ASTRONOMY 101A (Fall Semester 2002)

ESTIMATING THE SOLAR FLUX WITH YOUR HANDS

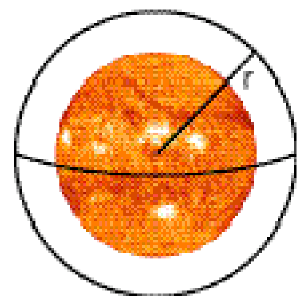
Objective: In the experiment today, you will estimate the solar flux at the surface of the earth. *Flux* is the amount of energy moving through a surface area in a certain amount of time. However, energy per time is just what astronomers call *luminosity* and is often expressed in units of *Watts*.

Procedure: Read the experimental description and do the activities working in pairs (or more). Answer the questions and turn in the experiment by the specified time.

Part I: Visualizing Luminosity and Flux

Luminosity: Luminosity is the term for the total energy output per second of an object. Luminosity has units of Watts (like a light bulb!)

Imagine you could completely surround the Sun with a sphere, or bubble, that is just a little bigger than the Sun itself (as shown in the picture to the right). If you did this, then you would be able to "capture" the complete energy output of the Sun with this sphere. The total solar luminosity passes through the sphere.



Q1: Suppose you now put a larger sphere (say twice the diameter) around the Sun. What would happen to the Sun's luminosity?

Flux: The flux through a surface is defined as the total luminosity passing through a surface per unit area. It has units of Watts per meter squared.

Since solar flux is essentially the energy from the Sun per unit area passing through a surface, it is equal to the total energy output of the Sun (its luminosity) divided by the surface area of the sphere diagrammed above.

Q2: How does the surface area of a sphere change if the radius of the sphere increases?

If the solar luminosity is constant, then as the surface area of the sphere decreases, we are dividing the same energy over a smaller area, resulting in an increased flux of energy per unit area…

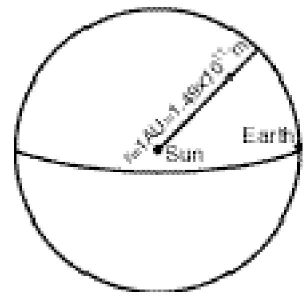
Q3: Now suppose you increase the size of the sphere around the Sun. How would the Solar flux through that sphere change?

Part II: Computing the Solar Flux

The solar flux can be described by as the total solar luminosity divided by the surface area of the sphere it is spread over. An equation that states this relationship between Flux and Luminosity for our Sun can be written:

$$F_{sun} = \frac{\text{Total Solar Luminosity}}{\text{Surface Area of Sphere}} = \frac{L_{sun}}{4\pi r^2} \qquad \text{[Eqn. 1]}$$

where L_{sun} is the total solar luminosity (the total energy per second output by the Sun) and r is your distance from the center of the Sun. And r is also the radius of the hypothetical sphere we have been talking about. Examine the term in the denominator: $4\pi r^2$. This is the expression for the surface area of a sphere with radius r.



We know that the Sun's Luminosity (it's total energy output) is 3.8×10^{26} Watts. Suppose that we put a huge sphere around the Sun that has a radius of 1.49×10^{11} meters (which is coincidentally the distance from the Earth to the Sun, a.k.a. one astronomical unit). The flux through that sphere will be the solar flux at the Earth's distance. Let's calculate it.

Q4: Compute the flux of the Sun through this huge sphere which has a radius equal to Earth's average distance from the Sun.

Q5: If you made the sphere even bigger (say the radius of Jupiter's orbit, 5.2 AU), how would the flux change?

Part III: Estimating the Solar Flux

Now, we don't happen to have a flux-meter available, so we can't measure the solar flux outside to test our calculation above (Question **Q4**). Instead we will estimate the value for solar flux, just using your memory of what a warm spring day feels like.

a. Turn on your 100 Watt light bulb. Without touching the light bulb, cup your hands around the light bulb *around the sides of the light bulb* to as if they were on the surface of a sphere centered on the light bulb. Note that you won't be able to completely enclose the light bulb with your hands (and probably shouldn't).
b. The luminosity of the light bulb is always 100 Watts. But the flux you measure with your hands depends on how big a sphere you make with them.

Q6: Do you feel the same flux from the light bulb when you're making a small and large sphere around the bulb with your hands? In other words, do your hands feel the same amount of heat in both cases?

c. Have each member of your group take turns and place their hand ***to the sides*** of the light bulb with palms toward the light bulb. Close your eyes (no peeking!) and adjust the distance your hands from the bulb until it feels as warm as the sun does on a calm, warm spring day (around 70ºF or 22˚C). Pause your hands at each distance to get a good feel of the warmth.

d. When you think it feels right have another member of your group measure and record the distance between your hands and the center of light bulb. **The easiest way to do this may be to measure the distance between your hands and divide by two, assuming the light bulb is half way between your hands.** Use the table below. Be sure to use the metric system and record in meters, not centimeters (1 cm = .01 meter). **Get the measurements from enough other people (ask them) to fill in the table below (*i.e.* – obtain a total of 6 measurements).**

Distance from Filament (in meters) (This is the sphere's radius)	**Compute the resulting Flux at hands (Watts/meter^2) (Your estimate of the Solar Flux using Eqn 2)**
1.	
2.	
3.	
4.	
5.	
6.	

e. Picture a spherical surface with the radius equal to the distance of your hands from the light bulb. All the luminosity of the light bulb (100 Watts) must uniformly cross this surface. With this knowledge, calculate the light bulb flux using each of the six measurements of the hands' distance from the light bulb filament, using a variant of equation 1 appropriate for this problem:

$$F_{hand} = \left(F_{sun}\right)_{estimated} = \frac{\text{Total Light Bulb Luminosity}}{\text{Surface Area of Sphere}} \qquad \text{[Eqn. 2]}$$

$$= \frac{100\,Watts}{4\pi r^2}$$

This is your estimate of the solar flux.

f. Now calculate the flux at the distances from the filament recorded in the table. Record these in the table above.

g. These flux measurements are estimates of the Solar Flux. Now any one measurement might be influenced by *a person's perception* of what a warm spring day feels like, but let's take the average of all the measurements to see if you can have a better estimate of the solar flux:

Average Estimate of the Solar Flux (W/m^2): _______________________

Using the multiple estimates of the Solar Flux, also compute the uncertainty in your above average solar flux estimate (**hint:** recall the uncertainty exercise we did a few weeks ago… use what you learned there).

h. Only 60% of the solar radiation incident on the top of the earth's atmosphere makes it to the surface of our planet! 40% is reflected off the cloud tops. Since you based your estimate on the value of the flux you experience at the bottom of the atmosphere, then you have underestimated the solar luminosity by 40%. Correct your estimate of the solar flux for this reflection. Explain how you went about correcting for it and record your new estimate for the total solar flux below.

Your corrected estimate of Solar Flux ($Watts/meter^2$): _______________________
(also correct the uncertainty in the average estimate you previously computed)

Q7: How does your corrected estimate of the solar flux compare to your original average estimate? Does this make sense?

How does your corrected estimate (with its uncertainty) for the solar flux compare to the number you calculated in **Q4**? Remember, your corrected estimate (given in **Q6**) is what you remember the solar flux to be at the Earth's distance whereas the answer you gave in **Q4** is what you calculated the solar flux to be from known values for the solar luminosity and the Earth's distance from the Sun.

If your corrected estimate is within a factor of two of the calculated value (from **Q4**), then you did very well! You are finished. Unplug your light bulb and go out and absorb some solar radiation!