Name ________________________________ Section ______________________

Lab Partners____________________________ Date _____________________

Stars Above, Earth Below

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Laboratory Exercise for Chapter 8

Equipment: Ruler

THE HERTZPRUNG-RUSSELL DIAGRAM

Purpose: This exercise will permit you to explore the family relations among the stars in the sky using H-R diagrams. An H-R diagram is a plot of the absolute magnitudes of stars against their spectral types. It is named after Hertzprung and Russell who discovered this relation. You will discover that there are many different kinds of stars of different brightness, surface temperature and size.

INTRODUCTION

An H-R diagram is a plot of stellar spectral type versus absolute magnitude (and sometimes luminosity). Familiarize yourself with Figure 1 which is an empty H-R diagram. Along the bottom of the diagram are the common spectral types (we have left off O type stars since there are no O stars anywhere near the Sun). Recall that each letter category is also broken into ten subcatagories. Thus you can have a B2 star, as well as a G8 star. There are A0 stars and F7 stars. Look at each of the tables and under 'spectral type' you will see these classifications. Remember that B0 stars are the hottest and M9 stars are the coolest. Thus the left side of an H-R diagram is for the hottest stars while the right side is for the coolest. Now look at the other axis. This is *absolute* magnitude (denoted by a capital M). This is the brightness a star would have if it was 10 parsecs away from the Earth. Do not confuse this with *apparent* magnitude (denoted by a little m), which is the brightness as seen from the Earth at whatever distance the star happens to be at. Recall how the magnitude scale works. The smaller the magnitude number, the brighter the star. Thus, the top of the diagram is for the very brightest stars while the bottom is for the very coolest stars. Given this distribution of temperature and brightness, we will now proceed to explore how stars are distributed on the H-R diagram.

PART 1: THE MAIN SEQUENCE

Instructions

You are going to make an H-R diagram. Plot all of the stars in Table 1 on the graph paper in Figure 1. You will plot absolute magnitude versus spectral type. Sketch a smooth curve through the heart of the collection of points (this does NOT mean that you should try to connect all the dots). This curve is called the **Main Sequence** because most of the stars in the galaxy fall along this line. Stars are grouped into six luminosity classes denoted by the Roman numerals Ia, Ib, II, III, IV, and V. Stars that fall on the main sequence are classed as luminosity class V stars. The Sun is thus noted as a G2V star since it is a G2 star on the main sequence. Add a V to each of the

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spectral types in Table 1. The main sequence is the line of hydrogen burning stars. Now add the stars in Table 2 to Figure 1 and draw a small oval around the collection of them.

Table 1: Main Sequence Stars

Star	**Spectral Type**	**M_V**
Sun	G2	+5.0
σ Per A	B0	-3.7
γ Cet	A2	+2.0
α Hyi	F0	+2.9
Kruger 60B	M6	+13.2
Procyon A	F5	+2.7
61 Cyg A	K5	+7.5
τ Cet	G8	+5.7
α Gru	B5	+0.3
Kapteyn's Star	M0	+10.8

Table 2: Giant Stars

Star	**Spectral Type**	**M_V**
Arcturus	K2	-0.3
Capella	G2	+0.0
Aldebaran	K5	-0.7
Pollux	K0	+1.0

1.1 Given the data in Tables 1 and 2, what differentiates the Giants from Main Sequence stars?

PART 2: GIANTS AND DWARFS

The stars in Table 2 are called **Giants**, and their spectral types are written with a III, such as K2III. Add a III to each of the spectral types in Table 2. The list of luminosity classes is given as follows:

List of luminosity classes.

Luminosity Class	**Type of Star**
Ia and Ib	Supergiants
II	Bright Giants
III	Giants
IV	Subgiants
V	Dwarfs (main sequence)

Notice that the Sun is a dwarf star. Sometimes class V stars are called main sequence dwarfs to distinguish them from white dwarfs, which do not fit into this luminosity classification scheme.

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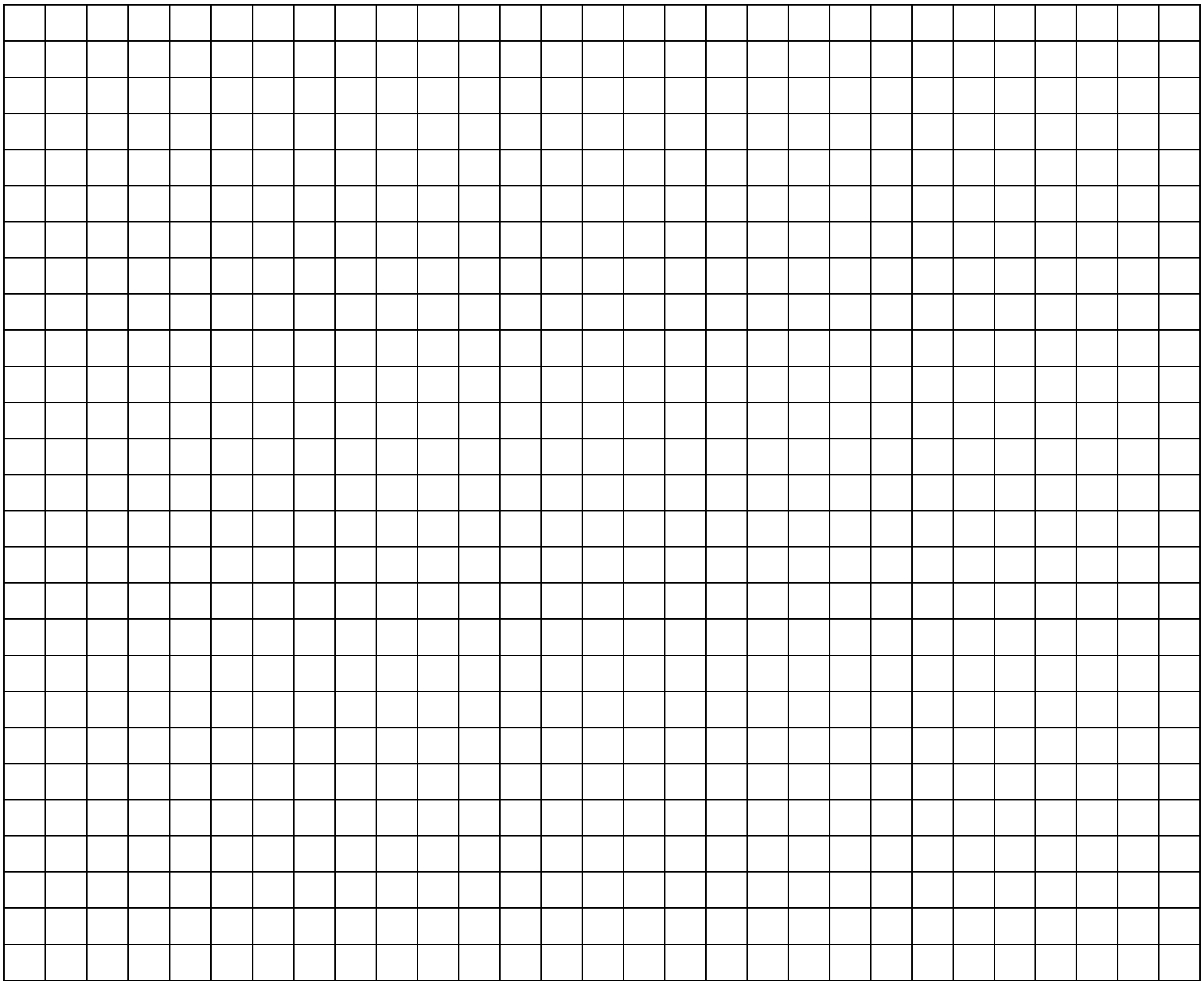
Figure 1



Are giants really bigger than dwarfs? Since Capella is a G2 star we know that it has the same surface temperature as the Sun, another G2 star. Consequently each star gives off the same amount of light from each square centimeter of surface. The flux (the amount of light given off by each square centimeter of surface) is proportional to the temperature raised to the fourth power. This is the Stefan-Boltzman Law we encountered before. But since Capella is more luminous than the Sun (it has a smaller absolute magnitude) it must have more surface area radiating energy. Think of it as crowding lightbulbs onto the surface of each star. Each light bulb, on each star has the same brightness, but on a larger star you can crowd more lightbulbs than on a smaller star. The net result is that the larger star is more luminous (even though each individual light bulb on each star is the same).

2.1 How many magnitudes is Capella brighter than the Sun?_________________________

2.2 How many times more luminous is Capella than the Sun?____________________________
(Hint: Recall that for every difference of one magnitude there is a brightness or luminosity difference of 2.51 times. A difference of three magnitudes is a difference of 2.51 x 2.51 x 2.51 in luminosity.) You can round to the nearest 10.

2.3 How many times more surface area must Capella have than the Sun? ____________________
(Hint: Remember Capella and the Sun have the same temperature. From the Stefan-Boltzmann Law: Flux = constant x T^4, this means each part of each surface is giving off the same amount of light. In other words, one square inch on the surface of Capella gives off as much light as one square inch on the surface of the Sun.)

2.4 How does the radius of Capella compare with that of the Sun? ______________________
(Hint: The area of a sphere is $4\pi R^2$. If one star has twice the radius of another, it has four times the surface area. If another star has three times the radius, it has nine times the surface area.)

Stars such as Capella are called giants because of their size. In this next part you will actually calculate the true radius of a Capella based upon the latest results using optical interferometers. These telescopes are able to resolve the miniscule angular sizes of distant stars. In conjunction with a distance measured using trigonometric parallax you will be able to calculate their true size and compare your theoretical size with an experimental one.

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PART 3: LINEAR RADII

In Part 2 we calculated how many times bigger Capella is than the Sun based upon how bright it is and its position in the H-R diagram. Now we will take a look at an actual measurement of Capella's size and see if it agrees with what we just calculated.

Table 3: Stars with Angular Diameters

Star	Spectral Type	Parallax (arcsec)	Angular diam. (arcsec)
Capella	G2III	0.0773	0.00520

The distance to a star is found from its stellar parallax angle. If the parallax angle is measured in arcseconds the distance is in parsecs.

$$\text{Distance (parsecs)} = \frac{1}{\text{parallax (arcsecs)}}$$

3.1 Calculate the distance to Capella. Write your answer in Table 4.

3.2 Given the distance you just measured in Table 4 and the angular diameter in Table 3, calculate the true diameter for Capella and tell me **how many times bigger than the Sun it is**.

$$\tan(\text{angular diameter}) = \frac{\text{true diameter}}{\text{Distance}}$$

(Hint 1: Now, your calculator should be set to degrees NOT radians. This means that when you enter a number and push any of the trigonometric functions, the calculator expects that number to be a degree. Is the angular diameter in Table 3 in degrees? No. Think how many arcseconds are in an arcminute and how many arcminutes are in a degree.)

(Hint 2: Since the distances you calculated are in parsecs, the true diameter you calculate will be in parsecs. The diameter of the Sun is 4.51×10^{-8} parsecs.)

Table 4: True Diameters

Star	Luminosity Class	Distance (pc)	Diameter (Solar Diam.)
Capella	Red Giant		

3.3 Is the size of Capella in Table 4 *about* the same size as what you estimated in Question 2.4?______________

3.4 Recall our model solar system. If the Sun is a 5-inch orange, what is Capella?______________

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PART 4: THE BRIGHTEST STARS IN THE SKY

Use a pencil to trace the main sequence and giant branch from Figure 1 on to Figure 2. In Figure 2 use a pen to plot all of the stars from Table 5. Remember, the y-axis of an H-R diagram is M_V.

4.1 What is the most common kind of bright star? (hot/cool)______________________________

4.2 Estimate the average *apparent* magnitude of these stars from the table.__________________

4.3 When you look at a bright, 1st magnitude star in the sky, you are probably looking at what kind of star? (hot/cool/blue/red)________________________________

Table 5: Bright Stars

Star	**m_V**	**M_V**	**Spectral Type**
Sirius	-1.4	1.5	A1V
Canopus	-0.7	-4.0	F0Ib
Rigil Kentaurus	-0.3	4.4	G2V
Arcturus	-0.1	-0.3	K2III
Vega	0.0	0.5	A0V
Capella	0.1	0.0	G2III
Rigel	0.1	-7.1	B8Ia
Procyon	0.4	2.7	F5IV-V
Betelgeuse	0.4	-5.6	M2Ia
Achernar	0.5	-3.0	B5IV
Hadar	0.6	-3.0	B1II
Altair	0.8	2.3	A7IV-V
Acrux	0.8	-3.9	B1IV
Aldebaran	0.9	-0.7	K5III
Antares	0.9	-3.0	M1Ib
Spica	0.9	-2.0	B1V
Pollux	1.2	1.0	K0III
Fomalhaut	1.2	2.0	A3IV
Deneb	1.3	-7.1	A2Ia
Beta Crucis	1.3	-4.6	B0III
Regulus	1.4	-0.6	B7V
Adhara	1.5	-5.1	B2II
Castor	1.6	0.9	A1V
Shaula	1.6	-3.3	B1V
Bellatrix	1.6	-2.0	B2III
Elnath	1.7	-3.2	B7III
Miaplacidus	1.7	-0.4	A0III
Alnilam	1.7	-6.8	B0Ia

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4.4 In pencil, draw a circle around the four stars at the blue end of the diagram which are much brighter than those stars on the main sequence. These are the **blue supergiants**.

4.5 In pencil, draw a circle around the two stars that are even brighter and redder than the giants. These are the **red supergiants**.

PART 5: THE NEAREST STARS

Plot all of the stars from Table 6 on Figure 2 using a different color of pen. These are the stars that are near the Sun in space. Since we believe that the Sun is in an ordinary part of our galaxy, we conclude that these are common, ordinary stars.

5.1 What is the most common kind of star near the Sun?(hot/cool)_____________________

5.2 Estimate the average apparent magnitude of these stars from the table._________________

5.3 Given where these stars fall on the H-R diagram, what is the most common luminosity class for stars near the Sun?

The bright stars that we see in the sky are rather far away. We see them only because they are intrinsically very bright. An ordinary star is rather faint, even though there are many near the Sun we do not see them easily because they are not very luminous.

5.4 What would our night sky look like if all the stars in our galaxy had the same *absolute* magnitude as the Sun? Would we see more stars or fewer? Why?

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Table 6: Nearby Stars

Star	m_V	M_V	Spectral Type
Sun	-26.8	4.8	G2
Proxima Centauri	11.0	15.4	M5
Alpha Centauri A	0.1	4.4	G2
Alpha Centauri B	1.5	5.8	K5
Barnard’s Star	9.5	13.2	M5
Wolf 359	13.5	16.7	M6
Lalande 21185	7.5	10.5	M2
Luyten 726-8A	12.5	15.3	M6
Ross 154	10.6	13.3	M5
Epsilon Eridani	3.7	6.1	K2
Luyten 789-6	12.2	14.6	M6
Ross 128	11.1	13.5	M5
61 Cygni A	5.2	7.5	K5
61 Cygni B	6.0	8.3	K7
Procyon A	0.3	2.7	F5
Cincinnati 2456A	8.9	11.2	M4
Groombridge 34B	11.0	13.3	M6
Lacaille 9352	7.4	9.6	M2
Tau Ceti	3.5	5.7	G8
Luyten’s Star	9.8	11.9	M4
Lacaille 8760	6.7	8.8	M1
Kapteyn’s Star	8.8	10.8	M0
Kruger 60B	11.2	13.2	M6

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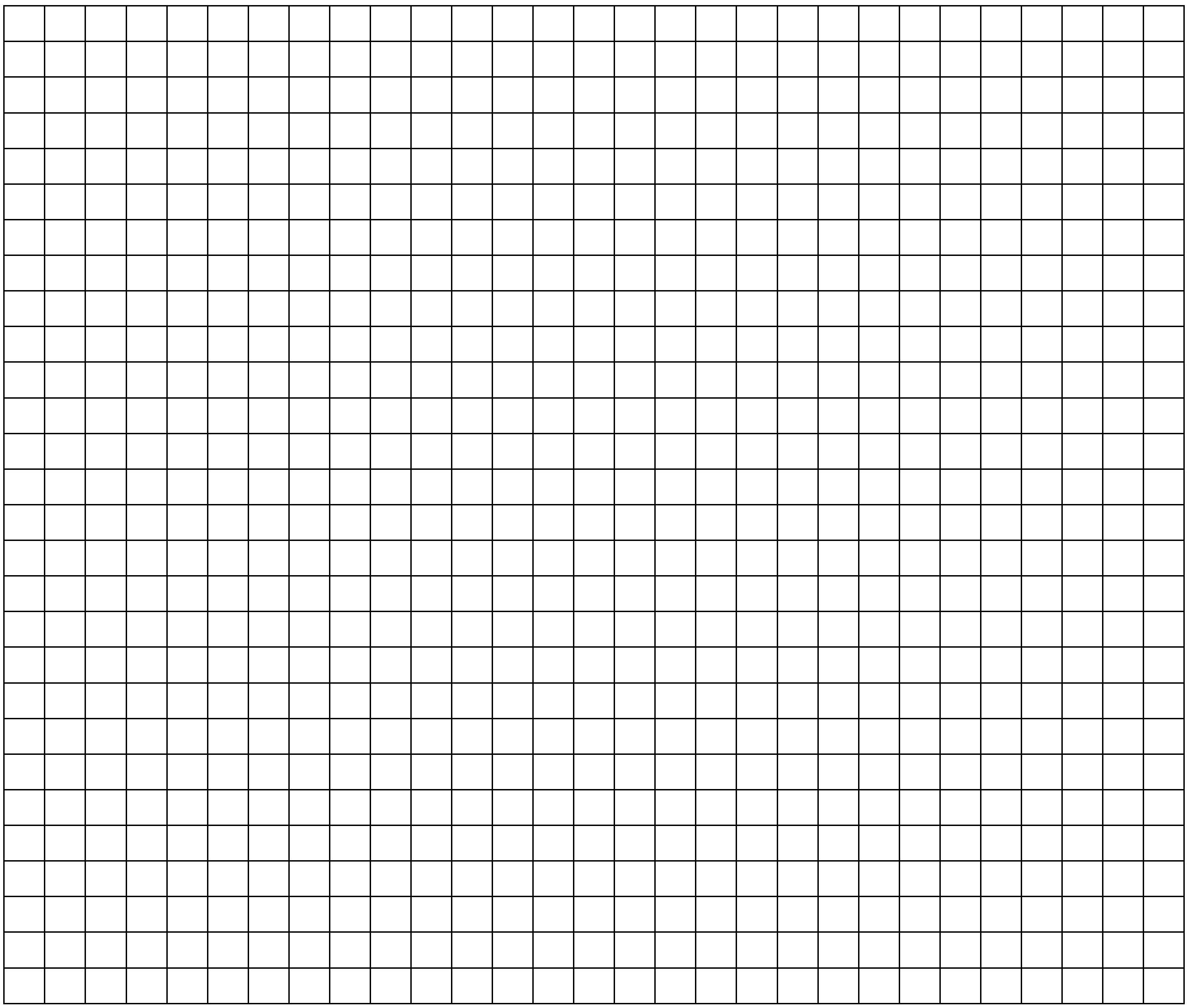
Figure 2



Adapted from Laboratory Exercises in Astronomy by Holzinger and Seeds, 1976, Macmillan Pub Co. New York