# Are There Groups of Stars With Similar Properties (Part 2)?

## Course Outcomes Met

1. Communicate scientific issues effectively in oral and written form;
2. Effectively collect, analyze and present data and correctly construct and interpret charts, graphs and tables to draw scientific conclusions;
3. Apply the fundamental concepts and methodologies of physics and/or chemistry to investigate a scientific theme.

Tools used in this lab:

1. Calculators
2. Excel or comparable spreadsheet. Online spreadsheets will not work because they are unable to do graphs properly. You need the desktop version.

## A. The Magnitude System

**Apparent magnitude**

You can always trust astronomers to take a simple idea and make it seem complicated. However, once you look at it closely, it may turn out to be the simplest way. The magnitude scale is such a thing.

The magnitude system began harmlessly enough. Scientists like to classify objects, and the Greek astronomer Hipparcos (160-127 B.C.) grouped the visible stars into six classes based on their apparent brightness. The only instrument he had to work with was his eyes, and he figured he could compare two stars and determine whether one was about twice as bright as the other.

The brightest stars he called first-class stars, those that were half as bright he called second-class stars, and so on. The brightness classes are now known as **apparent magnitudes**, and are denoted by a lowercase **m**. The system is counterintuitive in that we naturally associate larger numbers with increasing brightness. The magnitude system uses the reverse philosophy -- a first magnitude star is brighter than a sixth magnitude star. Although the magnitude system can be awkward, it is so deeply ingrained in astronomical literature (and databases) that it would be difficult to abandon the system now. For Hipparcos, magnitude 2 is half as bright as magnitude 1, magnitude 3 is half as bright as magnitude 2 and so ¼ as bright as magnitude 1 and so on. Once Hipparcos got down to magnitude 6, he was looking at the dimmest stars he could make out[[1]](#footnote-1).

A subscript may be added to the apparent magnitude to signify how the magnitude was obtained. The most common magnitude is the **V** magnitude, denoted **mV**, which is obtained instrumentally using an astronomical **V filter**. The V filter allows only light near the wavelength of 550 nanometers (the center of the visible spectrum; basically green) to pass through it (approximately 505-595 nm). V magnitudes are very close to those perceived by the human eye since 550 nm is the middle of the visible spectrum. The following chart lists the apparent V magnitudes of a few common celestial objects.

**Table 1: Some typical apparent magnitudes (mV)**

|  |  |
| --- | --- |
| **Object** | **mV** |
| Sun | -26.8 |
| Full Moon | -12.5 |
| Venus at its brightest | -4.4 |
| Jupiter at its brightest | -2.7 |
| Sirius | -1.47 |
| Vega | 0.04 |
| Betelgeuse | 0.41 |
| Polaris | 1.99 |
| Naked eye limit | 6 |
| Pluto | 15.1 |
| Proxima Centauri | 11.05 |

While you may perceive one star to be only a few times brighter than another, the intensity of the two stars may differ by orders of magnitude. (Light intensity is defined as the amount of light energy striking each square meter of surface per second.)

1. Take a look at the spreadsheet called Brightest Stars. In the luminosity column, what are the largest and smallest values? Suppose you were to plot these on the axis of a graph – how long would that axis have to be to contain them all? And these are just the brightest stars. There are even more dim stars that have to crowd in between 0 and 1.

As instruments were developed which could measure light levels more accurately than the human eye, and telescopes revealed successively dimmer stars, the magnitude system was refined a bit. The eye is a logarithmic detector. When the eye sees linear steps in brightness, the light intensity is changing by powers. This is fortunate; if the eye responded linearly instead of logarithmically to light intensity, if you could distinguish objects in bright sunlight, you would be nearly blind in the shade! You may not have heard of logarithms in your math classes, but think of them as the exponents when you raise something to a power. For powers of 10 (so a log base 10), the log of 100 = 102 is 2. The log of 1000 = 103  is 3, and so on.

Given that the eye is a logarithmic detector, and the magnitude system is based on the response of the human eye, it follows that the magnitude system is a logarithmic scale. In the original magnitude system, a difference of 5 magnitudes corresponded to a factor of roughly 100 in light intensity. The magnitude system was later formalized so that a factor of 100 in intensity corresponds exactly to a difference of 5 magnitudes. Since a logarithmic scale is based on multiplicative factors, each magnitude corresponds to a change by a factor of the 5th root of 100, or 2.512, in intensity. The magnitude scale is thus a logarithmic scale in base 1001/5 = 2.512. So instead of powers of 10, the magnitude scale is in powers of 2.512. The following table illustrates the point.

**Table 2: Magnitudes and intensity**

|  |  |
| --- | --- |
| **Magnitude Difference** | **Relative Intensity** |
| 0 | 1 |
| 1 | 2.512 |
| 2 | 6.31 = 2.5122 |
| 3 | 15.85 = 2.5123 |
| 4 | 39.82 = 2.5124 |
| 5 | 100 = 2.5125 |
| 10 | 10,000 = 2.51210 |
| 15 | 1,000,000 = 2.51215 |

To reiterate, each magnitude change of 1 corresponds to an intensity ratio of 2.512, and each magnitude change of 5 corresponds to an intensity ratio.

2. Look at the table of brightest stars AND the table of nearest stars. What are the largest and smallest absolute magnitudes in these tables? If you plotted those instead of luminosity, how would that improve your graph?

A few examples will help clarify the point.

3. Star A has an apparent visual magnitude of 7, and its light intensity is 100 times dimmer than that of star B. What is the apparent visual magnitude of star B? Start by finding the magnitude difference.

4. Star A has a magnitude of 2.5, and star B has a magnitude of 4.5. What is the relative intensity IA/IB, where IA is the intensity of star A, and IB is the intensity of star B?

Most of the time the numbers are not this simple, and we need general equations. How can we mathematically describe the relationship between intensity ratios and magnitude differences? When the magnitudes are increasing linearly, the intensity ratios are increasing logarithmically in base 2.512. Denoting magnitudes by **m**, intensities by **I**, and using subscripts **A** and **B** to denote stars A and B, we can express the relationship between intensity and magnitudes as follows:

IA / IB = (2.512)(mB - mA).

Convince yourself that this equation describes the numbers in Table 2. This form of the relationship is best when you know the relative magnitudes, and want to calculate the intensity ratio. We can manipulate the equation to put it in a more convenient form for the opposite case when we know the intensities, but wish to find the relative magnitudes. Taking the log of both sides we get

log10(IA / IB) = log10 (2.512)(mB - mA).

A general rule for logarithms is that log10 MP = p log10 M, so we can rewrite this as

log10(IA / IB) = (mB - mA) log10 2.512

or

log10(IA / IB) = 0.4 (mB - mA).

The result is most commonly expressed in the form

mB - mA = 2.5 log10 (IA / IB).

The red equations are the ones you’ll want in the future. Let's do an example of the magnitude system, this time using the equations.

5. The intensity of star B is a factor of 10 higher than that of star A. Star A has a magnitude of 2.4. What is the magnitude of star B? Let’s do this in steps.

a. First of all, think through the problem intuitively. Which star is brighter? Should B have a higher or a lower magnitude than A?

b. Use table 2 to estimate the magnitude difference, and then use that to estimate the magnitude of B.

c. Now that you have an idea what is going on, use one of the red equations to calculate the magnitude of B. How does your result compare to your estimate from step 2?

**Absolute magnitude**

Apparent magnitudes describe how bright stars appear to be. However, they tell us nothing about the intrinsic brightness of the stars. Why? The apparent brightness of a star depends on two factors: the intrinsic brightness of the star, and the distance to the star. The Sun is not particularly bright as stars go, but it appears spectacularly bright to us because we live so close to it.

If we want to compare the intrinsic brightness of stars using the magnitude system, we have to level the playing field. We will have to imagine that all the stars are at the same distance, and then measure their apparent brightness. We define the **absolute magnitude** of an object as the apparent magnitude one would measure if the object was viewed from a distance of 10 parsecs (10 pc, where 1 pc = 3.26 light years as we discussed in the star distances activity). We denote absolute magnitude by an upper case **M**. As before, we denote such magnitudes measured through a V filter by the subscript V. The absolute magnitude is thus a measure of the intrinsic brightness of the object. Let's look at the apparent and absolute magnitudes of the stars in Table 3.

**Table 3: Apparent and absolute magnitudes of common stars**

|  |  |  |
| --- | --- | --- |
| **Object** | **mV** | **MV** |
| Sun | -26.8 | 4.83 |
| Sirius | -1.47 | 1.41 |
| Vega | 0.04 | 0.5 |
| Betelgeuse | 0.41 | -5.6 |
| Polaris | 1.99 | -3.2 |
| Proxima Centauri | 11.05 | 15.6 |

6. Which of these stars is intrinsically the brightest? Which is intrinsically the dimmest? Which one appears to be brightest? Which appears to be the dimmest? Can you explain the difference?

How can we calculate the absolute magnitude of a star? One method is to determine the distance to the star, measure the apparent magnitude, and scale the apparent magnitude to a distance of 10 pc. Star distances are a thing we now know how to measure using parallax, though it doesn’t work for distant stars since the parallax angle is too small to measure. We’ll see how to do those in a later activity.

**Check your results with your instructor at this point**

## B. The Hertzsprung-Russell Diagram

Some time around 1910, Ejnar Hertzsprung and Henry Norris Russell independently made a scatter plot for all the stars for which they had reliable values of absolute magnitude and spectral class. What they obtained was a diagram that has been central to understanding stellar evolution ever since. So let’s follow in their tracks.

Open both the brightest stars spreadsheet and the nearest stars spreadsheet. Create a third spreadsheet to hold your graph.

You’re going to use four columns in the second spreadsheet. In the first two, copy the coded[[2]](#footnote-2) spectral class and absolute magnitude of the brightest stars. In the second two, do the same for the nearest stars. Be sure when you paste to use “paste values” on the Home tab since there are formulas in these columns and all you need are the numbers. There’s also some weird formatting inherited from Wikipedia, where I got the data, and we don’t want that either.

We’re going to create a scatter plot but it will have two data series. That way, the brightest and nearest stars will be different colors so we can visually distinguish them. So select an empty cell in your spreadsheet and insert a scatter plot there. Right click on it and choose select data. Create a series called Brightest Stars, and select the spectral class codes for the x values and the absolute magnitudes for the y values. Then create a second series called Nearest Stars and do the same for them. You should now have a graph of all the data but with Nearest and Brightest in different colors.

There’s one last thing we need to fix. Remember the magnitude scale runs backward, from brightest to dimmest. To make the graph a little more intuitive, we’d like the y axis to run the other way. So click on the numbers on the y axis and that should bring up a Format Axis window on the right hand side. In that window, you will find a check box to reverse the order so check that.

I’ve no clue how to do this on a Mac. GGC won’t let me have one.

Now you have something like a traditional HR diagram. Show it to your instructor before proceeding. Let’s see what we can notice about it.

1. By and large, are the near stars bright? Are the bright stars near?

2. Where in the diagram would you find each of the following: dim, hot stars; bright, hot stars; dim, cool stars; and bright, cool stars?

3. Concentrate on the parts of the diagram where you find the dim hot stars and the bright cool stars. Drawing on what we learned about the Stefan-Boltzmann law in the How Hot Are Stars activity, if all other things were equal, would the hot stars or the cool stars be the brightest? Explain.

4. But that is clearly not necessarily the case. In this diagram, we clearly have some cool, bright ones and some hot, dim ones. So something else is not equal. We actually discussed this in the How Hot Are Stars activity. How else could these stars differ that would account for the existence of cool bright ones and hot dim ones?

5. What direction on the diagram would take you from small stars to large stars?

6. Do the stars seem to group in particular parts of the diagram, or are they all distributed randomly? Explain.

7. Some of the many types of stars are white dwarfs, red giants, main sequence, red dwarfs and blue supergiants. In what regions of the diagram do you think each of these would be located? Explain your reasoning.

1. In Atlanta, you are doing good if you can see down to magnitude 3 stars. That’s because of all the lights. Installing lights that point down instead of up would almost eliminate this problem. It would also be cheaper in the long run since none of the light is being wasted by shining upward, all is directed toward the ground where you need it, so you need fewer lights or the same number but less energy consumption for each. This phenomenon is called light pollution and is a serious problem for astronomy. If you’ve never been far from cities, say out in a National Forest, you’ve never seen the sky and you owe it to yourself to make the trip. [↑](#footnote-ref-1)
2. Excel does not understand how to plot letters, especially out of alphabetical order. So I changed the spectral classes into numbers by using the code O=1, B=2, A=3, F=4, G=5, K=6, M=7 which puts them in order hottest to coolest. Usually, the interval between spectral classes is divided into 10 equal size units to get a little more precision, and that is the number after the decimal. So a spectral code 5.7, for instance, would be a G7 star. [↑](#footnote-ref-2)