In 1927 an american astronomer named Edwin Hubble announced a remarkable discovery. After years of careful measurements he found that most of the galaxies in the visible universe seem to be flying away from each other as if they had all originated in a gigantic explosion. His evidence was a linear graph of speed vs. distance from us. The graph shows that most galaxies very far from us are receding (moving away from us) at great speed, while galaxies closer to us are receding with smaller speed. Since then astronomers with better telescopes have repeated and refined Hubble's measurements and have added more data points to the graph. For example, some very distant quasars are now known to be moving away from us at more than nine-tenths the speed of light. (See **Edwin Hubble and the Expanding Universe**, by D. E. Osterbrook, J. Gwinn, & R. Brashear in the July 1993 issue of ***Scientific American***.. Also see www.astro.washington.edu/astro101/hubble/.)

1. If you made such a graph today you would naturally use SI units:
   a. Speeds would be expressed in ____ per ____.
   b. Distances would be expressed in _____.
   c. Using SI units, the slope of Hubble's graph would be in ______ per ______.
   Reducing that fraction, you get _____.

2. How could you use that slope to estimate the age of the universe, assuming that all of the velocities remained constant? ___________

3. We should not expect galaxies to continue moving with constant speed, because of gravitational attraction. Galaxies pull on each other just as the earth pulls on an arrow that has been shot up into the air. That pull causes the arrow's speed to ___crease as it coasts upward.
   a. Sketch a speed-time graph describing the upward motion of such an arrow, as on page 23 & 26. (Don't bother to show its return to the ground. Galaxies have not yet reached that stage in their journey, and we don't know yet if they ever will.)
   b. Sketch a graph of displacement vs. time to describe the same motion. Since the speed is not constant, the slope of this graph cannot be a constant. In other words, *it cannot be linear*.
   c. The curvature of the displacement graph suggests that the rough estimate discussed in #2 is too ______. (great, small)
   * d. Please explain your answer to 3c and illustrate your explanation. Remember that the original (simple-minded) displacement-time graph and the curved graph sketched in 3b must agree about the *present* values of speed and distance, so they *cannot* agree about the starting time.
   e. More recent observations suggest that there is some kind of long-distance "antigravity" that is causing the expansion of the universe to speed up rather than slow down. How does that information affect your estimate for the age of the universe?

4. Back in 1927 there was no standard international system of units. Each branch of science had its own favorite units. For example, astronomers at that time found it convenient to work with a huge distance unit called a "megaparsec", which is about 3 million light-years. The speed of light is about 300 million meters per second. A "light-year" is the distance travelled by a light signal in one year, or the speed of light multiplied by one year. Using those clues, please *show* how the following quantities are *estimated*. Please use scientific notation and round off liberally.
   a. Show that the number of seconds in one year is roughly $\pi \times 10^7$.
   b. How many meters are there in one light-year?
   c. One "million" in scientific notation is 10^6. How many meters are there in one megaparsec?
   d. Hubble's constant, (the slope of the graph mentioned in #1) is now thought to be "between 65 and 77 kilometers per second per megaparsec". (*Physics Today*, August 1999) What is its value in SI units? (Use #1.)
   * e. What can we conclude about the age of the universe? Please explain your answer carefully. Express it in SI units and also in years. Remember to round off properly. Try not to contradict 1c or 3c. Also try not to confuse "inverse" with "reciprocal". (An inverse sine is *not* a cosecant.)

Here is a summary of the general instructions explained on page 27 for solving motion problems:

a. Read the question. Sketch speed-time graphs to describe the motion(s).
b. Choose symbols to represent the quantities involved in the problem, such as initial speed, final speed, change in speed, time interval, etc.
c. Label the graphs, using those symbols. Avoid using two different symbols to represent the same thing. Also be careful not to represent different things with the same symbol.
d. For each graph, write two equations. Make one equation say something about the *slope* of the graph, and make the other say something about its *area*. *Use only the symbols already defined.*
e. Decide which symbols represent known quantities and which represent unknowns.
f. Solve algebraically for the unknowns. *Then* plug in the given data to calculate the answers.

1. A car accelerates uniformly at 5.0 ft/sec^2 for 4.0 seconds, starting from rest. (In this example the *final* speed is obviously _______ than the *average* speed.) Calculate its average speed, its final speed, and the distance it covers. How much time did it take this car to reach a speed of 10.0 ft/sec? Using the back of this paper, please *show* how you get your answers. *The instructions above may help.*

2. Write an equation describing the speed-time graph for example #1, above. (Refer to #1 on page 16.) Also give the numerical value and units of the constant in that equation. (Copy from #1.)

___ = _________ , where ___ = _____ _____

* 3. Create an equation describing the displacement-time graph for example #1, and give the value and units of the constants, as in #3. In other words, write a formula for calculating the displacement value corresponding to any given time. Explain your steps just as you did on pages 16 and 28. (Only *TWO* variables are allowed in this equation. As usual, their names are mentioned in the title of the graph.)

4. A banana accelerates uniformly from 40 to 50 m/sec while moving a distance of 6.0 m.
   a. Determine its *average* speed and its *change* in speed. (Use the instructions above.)
   b. Determine the amount of time that it spends accelerating. Then calculate its acceleration.

* 5. In we #4 know that the banana's initial displacement was zero and that it was yellow, but the speed was *NOT* constant, and its initial speed was *NOT* zero.
   a. Sketch the banana's velocity-time and displacement-time graphs.
   b. Using *SYMBOLS ONLY*, write equations describing the banana's velocity-time and displacement-time graphs. Define your symbols, give the values of the constants as in #3, and explain your logic clearly by following the instructions at the top of this page. (Also see page 27 or #1 on p. 28. Try not to confuse the speed at the *end* of the trip with the speed at any *other* time.
   c. As you know, only *one* variable is allowed on the right side of each final equation in 5b. Which symbol represents that "controlled" variable? ___ -Did you give the numerical values and units of the constants represented by the other letters in 5b? ___ (If not, explain why it was not necessary.)
   d. Use 5b & 5c to calculate the banana's displacement at 0.10 sec. *AND* at 0.20 sec. after the start.
   e. Copies of the equations in 5b have been recorded on RS ____.

6. It is easy to measure the amount of time required for a car to accelerate from 0 to 60 mph. It is also easy to calculate the car's average acceleration and the distance covered, as in #1. But if you *measure* that distance you find that the calculated distance is *wrong*. The reason is that an automobile's acceleration is usually not uniform, so the speed-time graph usually is not linear.
   a. Which acceleration *feels* greater: (1) increasing the car's speed from 50 to 55 mph as quickly as possible, or (2) increasing the same car's speed from 5 to 10 mph as quickly as possible? ____
   b. Use the clue in 6a to sketch a speed-time graph describing the motion of a car accelerating as rapidly as possible on a level surface
   c. This graph describes a gradually ___creasing speed with gradually ___creasing acceleration. -Does that answer agree with 6a? ____ -with 6b?___
   d. The “calculated distance” mentioned above was found by assuming that the speed-time graph had a _______ shape, as in #__ above. According to 6a, the *measured* distance must be _______ than the calculated distance. *Please illustrate your explanation, using #2 on RS II. Label the illustrations.*
   e. The process with which we use a velocity-time graph to calculate a distance travelled is called "__________tion". Is that word defined clearly on RS II? ___