

Uniformly Accelerated Motion - Centripetal Force

Introduction

When a particle moves in a circle with constant speed, the motion is called *uniform circular motion*.

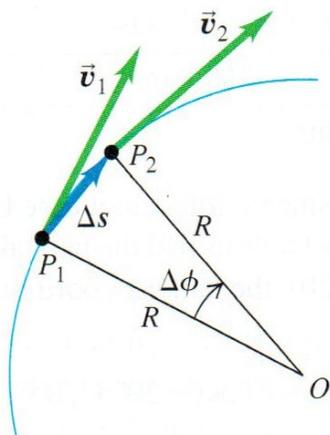


Figure 1: For Uniformly Accelerated Motion,

$$v_1 = v_2$$

Recall: $s = r\theta$	
Figure 1:	Figure 2:
$\Delta s = R \Delta \theta$	$\Delta \vec{v} = \vec{v}_1 \Delta \theta$
$\frac{\Delta s}{R} = \Delta \theta$	$\Delta \theta = \frac{\Delta \vec{v}}{\vec{v}_1}$
$\frac{\Delta s}{R} = \frac{\Delta \vec{v}}{\vec{v}_1}$	

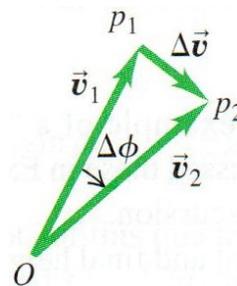


Figure 2: Recall that we can translate vectors.

Recall that $a_{avg} = \frac{\Delta \vec{v}}{\Delta t}$ such that by dividing both sides of the above equation by Δt , we can find centripetal acceleration:

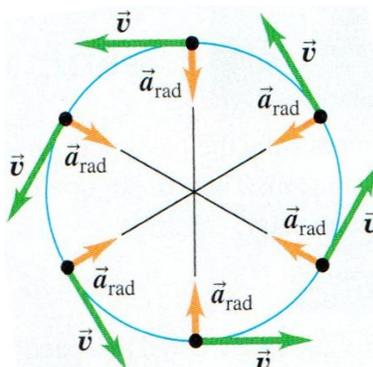
$$a_c = \frac{\Delta \vec{v}}{\Delta t} = \frac{\vec{v}_1}{R} \left(\frac{\Delta s}{\Delta t} \right) = \frac{\vec{v}_1}{R} \left(\frac{R \Delta \theta}{\Delta t} \right) = \frac{v_1^2}{R} \quad \text{where} \quad \vec{v} = R \omega = R \frac{\Delta \theta}{\Delta t}$$

Since $F = ma$, we can write centripetal force (dropping the subscript and using r for radius) as:

$$\vec{F}_c = m \vec{a}_c = m \frac{v^2}{r}$$

Thus, F_c and a_c are proportional to v^2 and *inversely* proportional to r .

Centripetal force is called a *center seeking* force. This is because the acceleration vector and thus the Force vector point to the origin O :



Goal

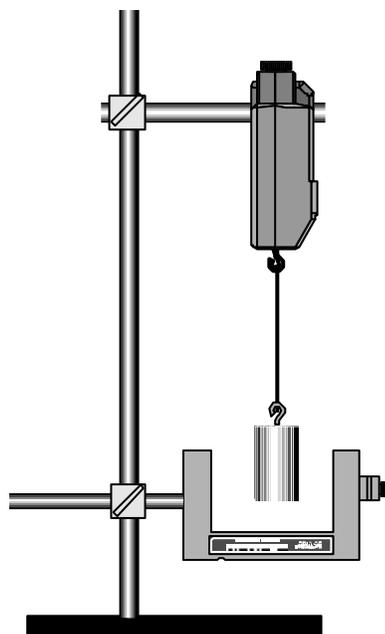
To understand how different factors affect the centripetal force of an object in uniform circular motion.

Equipment

Cylindrical Masses, brass and aluminum	Force Sensor
Photogate	String
Double Rod Clamp and Support	

Lab Notes

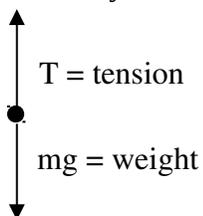
Since creating true uniform circular motion in a lab setting can be difficult, in this lab you will use the string and a cylindrical mass (bob) to create a pendulum that hangs from the Force Sensor. Thus, the setup will not be true uniform circular motion as the pendulum is affected by the acceleration due to gravity.



In this setup, the tension in the string causes the bob to follow a circular path and is the centripetal force, however, when the pendulum is at rest, the sum of the forces is:

$$\Sigma \vec{F} = T - mg = m\vec{a}$$

Thus, the force sensor must be tared to eliminate the gravitational force so that when the pendulum is in motion, it will read centripetal force only.



Setup

Pendulum

1. Ensure that the pendulum bob hangs low enough to be read by the photoeye, but high enough that it will not strike the photogate while in motion. Adjust by using the thumbscrews that attach the photogate and/or force sensor to the vertical rod (or use a longer/shorter string).
2. Measure the diameter of the bob with the vernier caliper and record the value in meters in Table 1a. **This measurement is critical to the success of this lab.**
3. Weigh the bob and record its mass in kilograms in the table.
4. Measure the length of the entire pendulum (not just the bob) from the bottom of the force sensor hook to the center of the pendulum bob, this is the radius of the circular motion, and record.
5. With the cylinder at equilibrium (not moving), tare the force sensor.

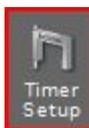
Computer

1. Log in, open Capstone, then click 'Hardware Setup':



2. Click the Digital Channel 1 button on the interface picture and add 'Photogate'.

3. Click the new tab that appears called 'Timer Setup':



1. Choose 'Pre-Configured Timer', click 'Next'
2. Choose 'Photogate, Ch. 1', click 'Next'
3. Select timer, 'Pendulum Timer'
4. Check 'Speed' only, click 'Next'
5. Set Pendulum Width, this is the measured diameter, in meters, of the bob. If this value is incorrect or measured incorrectly, you must redo the lab. Click 'Next'
6. You can use the default timer name, then click 'Finish'

4. Click the Analog Channel A button on the interface picture and add 'Force Sensor'. Set the frequency to 50 hz.



5. Click the 'Data Summary' tab:

1. Click 'Speed' under 'Pendulum Timer' to highlight, then click the Gear  icon to the right of it.
2. Click 'Numerical Format' and change the 'Number of Decimal Places' to 3, then click 'Ok'.
3. Repeat for 'Force'.

6. Click 'Graph' on the right hand pane and drag it into the center of the workspace. Do this again to show 2 graphs, side by side.



7. For one graph, click 'Select Measurement' on the y-axis and choose 'Force'. You should now have a Force vs. Time graph.
8. For the other graph, click 'Select Measurement' on the y-axis and choose 'Speed'. You should now have a Velocity vs. Time graph.

Helpful Hints:

1. When starting pendulum motion, ensure that the bob swings through the center of the photogate, not at an angle.
 2. Do NOT allow the bob to strike the photogate.
 3. When starting the pendulum motion, ensure there is not slack in the string as this will cause the bob to swing as it is swinging through the photogate. The effect is a double pendulum and this will cause error in your data.
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Procedure

Objective 1: Brass Bob

1. Practice swinging the bob: Displace the bob about 15-20 cm, ensuring there is no slack in the string, and set the bob in motion ensuring that it travels back and forth through the center of the photogate.
2. With the pendulum at rest, tare the Force Sensor.
3. Set pendulum in motion and allow secondary oscillations to dampen out. With the pendulum in motion and with a stabilized swing, start recording and stop after about 20 s.
4. On the Force vs Time graph, you should see a smooth, damped sinusoidal curve, symmetric about the x-axis. If it is not symmetric, you must set the bob at equilibrium, tare the force sensor, and repeat the motion. If the force sensor does not tare again, contact your TA.
5. The Velocity vs Time graph should be a decreasing, (nearly) linear progression.
6. Locate 5 consecutive troughs on the Force vs. Time graph. Click the "coordinates tool"  and position it at the bottom of the 1st trough. Record the Force value in Table 1b as 'F_c, measured' for Point 1.
7. Take note of the time at this point.
8. Go to the Velocity vs Time graph, click the 'coordinates tool' and use it to locate that time on the line. Record the corresponding velocity at this time in the table.
9. Using this velocity, calculate the centripetal acceleration and centripetal force and record in the table as 'a_c, calculated' and 'F_c, calculated', then find the % difference between the measured and calculated centripetal force.
10. Repeat this procedure for the next 4 troughs.

Objective 2: Aluminum Bob

1. Change the Brass bob to an Aluminum bob, repeating the same setup procedure.
 2. Measure the diameter of the bob, record in Table 2a, then click 'Timer Setup' as before, changing the pendulum width to the width of the Aluminum bob. Even though the diameter's of both bobs are similar, they are not the same. **Failure to do this introduces error into your data** which could cause you to have to redo this objective.
 3. Weigh the bob and measure it's length as was done for the brass bob, and record.
 4. Repeat the procedure as was done for the brass bob.
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Data

Table 1a

Item	Value
Bob Diameter (m)	
Bob Mass (kg)	
Length of Pendulum (m) (Radius of circular motion)	

Table 1b

Points	F_C, measured (N)	v (m/s)	a_C, calculated (m/s²)	F_C, calculated (N)	% difference
1					
2					
3					
4					
5					

Sample Calculations:

Table 2a

Item	Value
Bob Diameter (m)	
Bob Mass (kg)	
Length of Pendulum (m) (Radius of circular motion)	

Table 2b

Points	F_C, measured (N)	v (m/s)	a_C, calculated (m/s²)	F_C, calculated (N)	% difference
1					
2					
3					
4					
5					

Sample Calculations:

