LAB #7 - Luminosity of the Sun from a light bulb

Work with your lab partner and hand in one copy of the lab per group. All group members are expected to contribute equally.

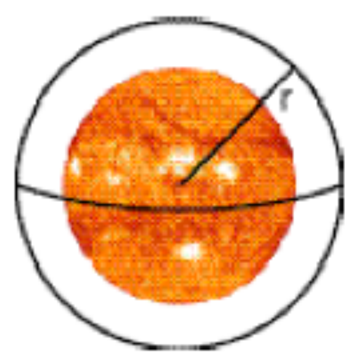
Purpose: Familiarize yourself with the concept of flux vs luminosity, and the workings of inverse-square laws. Use a light bulb and a rudimentary photometer (the palm of your hand!) to determine the luminosity of the sun.

Materials: A light bulb, your hands, and a tape measure.

Introduction: In the experiment today, you will estimate the solar **flux** at the surface of the earth and then use it to calculate the sun's **luminosity**. **Luminosity** is the total amount of energy output per unit time, and is often expressed in Watts (like a light bulb).
Flux is the amount of energy moving per unit surface area in a certain amount of time, and is expressed in Watts/m^2. Therefore, luminosity is independent of distance to the light source - it is an intrinsic property of the object emitting it, and flux is the measurement of the energy received at a certain distance from the light source.

A) Visualizing Luminosity and Flux

Imagine you could completely surround the sun with a sphere that is just a little bigger than the sun itself (as shown in figure below). If you did this, then you would be able to "capture" the total energy output of the sun within this sphere, and all of the light from the sun, it's total luminosity, would pass through it.



1. Suppose you now put a larger sphere around the sun. What would happen to the Sun's luminosity (luminosity = energy output per unit time)? Would it get large or smaller? Why?

2. The formula for the surface area of a sphere is $4\pi r^2$, where r is the radius of the sphere. If the radius doubles, how much does the surface area increase by? One quick way to figure it out would be to plug two numbers into the equation, one twice as much as the other. Try this with a number 3 and 4 times as large as well. What is the relationship between surface area and radius?

3. The solar luminosity is a constant no matter where you are relative to the sun (you may wish to revisit your answer to question 1 at this point), however the flux, or amount of energy received per unit area, varies according to the distance. Describe this phenomenon in your own words, and using the sun + imaginary sphere example. Drawing a picture may help.

In order to calculate the flux (F) at a certain distance (d) from an object with luminosity (L) you divide the luminosity by the surface area of the sphere with a radius equal to the distance d to the light source:

$$F = \frac{L}{4\pi d^2}$$

B) Your hand as a "photometer"

1. In order to measure brightness we need something called a photometer. As the name indicates, this is a device that measures (or meters) the amount of light (photons). Hold your palm up to the light bulb. If you place it very close to the bulb (but don't touch it!), it should feel very warm. As you increase the distance from the light bulb, your hand should feel cooler. What do you think is going on? Why is your hand getting hot? Which quantity – luminosity or flux – is your hand measuring and why?
2. In order to estimate the solar flux, hold the palm of your hand in front of the light bulb. Close your eyes, and adjust your distance to the bulb, so that the warmth your hand feels from the bulb is comparable to the warmth of the sun on a nice spring day (~75 degrees). Open your eyes when you find the right distance and have one of your lab partners use a measuring tape to find the distance between your palm and the filament (center) of the bulb. Repeat the experiment for each member of your group and record all of your answers in your lab sheet.
3. Now, average your individual distances to obtain a group average distance, d, and record it. Why is the average of your results in principle better than an individual measurement?
4. Compute the flux emitted by the light bulb at your group distance d using the equation in section A. Remember to express the distance and flux in the correct units. Ask your instructor for help if you are not sure.

C) Computing the Sun's Luminosity from its flux at 1 A.U.

In the previous section, you used your "hand photometer" and a light bulb to estimate the solar flux on a nice spring day. Using the light bulb's luminosity and the distance between your hand and the bulb, you obtained a numerical value for that flux.

1. You can now use this estimate for the solar flux on Earth to calculate the luminosity of the sun. You need one more quantity before you do this. What is it? Get the value from your instructor and write it down here.

2. Calculate the luminosity of the sun in Watts, showing your work.

D) Error Estimate

1. The true luminosity of the sun is 3.9×10^{26}W. How close is this to your estimate? Calculate the error in your estimate using the formula below, where V is the true value and E is your estimated value

$$\text{Error} = \frac{E-V}{V}$$

2. Your answer to question 1 is the error in your measurement represented as a decimal, but it is often most useful when represented as a percentage. Convert it to a percentage.
3. Write a paragraph reflecting on this answer. How good was your estimate? What were the sources of error in your measurement? Were you surprised by your answer?
4. How many times brighter is the sun than a lightbulb? How many times farther away is it? Are these quantities related?
5. Recent estimates place the world's total power consumption at 15 TeraWatts, where tera is the metric system prefix for trillion, or 10^{12}. How many light bulbs is this equivalent to? How does our global energy consumption compare to the energy output of the sun?

E) Seasons

The solar flux at 1AU is always the same, however the temperature at Earth's surface changes over the course of the year according to the season. We learned in the last unit that the small deviation in the Earth-Sun distance due to its (slightly) elliptical orbit is not the cause of the seasons, so it's reasonable to say that the solar flux arriving at Earth is a constant.

1. Based on what you know about the cause of the seasons, explain why the flux received by the Earth is always the same, but the temperature varies according to your location on the surface. (Hint: What is the luminosity of a flashlight? What is the flux in the spot it creates when you shine it on the wall? What factors affect it? There is more than one!)
2. Why did I have you estimate the luminosity of the sun on a spring day and not a summer or winter day? Did I have to choose spring? Why or why not?

F) On Jupiter

1. What will the solar flux be at the distance of Jupiter (5 A.U.)?
2. How far from the light bulb will you have to go to get the same flux?
3. Place your hands at that distance. Do you feel warmth from the bulb? The temperature at the surface of Jupiter is only -234 Fahrenheit! It's quite cold, and the sun is very faint in the sky.