3. Measuring the Sun's Luminosity in Watts

1. This is an outside activity. Each group of students will be given a 300-watt bulb, an extension cord, a photometer, a ruler, and a large piece of black poster board.

2. Turn the light bulb on.

3. Hold the photometer between the Sun and the bulb with the bulb's filament parallel to the face of the photometer. Hold the other face of the photometer towards the Sun (see Figure 4). One of you should hold the cardboard baffle around the paraffin block. Try to point the face of the paraffin block directly at the Sun.

4. Move the photometer toward and away from the Sun, stopping when the two sides have the same apparent brightness. The temperature difference between the Sun and the bulb will cause a color difference on either side of the paraffin. Just keep in mind that the apparent brightness on both sides of the paraffin should be similar rather than color.

5. Hold the photometer steady while a member of your group measures the distance in centimeters between the bulb filament and the aluminum in the photometer. Assume that the filament is at the center of the bulb. Make observations as carefully and consistently as you can. Record each measurement on the data sheet passed out in class (also shown at left). Record the weather conditions.

are needed. On the other hand, if the five measurements are fairly close in value, average them to yield a single measurement.

Table 1: Photometer measurements.

<table>
<thead>
<tr>
<th>Measurement #1</th>
<th>Bulb distance, $d_{\text{Bulb}}$ (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement #2</td>
<td></td>
</tr>
<tr>
<td>Measurement #3</td>
<td></td>
</tr>
<tr>
<td>Measurement #4</td>
<td></td>
</tr>
<tr>
<td>Measurement #5</td>
<td></td>
</tr>
<tr>
<td>Average Value =</td>
<td>Values from 3-20cm are likely</td>
</tr>
</tbody>
</table>

Weather Conditions: (circle best choice)

A. Clear
B. Some thin clouds away from the Sun -- B. was correct for a few students
C. Some thin clouds covering the Sun
D. Some thick clouds away from the Sun

Figure 4. Comparing the brightness of the Sun to a 300-Watt light bulb.
4. Viewing the Sun Through the Telescopes

As you look through the various telescopes that will be setup near the Lecture Hall, sketch what you see on the circle below representing the Sun. Indicate what color the feature has. Image might have been reversed.

Yellow

Black

might have seen a red flare
Name: ______________________________

Print out this page and the following three pages. Please turn in these four pages as well as your data sheet and drawing from the lab.

This portion of the lab is to be done on your own after class.

Answer the questions below. You can get views of the sun over the internet at the following URLs:

http://coolcosmos.ipac.caltech.edu/cosmic_classroom/multiwavelength_astronomy/multiwavelength_museum/sun.html

and some individual examples at:

http://sohowww.nascom.nasa.gov/sunspots/ for broad band visible


http://umbra.nascom.nasa.gov/images/latest_eit_171.gif for extreme ultraviolet/soft X-ray

Compare the appearance of the sunspots in the pictures at these web sites.

Use the images at these sites to answer the following questions (use the links above):

Because they are cooler than the surrounding photosphere, they are dark in the ______

a.) visible (continuum, sometimes called white light)  
b.) H alpha emission

c.) Ultraviolet/X-ray

Because they are the sites of high energy particles, they or the surrounding regions are bright in the __________

a) visible (continuum, sometimes called white light)  
b.) H alpha emission

c.) ultraviolet/X-ray

Hot gas streaming out into the corona from active regions becomes clear in the __________

a.) visible  
b.) H alpha emission

c.) Ultraviolet/X-ray either of these is OK
Computing the Sun’s Luminosity and Lifetime

These calculations are easiest using scientific notation. Visit http://janus.astro.umd.edu/astro/scinote/ if you need practice. We have also created a web site to assist you with these calculations in case you are unfamiliar with using scientific notation on your calculator. Go to http://ircamera.as.arizona.edu/Astr170B1/Web_sheet.htm to find it. You enter values in the yellow cells and values that correspond to some of the steps below have blue boxes around them. One quirk of this web site is that you must enter values using the format for scientific notation used in spreadsheets like Excel: \( 1 \times 10^{12} \) would be entered as \( 1e12 \), for example. Be careful that the default values that appear are completely overwritten by your entries. You may use the option to email your web sheet to the professors but please transfer your results to the appropriate places on these pages (and complete the steps that are not present on the web page).

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 distance to the Sun, \( D_{\text{Sun}} \) is about \( 1.5 \times 10^8 \) km from the Earth. How many meters is this? This distance in meters is the value of \( D_{\text{Sun}} \) to use in (b.). Be careful to express these distances as a number with a unit (eg., \( 10 \) cm rather than just the number \( 10 \)). You will find it convenient to use scientific notation.

   \[ d_{\text{Bulb}} \quad \text{-- range from 0.04 to 0.20 meters} \quad D_{\text{Sun}} = 1.5 \times 10^{11} \text{ meters} \]

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

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

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

   So

   \[
   L_{\text{Sun}} = \frac{L_{\text{Bulb}}}{d_{\text{Bulb}}^2} \times D_{\text{Sun}}^2
   \]

   Plug in your values on the right hand side of the equation and compute \( L_{\text{Sun}} \) either using the web site or your calculator.

   Write down the equation for \( L_{\text{Sun}} \) with your values entered:

   \[
   L_{\text{Sun}} = \frac{300 \text{ watts}}{(.13m)^2} \times (1.5 \times 10^{11} m)^2
   \]

   Computed value of \( L_{\text{Sun}} \) from the web site or your calculator \( 3.99 \times 10^{26} \text{ watts} \)
2. (a.) The accepted value of the Sun's luminosity is \( L_{\text{sun}} = 3.8 \times 10^{26} \text{ Watts} \). 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). 

5\% greater (but your values might be 200-300\% greater or smaller)

(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.)

- light bulb may have aged and no longer produces 300 Watts
- light bulb is cooler than the Sun so one is not comparing the output over the same set of wavelengths
- problems with estimating the location of the center of the bulb
- atmosphere might not have been completely transparent (clouds, dust, etc)

Need at least one of these items to get credit

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. 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 equation below using your value for \( L_{\text{sun}} \) from question 1 b:

\[
L_{\text{Sun}} = 3.99 \times 10^{26} \frac{\text{Energy}}{\text{second}} \quad (\text{units are the same as} \quad \frac{\text{kg} \ c^2}{\text{second}})
\]

(should be their value from previous page)

so doing some algebra and using \( c = 3 \times 10^8 \text{ meters/second} \), compute using the web site or your calculator

\[
\frac{L_{\text{Sun}}}{c^2} = \frac{4.44 \times 10^9}{\text{second}} \frac{\text{kg}}{\text{second}}
\]

(ie, divide your value for the Sun’s luminosity by the speed of light squared, web sheet can help here)

which gives the rate at which mass is being converted to energy in the Sun’s core meaning that every second some number of kilograms are turning into energy that powers the Sun.
Name:_____________________________

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:

\[
\text{Rate of hydrogen conversion to helium} = \frac{\text{rate of mass conversion from above}}{0.007} = \left(\frac{\text{L}_\text{Sun}}{c^2}\right) = \frac{\text{L}_\text{Sun}}{0.007} = \frac{6.34 \times 10^{11} \text{ kg/second}}{0.007} = 6.34 \times 10^{11} \text{ kg/second}
\]

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 x10^{30} kgs. Compute the mass of the Sun’s core.

\[
\text{Mass of the core of the Sun} = \frac{2 \times 10^{29}}{10\%} = 2 \times 10^{29} \text{ kg}
\]

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).

\[
\text{Time to convert all the mass in the core} = \frac{\text{Mass of the core}}{\text{Rate of conversion}} = \frac{2 \times 10^{29}}{6.34 \times 10^{11} \text{ kg/second}} = 3.15 \times 10^{17} \text{ seconds}
\]

\[
\frac{3.15 \times 10^{17}}{3 \times 10^{7}} \text{ years} = 1 \times 10^{10} \text{ years}
\]