

CENTRIPETAL FORCE

(L-9)

Until now, the only accelerations we have dealt with have been those that change the *magnitude* of a body's *velocity vector*--that make a body speed up or slow down. It is also possible to apply a force, hence acceleration, that does not change a body's *velocity magnitude* but does rather changes the body's *direction*. Such forces are labeled *centripetal* (i.e., center-seeking). They are always perpendicular to the *velocity vector* and are oriented so as to point toward the *instantaneous center of the arc upon which the body moves*.

This lab is designed to explore the ideas of *centripetal acceleration* and *centripetal force* using a pendulum system.

PROCEDURE--DATA

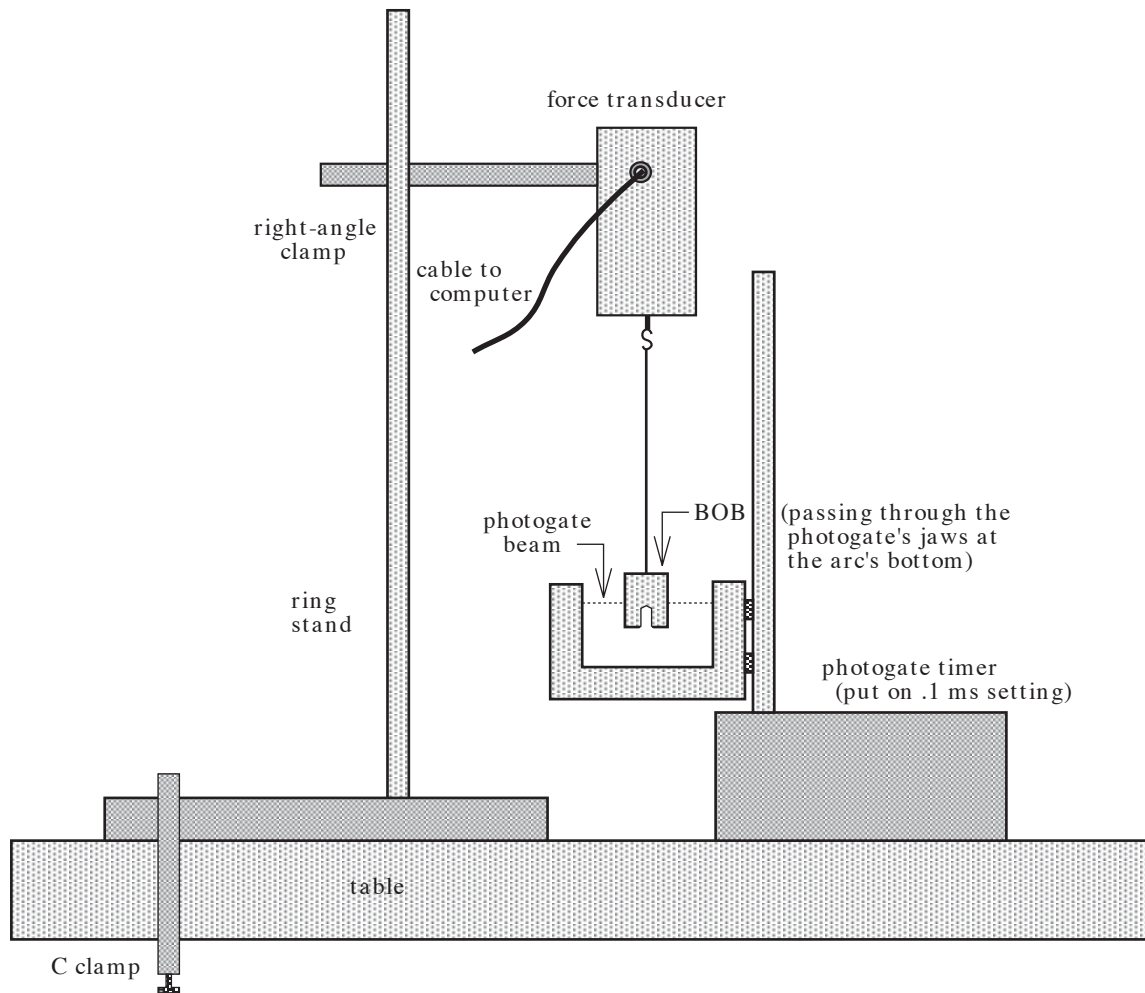
Part A: (the setup)

a.) Connect a FORCE TRANSDUCER to the Lab Pro interface, then open up the Logger Pro program on your computers. The program should recognize that there is a FORCE TRANSDUCER hooked to the interface and automatically give you a *Force versus Time* graph and a *data table*. Leave the table as is but change the *time setting* on the graph to 10 seconds. You will need to calibrate the Force Transducer. I will explain during class how to do this.

b.) Determine the mass and diameter of the pendulum BOB.

c.) Construct the set-up shown on the next page. If there isn't a hole in the eyelet through which you can secure your string, make a secure loop at the end of your string. The loop should be connected to the TRANSDUCER'S eyelet via a LASSO (in that way the string will be cinched to the eyelet and rubbing won't occur as the BOB swings). Position a free-standing PHOTOGATE TIMER so that the *center* of the PENDULUM BOB passes through the PHOTOGATE'S JAWS *when the BOB is at the bottom of its curved path*. Turn the PHOTOGATE on by setting it to GATE.

Note: The PHOTOGATE is powered by a line that goes from the PHOTOGATE to a TRANSFORMER (the *transformer* looks like a 2 inch cube with an electrical plug coming out of one face). It will be shown in lab.



d.) You need the length L of the pendulum arm. This is the distance between the string's connection-point to the TRANSDUCER at the top and the center of mass of the BOB. Make that measurement and record it in *meters*. BE ACCURATE (this is important).

e.) Before making your first run, remove all tension in the string (that is, gently grab the BOB and support it so it is not pulling down on the FORCE TRANSDUCER) and click on the EXPERIMENT icon found in the menus across the top of the computer program. With that menu opened, click on ZERO (this will be at the bottom of the list). This will calibrate your FORCE TRANSDUCER.

f.) Once zeroed, allow the BOB to hang down motionless and click on the COLLECT icon. When that icon changes to STOP, the TRANSDUCER will begin taking data and the graph should present a constant tension force being applied to the TRANSDUCER. That value should equal the weight (i.e., mg) of the BOB. Is it the same (or close)? If not, re-calibrate.

READ PARTS g, d, AND e before doing anything:

g.) Pull the pendulum BOB back to approximately 45° . Let off on the tension. Click COLLECT on the computer and wait for the STOP sign to show, then restore the tension and release the BOB. If you are set up correctly, the BOB should swing back and forth through the PHOTOGATE'S JAWS (be careful that the swing does not stray, possibly allowing the BOB to hit the JAWS after four or five swings). The computer will graph the *force* being applied to the TRANSDUCER'S ARM as time progresses. It should resemble a *sine wave* with the force a *maximum* when the BOB is in the vertical (i.e., when it passes through the photogate jaws).

h.) As was said above, you want to determine the TENSION FORCE in the line when the BOB is at its lowest point (i.e., when the tension force is greatest). Use the $x =$ icon on your menu to determine the maximum force from your graph (this should be obvious). If the graph dampens out with time, take an average.

i.) SIDE NOTE: This is where things get tricky. We have the information needed to determine the force on the BOB at its lowest point, but we also need the *velocity* of the BOB at that point in time. That is where the PHOTOGATE comes in.

1.) A PHOTOGATE TIMER has an infrared light beam that pass from an emitter on one side of its JAWS to a photosensitive cell on the other side of its JAWS. When set on GATE mode, a TIMER will activate and begin timing only when its beam is interrupted by something passing between its JAWS. The TIMER will continue until the beam is no longer blocked. Once this cycle is completed (at least in the GATE mode), the TIMER will not take another time reading until the BEAM is broken again.

2.) As the BOB passes through the PHOTOGATE'S jaws, it travels a distance equal to its WIDTH w before allowing the beam to re-establish itself and stop the TIMER. If the TIMER records an elapsed time of t during that period, we can find the BOB's *average velocity* at the bottom of the arc by dividing t into w (i.e., the *distance traveled* by the BOB during t divided by the *time of travel* for that distance).

3.) This process should be simple. Unfortunately, there is a small problem in that the TIMER is very sensitive to perturbations. To get a time for which we feel confident, we need to get THREE SUCCESSIVE TIME SAMPLES (we'll average them later). Sooo:

4.) Start by hitting the *RESET BUTTON* on the PHOTOGATE. As the BOB passes through the PHOTOGATE'S JAWS, it will leave a time in the PHOTOGATE'S TIMING-WINDOW. Before the BOB next passes through the JAWS, you need to RESET the TIMER as you *state that time* for your partner to record. When the BOB next passes through the JAWS, the TIMER will take *another reading*. Before the BOB next passes through the

JAWS, state *that* reading for your partner to record as you HIT RESET again. After the BOB passes through for the last time, stop the BOB and read the final time from the TIMER'S window.

This all has to be done quickly before the pendulum's motion dampens out.

CALCULATIONS

Part A: (pendulum problem)

1.) For the PENDULUM when at its lowest point:

a.) Do an f.b.d. for the forces acting when the BOB is at its lowest point in its arc.

b.) At the arc's bottom, are there any forces acting on the BOB in the *direction of its motion*? What does this tell you about the *acceleration* of the bob in that direction?

c.) At the arc's bottom, are there any forces acting on the BOB in the *direction perpendicular to the BOB'S motion* (i.e., in the vertical)? What does this tell you about the *acceleration* of the BOB in that direction (what *kind* of forces are these)?

2.) Use Newton's Second Law to derive a general algebraic expression for the *velocity* of the BOB when at the bottom of its arc (again, think about the *kind* of force acting when the BOB is at this point).

3.) Use the computer-provided tension in the string when the BOB was at its lowest point, the string length, etc., and the equation derived in Calculation 2 above to determine the theoretical velocity v_{th} of the BOB when at the bottom of its arc.

4.) Determine the experimental velocity v_{exp} of the BOB when at the bottom of its arc using the PHOTOGATE TIMER data (use the *average time* for this) and the DIAMETER of the BOB. If you aren't sure how to do this, look back at *Procedure i-2*.

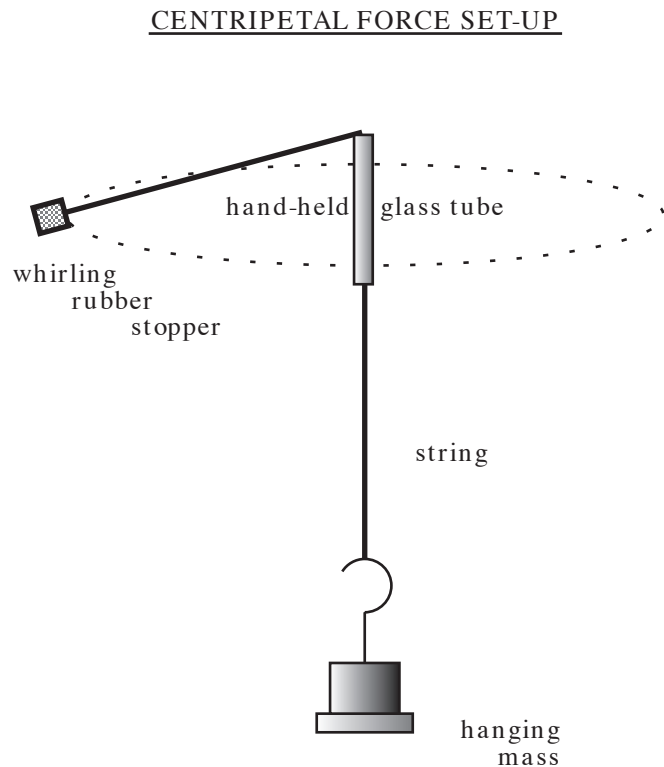
5.) The *theoretical velocity* calculated using the idea of centripetal force and the *experimental velocity* determined using the PHOTOGATE, etc., should be the same. Do a % comparison between the two. Comment completely (that is, identify major sources of possible discrepancy between the two values).

QUESTIONS

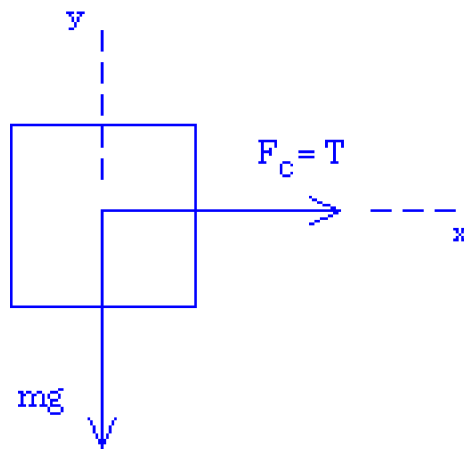
(In years past, the following questions have been a part of the lab proper. In an attempt to lighten the time load on writing up this lab, I am making them all extra credit (one point apiece). As such, each will be an “all or nothing” proposition. In any case, you do not need to do these if you haven’t the time or inclination.)

I.) Either in class or in lab, you have seen the setup shown to the right. It consists of a string threaded through a thick glass tube with a rubber stopper attached to one end of the string and a hanging mass attached to the other end. The sketch shows the stopper after it has been thrown into circular, horizontal flight (you are supposedly seeing a 3-D view in the sketch).

A number of years ago an intrepid student was asked to draw a realistic f.b.d. for the forces acting on the stopper. The young lady was also asked to write out Newton's Second Law for the situation. Her work is shown on the next page.



a.) Notice that her analysis suggested that the stopper's acceleration in the *y-direction* was 9.8 m/s^2 --a problem considering the stopper was accelerating only in the *horizontal*. WHAT DID SHE DO WRONG? That is, play teacher and find the error (you can re-do the problem correctly if you wish, but be sure to ANSWER THE QUESTION along the way).



$$\begin{aligned} \underline{\sum F_x:} \\ T &= ma_x \\ &= m(v^2/R) \\ \Rightarrow v &= (TR/m)^{1/2} \end{aligned}$$

$$\begin{aligned} \underline{\sum F_y:} \\ mg &= ma_y \\ \Rightarrow a_y &= g \end{aligned}$$

b.) Another student did the same lab and analyzed the problem exactly as did the student in *Part a*. He concluded that the *theoretical centripetal force* should be $F_c = T = mv^2/R$.

The student's graph of his *theoretical* F_c as a function of velocity is shown on the next page. On the same grid, he also graphed his *experimental* centripetal force T (according to his analysis, this was just the tension in the line)--versus experimentally observed velocities.

There is a very good reason why the two graphs are so far off at lower velocities and so much closer at the higher velocities. What do you suppose that reason is?

II.) A third student was asked to graph the *radius of rotation* versus *centripetal force* required to effect that motion (assuming a constant velocity). What would that graph look like? That is, make your own sketch of the graph. (HINT: Forget this experiment and think about how F_c varies on a curved road for larger and larger radius curves . . . given that the velocity is held constant throughout.)

