Calculation of the Age of the Universe (I)

Objective: To determine the age of the universe using a Hubble Plot.

Materials: Galactic spectra, vernier calipers, graph paper, straightedge, scientific calculator.

Discussion: In the late 1920's, astronomer Edwin Hubble demonstrated that the galaxies of the universe were moving away from one another; that is, from a vantage point in any particular galaxy, all other visible galaxies were receding, or moving away, from that galaxy. In the early 1930's Hubble and M. L. Humanson collaborated to show that the more distant a galaxy, the farther toward the red, or longer wavelength, end of the spectrum its spectral lines were shifted. This shifting spectral lines is referred to as the *law of redshifts*. Hubble produced a plot of the recession velocity of galaxies vs their distances from the Milky Way. The plot, now referred to as a *Hubble Plot*, revealed that the more distant a galaxy is from us, the higher its *recession velocity* will be, and that the velocity is directly proportional to the distance from us. In this experiment you will produce a Hubble Plot and use it to determine the age of the universe.

In this exercise you will be required to perform numerous calculations and to produce several plots. Example calculations are provided at each step of the way. Accuracy is important so take your time and be careful. Be especially careful to make your plots as precise as possible since most of the data you will collect will come from them.

Procedure

Observe Figure 1. The photograph shows five galaxies, along with a spectra of each galaxy, and a reference spectra at the top and bottom of the photograph. All five galaxies were photographed with the same magnification so the smaller the galaxy appears in the photograph, the farther away it is. The galaxies are similar in shape and for this exercise we will assume that they all have a diameter of about 100,000 light years. The spectra of each galaxy was obtained with the same diffraction grating. The reference spectra were included in order to calibrate the diffraction grating, but this has been done for you in this exercise. The reference spectra are labeled *a* through *g*, and their corresponding wavelengths (in angstroms or 10^{-10} meters) are:

a - 3889Å **b - 3965Å** **c - 4026Å** **d - 4144Å**

e - 4472Å **f - 4713Å** **g - 5016 Å**

We wish to develop a calibration curve by generating a plot of the wavelength ( ) of the reference spectra vs the distance the wavelength is shifted by the motion of the receding galaxy. The phenomena of wavelength shifting to a longer wavelength for a receding object (law of redshifts) is known in broader terms as a *Doppler Shift*. Recall that the Doppler Shift is proportional to the recession velocity of the galaxy.

Using a full sheet of graph paper (axes scaled to the full length and width of the paper) plot the following data:

displacement (x axis)	(y axis)
0.0 mm	3889 (a)
6.3 mm	4026 (c)
26.95 mm	4472 (e)
38.85 mm	4713 (f)

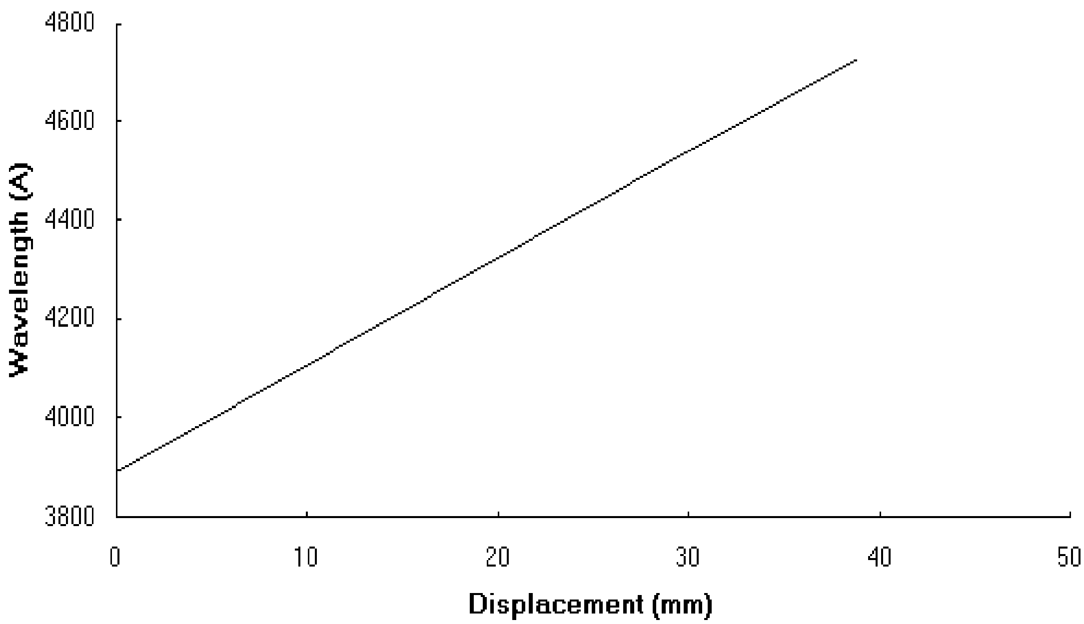

Figure 2. **Wavelength vs. Displacement calibration curve.**

Your calibration curve should look very similar to that in Figure 2. Notice that though we call it a curve it is actually a straight line. Be sure to label each axis correctly and draw the best ***straight line*** that fits your points.

Measurement of K and H Calcium Absorption Lines

The next step in this procedure is to measure the displacement of the K and H calcium absorption lines in each galaxy. Recall from the preceding discussion that in a receding galaxy all spectral lines are displaced toward the red end of the spectrum an amount proportional to the velocity of the galaxy. By measuring the wavelength shift of the K and H lines we can estimate the recession velocity of each galaxy.

Refer to Figure 1. On the left, under the heading *Galaxy in* (this refers to the area of the sky where these galaxies are found), are a series of galactic photographs. On the right, under the heading *Redshift*, are a series of spectral line photos composed of a white streak (the actual line spectra of the galaxy) and reference spectra above and below the line spectra. The reference spectra mark the positions the spectral lines would occupy in a stationary galaxy. Notice that the lines in the reference spectra are labelled a - g. Next examine first the white streak (Virgo line spectra) closely. You should see two vertical dark lines in the white streak quite close together marked by a horizontal arrow. These are the K and H lines. The K line is the first line, the H line is the second. Examine every photograph noticing the position of these lines in each.

Use the vernier calipers to measure from the **center** of the "a" spectral line to both the K and H lines in each photograph. Record your data in the following format:

Galaxy in	**a - K distance**	**a - H distance**
Virgo		
Ursa Major		
Corona Borealis		
Bootes		
Hydra	39.8 mm	41.9 mm

The measurements for Hydra have been done for you. Check these before proceeding to the next step.

Calculating K and H Wavelengths

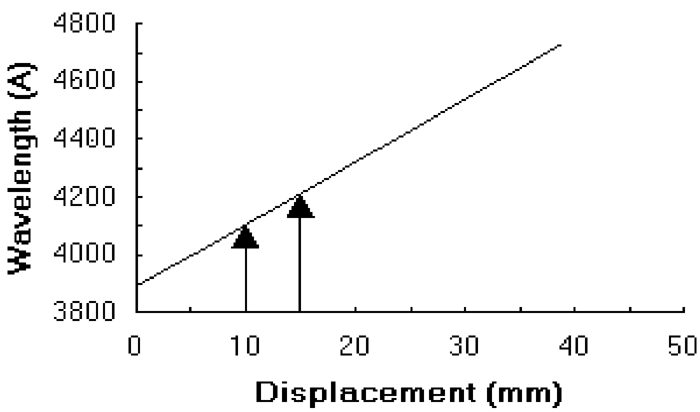

Figure 3. **Modified calibration curve**

You will now use the previously acquired displacement data and your calibration curve to calculate the K and H wavelengths. First take the K and H displacement measurements for the galaxy in Virgo and find the same values on the displacement (horizontal) axis of your calibration curve. Mark these points. Draw two vertical lines from these marks that intersect

the calibration curve. If we were, for example, to measure K and H displacement values of 10 mm and 15 mm respectively, our modified calibration curve would resemble the following:
To estimate the K and H wavelengths we need only draw horizontal lines from the intersection points on the calibration curve to the wavelength (vertical) axis as shown below.

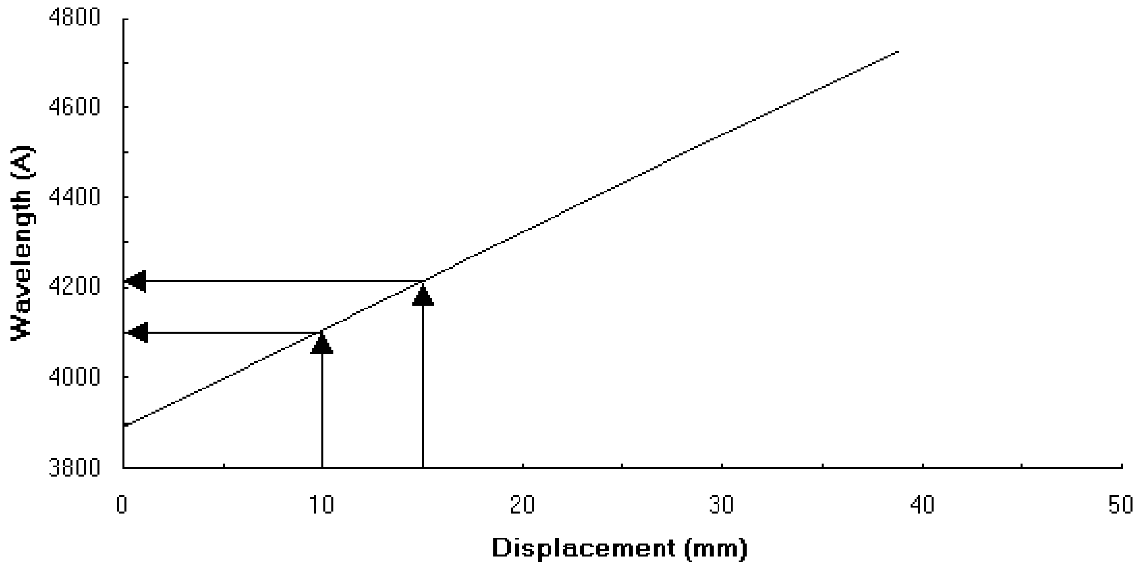

Figure 4. **Wavelength estimation from the modified calibration curve.**

Note that in this example the value for the K line is approximately 4100Å and the value for the H line is approximately 4210Å. It should be evident why it is important to make the calibration curve as large as possible, since the larger the axis, the easier it is to read values from them.

Make K and H line measurements of this type for each of the galaxies in Figure 1. You will want to construct a table similar to the one below in your notebook.

Galaxy in	**K disp**	**H disp**	**K**	**H**
Virgo				
Ursa Major				
Corona Borealis				
Bootes				
Hydra	39.8 mm	41.9 mm	4740Å	4762Å

The values for Hydra have been provided for you in order that you may double check your own calculations.