Computing the Sun's Luminosity and Lifetime
LAB IS NOW DUE MONDAY, MARCH 8

1. Solving for the Sun's luminosity (or the solar luminosity) requires several steps, which are outlined below.
(a.) What is the average distance between the 300-watt bulb and your photometer (in cm)? How many meters is this? This distance in meters is the value of $d_{\text{bulb}}$ to use in (b.). The Sun is about $1.5 \times 10^8$ km from the Earth. How many meters is this? This distance is the value of $D_{\text{Sun}}$ to use in (b.). Be careful to express these distances as a number with a unit (e.g., 10 cm rather than just the number 10).

(b.) Equation (3) is reproduced below and then re-arranged algebraically to isolate $L_{\text{sun}}$ which is the quantity we are measuring:

\[
\frac{L_{\text{Bulb}}}{4\pi d_{\text{Bulb}}^2} = \frac{L_{\text{sun}}}{4\pi D_{\text{sun}}^2} \quad (3)
\]

So

\[
L_{\text{sun}} = \frac{L_{\text{Bulb}}}{4\pi d_{\text{Bulb}}^2} \cdot 4\pi D_{\text{sun}}^2 = \frac{L_{\text{Bulb}}}{d_{\text{Bulb}}^2} \cdot D_{\text{sun}}^2
\]

Plug in the numbers on the right hand side of the equation and compute $L_{\text{sun}}$. This will be your derived value of the Sun's luminosity.

2. (a.) The accepted value of the Sun's luminosity is $L_{\text{sun}} = 3.8 \times 10^{26}$ W. How does your value compare to the accepted value (express this comparison mathematically by stating “My value is XX% greater [or smaller] than the accepted value).

(b.) Why do you think your derived values for the Sun's luminosity is different than the average accepted values? (Hint #1: The light bulb filament is cooler than the surface of the Sun, so it is only 1/3 as efficient in converting watts to visible light. Hint #2: Think about the sources of error in measurement, etc.)
3. Use your derived value of the Sun's luminosity from Question #1 to predict how long the Sun will continue to burn. Recall that the Sun is converting 4 hydrogen atoms to one helium atom in its core, and that a small amount of matter is converted to energy in this process. Einstein’s famous equation, $E = mc^2$, expresses how much energy is produced when mass is converted to energy. A Watt is the same as 1 Joule/second and a Joule is a unit of energy. The Sun’s luminosity can be equated to the energy produced from the rate at which mass is being converted in the core of the Sun: Fill in the blanks in the equations below:

$$L_{\text{Sun}} = \frac{\text{Energy}}{\text{second}} = \frac{\text{kg} \cdot c^2}{\text{second}}$$

$$\frac{L_{\text{Sun}}}{c^2} = \frac{\text{kg}}{\text{second}}$$

The value of $c$, the speed of light, is $3 \times 10^8$ meters/second. Substitute for $c$ and use your measured value for $L_{\text{Sun}}$ to compute the rate at which mass is being converted to energy in the Sun’s core:

$$\frac{L_{\text{Sun}}}{c^2} = \text{Rate of mass conversion to energy} = \frac{L_{\text{Sun}}}{c^2} = \frac{\text{kg}}{\text{second}}$$

When hydrogen is converted to helium, only a small fraction of the original mass of hydrogen is converted to energy; most of the mass remains as helium. Only 0.7% of the hydrogen mass disappears and is converted to energy. At what rate is hydrogen participating in the conversion of H to He:

$$\text{Rate of hydrogen conversion to helium} = \frac{L_{\text{Sun}}}{c^2} \times 0.007 = \frac{\text{kg}}{\text{second}}$$

Only the hydrogen in the core of Sun where the temperature and pressure are sufficiently high can be converted to helium. The core contains 10% of the mass of the Sun. The mass of the Sun is $2 \times 10^{30}$ kgs. Compute the mass of the Sun’s core:

$$\text{Mass of the core of the Sun} = \text{Mass of the Sun} \times 0.10 = \frac{2 \times 10^{30}}{10} = \text{kg}$$

If hydrogen is being converted to helium at the rate you calculated above, how long will it take to convert all the mass in the core of the Sun to helium? (express your answer first in seconds and then convert to years; The number of years is the number of seconds divided by 3 X $10^7$ seconds/year).

$$\text{Time to convert all the mass in the core} = \text{Mass of the core} / \text{Rate of conversion} = \frac{\text{kg}}{\text{kg/second}} = \text{seconds}$$

$$= \text{years}$$