Centripetal Force and Uniform Circular Motion

TA's signature allowing you to take the quiz or leave ______________

Your Name ______________________________

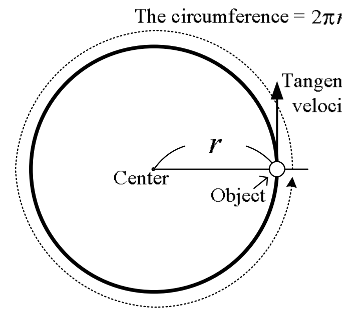
Partners' Names ______________________________

____

Obtained reasonable experimental results?	yes ☐
Answered questions?	yes ☐
Cleaned your table?	yes ☐

Introduction

This lab gives ideas of the uniform circular motion. This has a different concept from the previous labs, which are based on linear kinematics. Unlike a linear motion, the circular motion is always changing its direction although the speed is constant. The change of direction in a circular motion generates acceleration that is directed to the center of the motion. As we have already learned, acceleration acquires a force, which is, in circular motion, called centripetal force. In nature, we can find this all of the places, such as driving a car into curved roads, planets revolving about sun, etc. The centripetal force can be quantified as

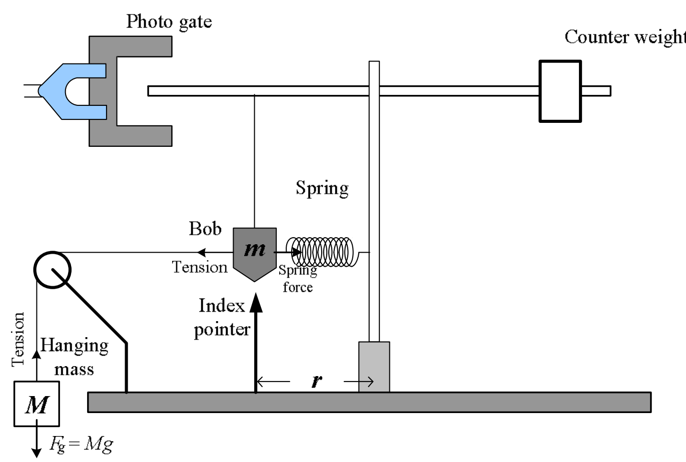


$$F_c = \frac{mv^2}{r}$$

where m is the mass of an object, v is the linear (or tangential) velocity, and r is the radius of the motion. From the expression, the force is proportional to the velocity squared and inversely proportional to the radius. (*That's why you have to slow down before driving into a curve!*) In a uniform circular motion, time repeated for one cycle is constant. The time for one revolution is called period and the expression is:

$$T = \frac{2\pi r}{v}$$

In terms of kinematics, time is defined as distance divided by velocity. The distance for a circle is the circumference, which is $2\pi r$. Therefore, the period can be expressed as above. The unit of period is second (s).



In the experiment, the radius of orbit (indicated by the pointer) and the period is measured by a ruler and a photo gate, respectively, and the linear velocity is calculated as

$$v = \frac{2\pi r}{T}$$

This can be substituted into the first formula above. Then, we have:

$$F_c = \frac{4\pi^2 mr}{T^2}$$

To calibrate the force, gravitational force is used when the system is static. The centripetal force (or centrifugal force which is the re-action force of centripetal force) can be calibrated by the hanging mass, $F_g = Mg$:

$$F_c = F_g$$ (This equation is only for the above setting.)

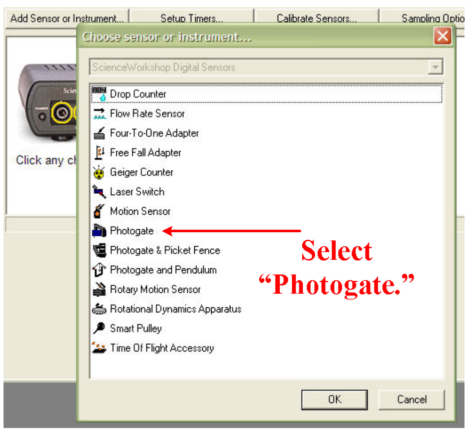
Objectives:

- To understand the property of the centripetal force
- To learn how to measure the centripetal force by imitating the centrifugal force (re-action force of the centripetal force) with the gravitational force.
- To find the how mass of the object affects its centripetal force.

🏳 Check the notations and names of parts of the equipment.

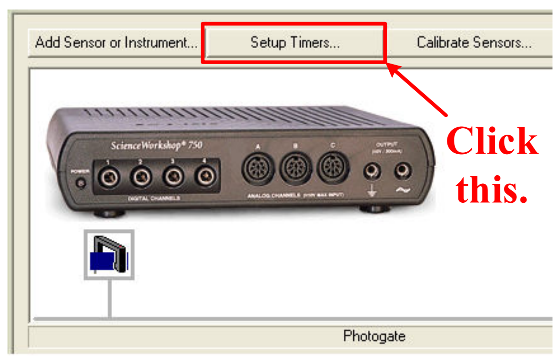
Question before the experiment:
What are the period, tangential speed, and centripetal force? Please write them down in layman's terms, or try to rephrase what your TA explains.

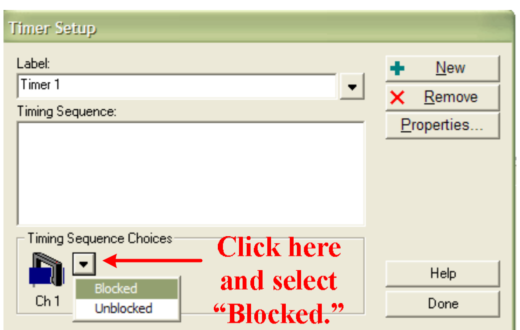
The procedure and data acquisition



⇐ Start up DataStudio. Click "Create Experiment." Click on the digital channel to select "Photogate."

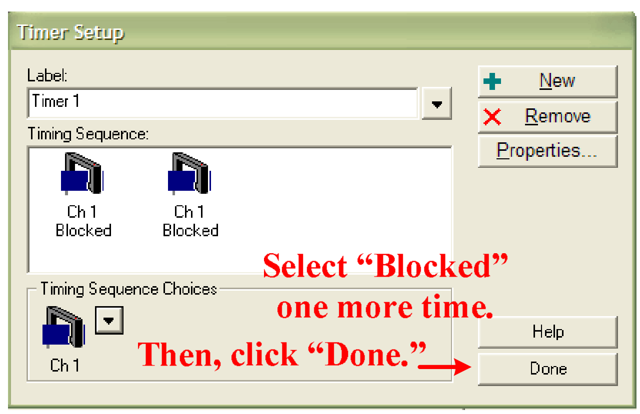
Click "Setup Timers." ⇒

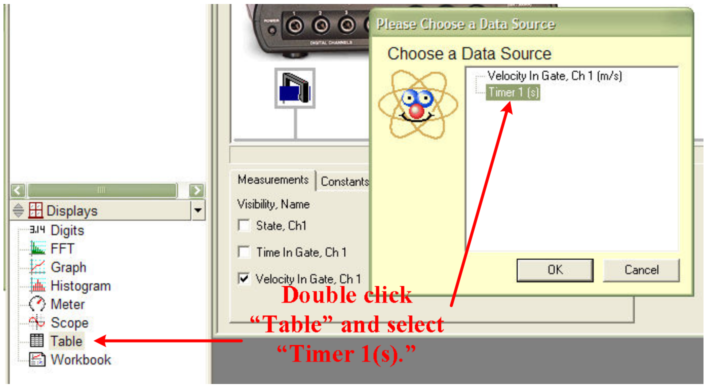




⇐ Click "Timing Sequence Choices" to select "Blocked."

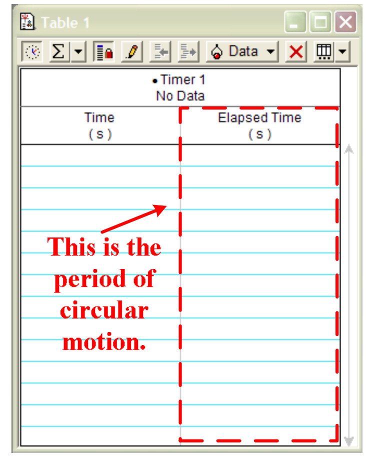
Repeat the above procedure to have two of the "Ch 1 Blocked" in the display. Then, click "Done." ⇒





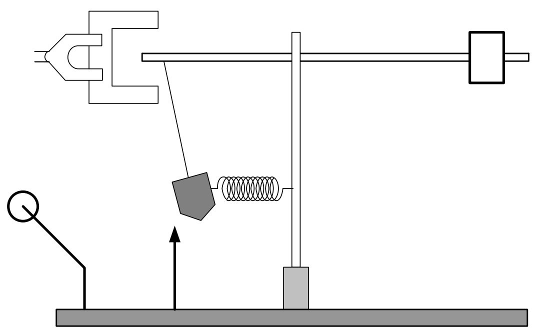
⇐ Choose "Table" for "Timer 1 (s)."

Each "Elapsed Time" is the period of the uniform circular motion. ⇒



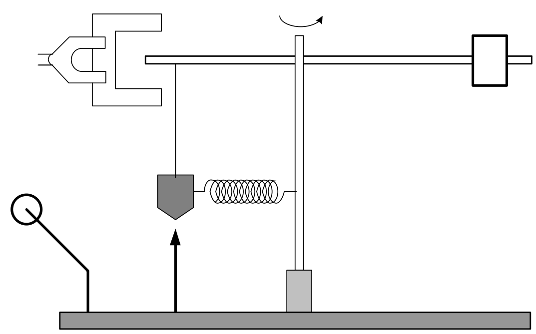
The experimental procedure **[Check each variables with the figure in introduction. They are case sensitive.]**

1. **Set up the position of index point.**

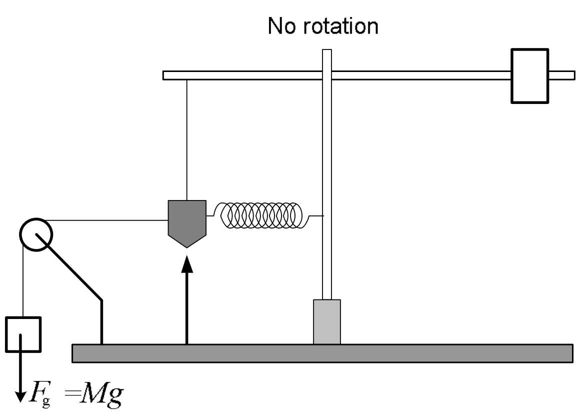


⇐ Measure the radius, r, <u>and record it in the table.</u> It is from the center of the axis to the pointer.

Warning **Make sure if the bob and pointer is lined up when you take it off from the spring.**



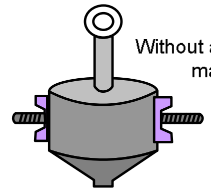
2. **Spin the bar and measure the period.**
Then, rotate the vertical bar. (Use the grip.) After the pointer and tip of the bob are lined up (or when the bob is touching the pointer), make sure that the recorded period is stable. [<u>Record the data of period, *T*.</u>]⇒



3. **Stop rotation and hang a weight.**
⇐ To find the centripetal force, F_c, you have to calibrate it with an equivalent force. The centripetal force is equal to the centrifugal one in this system, which can stretch the spring to the top of the tip. <u>To calibrate it, you may use the gravitational force.</u> Hang masses to the other side until the bob and pointer are lined up. The force will be the mass × gravitational acceleration which is supposed to be equal to the centripetal force.

Question: Do you understand why you have to hang masses as above? Yes_____ No _______ If you choose no, ask your TA to be convinced.

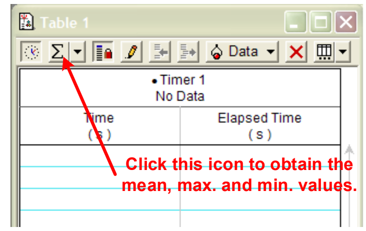
1. **Measurement of Centripetal Force (<u>for the different-mass object with a fixed radius</u>)**



Case 1: m = only bob

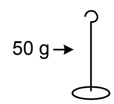
r (Radius of orbit) = ____________ (m) Mass of only bob = _________________ (kg)

After making stable circular motion, record about 6 periods. Remove mistakenly obtained values. Go to "Table" and click the icon, Σ. Write the mean value of period and calculate the difference between maximum and minimum data |Max. – Min.| as the fluctuation of data.



	m Total mass of object	T Average (mean) period	|Max. – Min.| Fluctuation of data of period	$v = 2\pi r/T$ Tangential speed	$F_c = mv^2/r$ Centripetal force	M Hanging mass **(This is not the mass of bob!)**	$F_g = Mg$ (g = 9.807 m/s^2) calibrated force	% difference b/w F_c and F_g
1	Only mass of bob							
2	Only mass of bob							
3	Only mass of bob							

The mass hanger itself is 0.050 kg to add.

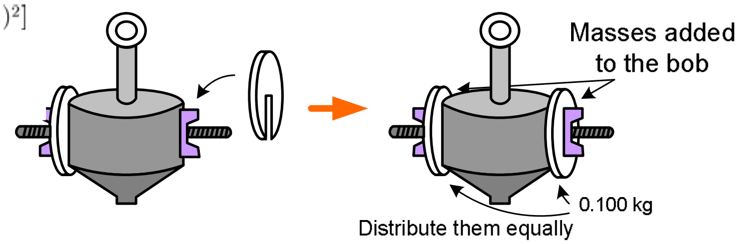


Average and standard deviation of (F_c):

(±) ( ) ⇐ write the unit

$$\text{Standard Deviation} = \sqrt{\frac{1}{N-1}[(\text{data1}-\text{Ave.})^2+(\text{data2}-\text{Ave.})^2+(\text{data3}-\text{Ave.})^2]}$$

$$\%\ \text{Difference} = \frac{|F_c - F_g|}{\frac{1}{2}(F_c+F_g)} \times 100$$



Case 2: m = bob + 200 g

r (Radius of orbit) = ____________ (m) Mass of only bob = _________________ (kg)

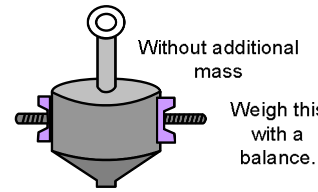
	m Total mass of object (bob + added)	T Average (mean) period	|Max. – Min.| Fluctuation of data of period	$v = 2\pi r/T$ tangential speed	$F_c = mv^2/r$ centripetal force	M hanging mass **(This is not the mass of bob!)**	$F_g = Mg$ (g = 9.807 m/s^2) calibrated force	% difference b/w F_c and F_g
1	Add 0.200 kg							
2	Add 0.200 kg							
3	Add 0.200 kg							

Average and standard deviation of (F_c):

(±) ( ) ⇐ write the unit

2. Measurement of Centripetal Force (<u>for the different-radius with a fixed mass</u>)

[You follow the same procedure as previous except calculating standard deviation.]

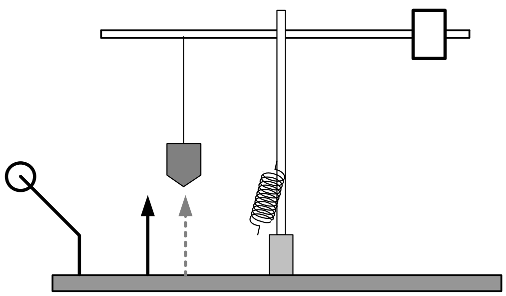


Case 1: The *r* is shorter. (Do not copy the result from the first part. The average period and its fluctuation may be different.)

r (Radius of orbit) = ____________ (m) Mass of only bob = _________________ (kg)

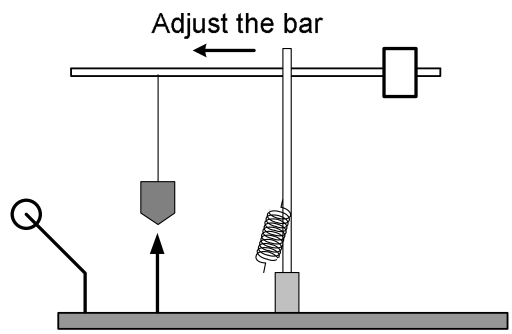
	m Total mass of object	T Average (mean) period	|Max. – Min.| Fluctuation of data of period	$v = 2\pi r/T$ Tangential speed	$F_c = mv^2/r$ Centripetal force	M Hanging mass **(This is not the mass of bob!)**	$F_g = Mg$ ($g = 9.807\ m/s^2$) calibrated force	% difference b/w F_c and F_g
1	Only mass of bob							

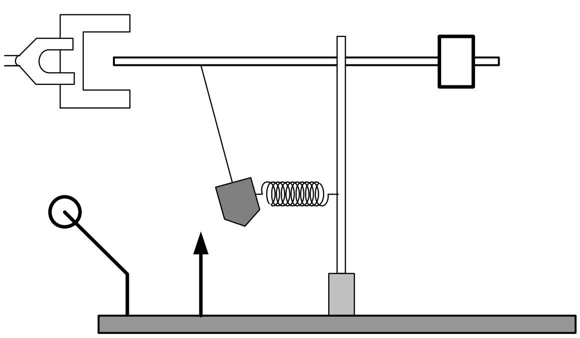
Case 2: The *r* is longer.



⇦ ① Take the spring off from the bob.

② For the new radius, adjust the bar so the bob can be lined up with the new index pointer. ⇨





⇦ ③ Hook the spring to the bob again and do the same procedure as previous.

r (Radius of orbit) = ____________ (m) Mass of only bob = _________________ (kg)

	m Total mass of object	T Average (mean) period	|Max. – Min.| Fluctuation of data of period	$v = 2\pi r/T$ Tangential speed	$F_c = mv^2/r$ Centripetal force	M Hanging mass **(This is not the mass of bob!)**	$F_g = Mg$ ($g = 9.807\ m/s^2$) calibrated force	% difference b/w F_c and F_g
1	Only mass of bob							

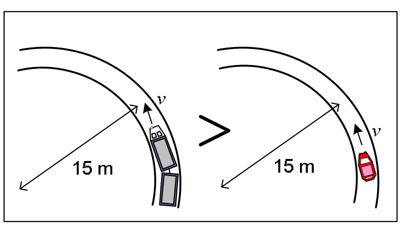
3. Analysis and discussions

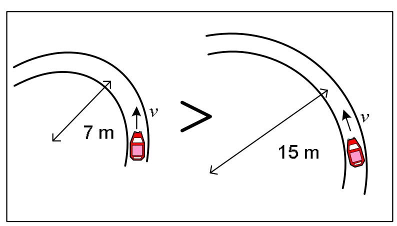
Question 1: In the first part, how does the centripetal force depend on the mass? In this set up, mass does not affect the force. Can you recognize it within the standard deviation? Think about why. [Hint: How does the period change according to the change of mass?]

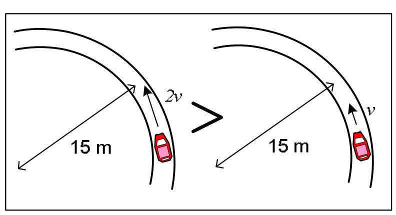
Question 2: In the second part, how does the centripetal force depend on the radius? Discuss this with the derived formula (in the introduction), $F_c = 4\pi^2 mr/T^2$.

Question 3: What are the possible errors in this lab? How do you improve the experimentation to obtain more accurate results? [This part must come from your observation and insights with the experimental results. Write also possible reasons. Discussion with your partners or TA is highly encouraged.]

Questions you want to explore [An advanced discussion]
For a simple case, the formula, $F_c=mv^2/r$, illustrates the following situations: When a trailer and a car go into each curve whose radius is 15.0 m, the trailer will obtain more centripetal force because of more mass than the car. Similarly, the shorter radius the curve has the more force the car attains. The more velocity the car takes the more force the car attains.







For this lab, strength of the centripetal force is fixed by the distance stretched by the spring; namely, it is constant. Because of that, the answer of Question 1 is not straightforward as you simply look at $F_c=mv^2/r$. Let's think of other daily life circular motions, such as planetary motions around sun, some rotating items in an amusement park, etc. How are the centripetal force, mass radius and period of the motion related each other? Which parameters are constant? Can you simply use the formula, $F_c=mv^2/r$?