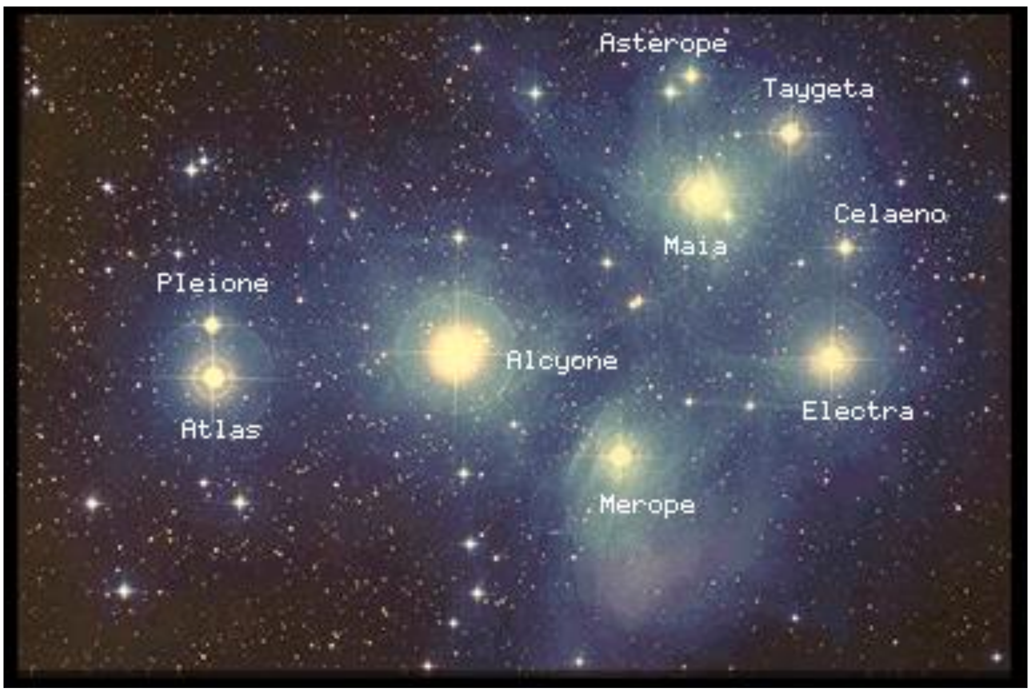
Physics 10263 Lab #3:
The Pleiades

Introduction

In the constellation Taurus, a familiar sight in the evening sky during the spring, there is a small asterism known as “The Pleiades”, which marks the location of a cluster of stars. In legend, the Pleiades are the seven sisters, daughters of Atlas, the titan who holds up the sky, and the Oceanid named Pleione. The sisters are Alcyone, Maia, Electra, Taygeta, Celaeno, Merope and Asterope. The great hunter known as Orion fell in love with them and chases them across the sky as they ride on the back of Taurus the bull.



Today there are only six stars in the Pleiades that are easily visible to the naked eye. There are many theories about what happened to the 7th one. Celaeno has often been called the “Lost Pleiad” because she was hit by lightning according to Greek mythology. In reality, the star we call Celaeno is just at the limit of human vision in terms of brightness. In today’s lab, we’ll take a closer look at this small cluster of stars with the help of some observational data collected by astronomers at Kitt Peak National Observatory.

From lecture, you may be familiar with the equation that relates the apparent luminosity and absolute luminosity of a star. This relationship is known as the inverse square law:

$$L_{app} = \frac{100}{r^2} L_{abs} - X$$

where "r" is the distance to the star (in parsecs) and "X" is the reduction factor that accounts for the extinction and reddening of starlight due to the intervening interstellar medium. If there is no material between us and the distant star, "X" = 0, and we are left with the simple form of the inverse square law.

In plain English, we say: "The more intervening material between us and the star, the fainter and redder the star appears to be." The value of "X" reflects changes in the apparent luminosity and the perceived absolute luminosity (estimated by looking at the apparent color and thus temperature of the star).

Because of a longstanding tradition, astronomers rarely express the inverse square law this way in practice. Instead of expressing the brightness of a star as a luminosity, astronomers use the magnitude system. Magnitudes are defined as follows:

$$m = \text{apparent magnitude} = -2.5 \log L_{app}$$

$$M = \text{absolute magnitude} = -2.5 \log L_{abs}$$

Notice the negative sign in the definition...this means that the larger the luminosity of an object, the smaller the magnitude. So the magnitude system actually goes in reverse. A star with a magnitude of 1 is actually much more luminous than a star with a magnitude of 15!

Using these definitions of apparent magnitude and absolute magnitude, we can substitute them into the inverse square law and rewrite the equation in terms of magnitudes. If you're pretty good at algebra, you can do this yourself, but we'll save you the work and just tell you what the resulting equation looks like:

$$r\ (pc) = 10^{\left(\frac{m - M + 5 - x}{5}\right)}$$

r(pc) = distance to the star (in parsecs)
m = apparent magnitude of the star
M = absolute magnitude of the star
x = correction term for extinction

So, if you can determine m, M and x, you can just plug them into this equation and solve for the distance to the star. As an example, suppose m = 6, M = 1 and x = 0. r(pc) is then equal to 10 to the [(6 - 1 + 5 - 0)/5] power, or 10 to the 2nd power, which is 100. So r would be 100 parsecs.

Most stars in our galactic neighborhood have distances from 10-1000 parsecs. You may recall the scale models lab we did at the beginning of the semester to give you an appreciation for such large distances. To drive at 60 mph average speed to the nearest star to our Sun, Alpha Centauri (about 1.3 pc away), would require about 45 million years.

Procedure

In order to find the distance to the Pleiades, we need to find the correction term for extinction, the apparent magnitude and the absolute magnitude. Let’s take these in order:

Extinction

We will assume for the sake of simplicity that the extinction term (which both reduces the apparent luminosity and causes the color of a star to appear redder than it actually is) is zero, but we will explore later how this (faulty) assumption affects our calculations.

Step 1

Some astronomical data for the Pleiades cluster has been gathered from the Australia Telescope National Facility and is reproduced in a table below.

Star	Apparent magnitude (m)	Color (B-V)	Absolute Magnitude (M)	Distance modulus (m-M)
1	10.44	0.62		
2	7.52	0.10		
3	6.60	-0.03		
4	7.97	0.18		
5	5.09	-0.08		
6	3.64	-0.08		
7	8.12	0.22		
8	11.35	0.78		
9	6.95	0.12		
10	10.91	0.86		
11	9.05	0.49		
12	10.02	0.56		
13	8.27	0.36		
14	9.25	0.55		
15	9.88	0.54		
16	7.66	0.21		
17	10.48	0.64		
18	6.81	0.06		
19	2.87	-0.09		
20	6.29	0.02		
21	8.25	0.26		
22	8.69	0.46		
23	7.26	0.05		
24	6.99	0.03		
25	6.82	0.02		

Star	Apparent magnitude (m)	Color (B-V)	Absolute Magnitude (M)	Distance modulus (m-M)
26	12.61	1.18		
27	9.46	0.47		
28	8.37	0.30		
29	9.29	0.46		
30	12.12	1.02		
31	11.71	0.87		
32	10.42	0.64		
33	11.34	0.86		
34	12.89	0.79		
35	7.35	0.10		
36	7.96	0.32		
37	4.18	-0.06		
38	9.70	0.55		
39	5.76	-0.04		
40	6.43	-0.02		
41	8.60	0.35		
42	11.27	0.92		
43	3.88	-0.07		
44	7.18	0.16		
45	9.45	0.52		

This data represents observations made of 45 different stars within the Pleiades cluster. Each star's apparent magnitude has been measured with two different color filters, B (Blue) and V (Visible, which is Yellow in practice).

Your lab instructor will split you up into groups and assign each group a different subset of 15 stars from this sample of 45. That way, we can compare results between groups.

For your set of 15 stars, write down the information from the reference table above into your data table on the next page in the first three columns.

Reference Number	Color	Apparent Magnitude (m)	Absolute Magnitude (M)	m-M

Step 2

Absolute Magnitude

Measuring the absolute (or intrinsic) properties of stars is somewhat more difficult, but we know that all stars radiate energy according to the following formula:

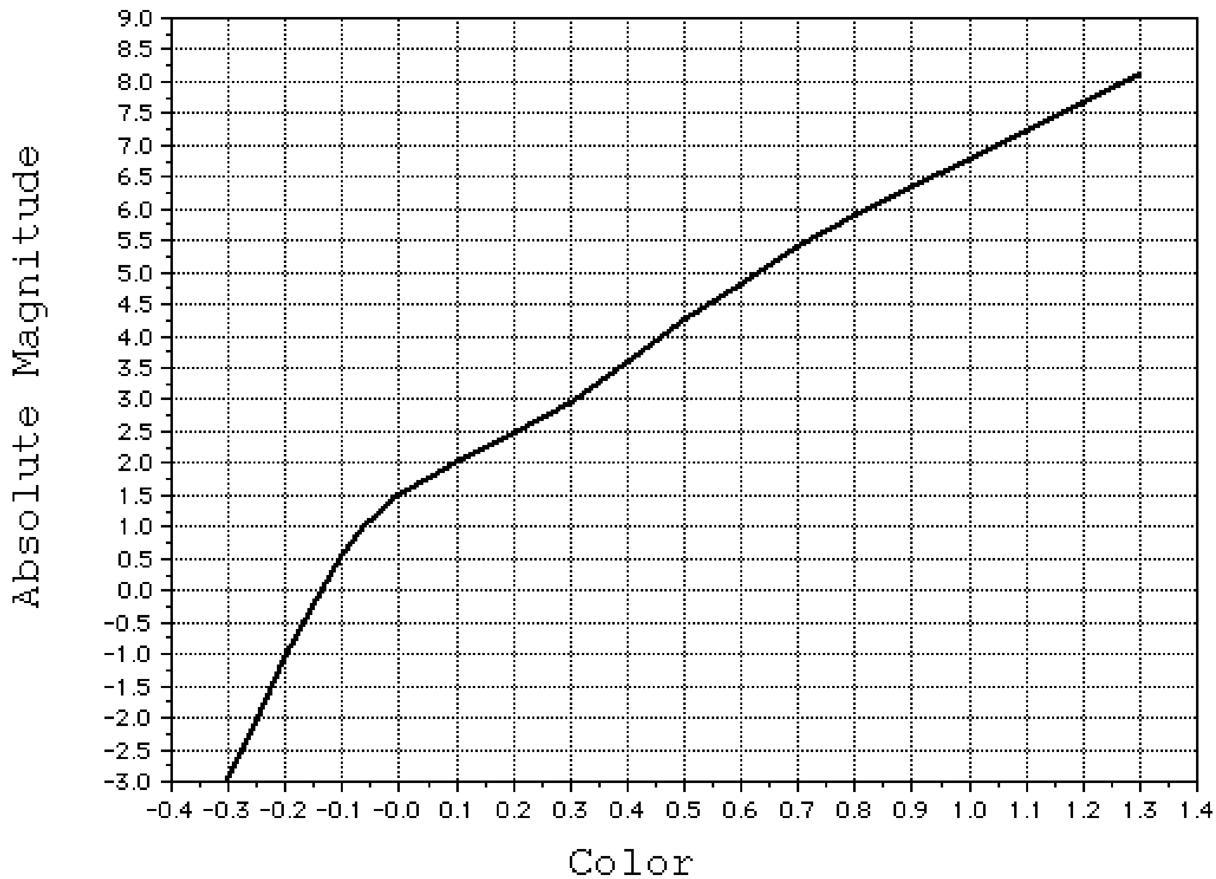
$$L_{abs} \propto R^2 \times T^4$$

The absolute luminosity (therefore, the absolute magnitude) of a star depends only upon its size (R) and its surface temperature (T). We know from the laws of continuous radiation that a star’s surface temperature can be derived from its color. Very blue stars tend to have temperatures much hotter than the Sun, for example, and very red stars tend to have temperatures much cooler than the Sun.

Astronomers have also studied stars like those found in the Pleiades, and from this collection of “standard stars”, they have determined how the size varies with star color (bluer, hotter stars tend to be somewhat larger than stars like the Sun). This information about the sizes and temperatures of standard stars leads us to the graph on the next page, showing the relationship between color and absolute magnitude for standard stars (the so-called “Main Sequence” stars) like the stars in the Pleiades. Note that “color” in this exercise is expressed as a difference in magnitudes (blue absolute magnitude - yellow absolute magnitude), so the lower the color number, the bluer the star appears to be on the sky. It is no surprise then that the bluer (more negative) the color, the brighter (more negative) the absolute magnitude of that star.

Using the graph in Figure 1 on the next page and the color information from your data table, estimate the absolute magnitude for each of the 15 stars in your sample and put this information in the appropriate column in your table. For example, a star with a color of -0.20 has an absolute magnitude of -1.0. As another example, a star with a color of +0.95 has an absolute magnitude of 6.5. Verify these two examples yourself on the graph to make sure you understand how to fill in your table.

<u>Figure 1</u>
Colors and Absolute Magnitudes for Standard Stars



<u>Step 3</u>

Now that we have estimates of the extinction (which we are assuming to be zero), the apparent magnitude and the absolute magnitude (from our table) for each of the stars in our sample, we can average these quantities in order to estimate the distance to the Pleiades.

In column 5 on your table, calculate "m-M", the apparent magnitude (column 3) - the absolute magnitude (column 4). Do this calculation for each star in your sample.

In the space below, write down the average of your 15 “m-M” values. Write your average with 3 significant figures.

Average m-M value from table: __________________

Step 4

The value “m-M” is often referred to as the “distance modulus” because it appears it appears in the distance equation back in the Introduction. Use your average distance modulus value in the distance equation in the Introduction and determine the distance in parsecs to the Pleiades cluster. Don’t forget that, for simplicity, we have assumed the correction term for extinction (X) is zero. Write down your distance value on the next page with two significant figures.

Estimated distance to the Pleiades cluster: ______________ pc

Given that the true distance to the Pleiades cluster is approximately 126 parsecs, calculate the percent error in your answer.

The formula for %error is:

$$\%\text{error} = 100 * \frac{|\text{observed value - true value}|}{\text{true value}} \quad \leftarrow \text{positive number}$$

Remember, when calculating percent error, use the rules for significant figures.

Percent error in distance estimate: _________________ %

Essay

Write the essay on your own paper, and turn it in with your lab exercise.

In your essay, discuss the effects of interstellar gas and dust on your final results. In the first paragraph, discuss reddening effects by answering the following questions:

- If we ignore reddening, will we underestimate or over-estimate the absolute luminosity of a star? Explain.

(Hint: If a star appears redder, will we think it is brighter and hotter or dimmer and cooler?)

- The answer to the previous question implies that we will overestimate or underestimate the distance to a star? Explain your answer.

(Hint: If our value of absolute luminosity is too big, what does that do to our calculated value for r in the formula?

In the second paragraph, use the web to find out more about the constellation Taurus and the Pleiades. A useful resource is found at http://www.dibonsmith.com/constel.htm. Use this to answer the following in this paragraph: Why is the constellation Taurus depicted as half a bull instead of the entire bull? In answering the question, summarize the story behind the constellation Taurus in 3-4 sentences.

Normally, I would end the lab at this point, but instead, I'm going to type up some more text to fill up this space so that you are not tempted to try to write a complete two paragraphs worth of material in such a tiny space, making it very difficult for your TA to grade due to lack of legibility.

Really, you should just write it on your own paper where you will have plenty of space. You are going to be scanning it in electronically anyway, and who cares how many pages it is at that point. I encourage you, of course, to recycle your completed lab when the course is over.

I've seen students try to squeeze two paragraphs even in a space as small as what remains on this page, and so I felt compelled to write a few more lines of text just to be sure that temptation would be removed. I hope you enjoyed them.