A. Uniform Circular Motion

1. On page 41 we investigated the forces acting on the bob of a swinging pendulum.
   a. How many such forces are there? ____
   b. The gravitational force is always directed _____ward. Its strength can be calculated with the formula ____. In that formula the letter ___ represents the mass of the bob, in ________s. The letter "g" represents gravitational _________ ___________, in ___ per ____.
   c. The other force on the bob is exerted by the __________. This "tension" is usually diagonal, but it is vertical when the bob passes through the _____est point in its curved path.
   d. We found that the ____ward force is *stronger* than the _____ward force at that time.
   e. We concluded that the *total* force on the bob must be ____ward at the moment when the bob passes through the lowest point in its path. Does this contradict 1d? ___

2. Newton's second law says that if the total force on the bob is not zero then the bob must accelerate, and that acceleration must be in the ______ direction as the total force. If that is true, the bob's acceleration must be ____ward when it is passing through the lowest point.

3. That conclusion seemed odd because the bob is neither speeding up nor slowing as it goes through the lowest point. Then we realized that accelerating means changing *velocity,* not just speed. There are *two* ways to change an object's velocity: You can change the *magnitude* of its velocity, (by changing its speed) -or you can change the *direction* of its velocity, as in #2.
   a. To see how that works, we drew two arrows to represent the object's velocity just *before* and just *after* passing through the lowest point. (In geometric language, they must be _________ to the curve, as on page 29.) We labeled them V_1 and V_2. *Please illustrate.*
   b. To calculate the change in velocity we used *vector subtraction:* (ΔV = ___ - ___)
   We had to reverse the direction of ____, draw it tail-to-head onto ___, and then draw a dotted arrow from the ______ end of ____ to the ______ end of ____. *Please illustrate.*
   c. That vector diagram clearly showed that the change in velocity was directed ____ward.
   d. To calculate the bob's acceleration we would divide that ΔV by the corresponding ______ interval. The result must be a vector pointing ____ward. -Does #2 agree? ____

4. Now imagine driving rapidly over the top of a hill: Just before you reach the top, the direction of your velocity is slightly _____hill. Just after passing the top, your velocity is slightly ____hill. Please draw arrows to illustrate, and label them V_1 and V_2. Then show how you subtract them to get your change in velocity.

5. The vector diagram in #4 shows that your acceleration must be _____ward when you are passing over the top of the hill, if your speed is not changing at that time. Therefore the total force on you must be ______ward at that time. The normal force exerted on you by the car seat must then be ______er than the gravitational force on you. (weaker, stronger, faster, darker)
   a. That explains why you feel _________er than normal when you drive too fast over the top of a hill. (lighter, heavier, smarter)
   b. When you go rapidly through the *lowest* point on a curved path such as a roller-coaster, you feel _______er than normal. *Does #1 agree?* ___

6. When you drive around a *horizontal* curved path, you feel the side of the car pushing you.
   a. If the car had no sides, your passenger might fall out of the right side of the car as you steer to the _______. (right, left) The sides (doors) of the car prevent the passenger from falling out by pushing him or her to the _______, toward the ________ of the circular path.
   b. In *each* of the examples above, the object's acceleration is ________ the center of the circular path. (toward, away from) That's why it is called a "centripetal" acceleration.
   c. A copy of the discovery in 6b has been saved in # ___ on RS VII.

1. On page 67 we made some discoveries:
   a. Whenever an object travels along a curved path, the object accelerates.
   b. IF the speed is constant, the direction of that acceleration is ___________ to the object's velocity, toward the _________ of the circular path. That's why we call it a "centripetal" acceleration.

2. To find the *total force* on the object in #1 we can multiply the object's centripetal acceleration by the object's ________. (That's _______'s second law.) If the speed is constant then the total force must be toward the ________ of the circular path. That's why it's called "_____________al force."

3. A rubber stopper tied to a string can be whirled overhead on a horizontal circular path, with constant speed. The string exerts an unbalanced force on the stopper in the ____________al direction. To make sure that the force on the stopper always has the value that we choose, run the string through a glass or plastic tube held vertically in your hand. Hang some metal at the lower end of the string, down near your knees. The metal must be *heavier* than the rubber stopper. *Each team must use a different amount of metal, covering the widest possible range of weights.*

4. When the rubber stopper is orbiting, the tension in the string is equal to the ________ of the metal stuff tied to the lower end. (That's why the metal does not accelerate.)
   a. That force pulls on the rubber object in the "___________al" direction. -Do #2 & 3 agree? ____
   b. The orbit radius is measured from the tip of the glass tube to the center of the rubber stopper. A diagram has been drawn on the _______ of this page to illustrate.

5. In this experiment the *dependent* variable is the orbiting object's *speed*. We can adjust (control) the values of the centripetal **force**, the orbiting **mass**, and the orbit **radius**. Choose *one* of those "controlled" variables to investigate. *The other two controlled variables must be kept constant.* Circle your choice above, and record it on the blackboard so that other teams can make different choices.

6. Adjust your chosen variable to the smallest value that is usable. Then begin recording measurements:
   a. The mass of the rubber stopper is about ____ ± ___ gram, or _____ kg, ± ____%.
   b. To convert that mass to kilograms I moved the decimal point ___ jumps to the _______.
   c. The mass of the metal is ____ ± ___ grams, or _____ kg ± ___%.
   d. To determine the weight of the metal in SI units, its mass must be multiplied by ___ ____, as in #8 on RS III. The result is _____ _____ ± ___%.
   e. To keep it in orbit, your hand must move back and forth roughly ____ cm., so the uncertainty of the orbit radius must be roughly ___ ___. The orbit radius is between _____ and ____ meter.

7. The "period" of the orbit is the amount of time it takes to go all the way around *once*. To measure the period it is best to measure the time needed for ten cycles and then divide by ten. (That's better because you get a ________er percentage uncertainty.) *That measurement must be repeated several times, taking turns with your partner.* Make a histogram of your results. Then use the olympic rule to decide on the SLV and GLV of the period. The orbit's **period** is between ____ and ____ ____

8. The distance travelled by the object in *one* cycle is equal to the _____________ of the circular orbit. To calculate that travelling distance we multiply the orbit's ________ (recorded in #___) by ____:

   SLV of Distance = [_____][_____ ___] = _____ ____
   GLV of Distance = [_____][_____ ___] = _____ ____

9. To calculate the object's *speed*, we __________ that distance by the _______ found in #___:

   SLV of speed = [_____ ___] ÷ [_____ ___] = _____ ____
   GLV of speed = [_____ ___] ÷ [_____ ___] = _____ ____

10. The variable that you circled in #5 must now be doubled *without* changing any other controlled variable. Make a new histogram and use the back of this paper to show how the new speed is calculated in range form, as in 6-9 above.

1. Suppose A and B are variables, and suppose that the value of A depends upon the value of B:
   a. In Chapter I we learned that if they are directly proportional then doubling one variable will cause the other one to ___crease by a factor of ___. That means it will be multiplied by ___.
   b. In Chapter II we learned that if they are *inversely* proportional (so that A is proportional to B^{-1}) then doubling the value of one variable will cause the other to ___crease by a factor of ___. That means it will be multiplied by ___.
   c. If A is proportional to B^2 then doubling the value of B causes A to ___crease by a factor of ___.
   d. If A is proportional to B^{-2} then doubling the value of B causes A to ___crease by a factor of ___.
   e. If A is proportional to $B^{1/2}$ then doubling the B-value causes A to ___crease by a factor of ___.
   f. If A is proportional to $B^{-1/2}$ then doubling the B-value causes A to ___crease by a factor of ___.
   g. If A is proportional to B^n then doubling the value of B causes A to be multiplied by ___.

2. In the orbit experiment on page 68 our team doubled the _______________ without changing the __________ or the _____________.
   a. The original orbit speed was between ______ and ______ _____. (from # __ on page 68)
   b. The *new* orbit speed was between ______ and ______ _____. (from # __ on page 68)
   c. Divide the new speed by the old speed, using the values in 2a and 2b:

      SLV of speed ratio = (_____ ____) ÷ (_____ _____) = ______

      GLV of speed ratio = (_____ ____) ÷ (_____ _____) = ______
   d. We find that doubling the ____________ causes the orbit speed to ___crease by a factor that is between _______ and ______.
   e. Which simple powers of 2 are between the SLV and GLV found in 2c and 2d? *Circle them.*

      2^1 2^2 2^{-1} 2^{-2} $2^{1/2}$ $2^{-1/2}$
   f. These results suggest that orbit speed may be proportional to ___________ to the ____ power.

      Please share that conclusion with the class by writing it on the blackboard, with your name(s). If you are not confident that these results are correct, please say so.

3. Some time ago we realized that an object's momentum is proportional to its velocity, and the object's momentum is also proportional to its mass. We concluded that momentum must be proportional to the __________ of those two controlled variables. (sum, difference, product, quotient) Similarly we found that work is proportional to the _________ of propelling force and displacement.
   a. Use similar logic to combine everybody's conclusions from 2e into one big relation, still using proportion language: **S may be proportional to ( ) ( ) ( ).**
   b. Use the rules of algebra to rearrange that statement, solving for centripetal force:

      F may be proportional to _________.
   c. What fundamental units must the proportionality constant have? _______ *Please explain.*
   d. Could a slightly different exponent in 3a lead to a simpler result in 3c? ______ *If so, explain.*

4. To test the opinions stated in 3b and/or 3d we must make a new graph of F vs _______. Use experimental data collected by the entire class. Show how you use that graph to calculate the SLV and GLV of the proportionality constant mentioned in 3c. You will earn no credit if the results contradict 3c.

Ch. VII Using a TI-82 or TI-83 To Analyze Circular Motion 68c

1. You can easily calculate ΔV for an object moving along a circular arc. Let "S" represent the speed of the object: For *half* a turn, θ = ____ deg. and ΔV = ____S. For a *quarter* turn, θ = ____ deg. and ΔV = ____S. For *one sixth* of a turn, θ = ____ deg. and ΔV = ____S.

2. Choose a speed and a circumference for the circle: S = _____ _____, C = _____ __ -To calculate the period of the motion you divide the ____________ of the circular path by the object's ________ :

   P = (_____ ____) ÷ (_____ _____) = ______ ______

3. The time needed to go a fraction of the way around is just a fraction of the period. For half a turn we find that ΔT = ___ ___. For a *quarter* turn, ΔT = ____ ___. For 1/6 of a turn, ΔT = ____ ___.

4. To get the object's average acceleration for each fraction of a turn, we divide ΔV by ____ . We find that for *half* a turn, **a** = ____ ____. For 1/4 turn, **a** = ____ ___. For 1/6 of a turn, **a** = ____ ___.

5. The θ values in #1 can be put into the "List 1" column on a graphing calculator. (To find that list, hit the "**STAT**" button and then "**ENTER**".) Then we put the acceleration values into "List 2". We then have a small data table for a graph of acceleration vs θ.

6. Next we must tell the calculator which numbers are the "Y" values and which are the "X" values so that it can make the graph for us. Hit **2ND-StatPlot**, and then **Enter**. Make sure that Plot 1 is ON. For *XList* select L1. For *YList* select L2. At the bottom of the screen select the first type of mark.

7. To choose appropriate scales for the graph, hit "**Zoom**", then "**9**". Then hit the "**GRAPH**" button. You will see your three data points, but the origin will not be visible. To fix that, hit the "**WINDOW**" button. Change *XMin* to 0, change *Ymin* to 0, and change *Xmax* to 360 degrees. Also make some room at the top of your graph. Hit the **GRAPH** button again and *show it to your teacher.*

8. Figure out a trigonometric formula for ΔV. (Use the right triangles that you get when you split the velocity triangle in half.) -Write it here: ΔV = _________________

9. In #2 you calculated the period of the motion. Write the formula that you used. (Use "S" for the speed and "C" for the circumference.) P = _______________

10. In #3 you figured out the ΔT values. Write the formula that you used. (Show how ΔT was calculated from C and S.) ΔT = (   )(____ /360^{o}) *Show this to your teacher.*

11. Divide the ΔV formula in #8 by the ΔT formula in #10. Remember to invert the divisor and then multiply. Also remember to simplify the result. The constants (S and C) should be placed in the first blank, and the θ's and fractions of θ should be in the last two. *Show this to your teacher also.*

    a = [   ] sin(   )÷(   )

12. Now plug in the chosen S and C values to get the numerical value and units of the constant in square brackets in equation 11. Use scientific notation, and show what you did:

    [   ] = (_______)(_____ _____)^2÷ (_______ ______) = ________ ______

13. Hit the "**Y=**" key and enter equation 11. Remember that Y represents the acceleration, and we are using X instead of θ. Remember to use the value of the constant found in #12.

14. Hit the "**GRAPH**" key to see how well the equation fits the data. *Show the result to your teacher.*

15. Hit "**2ND**" then "**GRAPH**" to make a data table appear. It shows that ***if*** ΔT is very small (so that θ is very _____) then the acceleration is ______ ________. (number with units)

New Idea: The average acceleration for a very short time interval like this is called an "instantaneous acceleration". The value that you found is different from everyone else's because your circle had a different ___________. *Show your teacher where you have recorded the definition of "instantaneous acceleration" on RS* ___.