RENEWABLE ENERGY TECHNOLOGIES

Unit 2 : **SOLAR RADIATION**

Module : 1

Solar radiation, Measurement of solar radiation and sun shine – solar spectrum.

Introduction:

Solar energy is an important, clean, cheap and abundantly available renewable energy. It is received on Earth in cyclic, intermittent and dilute form with very low power density 0 to 1 kW/m2.Solar energy received on the ground level is affected by atmospheric clarity, degree of latitude, etc. For design purpose, the variation of available solar power, the optimum tilt angle of solar flat plate collectors, the location and orientation of the heliostats should be calculated.

Units of solar power and solar energy:

In SI units, energy is expressed in Joule. Other units are angley and Calorie where

1 angley = 1 Cal/cm2.day

1 Cal = 4.186 J

For solar energy calculations, the energy is measured as an hourly or monthly or yearly average and is expressed in terms of kJ/m2/day or kJ/m2/hour. Solar power is expressed in terms of W/m2 or kW/m2.

Essential subsystems in a solar energy plant:

Solar collector or concentrator: It receives solar rays and collects the energy. It may be of following types:

- Flat plate type without focusing
- Parabolic trough type with line focusing
- Paraboloid dish with central focusing
- Fresnel lens with centre focusing
- Heliostats with centre receiver focusing

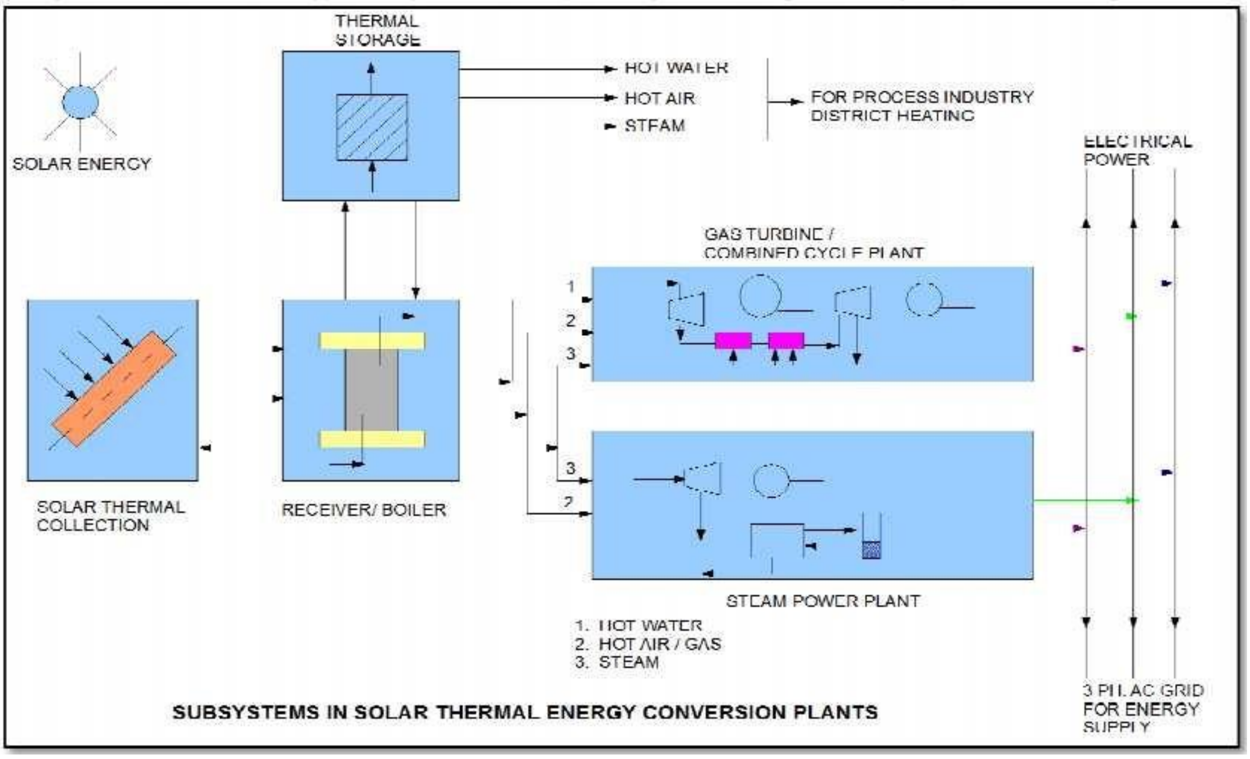
Energy transport medium: Substances such as water/ steam, liquid metal or gas are used to transport the thermal energy from the collector to the heat exchanger or thermal storage. In solar PV systems energy transport occurs in electrical form.

Energy storage: Solar energy is not available continuously. So we need an energy storage medium for maintaining power supply during nights or cloudy periods. There are three major types of energy storage: a) Thermal energy storage; b) Battery storage; c) Pumped storage hydro-electric plant.

Energy conversion plant: Thermal energy collected by solar collectors is used for producing steam, hot water, etc. Solar energy converted to thermal energy is fed to steam- thermal or gas-thermal power plant.

Power conditioning, control and protection system: Load requirements of electrical energy vary with time. The energy supply has certain specifications like voltage, current, frequency, power etc.

The power conditioning unit performs several functions such as control, regulation, conditioning, protection, automation, etc.



SUBSYSTEMS IN SOLAR THERMAL ENERGY CONVERSION PLANTS

Alternative or standby power supply: The backup may be obtained as power from electrical network or standby diesel generator.

Energy from the sun:

The sun radiates about 3.8 x 1026 W of power in all the directions. Out of this about 1.7 x 1017 W is received by earth. The average solar radiation outside the earth's atmosphere is 1.35 kW/m2 varying from 1.43 kW/m2 (in January) to 1.33 kW/m2(in July).

Solar thermal energy (STE) is a form of energy and a technology for harnessing solar energy to generate thermal energy or electrical energy for use in industry,

Measurement of Sunshine Duration

Sunshine duration is the length of time that the ground surface is irradiated by direct solar radiation (i.e., sunlight reaching the earth's surface directly from the sun). In 2003, WMO defined sunshine duration as the period during which direct solar irradiance exceeds a threshold value of 120 watts per square meter (W/m2). This value is equivalent to the level of solar irradiance shortly after sunrise or shortly before sunset in cloud-free conditions. It was determined by comparing the sunshine duration recorded using a Campbell-Stokes sunshine recorder with the actual direct solar irradiance.

Sunshine Duration Measuring Instruments

Campbell-Stokes sunshine recorders and Jordan sunshine recorders have long been used as instruments to measure sunshine duration, and are advantageous in that they have no moving parts and require no electric power. Their disadvantages are that the characteristics of the recording paper or photosensitized paper used in them affect measurement accuracy, differences between observers may arise in determining the occurrence of sunshine, and the recording paper must be replaced after sunset.

As sunshine is defined quantitatively at present, a variety of photoelectric sunshine recorders have been developed and are used in place of these instruments. As the threshold value for the occurrence of sunshine is defined in terms of direct solar irradiance, it is also possible to observe sunshine duration with a pyrheliometer.

Campbell-Stokes Sunshine Recorders

Principles and Structure

A Campbell-Stokes sunshine recorder concentrates sunlight through a glass sphere onto a recording card placed at its focal point. The length of the burn trace left on the card represents the sunshine duration.

The device’s structure is shown in Figure. A homogeneous transparent glass sphere L is supported on an arc XY, and is focused so that an image of the sun is formed on recording paper placed in a metal bowl FF' attached to the arc. The glass sphere is concentric to this bowl, which has three partially overlapping grooves into which recording cards for use in the summer, winter or spring and autumn are set. Three different recording cards are used depending on the season. The focus shifts as the sun moves, and a burn trace is left on the recording card at the focal point. A burn trace at a particular point indicates the presence of sunshine at that time, and the recording card is scaled with hour marks so that the exact time of sunshine occurrence can be ascertained. Measuring the overall length of burn traces reveals the sunshine duration for that day. For exact measurement, the sunshine recorder must be accurately adjusted for planar leveling, meridional direction and latitude. Campbell-Stokes and Jordan sunshine recorders mark the occurrence of sunshine on recording paper at a position corresponding to the azimuth of the sun at the site, and the time of sunshine occurrence is expressed in local apparent time.

1) Exchange and reading of the recording paper are performed after sunset.

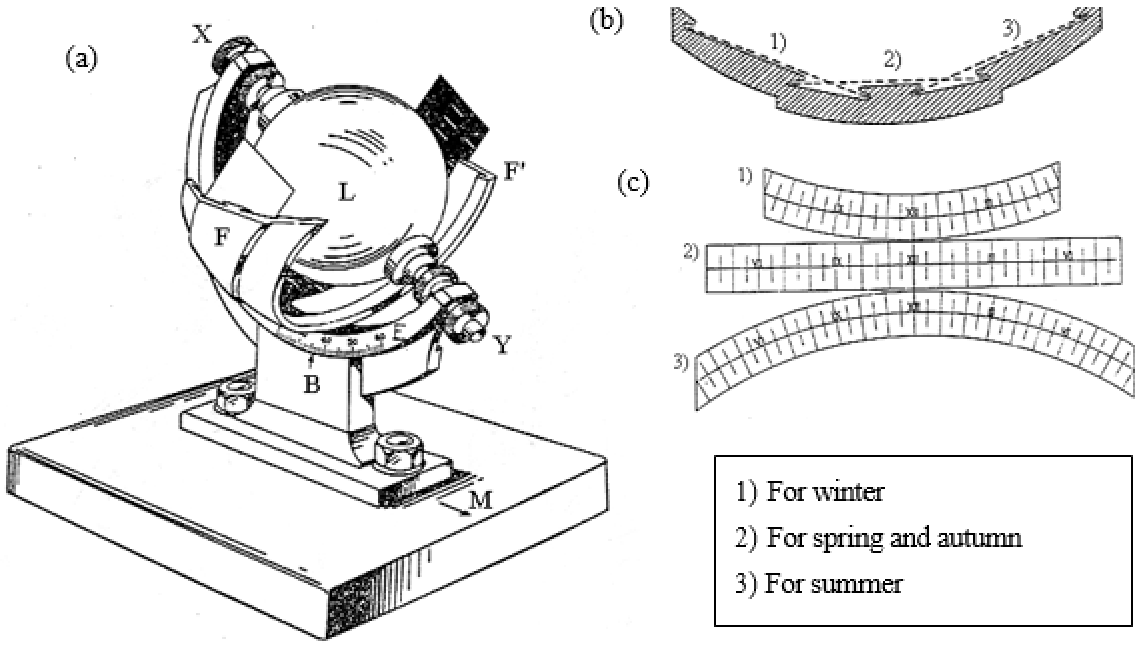


Figure . Campbell-Stokes sunshine recorder

(a) **Structure**

(b) **Cross section of bowl and grooves**

(c) **Recording cards**

2) Reading of Recording Paper

To obtain uniform results for observation of sunshine duration with a Campbell-Stokes sunshine recorder, the following points should be noted when reading records:

If the burn trace is distinct and rounded at the ends, subtract half of the curvature radius of the trace's ends from the trace length at both ends. Usually, this is equivalent to subtracting 0.1 hours from the length of each burn trace.

If the burn trace has a circular form, take the radius as its length. If there are multiple circular burns, count two or three as a sunshine duration of 0.1 hours, and four, five or six as 0.2 hours. Count sunshine duration this way in increments of 0.1 hours.

If the burn trace is narrow, or if the recording card is only slightly discolored, measure its entire length.

If a distinct burn trace diminishes in width by a third or more, subtract 0.1 hours from the entire length for each place of diminishing width. However, the subtraction should not exceed half the total length of the burn trace.

Jordan Sunshine Recorders

A Jordan sunshine recorder lets in sunlight through a small hole in a cylinder or a semi cylinder onto photosensitized paper set inside the cylinder on which traces are recorded. One common type has two hollow semi cylinders arranged back to back with their flat surfaces facing east and west. Each flat surface has a small hole in it. The Jordan sunshine recorder used by JMA is the same in principle, but consists of a hollow cylinder with two holes as shown in Figure. The instrument has its cylinders inclined to the relevant latitude and their axes set in the meridional direction. Photosensitized paper with a time scale printed on it is set in the cylinders in close contact with the inner surface. When direct solar radiation enters through the hole, the paper records the movement of the sun as a line. Sunshine duration is ascertained by measuring the length of time the paper was exposed to sunlight.

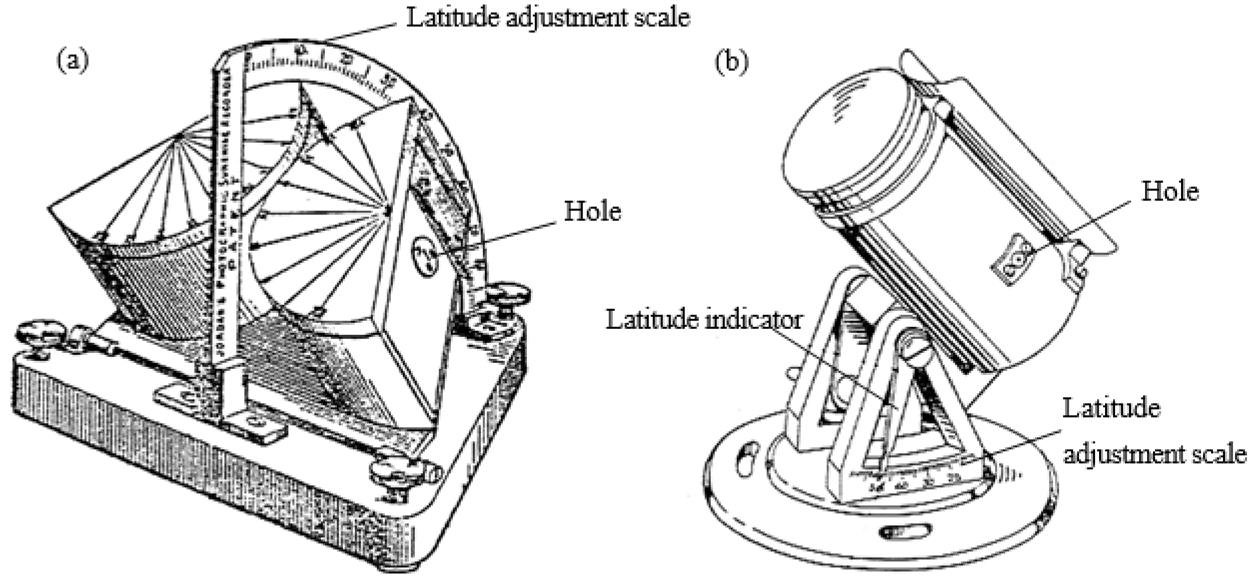


Figure. Jordan sunshine recorders

(a) Common type

(b) JMA type

Measurement of Solar Radiation

Definitions and Units

Definitions

Everything in nature emits electromagnetic energy, and solar radiation is energy emitted by the sun. The energy of extraterrestrial solar radiation is distributed over a wide continuous spectrum ranging from ultraviolet to infrared rays. In this spectrum, solar radiation in short wavelengths (0.29 to 3.0 μm) accounts for about 97 percent of the total energy. Figure 7.5 shows the spectrum distribution of solar radiation.

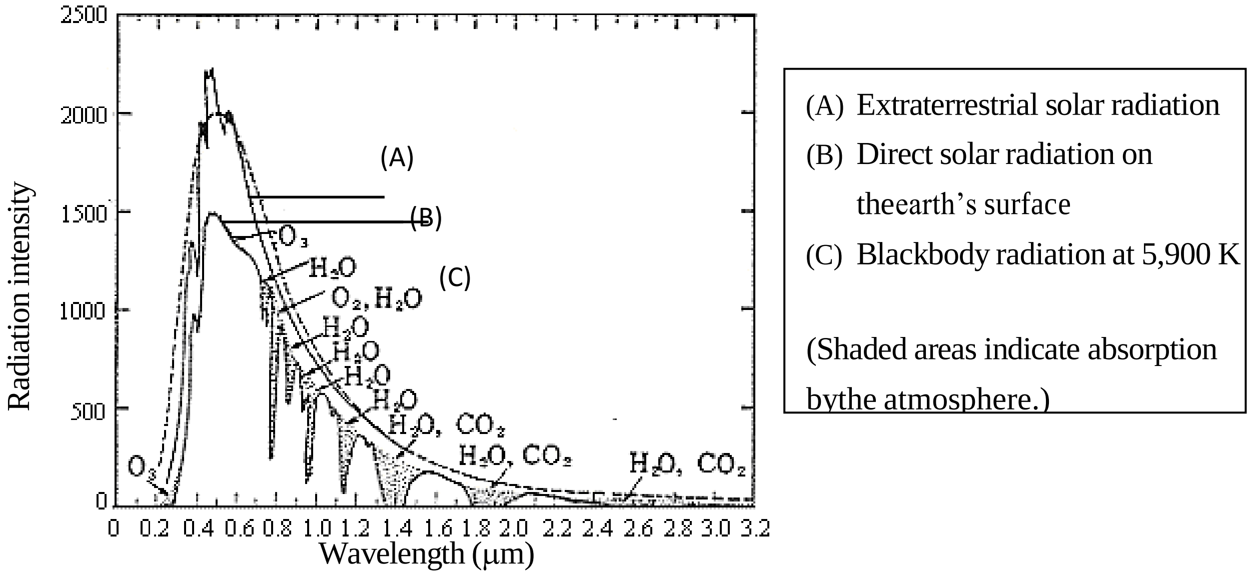


Figure . Spectrum distribution of solar radiation

Solar radiation is partly absorbed, scattered and reflected by molecules, aerosols, water vapor and clouds as it passes through the atmosphere. The direct solar beam arriving directly at the earth's surface is called direct solar radiation. The total amount of solar radiation falling on a horizontal surface (i.e. the direct solar beam plus diffuse solar radiation on a horizontal surface) is referred as global solar radiation.

Direct solar radiation is observed from sunrise to sunset, while global solar radiation is observed in the twilight before sunrise and after sunset, despite its diminished intensity at these times.

Units

The solar irradiance is expressed in watts per square meter (W/m2) and the total amount in joules per square meter (J/m2). Conversion between the currently used unit (SI) and the former unit (calories) can be performed using the following formulae:

Solar irradiance: 1 kW/m2 = 1.433 cal/cm2/min

Total amount of solar radiation: 1 MJ/m2 = 23.89 cal/cm2

In Japan, the total amount of global solar radiation per day is about 20 MJ/m2 in the summer in Okinawa and about 5 MJ/m2 in the winter along the Sea of Japan. The value of direct solar irradiance is about 120 W/m2 at around sunrise and sunset, and about 800 W/m2 at around noon on a clear day in summer. Being aware of mean solar radiation levels in clear conditions for each season is useful for checking normal operation of instruments.

Solar Radiation Measuring Instruments (Radiometers)

A radiometer absorbs solar radiation at its sensor, transforms it into heat and measures the resulting amount of heat to ascertain the level of solar radiation. Methods of measuring heat include taking out heat flux as a temperature change (using a water flow pyrheliometer, a silver-disk pyrheliometer or a bimetallic pyranograph) or as a thermoelectromotive force (using a thermoelectric pyrheliometer or a thermoelectric pyranometer). In current operation, types using a thermopile are generally used.

The radiometers used for ordinary observation are pyrheliometers and pyranometers that measure direct solar radiation and global solar radiation, respectively, and these instruments are described in this section. For details of other radiometers such as measuring instruments for diffuse sky radiation and net radiation, refer to "Guide to

Meteorological Instruments and Observation Methods" and "Compendium of Lecture Notes on Meteorological Instruments for Training Class III and Class IV Meteorological Personnel" published by WMO.

Pyrheliometers

A pyrheliometer is used to measure direct solar radiation from the sun and its marginal periphery. To measure direct solar radiation correctly, its receiving surface must be arranged to be normal to the solar direction. For this reason, the instrument is usually mounted on a sun-tracking device called an equatorial mount.

The structure of an Angstrom electrical compensation pyrheliometer is shown in Figure. This is a reliable instrument used to observe direct solar radiation, and has long been accepted as a working standard. However, its manual operation requires experience. This pyrheliometer has a rectangular aperture, two manganin-strip sensors (20.0 mm × 2.0 mm × 0.02 mm) and several diaphragms to let only direct sunlight reach the sensor. The diaphragms are the same as those in the silver-disk pyrheliometer in Figure. and in the thermoelectric pyrheliometer in Figure. The sensor surface is painted optical black and has uniform absorption characteristics for short-wave radiation. A copper-constantan thermocouple is attached to the rear of each sensor strip, and the thermocouple is connected to a galvanometer. The sensor strips also work as electric resistors and generate heat when a current flows across them (see the principle drawing in Figure.

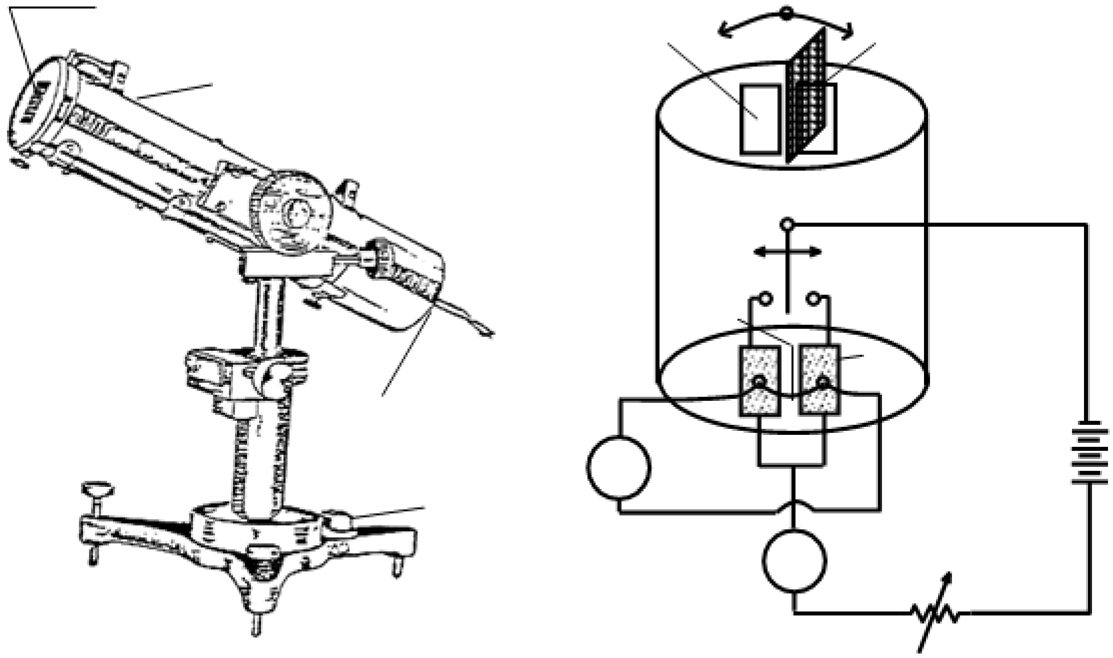


Figure Angstrom electrical compensation pyrheliometer

(a) Structure

(b) Circuit

A: Aperture B: Battery C: Sensor surface D: Cylinder

P: Switch R: Variable resistor S: Shutter

T: Thermocouple G: Galvanometer mA: Ammeter

When solar irradiance is measured with this type of pyrheliometer, the small shutter on the front face of the cylinder shields one sensor strip from sunlight, allowing it to reach only the other sensor. A temperature difference is therefore produced between the two sensor strips because one absorbs solar radiation and the other does not, and a thermos electromotive force proportional to this difference induces current flow through the galvanometer. Then, a current is supplied to the cooler sensor strip (the one shaded from solar radiation) until the pointer in the galvanometer indicates zero, at which point the temperature raised by solar radiation is compensated by Joule heat. A value for direct solar irradiance is obtained by converting the compensated current at this time. If S is the intensity of direct solar irradiance and i is the current, then

S = Ki2,

where K is a constant intrinsic to the instrument and is determined from the size and electric resistance of the sensor strips and the absorption coefficient of their surfaces. The value of K is usually determined through comparison with an upper-class standard pyrheliometer.

The structure of a silver-disk pyrheliometer is shown in Figure 7.7. This instrument was developed as a portable version of a water flow pyrheliometer, which was the former primary standard.

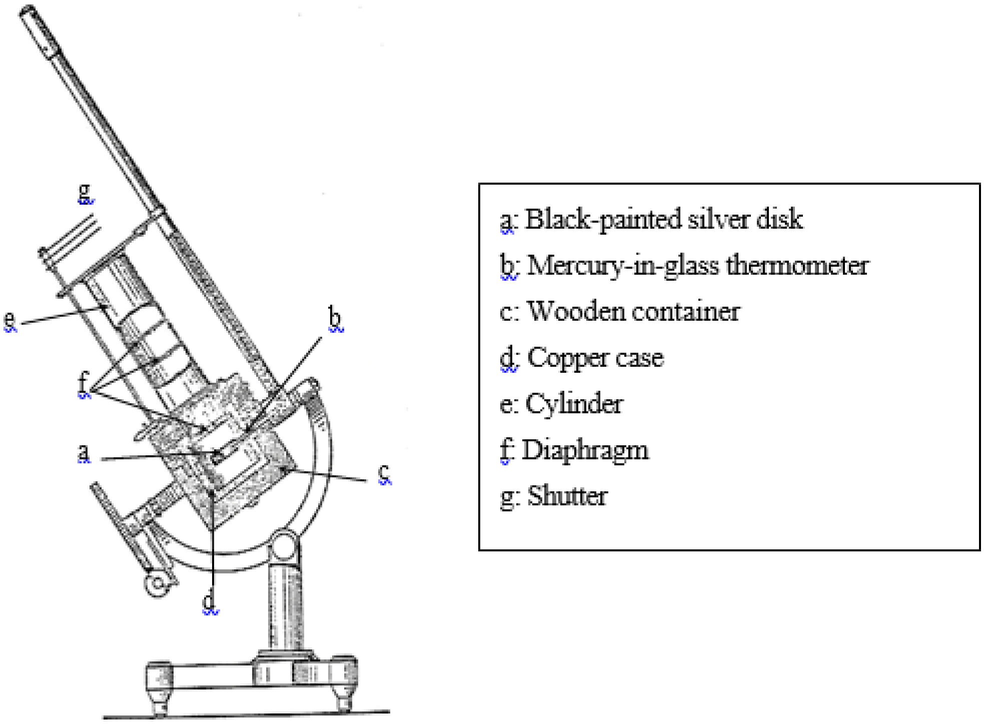


Figure | Silver-disk pyrheliometer

The sensing element is a silver disk measuring 28 mm in diameter with a thickness of 7 mm that is painted black on its radiation-receiving side. It has a hole from the periphery toward the center to allow insertion of the bulb of a high-precision mercury-in-glass thermometer. To maintain good thermal contact between the disk and the bulb, the hole is filled with a small amount of mercury. It is enclosed outside by a heat-insulating wooden container. The stem of the thermometer is bent in a right angle outside the wooden container and supported in a metallic protective tube. A cylinder with diaphragms inside is fitted in the wooden container to let direct solar radiation fall onto the silver disk. There is a metallic-plate shutter at the top end of the cylinder to block or allow the passage of solar radiation to the disk.

During the measurement phase, the disk is heated by solar radiation and its temperature rises. The intensity of this radiation is ascertained by measuring the temperature change of the disk between the measurement phase and the shading phase with the mercury-in-glass thermometer.

The structure of a thermoelectric pyrheliometer is shown in Figure. This instrument uses a thermopile at its sensor, and continuously delivers a thermos electromotive force in proportion to the direct solar irradiance. While Angstrom electrical compensation pyrheliometers and silver-disk pyrheliometers have a structure that allows the outer air to come into direct contact with the sensor portion, this type has transparent optical glass in the aperture to make it suitable for use in all weather conditions. It is mounted on a sun-tracking device to enable outdoor installation for automatic operation by JMA.

There are several types of thermoelectric pyrheliometer, but their structures are similar. Figure shows the structure of the one used by JMA. Copper-plated constantan wire is used as the thermopile in the sensor portion, which is attached to the bottom of the cylinder at right angles to the cylinder axis. The cylinder is fitted with diaphragms to direct sunlight to the sensor portion. It is made of a metallic block with high heat capacity and good thermal conductivity, and is enclosed in a polished intermediate cylinder and a silver-plated outer brass cylinder with high reflectivity to prevent rapid ambient temperature changes or outer wind from disturbing the heat flux in the radiation-sensing element. The cylinder is kept dry using a desiccant to prevent condensation on the inside of the aperture window.

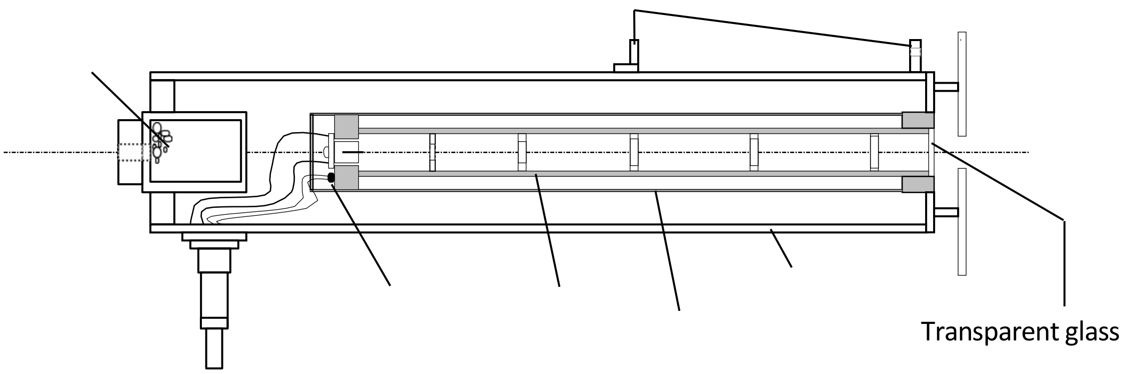


Figure .Thermoelectric pyrheliometer

In this pyrheliometer, a temperature difference is produced between the sensor surface (called the hot junction) and the reference temperature point, i.e., the metallic block of the inner cylinder (called the cold junction). As the temperature difference is proportional to the intensity of the radiation absorbed, the level of solar radiation can be derived by measuring the thermos electromotive force from the thermopile. Since this type of pyrheliometer is a relative instrument, calibration should be performed to determine the instrumental factor through comparison with a standard instrument. As the thermoelectromotive force output depends on the unit’s temperature, the temperature inside the cylinder should be monitored to enable correction.