1. Draw a big circular arc representing the path of an orbiting object. Label the center of the circle with the letter O. Make two dots close together on the arc. Label them A and B. Draw lines OA and OB. *They should be labelled with the letter ___ because their lengths are equal to the _______ of the circle.*

2. How can we calculate the distance between A and B if we know the speed of an object moving along the arc from A to B and the time it takes to go from A to B? For example, how far do I go in two hours if I drive at 50 mph? Write a formula for distance AB in terms of V and Δt. *Write it on the short side of triangle AOB. Remember to check units.*

3. Draw a long, straight arrow through A to represent the velocity of the object as it passes through that point. Label it "V_1".
   a. This arrow indicates that the object is going around the circle in the _________wise direction
   b. The angle between velocity V_1 and radius line OA must be ____ degrees.

4. In similar fashion draw and label a "V_2" arrow through B. This arrow must indicate ___________wise motion, as in 3b. Make both arrows long enough to intersect. How does the acute angle between those two velocity arrows compare with the angle between the two radius lines that you drew in #1? ______ (See page 0)

5. Show how the two velocities are subtracted (as on pages 42 and 67) to obtain the object's *change in velocity*. Label the arrows clearly. Don't forget the new sign. Label the resulting dotted arrow in your diagram as "ΔV".
   a. How must the lengths of the two velocity arrows compare? _______
   b. How does the smallest angle in that "velocity triangle" compare with the angles mentioned in #4? ________

6. What word from geomety describes the relation between triangle AOB and the velocity triangle in #5? __________ (congruent, proportional, similar, equilateral, pascal)

7. Use #6 to make an equation relating V, ΔV, R, and the formula that you wrote on the short side of triangle AOB. (See page 0)

8. Solve that equation for ΔV.

9. Divide each side of equation 8 by Δt, to obtain a "centripetal acceleration formula". This discovery is being saved in #__ on RS ___.

10. Multiply both sides of equation 9 by the mass of the object: ma = ________
    The resulting equation tells us how to find the total ________ acting on the orbiting object. That force is called "____________al force" because it is directed toward the _________ of the orbit. (Saved in #___ on RS ___)

11. On page 68R you concluded that the proportionality constant in equation 10 is probably between ________ and ________. The theory developed on this page predicts that that the constant must actually be ______. Does the experiment agree with the theory? ____

12. Please learn to spell these adjectives, illustrate them below, and save their definitions on RS VII:
    "Centrifugal" means "*away* from the center of a circle". **"Radial"** means "along a *radius"*. **"Centripetal"** means "*toward* the center". **"Tangential"** means "along a line *tangent* to the circle". Both the ____________ and the ___________ directions are radial. The centrifugal direction is the "*positive* radial direction". The *negative* radial direction is _________al.

1. A “fine-scale” measurement is affected by many little unpredictable things that can cause the outcome to deviate a bit from the true value. We'll call them "gremlins". It is *possible* for all the gremlins to act in the same direction, causing the measurement to be pretty far off. But if they are truly random and independent it is more likely that some will pull one way while others pull in the other way.

2. The gremlins flip coins to decide whether the errors they create should be positive or negative. Whenever a gremlin's coin lands "tails", he throws the result off by one **"gremlin unit"** in the negative direction. If it lands "heads", he fudges the result by one _____ ____ in the *positive* direction.

3. If *two* gremlins flip coins, the equally probable outcomes are H-H, T-H, H-T, and T-T. (H means “heads”, T means “tails”.) When they both get “heads” the result will be off by ___ gremlin units.
   a. In that case there are twice as many equally probable outcomes with one head and one tail as there are with a pair of heads, so the former will occur roughly ___ times as often in the long run.
   b. With only two gremlins working we expect a histogram of repeated measurements to have only three columns. The central column will be roughly ___ times as high as the side columns.
   c. One side column will be ___ g. units to the left of the center, and the other will be __ g.u. to the right.

4. If *four* gremlins are working (so that four coins are being flipped) then there are many equally probable outcomes. Complete the list: HHHH, HHHT, HHTH, HTHH, THHH, HHTT, HTHT, THHT, HTTH, TTHH, THTH, ______ , ______ , ______ , ______, ______
   a. How many columns will the resulting histogram have? ___
   b. The column on the far left will be called "column number one". It will have a height of one block, and will be ____ gremlin units to the left of the center because all ___ gremlins contribute to it.
   c. Column Two will be ___ g.u. to the left of center and will be ___ blocks tall.
   d. The entire histogram will have one block for each equally probable outcome, or ____ blocks in all.

5. On page 30b you determined the uncertainty or “standard deviation” of a measurement by a crude method using a histogram. We called it the "2/3" method. There is a *better* method for doing the same thing, called the "RMS Deviation" method. It is a four-step process:
   a. *Subtract* each measured value from the mean to get a list of "deviations".
   b. *Square* the deviations of all the measurements.
   c. Find the *mean* (average) of all the squared deviations.
   d. Find the square *root* of that mean value. (The initials RMS stand for "*Root-Mean-Square*".)

6. Show by the RMS method that when four gremlins are at work the uncertainty is just 2 gremlin units.
   * How well does the 2/3 method agree with this result? *Please explain your evidence.*

7. Use the same method to find the uncertainties of measurements influenced by 2 and by 1 gremlin.

8. Of course a real fine measuring process is probably influenced by a much larger number of gremlins. However, there seems to be a simple relation between the RMS deviation and the number of gremlins. If the number of gremlins at work on each single measurement is “X”, then the RMS deviation is ______ g.u. For example, if 100 gremlins are at work then the RMS deviation will be ______ g.u.

9. What happens when you average N measurements together? Each gremlin has one coin.
   a. As in #8, each single measurement is influenced by ___ coin-flips.
   b. Completing N such measurements will require N times as many coins to be flipped by the gremlin team, or _____ flips altogether, instead of the ___ coins that were flipped in #8.
   c. The first step in averaging the N measurements is to add them up. That sum will be influenced by the flipping of ___ coins, as in 9b. Using #8, we see that the *uncertainty* of that sum must be ________ g.u. (Answer in terms of N and X.)
   d. The second step in averaging is to divide the sum by ____. The distributive law requires us to divide the uncertainty by ___ also. We find that the uncertainty of the average must be ___ divided by ___.
   e. After routine simplification that formula becomes ______.

10. Summary: Let "U_1" represent the uncertainty of a single measurement: In #8 we found that U_1 = ___. Let "U_n" represent the uncertainty of the average of "N" repeated measurements. Then U_n can be calculated from U_1 and N with a simple formula: (Use #8 and #9.) **U_n =** _______

Checking: Do U_1 and U_n have the same units? ___ If N is increased then U_n should ___crease. -Does it? ____ Furthermore, if U_1 is increased then U_n should ___crease. -Does it? ___