8. There is an ambulance that emits sound wave of 1m in wavelength. Suppose we hear the sound wave with a wavelength of 1.3m. Sound travels in air with a speed of 343 m/s (not speed of light!). Calculate the speed of the ambulance. Is the ambulance moving away or towards us?

____

9. Suppose the same ambulance emits soundwave with a wavelength of 1m, and we hear the sound with a soundwave of 1.5m. Calculate the speed of the ambulance.

____

10. Compare your answers to questions 8 and 9. Which is moving faster? Which wavelength had a larger shift?

____

____

____

Takeaway: Stars or galaxies with high speed with respect our line of sight will show a large shift, whether it is towards us or away from us. A star that is moving away from us at high speed will produce a spectrum that is very, very redshifted. A star that is moving towards us at high speed will produce a spectrum that is very, very blueshifted.

Start

Magnitudes and Distance

Distance determines how bright a star looks

A star's energy output is measured by numbers called magnitude. There are two types of magnitudes. Apparent Magnitude measures how much light reaches Earth (how bright it looks). Absolute Magnitude measures how bright stars would appear if the stars were observed from the same distance. The smaller the number, the brighter it is.

11. Vega has an apparent magnitude of 0.03. Deneb has an apparent magnitude of 1.25. Which star appears brighter?

0.03

12. Based on your answer to question ~~9~~ 11, can you determine which star will have a larger Absolute Magnitude? Why or why not? If yes, which will have a larger absolute magnitude?

No because

Takeaway; Stars appear brighter because they actually produce that much light (luminous), or because they are close to Earth. Absolute Magnitude measure the star's brightness from the same distance, so it is a measure of luminosity. There are numerous ways to determine Absolute Magnitude. We will not discuss the method in this lab.

We can determine distance by knowing absolute and apparent magnitudes

Apparent magnitude is determined by observing how much light enters the detector. Absolute magnitude is known for many cases. Then the distance to the object is determined by $D = 10 \times 10^{\left(\frac{m-M}{5}\right)}$. m is the apparent magnitude. M is the absolute magnitude. Distance is measured in parsec (pc). 1 pc is about 3.26 LY.

For example, Vega has an apparent magnitude of 0.03 and absolute magnitude of 0.58. Then Vega is

$D = 10 \times 10^{\left(\frac{0.03-0.58}{5}\right)} = 10 \times 10^{-0.11} = 7.76pc = 25.31L$ away from Earth.

13. Deneb has an apparent magnitude of 1.25 and absolute magnitude of -8.73. Calculate the distance to Deneb in pc.

Hubble's Law

Hubble discovered that distant galaxies move at high speed

In the 1920s, Edwin Hubble observed numerous galaxies and determined their speed and distances. In this part of the lab, we will retrace Hubble's steps to understand his remarkable discovery.

14. Below is a table of several galaxies along with their apparent magnitude. Assume that all galaxies have absolute magnitude of -22. Complete the table.

Galaxy	Apparent magnitude	m-M	Galaxy	Apparent Magnitude	m-M
A	14.95		J	16.59	
B	13.44		K	14.81	
C	16.71		L	16.16	
D	15.32		M	16.94	
E	16.94		N	15.21	
F	16.16		O	16.00	
G	14.66		P	16.59	
H	14.83		Q	14.95	
I	16.71				

15. Use the equation from Question 13 to determine the distance of each galaxy in parsec, then convert it to MLY.

For example, a galaxy is 13,255,637 pc away. Then this galaxy is

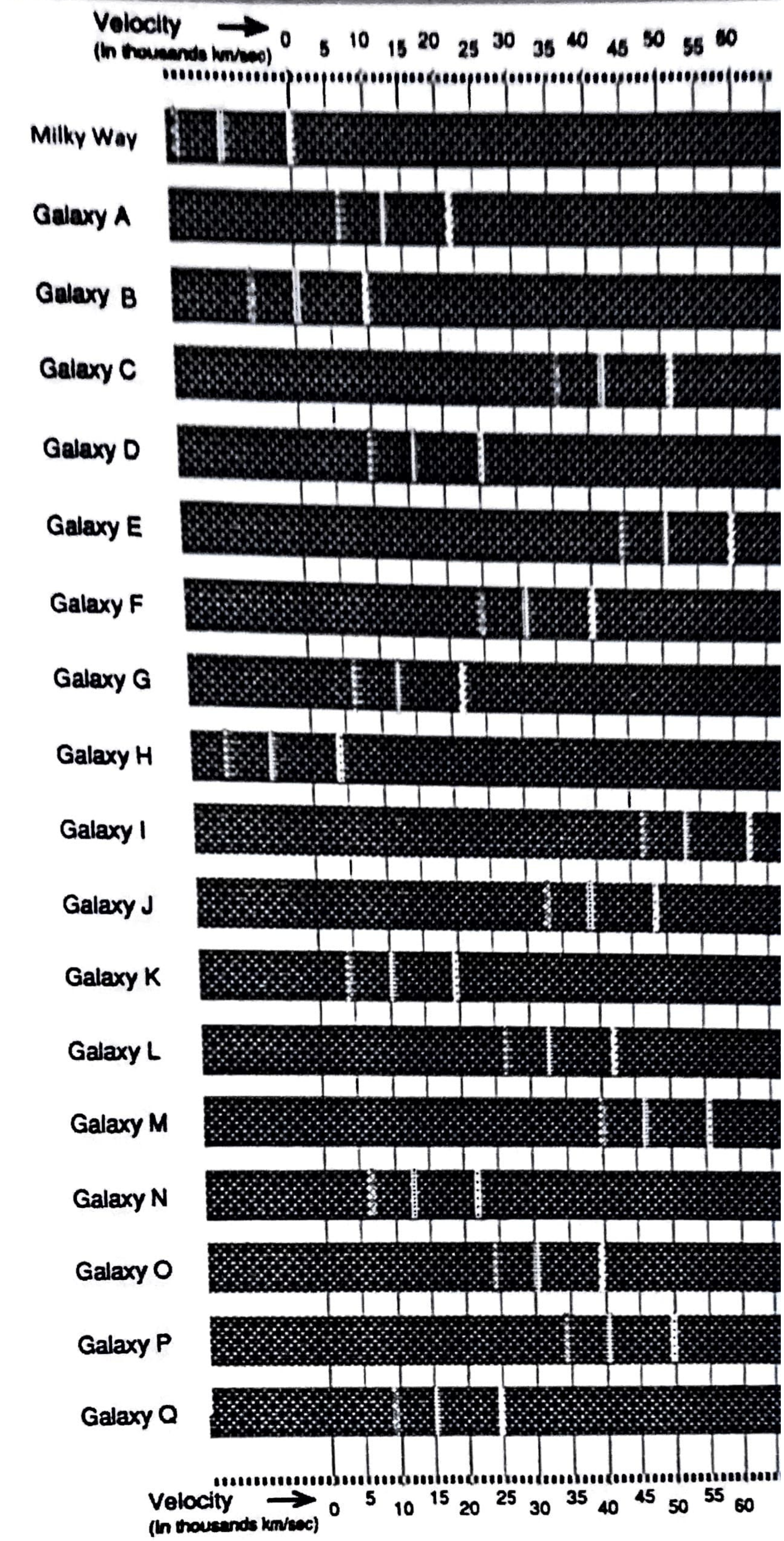
$13{,}255{,}637 pc \times 3.26 \, {}^{LY}/_{pc} \times 10^{-6} \, {}^{MLY}/_{LY} = 43.213 MLY$ away.

Show an example work for one of the galaxies. Keep 3 decimal points. Complete the table in page 8.

Now we will determine the speed of each galaxies. Below is a picture showing the spectra of all the galaxies. The first galaxy is the Milky Way galaxy. This will be the galaxy that is "at rest". Notice that you see 3 emission lines in the spectrum. All the other galaxies also show the same emission line spectra, but they are heavily shifted.

16. Are all the galaxies redshifted or blue shifted? ______________________
17. From the plot estimate the recessional speed of each galaxies. The shows that the right-most line of the Milky Way Galaxy spectrum is set to $0X10^3$ km/s. All you have to do is to determine how much the right-most line of all the galaxy spectra are shifted, and record the velocity.

Spectra of Fast Moving Galaxies



Galaxy	Distance (MLY)	Velocity (10^3 km/s)	Galaxy	Distance (MLY)	Velocity (10^3 km/s)
A			J		
B			K		
C			L		
D			M		
E			N		
F			O		
G			P		
H			Q		
I					

18. Use this table to plot speed vs. distance in the graph below.
19. What can you say about the relationship between the galaxies' distances from us and their recessional speeds? If a galaxy is far away from us, does it move at a higher or lower speed?

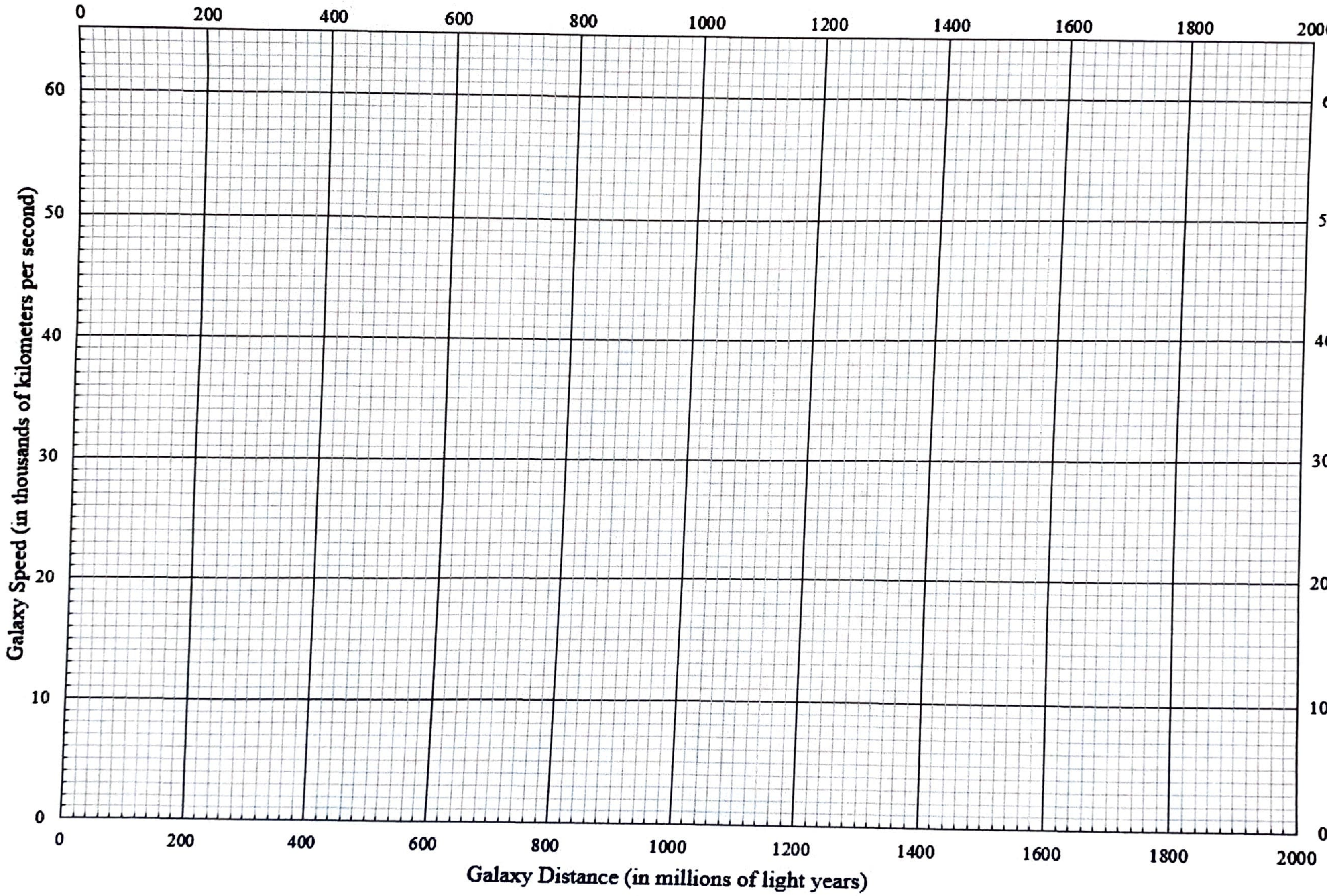
____

____

____

Takeaway: **Hubble discovered that distant galaxies move away at a high speed from the Milky Way galaxy. However, the galaxies are not selectively moving away from the Milky Way. The universe is expanding and dragging all the galaxies with it. Suppose our classroom stretched and dragged all chairs apart. Students near edge of the classroom will see the other end of the classroom move quicker than their peers. Hubble discovered that the universe is expanding!**

Hubble Law



0
200
400
600
800
1000
1200
1400
1600
1800
2000
60
50
40
30
20
10
0
Galaxy Speed (in thousands of kilometers per second)
Galaxy Distance (in millions of light years)

Show all your work! Note: For your guidance in these calculations, approximate values for the answers are given in parenthesis beside each answer. These values are given as ballpark figures, and you should record your calculated answer even if it is not exactly the same.

20. After graphing all of the galaxies, make a best-fit linear line (straight line) that fits your data and that goes through the point (0,0). The line should not connect all the points. Rather, the line should end with about half of the points above the line and the other half below the line.
21. Use this line to calculate the slope of the line, which is the Hubble constant. First, pick a single point on your best-fit line, **near the upper right of your graph**. As high as possible. *You should pick a point ON your best fit line (not one of your data point), and it should be at the upper right of your line. If your point does not meet the criteria, you will not receive credit for the rest of the lab*

Velocity of the point you picked: ______________

Distance of the point you picked: ______________

22. The slope of the line (which is also the Hubble constant) is the velocity of the point you picked, divided by the distance of the point you picked. Show work and units.

Using the Graph: Average Value of H_0 = ____________ 10^3 km/sec/MLY ($2.85X10^{-2}$)

Takeaway: This is the famous Hubble Constant! Your best fit line is simply a straight line that goes through (0,0), which follows the form y=mx. With our plot, this is $V=H_oD$, called the Hubble's Law.

The Age of the Universe

The Hubble Law can be used to determine the age of the universe.

First, we will go through a series of example calculations to see how this is determined.

23. Using ***your*** average value of H_0 determined from your graph, and Hubble's Law, calculate the recessional velocity of a galaxy that is 2,000 MLY away. Show work.

V = ________ 10^3 km/sec *(57)*

Think about a trip in your car. If you tell a friend that you are 120 miles away from your starting point and that you traveled 60 miles per hour, your friend would know you had been traveling two hours. That is, your trip started two hours ago. You know this from the relationship:

Distance = Rate (or velocity) X Time, which we can write as D = VxT.

We can rewrite this as T = D/V. Thus, 120mi/60 (mi/hr) = 2 hours.

24. Now let's determine when the universe "started its trip". The distance is 2,000 MLY, but first convert MLY into km because the velocity is in km/sec. One MLY is $9.461x10^{18}$ km)

D = ______________ km *($2 x 10^{22}$)*