HUBBLE'S LAW

15

OBJECTIVES

After completing this exercise the student will be able to:

1. measure the value of Δl for the calcium K and H lines with respect to a known reference line.
2. calculate the redshift velocity from the Δl values.
3. measure the angular size of a galaxy and use this to estimate its distance.
4. make a plot of velocity *vs* distance and determine the value of the Hubble constant.

STUDENT MATERIALS

pencil
mm scale
calculator

LAB MATERIALS

magnifying lenses
spare copies of ***Sky and Telescope*** reprint "Hubble's Law"
list of other galaxies' diameters and velocities (optional)

STUDENT REQUIREMENTS

This lab is to be completed individually, without lab partners. After completing the exercise, turn in **Tables I** and **II** and the Hubble's Law graph.

INTRODUCTION

Most astronomers believe that the universe began as a huge explosion called the "**Big Bang.**" This explosive birth was first indicated from observations of galactic spectra. Absorption lines observed in these spectra were seen to be shifted to the red side of the positions expected for these lines. Astronomers interpret this as a Doppler shift caused by the galaxies racing away from the observer. The faster the galaxy recedes, the greater is the observed redshift. Hubble discovered that the redshift velocities were related to the distance of each galaxy in a linear fashion. In today's lab, you will make estimates of redshift velocities and galactic distances for several elliptical galaxies. These data will be used to confirm "**Hubble's Law.**"

PROCEDURE

Please estimate all measurements in this lab to a tenth of a millimeter.

I. Scale of the Spectra

In one of the spectra, draw a line vertically through the centers of each of the two spectral lines labeled ***a*** (3888.7Å) and ***g*** (5015.7Å). These two spectral lines will serve to determine the scale of the photograph and as reference lines for measuring the Doppler shift.

Measure the distance in the spectrum, in mm, between the lines labeled ***a*** and ***g***. Determine the wavelength difference, in angstroms, between these two lines by subtracting the wavelengths given above. Finally, calculate the scale on the photograph in Å/mm by dividing the difference in Å by the separation in mm. Record this scale on **Table I.**

II. The Doppler Shift and the Recessional Velocities

1. The Doppler shift of the K and H lines of calcium in each galactic spectrum will give us the recessional velocity for each galaxy. Using the reference line labeled ***a*** in each spectrum, measure the distance to a tenth of a mm, from ***a*** to each K and H absorption line, and record these measurements in **Table I** for the column labeled $\Delta\lambda$ in mm.

2. Using the scale factor for each spectrum as determined in Part I, convert each K and H measurement from $\Delta\lambda$ in mm to $\Delta\lambda$ in Å by multiplying each K and H number by the scale factor. Record your values in **Table I.**

3. Since each of the K and H line shifts were measured from the reference line ***a*** (3888.7Å) and not the true rest wavelengths for K(3933.7Å) and H(3968.5Å), then $\Delta\lambda$ determined in step 2 needs a zero-point correction to get to the proper wavelengths. To do this, subtract 45.0Å from each $\Delta\lambda$ for the K line, and 79.8Å from each $\Delta\lambda$ for the H line, and record these new values in the corrected $\Delta\lambda$ in Å columns for K and H in **Table I.**

4. Calculate the recessional velocity of each galaxy according to the Doppler formula

   $\mathbf{V} = (\Delta\lambda / \lambda)\mathbf{c}$, where $\mathbf{c}$ = 300,000 km/sec.

   Do this for each K and H line measured. The rest wavelength λ in the denominator will either be 3933.7Å, if $\Delta\lambda$ for K is used in the numerator, or 3968.5Å, if $\Delta\lambda$ for H is used. Record your answers in **Table I.**

5. Finally, average the two velocities determined for each galaxy and record this average value in the last column in **Table I.** You should notice that the two individual determinations of **V** do not agree perfectly. This disagreement indicates the approximate error in the averaged **V** values. So you can write **V** as 1200, or 52000, etc.

III. Scale of the Photograph

1. Measure the length of the line at the bottom of the galaxy photographs to the nearest tenth of a millimeter.

2. This line is known to be 150 seconds-of-arc long. Calculate the scale of the galaxy photographs in seconds-of-arc/mm by dividing 150 seconds-of-arc by your millimeter measurement obtained in step 1 above. Record the result at the top of **Table II.**

IV. Galaxy Distances

We will assume that the galaxies in each cluster as illustrated here are about the same average size; that is, they measure about 0.03 megaparsecs or about 100,000 light years in diameter. If we know their actual diameters, which we just assumed, their distances, *D*, can readily be determined from the following:

$$D = \frac{(0.03)\,(206{,}265)}{d} \qquad (1)$$

where ***d*** is the angular size in arc seconds, and 206,265 is the number of second-of-arc in a radian.

1. Measure the linear diameter, ***d***, of each image accurately to tenths of a millimeter. If the image is elliptical, use the average of its shortest and longest diameters. Record your answer in **Table II.**

2. Convert each diameter, ***d***, from mm to seconds-of-arc by multiplying by the scale factor as determined in part III and record your results in **Table II.**

3. Use equation **1** and determine the distance, ***D***, in megaparsecs (Mpc) for each galaxy. Record these values in **Table II.**

V. Plotting the Velocity-Distance Relationship and Determining Hubble's Constant

1. On the graph paper provided on page 16-9, plot the average redshift velocities (**V**) *vs* the calculated distances (**D**) for each cluster of galaxies.

2. Starting from the origin of the graph draw a best-fit straight line through the plotted points. This straight line will represent the Hubble relationship **V = HD**, where **V** = recessional velocity, **H** = Hubble's constant, and **D** = distance. Notice this is the equation of a straight line **y = mx + b**, where **b** = 0. Thus **H** is the slope of the line you drew on the graph. Find the slope of the line to determine the value of Hubble's constant in km/sec/Mpc units. Record your value of **H** in the space provided at the bottom of **Table II.**

3. Because the Hubble constant represents the present-day rate of the universe's expansion, we can determine, to a first approximation, the age of the universe by taking the reciprocal of Hubble's constant,

$$\textit{Age of Universe} = T = \frac{1}{H} \times 10^{12} \qquad (2)$$

   where the 10^{12} converts the time units from seconds to years.

   From your value of **H** calculate the age of the universe in years using **eq. (2)**. Record your results in the space provided at the bottom of **Table II.**

4. A very simple approximation of the universe's radius can be obtained from the following relationship,

$$R = c/H \qquad (3)$$

   This represents the distance at which the straight-line Hubble Law would predict a radial velocity equal to the speed of light. Using $c = 3 \times 10^5$ km/sec and your value for **H**, calculate the radius of the universe in Mpc and record your answer in the space provided at the bottom of **Table II.**

NAME: ____________________

SECTION: ____________________

TABLE I

Scale of Galaxy Spectra = ____________________

GALAXY in	Δλ in mm		Δλ in Å		corrected Δλ		recessional velocities		average velocity in km/sec.
	K	H	K	H	K	H	V_K	V_H	V
Virgo									
Ursa Major									
Corona Borealis									
Bootes									
Hydra									

NAME: ______________________________

SECTION: ______________________________

TABLE II

Scale of Galaxy Photographs = ______________________________

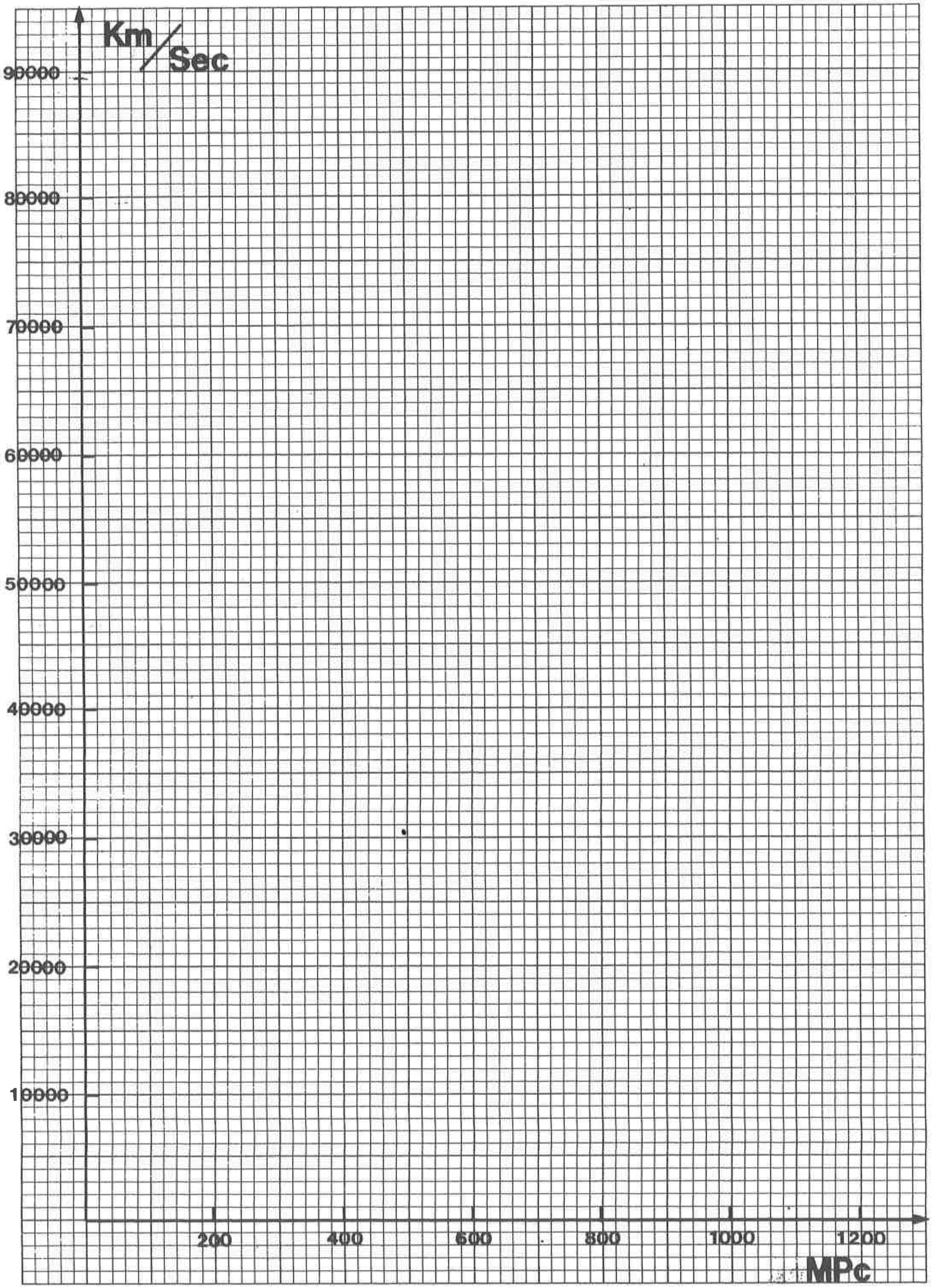
GALAXY PHOTOGRAPH	d in mm	d in arcsec	D in Mpc
Virgo			
Ursa Major			
Corona Borealis			
Bootes			
Hydra			

H = ______________________________

Age of Universe = ______________________________

Radius of Universe = ______________________________

HUBBLE'S LAW



Km/Sec
90000
80000
70000
60000
50000
40000
30000
20000
10000
200
400
600
800
1000
1200
MPc