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Estimate the Sun's temperature without leaving the school

Worksheet 2: Calculating the Sun's surface temperature

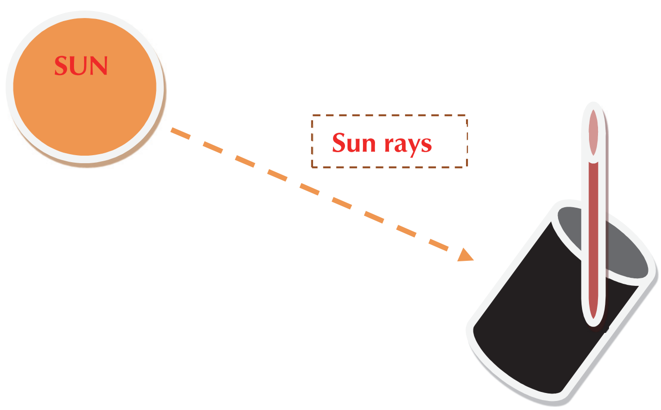

Image courtesy of the author

1. Fill the can and either measure the volume of water used or measure the change in mass. Also record the initial temperature of the water.
   Tip: the density of water is 1 g/ml, so 350 ml weighs 0.35 kg.
   Water volume (V) = _______________
   Initial temperature (T_{in}) = _______________

2. Determine the dimensions of the black cylindrical can and calculate the surface area that is directly exposed to solar radiation.

   Height of the can (H) = _______________
   Diameter of the can (d_c) = _______________
   Surface of the can projected to the Sun (A_{cp}) = _______________

3. Why do we use a black metal can?

   ____
   ____
   ____

4. Note down the following astronomical information, which will be needed for later calculations:
   Distance between the Sun and the Earth ($D_{S\text{-}E}$) = _______________

   Radius of the Sun (R_{sun}) = _______________

   Surface area of the Sun (A_{sun}) = _______________

   Surface of a sphere with a radius equal to the distance between the Sun and the Earth (A_{sph}) = $4 \times \pi \times (D_{S\text{-}E})^2$ = _______________

5. After Δt = 15 min = 900 s, measure the final temperature with the thermometer and calculate the difference between the initial and final temperatures.
   a. Final temperature (T_f) = _______________
   b. $\Delta T = T_f - T_{in}$= _______________

6. Calculate the amount of heat required, E_{can} ($Q = mc\Delta T$), and the rate of heat transfer to the can (P_{can}). The specific heat of water is approximately 4186 J kg^{-1} K^{-1} or 1 cal g^{-1} °C^{-1}.

   $Q = E_{can}$ = _______________ $P_{can} = Q/\Delta t$ = _______________

The can only captures a tiny fraction of the Sun's total energy. To estimate the Sun's total energy output, we need to scale up the energy absorbed by the can to the total energy emitted in all directions. We do this by multiplying the energy transfer to the can (Ecan) by the ratio of the surface area of a sphere at Earth's distance, with radius 1 astronomical unit (AU) – the distance between the Sun and the Earth (Asph) – to the can's projected area (Acp). This effectively calculates the total energy that would spread out over that sphere.

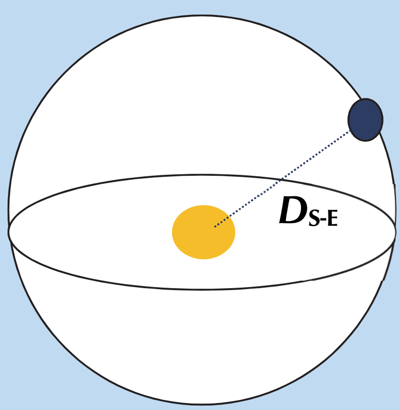

Image courtesy of the author

7. Calculate the total energy output of the Sun:

   $E_{sun} = E_{can} \times (A_{sph} / A_{cp}) =$ ________________________________

8. Calculate the estimated total power of the Sun, based on the experiment, by dividing the total energy of the Sun by the exposition time of the can.

   $P = E_{sun}/\Delta t =$ ________________________________

9. Determine the total intensity, I (power per total area), by dividing the power by the surface of the Sun.

   $I = P/A_{sun} =$ ________________________________

10. Finally, use the Stefan–Boltzmann law to calculate the temperature of the Sun's photosphere.

    $T_{sun} = (I/\sigma)^{1/4} =$ ________________________________

11. Look up the temperature of the Sun and determine the absolute error (difference between the calculated value and the actual value) and relative error of the measurement (ratio between the absolute error of a measurement and the actual value).

    Actual temperature of the Sun: _______________

    Absolute error: _______________

    Relative error: _______________