Name__________________________ **Section**______________

Partner(s)________________________ **Date**________________

THE EXPANDING UNIVERSE

Galaxies are organized in groupings called "clusters." Earlier this century the astronomer V.M. Slipher determined that the spectra of what we would now call the galaxy clusters all possess a Doppler shift toward the long wavelengths called a *red shift.* What would this mean they were doing relative to us?

Astronomers have concluded that the universe--space itself--is expanding, and that this is the source of the red shift of the clusters. Let's illustrate this with a simple model, which many astronomers believe is indicative of the overall structure of the universe.

Activity 1: A Balloon Model of the Universe

Take the balloon assigned to your group and draw a red dot, which will represent the cluster of galaxies in which we live (the Local Group, which includes the Milky Way). Now draw several other dots of other colors on it with a felt-tip pen or marker. These represent other galaxy clusters.

Inflate the balloon just a bit (but don't tie it off). Look at the red dot in relation to the other dots. Make a mental note of how far apart they all are.

Now inflate the balloon to a larger size. (Again, don't seal it.) What has happened to the distances between the galaxy "dots?"

If you were living on the red dot, what kind of shift would you observe in the spectrum of the other dots?

If you lived on one of the other dots, what kind of shift would you observe in the spectrum of the red dot, as well as all the others?

In this model, the balloon represents the entire universe, sometimes called the "spacetime continuum, " and its expansion causes the red shift. This theory has been verified in numerous experiments.

The Andromeda Galaxy is another galaxy within the Local Group. Yet we measure a *blue shift* in its spectrum. What does that mean the Andromeda Galaxy is doing relative to the Milky Way?

Does this contradict the expanding universe model as outlined above? Explain.

Activity 2: Galaxy Clusters

Let's examine the nature of this expansion in more detail. Look at Column Four in the table below. In it you will find the distance to each of several galaxy clusters from the Milky Way. (Edwin Hubble was the astronomer who first determined a method for measuring such huge distances.)

	Column One	Column Two	Column Three	Column Four
Galaxy Cluster	Length of Arrow in mm	Doppler Shift (*Äë*) in nm	Velocity (*v*) in km/s	Distance (*d*) in ly from Milky Way
Virgo				0.1×10^9
Ursa Major				1.1×10^9
Corona Borealis				1.45×10^9
Boötes				2.6×10^9
Hydra				3.9×10^9

These are enormous distances. The Hydra cluster, being about 4 billion light-years away, is so distant that the light from it has been on its way to us for 4 billion years! That is, we are seeing it *as it was* 4 billion years ago!

To examine the recession properly, we'll need the speed at which each cluster is receding from us as well. We will get this from the red shift of each one.

Turn to figure on the next page, where you will find a photograph of a galaxy in each of five distant clusters. Next to each cluster is its spectrum; on the first spectrum you will see a *vertical* arrow that marks lines of hydrogen and potassium. This is the position when there is no Doppler shift. The red shift of a the hydrogen and potassium line is noted by the *horizontal* arrow in each. Measure the length of each *horizontal* arrow and record the length in Column One of the table. (**Note:** the arrow for the Virgo cluster is very small.)

Now convert your measurement of the arrow in millimeters to a Doppler shift (*Äë*) in nanometers, nm. (1 nm = 10^{-9} m) The conversion from millimeters to nanometers is simply to multiply each value in Column One by 2.2. Record these new numbers in Column Two.

Once you have the Doppler shift (*Äë*) into the Doppler formula can be used to calculate the velocity of recession of each cluster from us, that is, how fast it is moving away. The Doppler formula is

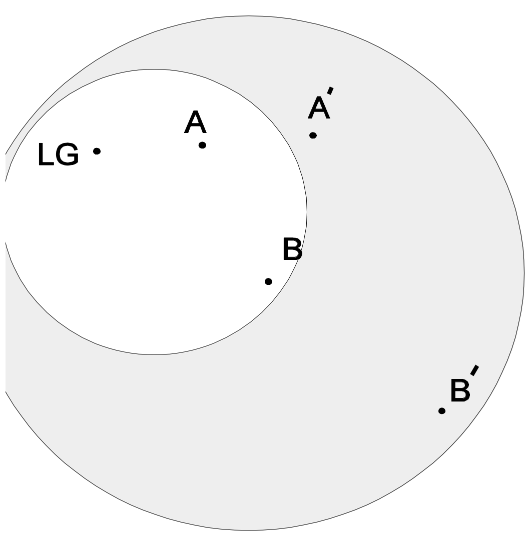
$$v \;\text{'}\; \frac{c\ \text{Äë}}{\text{ë}}$$

where *c* is the speed of light (3 x 10^5 km/s) and *ë* is the unshifted wavelength (396.8 nm). Use your calculator to determine the velocity of each cluster away from us and enter it into Column Three. (Remember to use the EXP or EE key on your calculator to enter exponents properly. Your instructor can refresh your memory on how to do this if you have forgotten.)

How do the velocities of the clusters change with increasing distance?

Activity 3: Is Expansion Uniform?

Many astronomers believe the universe is expanding *uniformly,* that is at the same rate everywhere. Yet, the furthest galaxies seem to be going faster. To understand how this can still represent a uniform expansion, consider the following drawings of our "balloon model" of the universe from earlier. Once more, the dots represent the galaxy clusters.



With your ruler measure the distance in centimeters between the Local Group (marked "LG") and both the nearby cluster (marked "A") and the more distant one (marked "B") inside the small balloon (unshaded circle).

Distance to A = _____________cm
Distance to B = _____________cm

Now we will let our model universe expand over a time of, say, one hour. Suppose it doubles in size to the shaped circle.

Measure the new distance from the Local Group (LG) to each cluster.

New Distance to A_N = _____________cm
New Distance to B_N = _____________cm

For each cluster subtract the original distance of each one from the new distance to get the distance each receded in the hour of expansion.

Distance receded for A = _____________cm
Distance receded for B = _____________cm

Since the expansion took one hour, what velocity (distance receded/time) would we measure for A and B?

Velocity for A = _____________cm/hour
Velocity for B = _____________cm/hour

So even though the whole system doubled uniformly in the hour, the further galaxies would be receding fastest!

Activity 4: Further Aspects of the Universe

Let's consider further aspects of this model of the universe. Reinflate the balloon assigned to your group. Remember, in this model, the entire universe--space itself--is represented by the ***surface*** of the balloon. If it's in the universe, it's on the surface. Things not on the surface are not within the universe.

Is space flat or curved in this model?

Is this universe finite or infinite?

Now we will consider whether this model is *bounded* or *unbounded.* Imagine you are an ant living on the balloon. You have decided to take a trip, so you start walking. Would you ever come to a boundary, or "brick wall" that marked the "end of the universe?"

So, in this model, is the universe bounded or unbounded?

Where would the center of the universe be in this model? (Hint: remember, only the ***surface*** of the balloon represents our universe.) Is there a center on the ***surface*** of the balloon? Explain.

Does the term "center of the universe" have a meaning for this model of the universe.

How many dimensions does normal space have? That is, in how many directions are we free to move?

How many dimensions does the ***surface*** of the balloon have? That is, in how many directions (*i.e.,* left or right, forward or backward, etc.) could the ant living on the balloon travel?

Our balloon model is a projection of sorts: the three dimensions of space represented by a two-dimensional surface. It's similar to a photograph: photos are two-dimensional images of our three-dimensional reality.

One of the difficulties of understanding models of the universe is trying to get a grasp of how space--something that has three dimensions--can be curved. As hard as it is to imagine, this is what the experimental evidence indicates.

This raises a number of interesting questions. For instance, if our universe is like the surface of a balloon, are there other "balloons" out there? And, if space is curved, what is it curved "into?" Think about the balloon. If the surface represents the universe, what do the spaces outside and inside of the balloon represent?

Sometimes those theoretical areas are called "Hyperspace."

Here's another analogy to try to put it in perspective: imagine 2-dimensional beings shaped like rectangles living on what they believe to be a flat plane--a 2-D world. They have never left their 2-D world and have no idea there's anything outside it.

Now suppose you come along, and you pluck one of the little rectangle beings off the plane. You show him that there is another dimension called "up and down" that he had no idea even existed. And you further show him that his flat plane world is actually a curved surface. Then you set him back down with his rectangle friends. How would he describe what he'd seen to his friends? Could he? Would he even have the vocabulary to describe it? What do you think?

When we try to describe or comprehend a 3-D world curved into higher dimensions, we face a similar challenge.

Activity 5: The Age of the Universe

We can also use the things we've learned to estimate the age of the universe. To do this we will need to make a graph of some of the information in the Table you filled out on page two.

On a sheet of graph paper, plot the velocity of the clusters on the y-axis of your graph, and distance on the x-axis. Remember to label the axes of the graph and to include the units.

Once you've plotted the graph, draw the best-fit straight line for the points. Remember, draw one, straight line--don't connect the dots! Just try to get as many points above the line as below it.

The equation of a line crossing the origin (0,0) is given by

$$y = mx$$

where m is the slope of the line. Since we've plotted velocity on the y-axis and distance on the x-axis, this becomes

$$v = md$$

The slope of this graph (m) is called H, the Hubble Constant. So the equation now becomes:

$$v = Hd$$

Determine the slope of the line to determine the value for H. Pick two points on the line you drew--not data points off the line! The slope is given by:

$$H = \text{slope} = \ddot{A}y/\ddot{A}x = \text{change in y/change in x} = (y_2 - y_1)/(x_2 - x_1)$$

H = ________________ km/sec/ly

Since v = distance/time or d/t, the equation above becomes

$$d/t = Hd$$

or more simply

$$1/t = H$$

The time in this equation is the time since the expansion started, or the age of the universe! The currently accepted value for this is about 15 billion years.

Let's see how close your value is. First, we must convert the units of H into more useful ones. Multiply your H to convert by using the following conversion factors:

$$H = \underline{\hspace{3cm}} \frac{\text{km}}{\text{sec-ly}} \times \frac{3.16 \times 10^7 \text{ sec}}{1 \text{ year}} \times \frac{1 \text{ ly}}{9.5 \times 10^{12} \text{ km}} = \underline{\hspace{3cm}} \text{years}^{-1}$$

Now invert your H to determine the age of the universe.

t = age of universe = ________________________years

How close were you to the current value of about 15,000,000,000 years?

For many years, the distances to the galaxy clusters were incorrectly calculated. This made the slope of the line (H) too large by about a factor of ten. How would this have affected the calculated age of the universe? (Try the math!)

We know from radioactive dating of meteors that the age of the solar system (and therefore the Earth) is only about 4.6 billion years. Would such an age for the universe make any sense? What would this imply about the formation of objects in the universe?

Let’s think about the origin of the universe. If the universe is expanding outward as time flows forward, what would be happening if you moved backward in time? Simulate this by returning to the balloon model. Start with the balloon fully inflated then let the air slowly leak out of it. What is happening to the distance between the galaxy clusters (dots)?

If you went back to the beginning of the expansion (around 15 billion years), describe the state of the universe. HINT: Think about the balloon--not only let all the air out of it, but now also compress the balloon itself so the dots get even closer together.

The initial state of the universe is like the compressed balloon--not only was all the matter (dots) crammed together, but space itself (the material of the balloon) was as well. Scientists refer to this initial state as the “Primeval Atom.” The explosion of the Primeval Atom that triggered the expansion, and thus formed the universe, has become known as the “Big Bang.” There are numerous forms of evidence that this explosion indeed happened.

Returning one last time to the balloon model, would it be possible to describe where the Big Bang occurred? HINT: remember the entirety of space and all the matter within it was compressed into the Primeval Atom.