Solar constant by pyrometer

FizziQ activity · High school · 120 min

Scan to open in FizziQ

A blackened pyrometer heats in sunlight while FizziQ Connect logs its temperature on a smartphone; students extrapolate the solar constant by Bouguer's method.

Learning objectives

- Measure solar irradiance at ground level with a simplified pyrometer
- Apply Bouguer's method to extrapolate irradiance to the top of the atmosphere
- Understand atmospheric absorption of solar radiation
- Calculate the Sun's surface temperature from the solar constant
- Use thermal measurements for energy calculations

Instruments and sensors

Temperature · Temperature probe (FizziQ Connect)

Materials

- Smartphone or tablet with FizziQ Connect
- M5 Stack with temperature probe
- Blackened metal cylinder pyrometer
- Insulated housing
- Protractor and plumb line
- Stopwatch
- Note: the protocol remains adaptable to any comparable temperature data-acquisition tool.

Protocol

1. Weigh the metal cylinder and note its mass m (in kg). Note its specific heat capacity c (in J/(kg·K)), given by the manufacturer.
2. Measure the radius Rc of the cylinder's circular cross-section to calculate the receiving area $S = \pi \times Rc^2$.
3. Connect the temperature probe to the M5 Stack and open FizziQ Connect. Place the probe in contact with the metal cylinder.
4. Set up the pyrometer with the shutter closed, orienting its entrance perpendicular to the Sun. Use the shadow cast by the device to align.
5. Wait for thermal equilibrium (stable temperature for 1 minute). Start recording and note the initial temperature θi.
6. Open the shutter at time ti. The cylinder heats up in the sunlight. Record for 2 to 5 minutes.
7. Close the shutter and note the final temperature θf at time tf. Calculate $\Delta t = tf - ti$ and $\Delta\theta = \theta f - \theta i$.
8. Measure the Sun's zenith angle z using the protractor and plumb line (z = 90° - Sun's altitude above the horizon), or calculate it from time and date.
9. Calculate the ground-level irradiance: $Es = m \times c \times \Delta\theta / (S \times \Delta t)$. Repeat measurements at different times of day (4 to 6 measurements).
10. Plot log(Es) versus 1/cos(z). The y-intercept of the straight line gives log(E_HA), where E_HA is the extraterrestrial irradiance. Compare with 1370 W/m².

Expected results

Ground-level irradiance Es typically varies from 400 to 900 W/m² depending on the Sun's height, sky clarity, and time of day. The plot of log(Es) versus 1/cos(z) gives a straight line whose y-intercept extrapolates to E_{HA} ≈ 1200-1500 W/m². With careful measurements, the value is within 10-20% of the accepted 1370 W/m².

Questions

- Why does ground-level irradiance vary during the day?
- What gases in the atmosphere are responsible for absorbing solar radiation?
- Why does Bouguer's method use the logarithm of irradiance?
- How can you estimate the Sun's surface temperature from the solar constant?
- What is the difference between direct and diffuse solar radiation?
- How is the solar constant used in climate models?

Going further

- Compare irradiance on a clear day versus a hazy day and quantify the atmospheric effect
- Measure the irradiance through different colored filters to determine the spectral distribution
- Calculate the total solar power received by the Earth and compare with global energy consumption
- Estimate the efficiency of a solar panel by comparing its electrical output with the measured irradiance
- Repeat measurements over several days and investigate the effect of weather on atmospheric transparency