Activity 4

Luminosity of the Sun and Stars

Relevant Reading

Chapter 1, section 4; Chapter 2, sections 2, 3, and 4; Chapter 3, sections 1–4

Purpose

Two different types of photometers will be described here with slightly different purposes in mind. One is for bright objects such as the sun, moon, close lights, etc., and the other is for very dim light comparisons such as stars in the night sky. The second type is easier to make and use, so it will be described first.

Materials

Dim Light Comparator

> 2 index cards per student
> scissors or paper punch
> cellophane
> glue

Bright Light Photometer

> aluminum foil
> block of paraffin
> rubber bands
> nail or knife
> different wattage light bulbs

Procedures

A. Making a dim light comparator:

1. Get 2 3"x5" index cards and with them aligned, cut 5 holes about 10 mm square (or round) equally spaced across the card.

2. Separate the cards and across all 5 holes on one card, place a strip of clear cellophane so that all 5 holes are covered. Glue it in place.

3. With a shorter strip of cellophane, cover 4 of the holes, leaving the first hole with only one layer of cellophane, but the next 4 holes having 2 layers. Glue this strip into place.

4. Repeat this process so that each hole has one more layer of cellophane than each preceding hole—1 layer for hole 1, 3 layers for hole 3, etc.
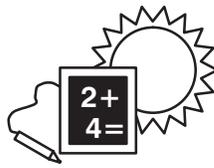
5. Place the second card over the first so that the cellophane is sandwiched between them and tape the edges closed.

6. When using this with dim objects, look at the objects through the different holes until it is just barely visible. After this is calibrated as described below, this can be used to measure the visual light magnitude of different stars.

Calibration:

1. Take your comparator out on a clear night, preferably to a location with little light pollution and locate the constellation of Draco (the Dragon) or the asterism called the Big Dipper.

2. If Draco is used, find the 4 brightest stars in the head. The brightest star should be visible through the fifth hole, but if not, move to the fourth hole, and so on until it is visible. Mark the hole with a "2.2" value.

3. Use this table to calibrate the other holes.

Stars in Draco	Visual Magnitude	Approximate Magnitude
Elatin	2.2	2
Rastaban	2.8	3
Grumium	3.8	4
Kuma	4.9	5

4. If the Big Dipper is easier to find, calibrate the holes in the same way using these values:

Stars in the Big Dipper	Visual Magnitude	Approximate Magnitude
Dubhe	1.8	2
Alkaid	1.9	2
Mergret	3.3	3
Alcor	4.0	4

5. If you feel you need a more accurate calibration, or you modify the comparator to have a wider range, here are some more values.

Star	Constellation	Visual Magnitude
Sirius	Canis Major	−1.46
Arctaurus	Bootes	−0.04
Vega	Lyra	+0.03
Betelgeuse	Orion	0.5
Antares	Scorpius	0.96
Spica	Virgo	0.98
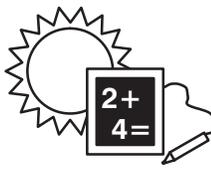
Polaris	Ursa Minor	2.02
Sadalmalik	Aquarius	2.96
Alberio	Cygnus	3.08
Alcor	Ursa Major	4.01
Kuma	Draco	4.88

6. The list below gives some magnitudes for a number of the more familiar objects.

Apparent Magnitude	Object
–26.7	Sun
–12.5	full moon
–1.5	Sirius (brightest star)
+0.5	Betelgeuse
2.0	Polaris (the north star)
6.5	limit of unaided eye under ideal conditions
9.0	limit of 7x50 binoculars
13.0	visual limit of 8" telescope
24.0	photographic limit of 200" telescope
28.0	limit of the Hubble Space Telescope

Using the comparator:

1. Once calibrated, the comparator can be used to find the magnitudes of any of the stars you see. The accuracy will depend on several factors:

    The "seeing" conditions of the sky being the same as the night the device was calibrated (or recalibrate with each use)

   How well the calibration was done

    Your judgment in matching the visibility through the holes

2. Measure a number of well known stars and compare your values to the accepted values from a reference book or chart. You should be able to get the whole number values fairly well after a little practice, but fractions will be difficult without more sophisticated techniques.

3. Use the comparator to find the magnitude of lights in your neighborhood. Look at bulbs of the same wattage but placed at different distances from you. By carefully measuring the distances and the magnitude, you might be able to determine the mathematical relationship that describes brightness and distance.

4. Use your device to place lights of different wattages (maybe 60 watts and 100 watts) at different distances so that they appear equally bright. Try
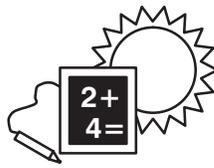
this with several wattages and again see if you find the brightness-distance relationship.

5. Does the size of the light source make a difference and how could this be tested? Explain how a large object and a small one could appear equally bright at the same distance. What could this reveal about the actual energy released by each object?

6. How could you modify the design of this comparator to measure much brighter objects?

B. Making a bright light photometer:

1. Obtain a piece of aluminum foil about 60 mm×120 mm, two rubber bands, and a block of paraffin wax also 60 mm×120 mm.

2. Make a deep scratch in the center of the wax block with a nail or point of a knife. Snap the block in half along the sharp edge of a table or desk.
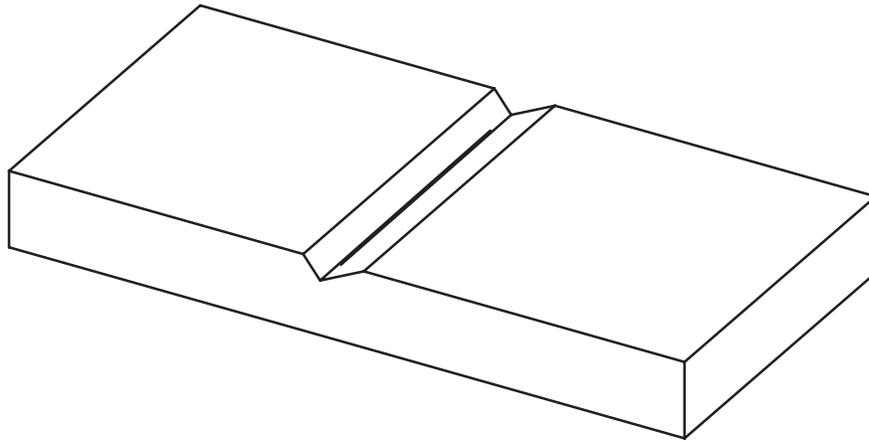

3. Fold the foil in half to form a 60 mm×60 mm square, shiny side out, and place it between the paraffin blocks.

4. Rubber band the unit together near the edges

two paraffin blocks

foil layers

A   B

rubber bands
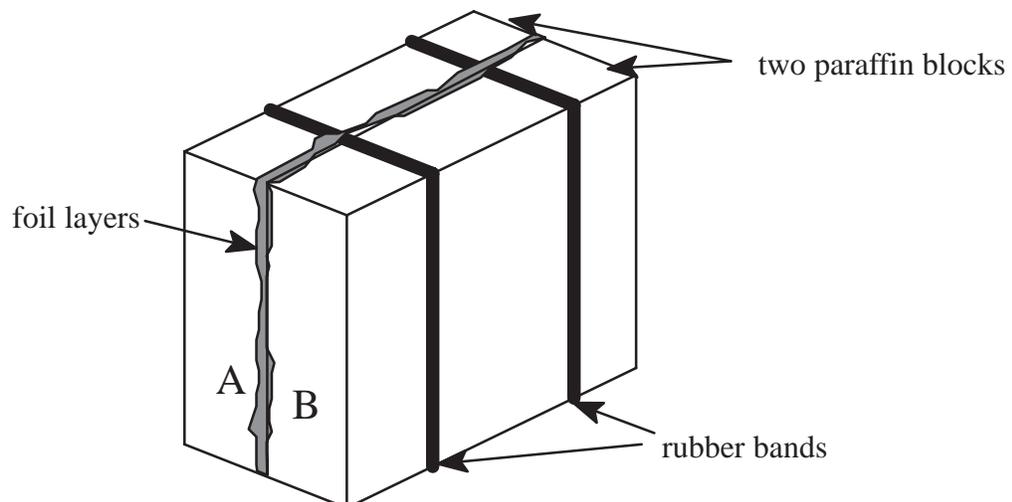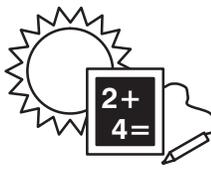
5. Lights placed on opposite sides of the foil illuminate the blocks and the brightness of the wax at points A and B can be compared. See the arrangement below.

Photometer

Light source 1

Light source 2

d

D

Compare
brightness
of each
source here
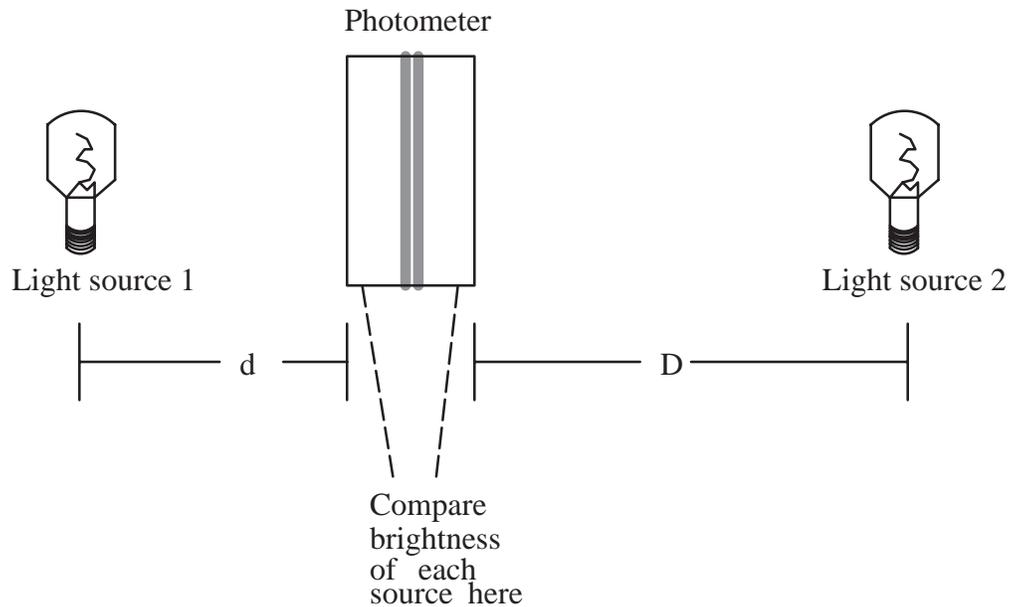
6. 2 equal wattage bulbs placed at the same distance should produce the same brightness in the photometer.

Using the Photometer:

1. Obtain four or five light bulbs of various wattages such as 25 W, 50 W, 75 W, 100 W, and 200 W.

2. To test the photometer, place it midway between two equal-wattage bulbs. Use 100 W or 200 W bulbs with D = 1 meter.

1 m

1 m
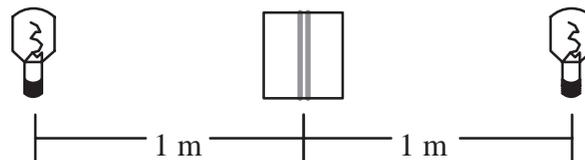
The brightness of each side of the photometer should appear the same. If not, check the wattages of the bulbs, check the distance, and check the thickness of each side of the photometer. All three of these parameters should be the same.

3. With a working photometer, place the lowest wattage (25) bulb at 0.5 m from one side of the photometer. On the other side, place a higher wattage bulb and adjust its distance until the photometer shows equal brightness on both sides. Record the distance in the table below.

4. Repeat the process in step #3 with as many bulbs as possible, recording the distances you find in the same table.
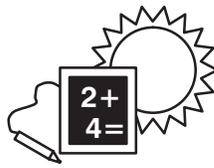
Watts	Distance	Watts	*Multiple of low-watt bulb	Distance	*Multiple of 0.5 meters
EXAMPLE: 25	0.5 m	100	4	1 m	2
25	0.5 m				
25	0.5 m				
25	0.5 m				
25	0.5 m				
25	0.5 m				

5. Look carefully at the values in the starred columns. What appears to be the mathematical relationship between the starred columns? (It should be very close to a squared relationship.)

6. Now that the brightness-distance relationship has been established, the photometer can be used to determine the brightness of the Sun. Take the photometer and a 200 W bulb outside on a sunny day.

7. Face one side of the photometer at the Sun, and place the lighted bulb on the other. Have an assistant move the bulb towards or away from the photometer until the brightness from the Sun and the bulb match as closely as possible. Measure the distance from the bulb to the photometer.

8. Repeat the process in step #8 several more times and record the average distance of the bulb in centimeters.

9. The Sun is about 1.5×10^{11} m from Earth (150,000,000,000 m !). Use your average distance in m from step #8 and determine the multiple needed to equal the solar distance. For example, if the bulb distance is 3 meters, then $1.5 \times 10^{11} / 3 = 5 \times 10^{10}$. This value, 5×10^{10}, is the number of "bulb distances" to the Sun.

10. Now use the mathematical relationship that was determined in step #5 to find how many 200 W bulbs would be needed to equal the solar luminosity.

11. Since a 200 W bulb was used to compare brightness with the Sun, the value calculated in step #10 is based on units of 200 W. Simply multiply the value from step #10 by 200 to convert to 1-watt units.

12. State the final solar luminosity in 1-watt units.

Solar Luminosity = _____ watts