmental phenomena.

**6. Considerations:**

- Limitations include difficulties in recording during low sun angles (dawn and dusk) when sunlight intensity is insufficient for burning marks effectively.
- Weather conditions such as rain can damage the record card or interfere with accurate measurements.

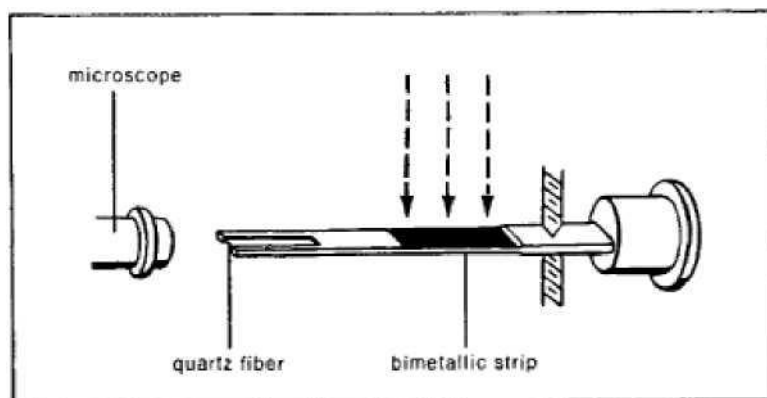
## ACTINOMETER

An actinometer is a device used to measure the intensity of solar radiation by determining the number of photons through the rate of change in photo-induced chemical reactions. The actinometer operates on the principle that the rate of photolytic conversion of molecules within an actinometer cell matches the rate of photon absorption.

### Working Principle

A chemical actinometer operates through the following steps:

- 1. Preparation:** The gas of interest is filled into a photolysis reactor.
- 2. Exposure:** The actinometer is exposed to solar radiation.
- 3. Measurement:** The photochemical reaction rate is measured.



In this process, the gas is exposed to actinic flux without significantly altering the radiation's intensity or spectral composition. A transparent quartz cell with a suitable geometrical shape is employed, and gases with small optical absorbance values are used to allow for easy evaluation of the photolysis frequency.

### Modes of Operation

There are two basic modes of operation for actinometers:

#### 1. Static Batch Mode:

- The photolysis reactor is filled with actinometer gas and sealed.
- An opaque hood covers the reactor to prevent sunlight exposure.
- During measurement, the hood is removed, and the actinometer is exposed to radiation for a fixed time.
- The reactor is sealed again, and the gas composition is analyzed for changes.

#### 2. Flowing Gas Mode:

- Actinometer gas continuously flows into the reactor exposed to solar radiation.
- The mean residence time of the gas in the illuminated reactor is considered for the time interval.
- The gas composition is analyzed using an online gas detector, allowing for continuous monitoring of photolysis frequencies.

### Applications

1. **Meteorology:** Measuring solar radiation emitted by the sun, reflected by the earth, or scattered by the atmosphere.
2. **Photochemical Experiments:** Used in experiments with complex irradiation geometry.
3. **Calibration:** Serve as a primary tool for calibrating photochemical detectors used in radiation measurements.
4. **Laser Measurements:** Combined with joulemeters to measure laser pulse energies, although they require repeated calibration at high photon densities due to various photon



processes affecting sensitivity and precision.

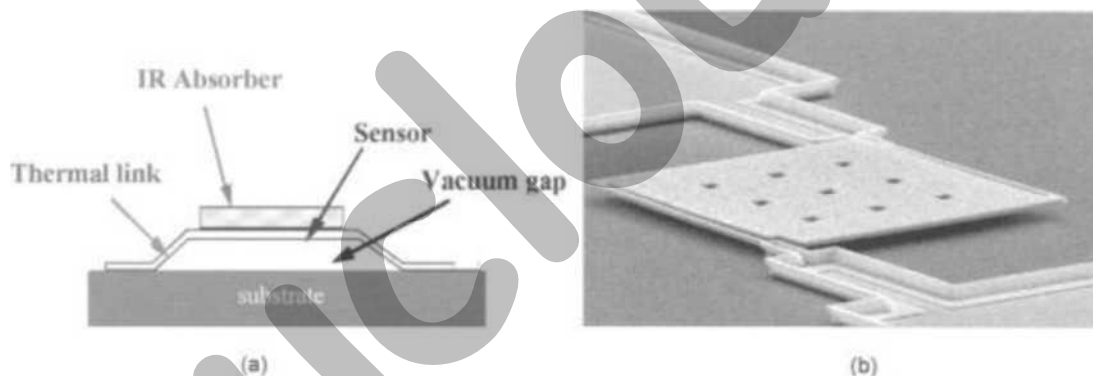
## BOLOMETER

A bolometer is an instrument designed to measure the power of incident electromagnetic radiation through the heating of a material with a temperature-dependent electrical resistance. The change in resistance is then measured and used to determine the energy of the radiation.

### Working Principle

The working principle of a bolometer involves the following steps:

- 1. Absorption of Radiation:** Incident radiation is absorbed by a material, causing it to heat up.
- 2. Change in Temperature:** The absorbed energy raises the temperature of the material.
- 3. Change in Resistance:** The material's electrical resistance changes as a function of temperature.
- 4. Measurement:** This change in resistance is measured using a connected circuit, often a Wheatstone bridge, and correlated to the amount of absorbed radiation.



### Components

A typical bolometer consists of:

- 1. Absorptive Element:** Made of materials like metals (e.g., platinum) or semiconductors that have a well-defined temperature coefficient of resistance.
- 2. Substrate:** A material with low thermal conductivity to minimize heat loss and ensure that the temperature change is primarily due to absorbed radiation.
- 3. Electrical Circuit:** Measures the resistance change. A common configuration is a Wheatstone bridge, which allows for precise determination of small changes in resistance.

### Types of Bolometers

There are several types of bolometers, each tailored for specific applications:

- 1. Metallic Bolometers:** Use metals with a significant temperature coefficient of resistance,

such as platinum or nickel.

**2. Semiconductor Bolometers:** Use semiconducting materials, which generally have a higher temperature coefficient of resistance compared to metals, making them more sensitive.

**3. Superconducting Bolometers:** Utilize superconducting materials, which have a very sharp change in resistance at a critical temperature, providing extremely high sensitivity.

### **Applications**

Bolometers have a wide range of applications due to their sensitivity to various forms of electromagnetic radiation, including:

- 1. Astronomy:** Measuring the cosmic microwave background radiation and other astronomical observations.
- 2. Terahertz Imaging:** Used in security screening and non-destructive testing.
- 3. Infrared Spectroscopy:** Detecting infrared radiation for chemical analysis and environmental monitoring.
- 4. Remote Sensing:** Measuring radiation from the Earth and other celestial bodies.

### **Advantages:**

- **High Sensitivity:** Can detect very low levels of radiation.
- **Broad Spectral Response:** Effective across a wide range of wavelengths, from microwave to infrared.

### **Limitations:**

- **Slow Response Time:** Due to the thermal nature of the detection process, bolometers typically have slower response times compared to other types of detectors like photodiodes.
- **Cooling Requirements:** High-sensitivity bolometers, especially those using superconducting materials, often require cryogenic cooling to achieve optimal performance.