Name:

Lab Partner:

Photoelectric Photometry of the Pleiades

Student Manual

A Manual to Accompany Software for
the Introductory Astronomy Lab Exercise
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Contemporary Laboratory Experiences in Astronomy

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Goals

You should be able to use photometry to determine the relative apparent and absolute magnitude of stars in a cluster in order to calculate the distance to the cluster.

Objectives

If you learn to …….

Use a simulated photometer to measure the apparent UBV magnitudes of stars.

Make and compare H-R diagrams to find the relationship between absolute and apparent magnitudes.

You should be able to …….

Determine the distance to a star cluster.

Equipment

You will need a scientific pocket calculator, graph paper, ruler, plastic transparency, black marker pen, PC compatible computer running Windows 3.1 (VGA graphics) or Win95, and the **CLEA** Program *Photoelectric Photometry of the Pleiade*s.

Share the use of the computer and program with your partner to collect data. All calculations and graphing, as well as your narratives, must be your own original work.

Introduction

The computer program you will use is a realistic simulation of a UBV photometer attached to a moderate sized research telescope. The telescope is controlled by a computer that allows you to move from star to star and make measurements. Different filters can be selected for each observation, and the integration time (the length of time the photometer samples the starlight) is adjustable. The computer also does much of the busy work needed to convert photon counts into apparent magnitude and provides an estimate of the quality of the collected data.

You will use this instrument to collect data on 24 stars in the region of the Pleiades star cluster. The apparent magnitudes will be measured for each star, in each of three colors. *We will assume all of these stars are approximately the same distance awa*y. This is a necessary and reasonable assumption because all of the stars are members of the same cluster. If we did not make this general assumption, the apparent magnitudes of the stars would also depend on their individual distances, an effect we cannot easily take into account in this lab.

From this information, you will plot a Hertzsprung-Russell (H-R) diagram which will display the apparent magnitude of the cluster of stars as a function of their color index. The color index, B-V, is the apparent blue magnitude (B) minus the apparent visual magnitude (V). For your H-R diagram, plot the calculated B-V data on the horizontal *x* axis, and apparent magnitude on the vertical *y* axis using graph paper. Recall that the dimmer a star is, the greater the apparent magnitude number. Bright stars have a small apparent magnitude number; in fact, very bright stars actually have negative apparent magnitudes. Plot your y axis in such a way that zero magnitude is at the top, and 25th magnitude (a very dim star indeed) is at the bottom. The x axis should range from -0.4 on the left to 1.8 at the right. Figure 1 is an example of the H-R diagram.

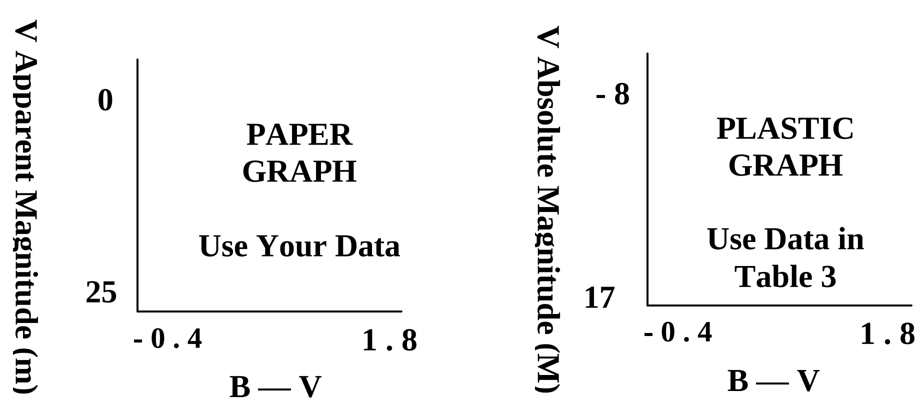

Figure 1
The H-R Diagram

Lay out your graph as shown at the bottom of the previous page in Figure 1 (a). Expand this miniature example so it occupies most of a sheet of paper. Be sure the y axis runs from 0 at the top to 25 at the bottom as shown in the example. Creating too small a graph will make it difficult to plot the data accurately.

You will then create a second graph like the first on a clear plastic sheet. On this second graph you will plot a group of main sequence stars with known absolute magnitudes. By overlaying and aligning these main sequence stars on top of your apparent magnitude H-R diagram, you will be able to relate the apparent magnitude **(m**) of a cluster star to an absolute magnitude **(M**) from the main sequence plot.

Knowing the apparent and absolute magnitude of a star, you can determine its distance (in parsecs) from the equation:

$$\mathbf{D = 10 \times 10^{(m-M)/5}} \qquad \mathbf{(1)}$$

where **m** = the apparent magnitude
M = the absolute magnitude
d = the distance in parsecs

Overall Strategy

This is the overall plan of action for the laboratory exercise:

- Log in and enter student information.
- Access and display the Help screens.
- Familiarize yourself with the controls.
- Open the observatory.
- Take “sky” counts.
- Take “star” readings, and record your results.

Using the Photometry Program

1. Starting the Program

Start the Photometry program by double clicking on the **Clea_pho** icon.

2. Entering the Student Account Information

You must first select **Login** from the menu bar. Enter your name (first and last) and those of your lab partners. Do not use punctuation marks. Press **Tab** after each name is entered, or **click** in next student block to enter the next name. Enter the Laboratory Table Number you are seated at for this experiment. You can change and edit your entries by clicking in the appropriate field and making your changes. When all the information has been entered to your satisfaction, click **OK** to continue, and click **YES** when you are asked if you are finished logging in. The opening screen of the photometry lab will appear.

Accessing the HELP Files

You may, at any time, select **Help** from the menu to receive on-line help. Click **Help…Getting Started** located on the right hand side of the menu bar. **Getting Started** gives you a brief overview on how to operate the telescope. When you have finished with the **Getting Started** help screen, select **Help…Taking Dat**a. **Taking Data** provides information on how to access and operate the photometer, and take the photometric data. There is no user help for this program therefore **User** is disabled. **About This Exercise** displays the title and version number of the program as well as the copyright information.

3. Open the Observatory

To begin the exercise, choose **Start** from the menu bar, then **Run**. The screen shows the control panel and the view window as found in the "warm room" at the observatory. Notice that the **dome** is closed and the **tracking** is off. Controls and readouts for the telescope are to the left of the dome and the controls and readouts for the photometer are to the right of the dome. Take a moment to study the various controls available to you using Figure 2 and the following explanations.

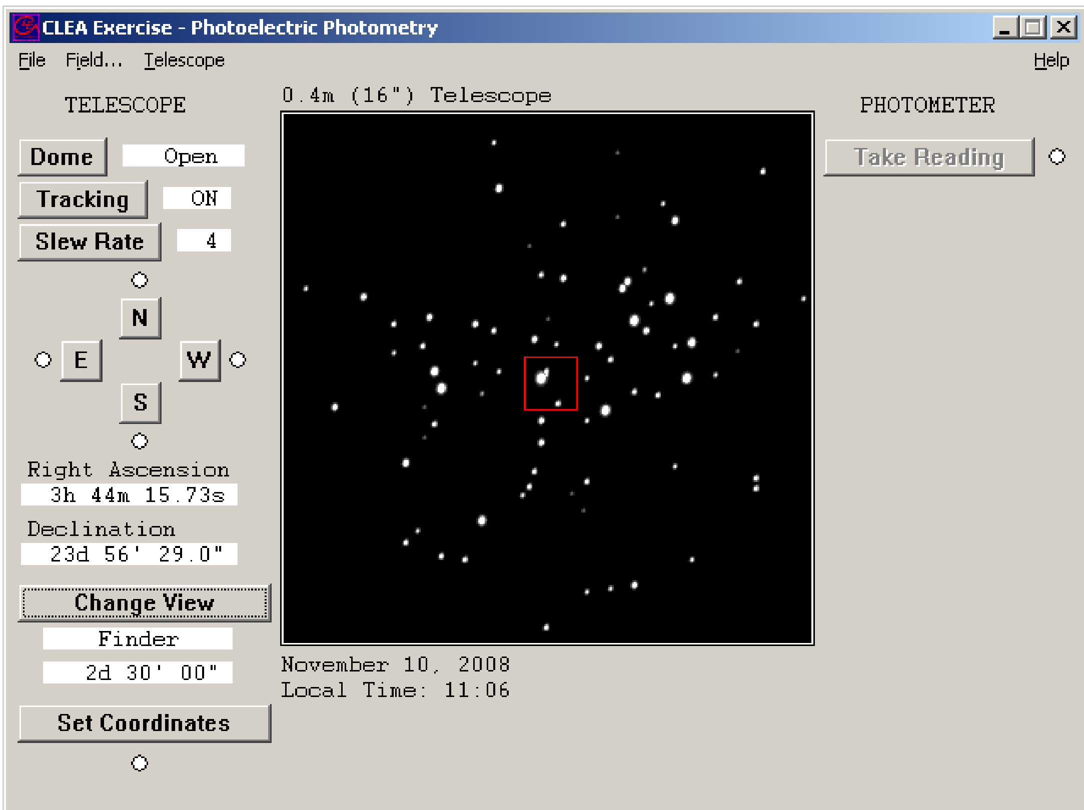

Figure 2
Telescope Window

4. Telescope Controls and Readouts (left hand side of screen)

Dome Opens and closes the observatory dome. Open the dome to activate the controls, and a view of the night sky will appear.

Tracking Turns on/turns off the telescope drive. Turning tracking **ON** causes the telescope to counteract the effect of the Earth's rotation and is necessary in order to take measurements. Turning tracking **OFF** allows the star field to drift through the field of view as the Earth turns.

Slew Rate Controls the rate of telescope movement when the **N, E, S, W** direction controls are pressed. The slew rate can be set to **1, 2, 4, 8, or 16**. The larger the number, the faster the movement rate. Slow speeds are useful for centering a star image. Faster rates are useful for quickly moving from star to star.

N, S, E, W Directional controls. Click one of these buttons to cause the telescope to move north, south, east, or west. When the telescope is moving, a red light next to the direction button glows. Movement in the selected direction continues only while the button is depressed.

Right Ascension Displays the celestial coordinates of the center of the field of view. Right Ascension is displayed in hours, minutes and seconds.

Declination Declination is displayed in degrees, minutes and seconds.

Change View Click to select the **Finder** mode or the **Instrument** mode. Select **Finder** to see a wide angle view of the stars. The red square identifies the outline of the instrument field of view. The **Instrument** mode shows a close-up of the star field. It is necessary to select the **Instrument** mode to use the photometer. The numbers directly beneath the **Finder or Instrument** button display the field of view of the screen, that is, how much of the sky is being viewed.

Set Coordinates When the dome is open, you can click on this button to move to a specific location in the sky. Enter the desired Right Ascension and Declination.

5. Photometer Controls and Readouts (separate window)

In order to view and operate the photometer controls, you must select the **Instrument** mode by clicking on the **Change View** button, shown in Figure 3.

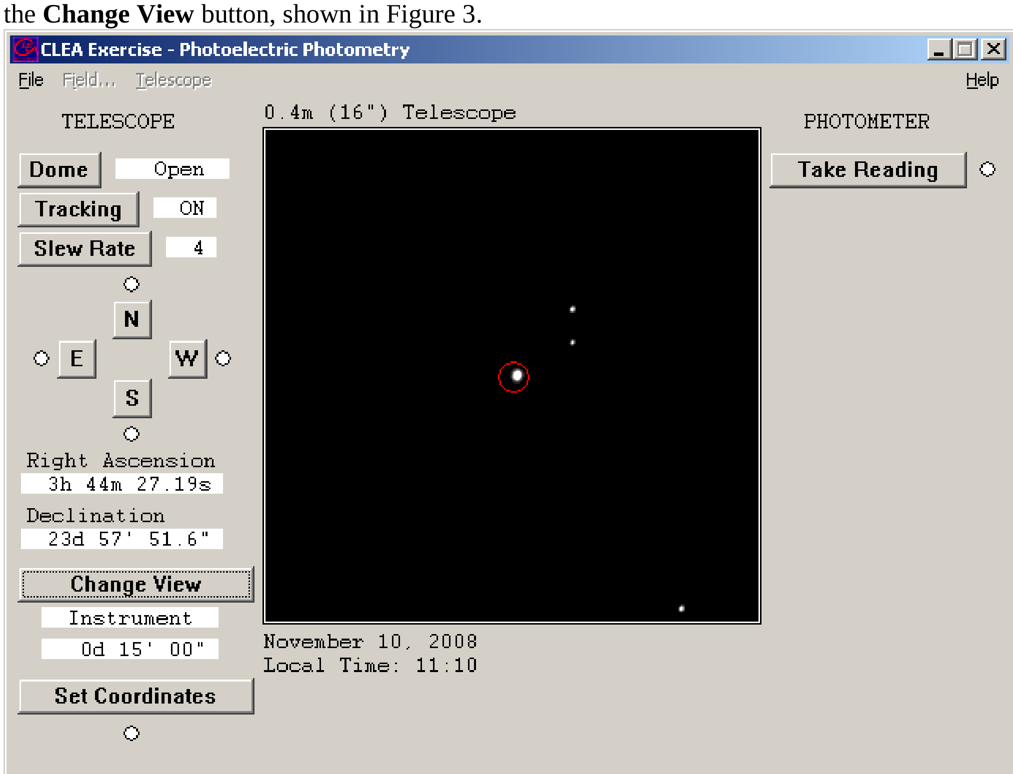

Figure 3
Photometer Window

Then select **Take Reading** on the right side of the window to access the Photometer controls as shown in Figure 4.

NOTE: *Before you can start taking readings of stars you must first take initial "sky" readings through the B and V colored filters. If you forget to take a sky reading, an error message is displayed and a real reading is not taken.*

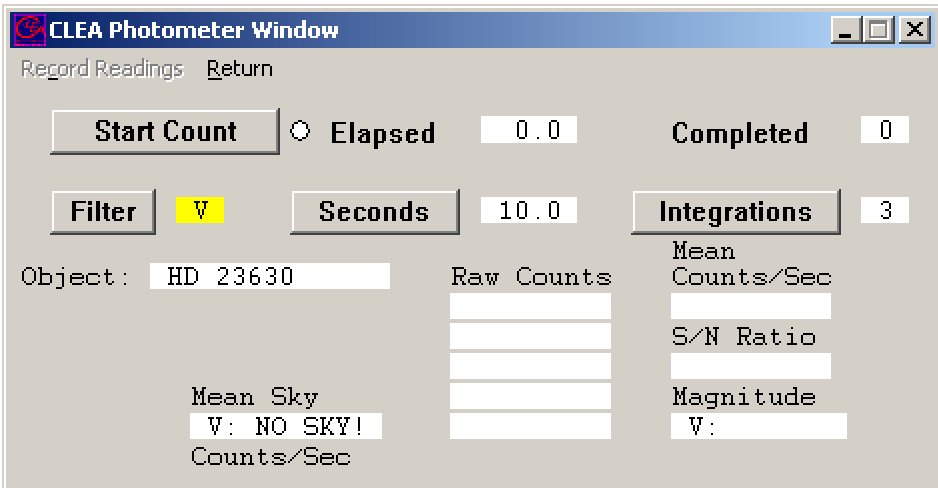

Figure 4
Photometer Controls

Start Count Clicking this button starts the collection of photons. Click this button again to stop collecting photons.

Elapsed How many seconds have elapsed for the current integration

Completed Number of integrations completed

Filter Clicking this button cycles the color filters through **U** (ultraviolet), **B** (blue) and **V** (visible). For this lab, we will only use the **B** and **V** filter.

Seconds Selects the duration of any given integration, or how long light is collected for each reading. The time can be set from 0.1 to 100 seconds. The dimmer a star, the longer the integration time will have to be in order to get an accurate measure of the light.

Integrations Adjusts the number of times a measurement is repeated. Multiple readings are averaged.

Object Object identification number

Raw Counts The photometer simulates a photon-counting photometer. This is the count of the number of photons captured during the individual reading.

Mean Counts / Sec The number of mean counts contributed by the sky through a particular filter (determined when the sky reading is taken) divided by the seconds, giving a normalized photon rate in counts per second.

S/N Ratio We assume that the only error in the counting of the photons is their randomness defined by quantum mechanics. The square root of the sum of the **Raw Counts** is the fractional error in the reading. A **S/N Ratio** of 100 is needed for a fractional error of 1% (which is 0.01 magnitude). The higher the **S/N Ratio**, the lower the fractional error. The **S/N Ratio**, if not high enough, can be raised by increasing the **Seconds** or the number of **Integrations**.

Magnitude The apparent magnitude of the star, through a particular color filter, based on the mean of the counts adjusted by the appropriate Mean Sky Count/Sec.

6. Move to a Star

You will now need to open the dome and turn on tracking. Once the observatory is opened and the tracking turned on, the directional controls can be clicked to move the telescope around in the sky. The red circle in the center is the field of view seen by the photometer when you engage the **Instrument** mode (by clicking on **Change View**). When you are in the **Instrument** mode, the small red circle in the center of the field of view is called the photoelectric aperture and is that portion of the sky being examined by the photometer. The desired star must be carefully centered within the aperture, otherwise, some of the light from the star spills out of the aperture and is missed during measurement. The rotation of the earth will cause the stars to drift through the view. Observe this phenomenon by carefully watching the stars with **Tracking** turned off.

Do the stars seem to drift east or west?

The stars drift ________________

Does the Earth rotate to the east or to the west?

Earth rotates to the ______________

Telescopes are equipped with a motor drive which moves the telescope in a direction opposite to the drift and at the same rate. The motor (often called the clock drive) cancels the effect of the earth's rotation and the star seems to stand still permitting extended study. Click on **Tracking** and note how the stars cease to drift.

The directional controls, **N, E, S, W**, move the telescope with respect to the sky. Moving the *telescope* to the west appears to make the *stars* move to the east. Try it. The **Slew rate** control adjusts in steps and changes the rate of movement of the telescope when the directional controls have been activated. Try various settings of the **Slew rate** and move the telescope around in all directions.

7. Set up and Take SKY Readings

Since the aperture is much larger than the star under study, and the sky is not perfectly dark, the sky within the aperture contributes a certain number of photons. These unwanted photons are counted by taking a *sky reading*. The star to be measured is then centered in the aperture and a *star reading* is taken. It is important that both the sky and the star reading be taken through the same color filter. Then the true photon count for the star by itself is approximated by the star reading minus the sky reading.

1. Make sure the **Tracking** is on, and click on the **Change View** button to turn on the photometer in **Instrument** mode. Move the telescope until the aperture (red circle) is free of any star. Click on **Take Reading** on the right hand side of the window.

2. Select a filter by clicking on the **Filter** button until the appropriate filter appears. Set **Seconds** to 10 seconds, and **Integrations** to 5.

3. Then click on **Start Count** and wait for the readings to appear. When the measurement is completed, the mean sky count will appear in the box labeled **Mean Sky.**

4. Repeat the measurement for each filter V and B.

After you have taken a sky reading for each filter, record your written results below.

Sky Readings

Filter	**Mean Sky (Counts/sec)**
B	____________________
V	____________________

8. Take a Star Reading and Record the Results

1. Click on the **Change View** button to activate the **Finder** mode. Click on **Set Coordinates** to enter a **RA** and **Dec** from the Data Table on Page 14. Move the telescope using the directional buttons to center a star in the red square.

2. Click on the **Change View** button to activate the **Instrument** mode. Accurately center the star in the red aperture circle. Click on the **Take Reading** button.

3. Select a filter (B, or V - they cycle when clicked, do not use U filter) by pressing on the **Filter** button.

4. Select an appropriate integration time by clicking on the **Seconds** button. Use short integration times for bright stars to save time, and long integrations for faint stars. Integration times are in seconds. Bright stars generate many photons, and cause high counts. The integration time should be adjusted if the signal to noise ratio is below 100. For some dim stars, a S/N Ratio of 70 is acceptable.

5. Select the number of integrations by clicking on the **Integrations** button. The computer will take a series of integrations depending upon this setting, and display the individual and average photon counts in the raw count box. After the integrations are completed, the computer considers the appropriate sky reading for the filter you used and the apparent magnitude of the star is displayed in the lower right corner of the photometer window.

6. Record the magnitude measurements of the star reading on the **Photoelectric Photometry Data Sheet** on page 14 of this manual. Record the measurements of the star reading for both the B and V filters before choosing another star.

Also displayed is the signal-to-noise ratio or **S/N Ratio** of the reading. A high S/N Ratio means you have a lot of desired photons, and only a little noise. To obtain the most accurate readings, you should strive for S/N Ratio's of 100 or more. You can increase the S/N Ratio by *increasing* the integration time because the S/N Ratio is directly proportional to the square root of the total collected raw counts.

Take star readings for each star listed on the **Photoelectric Photometry Data Sheet** (located at the end of this manual). Use the right ascension and declination given in this table to locate the star. Measure the B and V apparent magnitudes. Do not collect data through the U Filter. Record all magnitudes to the nearest 0.01 magnitude on the data sheet.

7. Calculate the color index B-V for each star to the nearest 0.01 magnitude and record it on the data sheet by subtracting the V magnitude from the B magnitude. Hot blue stars have low and even negative B-V. Cooler red stars have B-V values somewhat over 1.

8. Create an H-R diagram of your data, as explained in the Introduction section. Use regular graph paper.

9. While you are collecting data you can start to label your plastic and paper graph as described in the introduction and in the next section.

Distance to the Cluster

Place the clear plastic over your paper graph, and using the ruler trace both x and y axes. Label and scale the x axis the same as the graph paper, but number the scale of the y axis of the plastic overlay to range from -8 (at the top) to +17 (at the bottom). Label this new y axis **V ABSOLUTE MAGNITUDE** (See figure 1 (b)). Leave the plastic laying on the graph paper so you can use the grid lines.

Now plot the following calibration stars on the plastic overlay. They are main sequence stars for which absolute visual magnitudes have been determined (adapted from Allen, *Astrophysical Quantities*). The table of these values is located in Table 3 located below.

Slide the plastic overlay up and down until the main sequence on the overlay best aligns with the main sequence on your paper graph. Keep the y axes precisely parallel and over top one another. Seek a best fit for the central portion of the combined patterns. The cool red stars in the lower right of your *paper* graph are quite scattered and may not fit very well.

Consider what you are doing: You have graphs of two groups of main sequence stars. One graph is in terms of visual apparent magnitude **(m)** and the other one in visual absolute magnitude **(M)**. When the patterns are matched, it is clear that each star of the combined main sequence can be described either in terms of **m** (by reading the y-axis on the graph paper) or **M** (by reading the y-axis on the plastic overlay). It just depends on which scale you read.

Notice that once the two main sequences are aligned, a fixed relationship is established between the apparent and absolute magnitude scales, no matter where you read the y axis or which star you pick. So, pick *any* convenient magnitude on the absolute magnitude scale and read its corresponding apparent magnitude on the paper scale. Read each scale to the nearest 10th of a magnitude. V Absolute Magnitude is big **M** and read from plastic overlay. Corresponding V Apparent Magnitude is small **m** and read from graph paper.

(V) Absolute Magnitude	**B-V**	**Spectral Type**
-5.8	-0.35	O5
-4.1	-0.31	BO
-1.1	-0.16	B5
-0.7	00.0	AO
2.0	0.13	A5
2.6	0.27	F0
3.4	0.42	F5
4.4	0.58	GO
5.1	0.70	G5
5.9	0.89	KO
7.3	1.18	K5
9.0	1.45	MO
11.8	1.63	M5
16.0	1.80	M8

Table 2
Absolute Magnitude of Main Sequence Stars

Questions

1. **a**. The Main Sequence is a curved line that should follow the data on the plastic graph. Draw and label the main sequence line on the plastic graph. With the y-axes aligned, move the plastic graph up or down to align the main sequence line on the plastic graph with the data on the paper graph. Draw the Main Sequence on the paper graph and label it clearly.

b. Identify three possible red giant stars.

Star Number	**V**	**B – V**
____________	____________	____________
____________	____________	____________
____________	____________	____________

c. Consider Star Number 15. It seems curiously out of place with respect to the main sequence. What type of star might this be? Upon what did you base your decision?

2. Using the method described in question 1, use the magnitude-distance formula to calculate the distance to the cluster in parsecs. Then convert your answer to light years. Recall that 1 pc = 3.26 ly. Show all work in the space provided.

Recall that $D = 10 \times 10^{(m - M)/5}$

a. What is the distance modulus (**m – M**): ________________

b. Distance to cluster: ____________________________ parsecs

c. Distance to cluster: _____________________________ light years

3. In 1958, H.L. Johnson and R.I. Mitchell calculated the distance to this cluster to be about 410 light-years. As a percent-age, how does your calculated value compare? SHOW YOUR WORK. If your calculated % difference is large, explain a possible reason for the large error.

% Difference = (Calculated Value – Known Value)/Known Value x 100

4. Using only your graphs and results from question 1, calculate the apparent magnitude of the Sun if it were located in the Pleiades cluster.

a. You should be able to use the plastic graph to determine the absolute magnitude of the Sun, **M**, by knowing that the Sun is a G2 type start with a B-V value of +0.62. Write your value for the absolute magnitude as found from your graph.

M = ________

b. There are two ways to determine the apparent magnitude of the Sun if it were located in the Pleiades cluster. You should get the same answer for **m** using both approaches.

b1. First, using the paper graph, you can determine what the apparent magnitude**, m**, would be for a star in the Pleiades cluster if it had a B-V value of +0.62. Use the same approach used in question 1.

m = _________

b2. Second, you can determine **m** by using the magnitude-distance formula and the value for **M** found in part **a**, and the value for **D** (pc) calculated in question 1. Show your work below for this approach.

Recall that m = M – 5 + 5 log D

m = _________

c. What is the distance modulus (**m – M**) for part 4b?

d. Is it the same as in question 2b? If not, why?

Photoelectric Photometry Data Sheet

Star	RA hr min sec	Dec deg min sec	U	B	V	B-V
1	3 41 05	24 05 11				
2	3 42 15	24 19 57				
3	3 42 33	24 18 55				
4	3 42 41	24 28 22				
5	3 43 08	24 42 47				
6	3 43 08	25 00 46				
7	3 43 39	23 28 58				
8	3 43 42	23 20 34				
9	3 43 56	23 25 46				
10	3 44 03	24 25 54				
11	3 44 11	24 07 23				
12	3 44 19	24 14 16				
13	3 44 27	23 57 57				
14	3 44 39	23 27 17				
15	3 44 39	24 34 47				
16	3 44 45	23 24 52				
17	3 45 09	24 50 59				
18	3 45 27	23 17 57				
19	3 45 28	23 53 41				
20	3 45 33	24 12 59				
21	3 46 26	23 41 11				
22	3 46 26	23 49 58				
23	3 46 57	24 04 51				
24	3 47 29	24 20 34				