LAB # 10 Understanding Luminosity & A Standard Candle Application

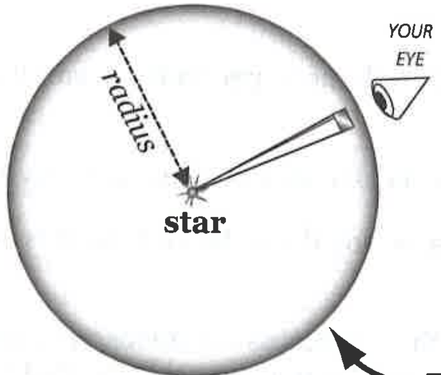
OVERVIEW

Stars fill our night sky. The Sun is a star. What are stars? How do they shine and how do they evolve? In order to answer these questions, astronomers need to examine the fundamental properties of stars. In this lab we will look at an important one, **luminosity**. In the second part, we will see how luminosity and brightness are used to find the distance to a nearby galaxy.

The amount of light that a star emits gives astronomers important information about the star. We define the luminosity of a star as the total amount of radiation (or light energy) that it emits in a time interval such as one second. You are probably already familiar with luminosity. When you purchase a light bulb, you need to know the amount of light energy that the bulb will emit. Astronomers want to compare the luminosities of stars and they usually compare them with the Sun's luminosity or **one solar luminosity**. A few stars outshine the Sun by 100,000 times but most stars have luminosities of less than one solar luminosity.

How do astronomers measure the luminosities of stars?

Two things are needed to measure luminosity: the **brightness** of the star and its **distance**. The first one is relatively simple to obtain - just look at it with the eye or, for more precision, point a special device at the star to reveal how much light is falling on a given area. The device could be a piece of photographic film, a light meter or a CCD *(charge-coupled device)* similar to the one used in a video camera. The second quantity is not so easy to get. The star's annual parallax can provide its distance, but if its parallax can't be detected, indirect, less precise means must be used to find its distance. The luminosity is computed by adding up the amounts of light that would pass through an imaginary sphere surrounding the star. The radius of that sphere is equal to the star-Earth distance.



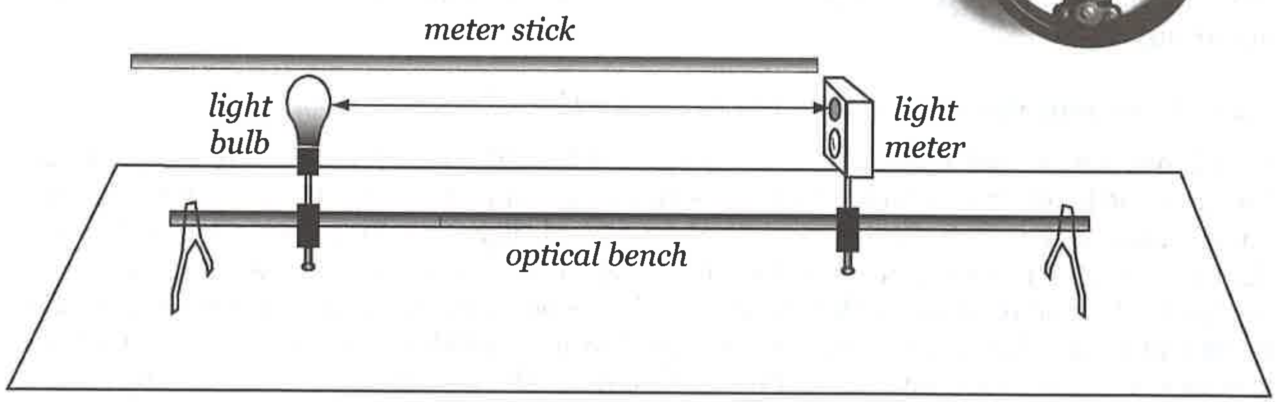
To find the luminosity of a star, measure the light passing through one small area (brightness) and multiply it by the number of areas in an imaginary sphere with a radius equal to the star-Earth distance.

The area of this sphere equals 4π(star-Earth distance)^2

Part 1: The Luminosity of a Light Bulb

A number and the word **watt** is printed on the top of most light bulbs. That quantity is a measure of the amount of electrical energy (*power*) that the bulb uses when it is fully illuminated. Some of the electrical energy is converted into heat energy and invisible radiation. To indicate the amount of light energy that a bulb emits, the luminosity in units of **lumens** is printed on the bulb or the bulb's box.

In this exercise, you will determine the luminosity of a 40-watt light bulb by measuring its brightness at various distances. A light meter is used to measure the brightness of a light source. The detecting surface is the circular gray area at the top of the device. Note that the light meter used in this lab measures brightness in **foot-candles**. One foot-candle equals one lumen per square foot.



- To measure the luminosity of the bulb and see how brightness varies with distance, set the light meter's distance from the bulb at each of the values listed in the table on the next page and measure the brightness in foot-candles.

- Convert the brightness in foot-candles to the modern unit of lumens per meter squared by dividing the brightness in foot-candles by 0.093.

- Convert the distances in centimeters to meters by dividing the distance in centimeters by 100.

- Find the area of the sphere surrounding the light bulb by squaring the distance in meters and multiplying that value by 4π where π is 3.14.

- Find the luminosity of the bulb in lumens by multiplying the brightness in lumens per meter squared by the area in square meters. Then compute the average luminosity using the first five values.

Lab #10: Understanding Luminosity (continued)

DISTANCE cm	m	BRIGHTNESS foot-candles	BRIGHTNESS lumens/m^2	AREA m^2	LUMINOSITY lumens
2					
5					
7					
10					
15					
20					
25					
30					
35					
40					
				Average Luminosity	

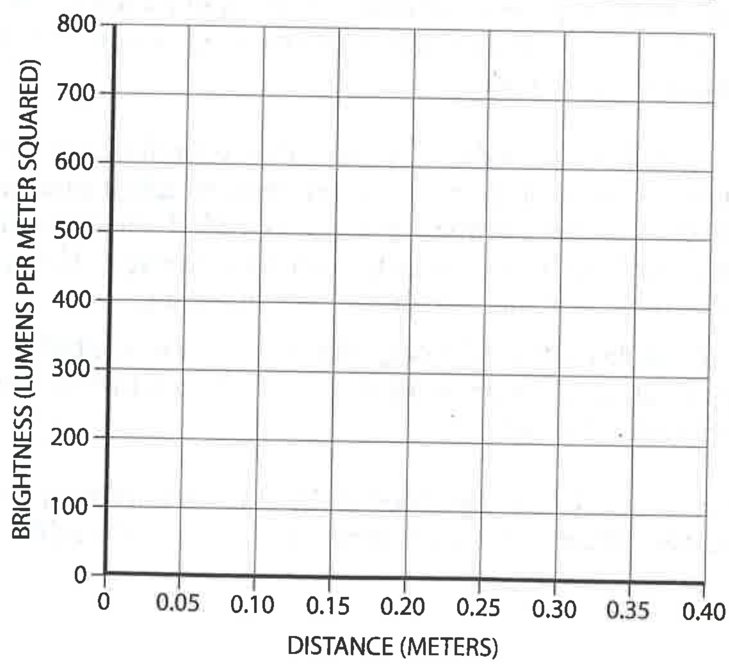
• Is the average luminosity you measured within the manufacturer's range of 440-490 lumens? ______ If it is not, suggest an explanation for the deviation. ____________

____

In the graph at right, plot the **BRIGHTNESS** in lumens per meter squared versus the **DISTANCE** in meters.

Draw a <u>*smooth*</u> curve that represents the relationship between brightness and distance.

The curve you drew depicts a relationship known as the ***Inverse Square Law.*** More on this relationship is discussed on the next page.



Part 2: The Brightnesses and Distances of Nearby Stars

In this exercise you will determine whether the brightness of a star can be used as an indicator of the star's distance from Earth.

Suppose that you are surrounded by 100-watt light bulbs that are at different distances from you. Bulbs that are near you will appear brighter than those that are farther away. This should also be true of stars *if they all have the same luminosity* and there is nothing in between the stars and you that might diminish the light you receive.

As you discovered in the preceding exercise, the amount of light that an observer receives depends on the *inverse* of the distance between the observer and the light source *squared*. In the figure below, Observer 2 is twice as far from a star as is Observer 1. Observer 3 is three times as far as is Observer 1. The light that Observer 2 receives is one-quarter that which Observer 1 receives. Observer 3 receives one-ninth that which Observer 1 receives. Do you perceive the inverse square relationship? If so, find the star's brightness at the distance of Observer 4.

To designate brightness, astronomers have traditionally used the **apparent magnitude scale**. Stars with apparent magnitudes of less than six are visible to the naked eye, those with apparent magnitudes between six and ten are visible in binoculars, those with apparent magnitudes between ten and fifteen are visible through small telescopes, and those with apparent magnitudes between fifteen and twenty are visible through large telescopes. *Note that bright stars have low apparent magnitudes and dim stars have high apparent magnitudes.*

The graph you made on page three describes the inverse square relationship between brightness and distance for a source of constant luminosity, a light bulb. From that graph you can find the distance of the light bulb if you know the brightness. What about the stars in the sky? Do they all have the same luminosity? They certainly have different brightnesses! In the next part you will answer this question.

In the table on the next page, the apparent magnitudes and parallaxes of 36 stars are listed. Apparent magnitude (***m***) is a measure of brightness - *as the magnitude value increases, the brightness decreases.*

First, compute the distances of the stars in parsecs (pc) using the relationship introduced in Lab #8: Distance (pc) = 1/parallax (arc sec). Then plot the stars on the graph.

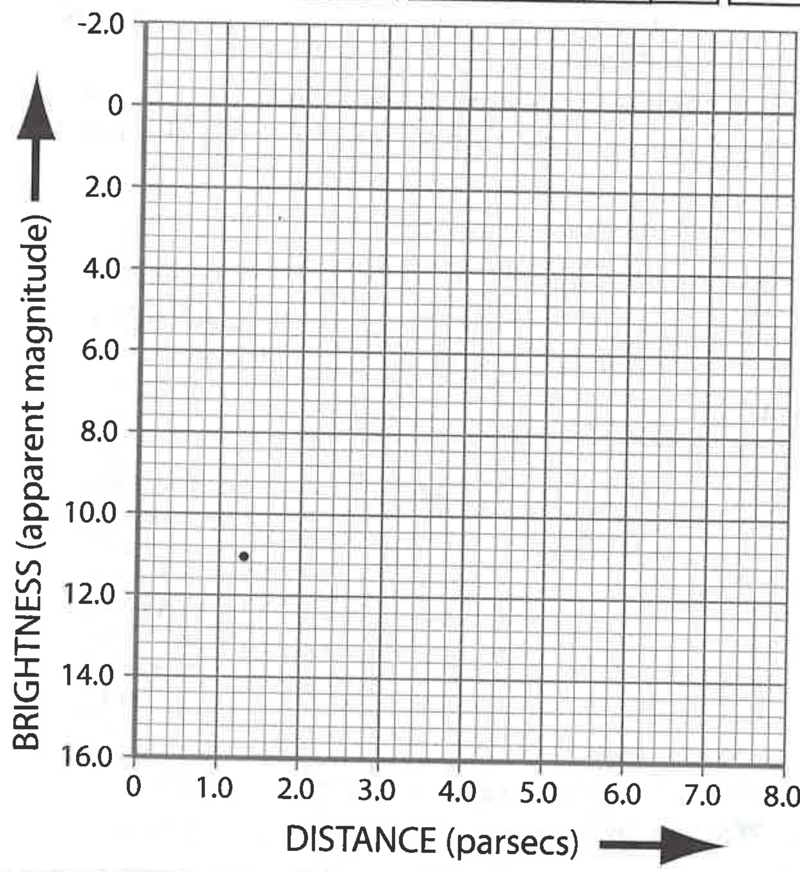
The first point has been plotted.

Star No.	m	p(")	d(pc)
551	11.1	0.77	1.3
559A	0	0.75	
559B	1.3	0.75	
699	9.5	0.55	
406	13.4	0.42	
411	7.5	0.39	
244A	-1.4	0.38	
244B	8.4	0.38	
65B	13.0	0.37	

Star No.	m	p(")	d(pc)
905	12.3	0.32	
144	3.7	0.31	
887	7.3	0.30	
447	11.1	0.30	
866C	14.0	0.29	
280A	0.4	0.29	
280B	10.7	0.29	
820B	6.0	0.29	
725B	9.7	0.28	

Star No.	m	p(")	d(pc)
845A	4.7	0.28	
1111	14.8	0.28	
71	3.5	0.27	
1061	13.0	0.27	
191	8.8	0.26	
860A	9.8	0.25	
860B	11.4	0.25	
234B	14.2	0.24	
628	10.1	0.24	

Star No.	m	p(")	d(pc)
35	12.4	0.23	
473A	13.2	0.23	
674	9.4	0.22	
440	11.5	0.22	
380	6.6	0.21	
166A	4.4	0.20	
166B	9.5	0.20	
1005B	14.3	0.19	
251	10.0	0.18	



Does the graph you made at left resemble the one you made on page three? ______

Recall that the graph on page three depicts an inverse square relationship, namely, that brightness depends on the inverse distance squared.

What can you conclude from these two graphs? ____________

____

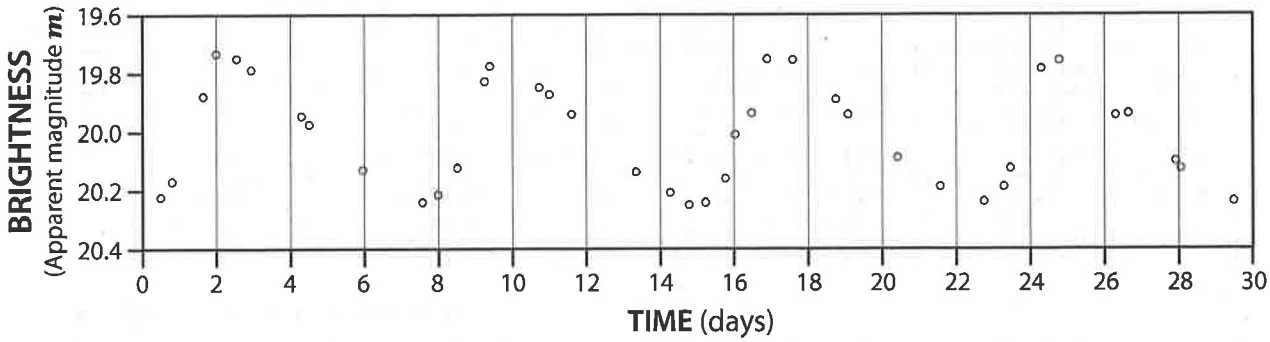
____

Should brightness be used as a good indicator of a star's distance? _____

Part 3: Variable Stars and the Period-Luminosity Relationship

A star that undergoes a periodically changing luminosity is called a variable star. One type of yellow variable star is called a classical **Cepheid variable**. Early in the previous century an important discovery was made by Henrietta Swan Leavitt concerning these stars - *their periods of pulsation were related to their average luminosities*. Because a Cepheid variable can be identified by its period, its average luminosity can be easily determined. By comparing the average luminosity with the Cepheid's brightness, the star's distance can be calculated. The technique is an example of a **standard candle method.** Cepheids can be used to find the distances of nearby galaxies as well as to uncover characteristics about our galaxy, the Milky Way.

Cepheid variables have been used to determine the distance to the Andromeda Galaxy. Suppose you were the astronomer who observed a Cepheid variable in that galaxy over a period of a few weeks and plotted the brightness as apparent magnitude (***m***) versus the time in days in the graph below.



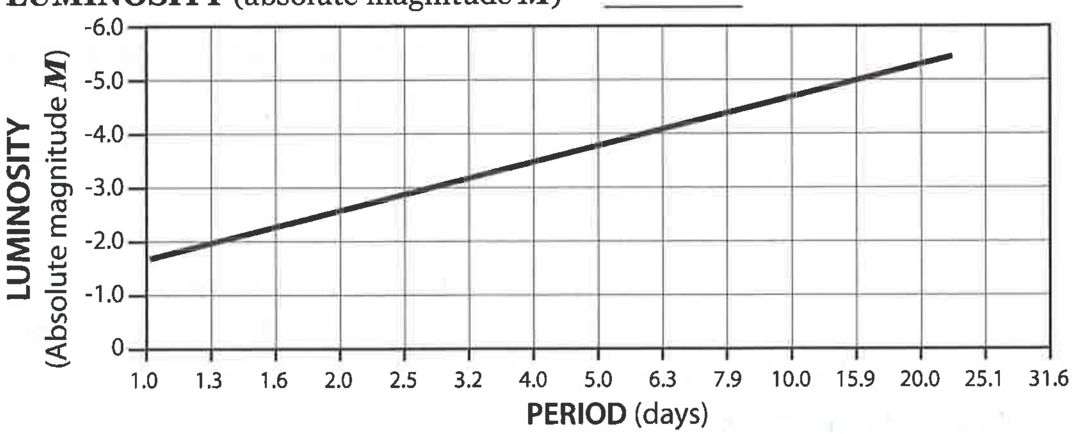
Step 1: Draw a smooth curve that best represents the plotted points. Find the period of that Cepheid by determining the number of days it takes for four full cycles of pulsation and dividing that value by four.

Four pulsations = ___ days **PERIOD** (one pulsation) = ______ days

Then find the average **BRIGHTNESS** (apparent magnitude ***m***) = ______

Step 2: Use the Period-Luminosity Graph below to find the luminosity of the Cepheid as an absolute magnitude (***M***). (*This is the relationship that Leavitt established.)*

LUMINOSITY (absolute magnitude ***M***) = ________



To simplify this graph, the x-axis has been graduated as shown. Interpolate prudently.

Step 3: Find the difference between the apparent magnitude (***m***) and the absolute magnitude (***M***).

m-M = _______ (Astronomers call this difference the *distance modulus*.)

Finally, use the graph at right to find the distance to the Cepheid in parsecs.

DISTANCE = ________ parsecs

That's the distance from Earth to the Andromeda galaxy.