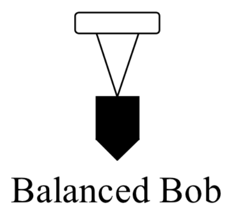
SAFETY: never turn on the power without the front/all side panels in place!

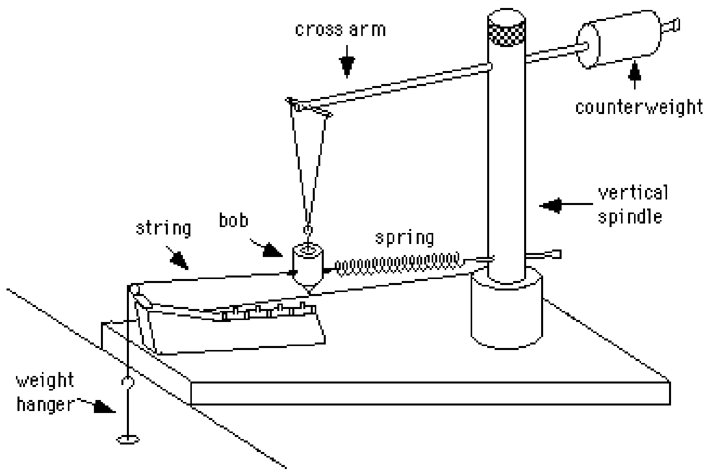
Centripetal Force

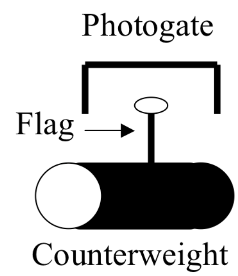
Introduction.

A centripetal force is any force (gravity, normal force, tension) causing an object to move in a circle. Without it, the object would move in a straight line. Satellites orbit the Earth because of the centripetal force exerted by gravity. If gravity were somehow "cut" a satellite would move away from the Earth in a straight line.

For a mass M with tangential speed v at radius R, the centripetal force is $F_c = Mv^2/R$. With a period of T, the linear speed is $v = 2\pi R/T$ and the centripetal force is $F_c = 4\pi^2 MR/T^2$. You will change Fc, mass, and radius to measure the effect on the period of rotation.







Study I Equipment: Meet "Bob"

1. Remove the spring and adjust the apparatus: check that the forces are balanced and it will rotate freely. Check that the "flag" on the counterweight will pass through the photogate.

2. Measure the mass, $\mathbf{M_B}$, of Bob**.** There are triple-beam balances available at the back and sides of the lab. Estimate $\boldsymbol{\delta}\mathbf{M_B}$ as you would estimate error of a ruler (or any analog device).

3. Select a constant radius **R** from the teeth marks below the hanging mass. You can adjust the radius with the screw on the central post (vertical spindle). Check whether the counter-weight needs to be moved in order to easily change the radius. Estimate $\boldsymbol{\delta}\mathbf{R}$.

4. Choose a spring, weak or strong, and attach it to Bob and vertical spindle. You'll repeat the experiment with the second spring.

5. Check that all screws (on Bob, the counter balance, and central spindle) are tight.

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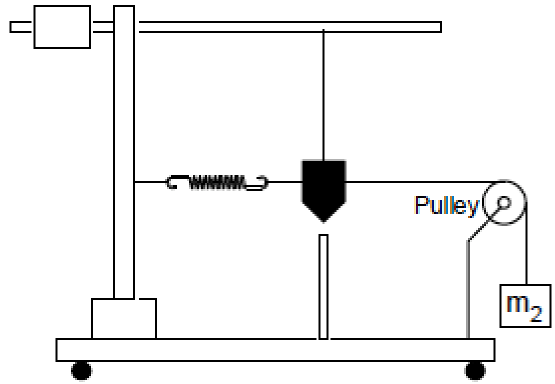

Static Force: Bob at rest

Once everything is aligned/rotating freely, find the force, Fs, the spring will exert on Bob when he's stretched to the chosen radius **R**. Since the spring pulls him inward when system is static, you'll be adding (easily measured) force to balance the spring force and estimate Fs.

Measure the tension to balance the spring force, Fs, at **R**:

1. Pass a string from over the pulley and attach the weight holder. Be sure the weight hangs straight down.
2. Add mass to the weight hanger until the string and the spring are horizontal (as pictured above). Bob should be at **R.**
3. Record your results as **m2** (kg). DON'T FORGET THE MASS OF THE WEIGHT HANGER. Calculate Fs = **m2***g.
4. Estimate the error **δm2** using the small masses and calculate **δFs**.
5. Remove the string and weight holder. The spring will naturally pull Bob inward.
6. Close the panels.

Centripetal Force: Bob in motion

Next use the power supply to rotate Bob. He will want to fly out to the end of the string, and beyond, but the spring will hold him in place. As you change the current, rotation speed and radius will change. Adjust the current to get **R** back. Use **DataStudio** to measure the period of rotation at your chosen radius:

1. Turn on the power supply. If you have a current dial, turn the dial up a bit (there is no correct value, but keep it fairly low).
2. Use the coarse voltage adjustment to get the spindle rotating close to the proper radius. Use the fine adjustment for "fine tuning". Adjust the voltage until Bob to passes directly over **R**. ***Equipment note:*** *Sometimes the rotation of the spindle is unbalanced, resulting in strange ticking noises and poor data. Adjust the counterweight if necessary.*
3. Start up **DataStudio** and double-click the digital plug located in Channel 1 to connect the photogate. From the pop-up menu, scroll down and select "photogate and picket fence".
4. Check the box "Time between bands (tDelta)." This will be your measured period T.
5. Create the data table and graph by dragging each little image (in the lower left box) to "Time between bands (tDelta)" (in the upper left box).
6. Start recording data once Bob has reached the desired radius. Record about 50 revolutions

and then hit Stop. While recording don't disturb the table. Slight shakes can affect the time readings.

7. The mean value of the period ($\overline{T}$), the count (N), and the standard deviation $\sigma(T)$ may be obtained directly from Data Studio using the Statistics Tool. Calculate $\sigma(\overline{T})$.

Next run down the voltage on your power supply so that rotation stops. Make sure both coarse and fine voltage controls are fully counterclockwise (the off position).

Complete Study I by changing the spring. Changing the spring will modify the centripetal force on the hanging mass. Observe what happens to the period when you change the centripetal force. For your analysis, you will calculate Fc and compare this force to the equivalent "static force" Fs applied with tension.

Study II: Design an experiment to study the effects of mass on period. You must use this to confirm the equation for centripetal force. Since mass, radius, and Fc all affect period, make sure to isolate independent variables in your study.

1. First notice that you can rearrange the equation for centripetal force:

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

2. Measure T while changing the mass. Bob is equipped with a screw on top so you can attach slotted weights. **You will need at least 5 independent data points.**

3. Remember to use the total mass (Mass Bob + added mass) in any calculations or graphs. When making adjustments, continually check your alignment.

4. Make a plot with the independent variable on the x-axis and the dependent variable $\mathbf{T^2}$ on the y-axis. If you get a linear relationship, you've qualitatively confirmed the centripetal force equation $F_c = 4\pi^2 MR/T^2$.

5. Use the slope of your graph, quantify your results by comparing to the constant quantities in your experiment.

Before you leave the lab:

- ***Turn the power supply off!***
- Complete the data table for Study I (Constants, Bob in Motion, Bob at Rest).
- A plot for Study II that confirms $F_c = 4\pi^2 MR/T^2$. The slope of the graph should compare with your measured values (within error). Be sure to include the usual labels and errors.

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Analysis for Study I: Calculate Centripetal and Static Forces

1. Calculate the static force Fs and its error (you've probably done this already).
2. Calculate the centripetal force F_c.
3. Determine the greatest source of uncertainty in Fc: M, R, or T, and use it to calculate the error in Fc (it will have the same relative uncertainty).
4. Calculate the difference between the calculated F_c and the measured F_s
5. Calculate the error in the difference using the rules of error propagation (go back to the "hands" lab if you need to).

Lab Diagram: Draw the free body diagram of the bob, for both the cases, while measuring the static force Fs and when Bob is rotating.

Theory: Use these force diagrams to clearly show why you are comparing two different forces Fc and Fs.

Discussion Questions

1. Do Fc and Fs agree within error?
2. While measuring the static force Fs, if the pulley is not completely frictionless, let's say there is a friction f present. Comment on the relationship between Fs, Fc and f.
3. Answer the following questions using your data to support your conclusions:

   a. Given the same mass and radius, which spring (weak or strong) will have the greater period? Does this agree with the theoretical equation?

   b. Given the same spring, will a greater mass have a greater period? Will a greater radius give a greater period?

A NOTE FOR LAB REPORTS: Treat Study I as a calibration (as long as Fc = Fs, or close) you know your equipment is working properly. Include all data to support this and answer the discussion questions. Write Study II up formally. Your theory section should show you understand the essential physics used in both studies, referring to your force diagrams.

Attention: For safety, never turn on the power supply without the front panel and all side panels in place.

STUDY I: Constants

Remember m, kg, and seconds allow you to calculate forces directly in Newtons

M_{bob} (kg)	δM_{bob} (kg)	Relative Error in M	R (m)	δR (m)	Relative Error in R

STUDY I: Bob at Rest (remember to add the mass of the hanger to m2!)

Spring	Weak Spring	Strong Spring
m2		
δm2		
Fs		
δ Fs		

STUDY I: Bob in Motion

N (# periods)		
$\overline{T}$ (s)		
$\sigma(T)$ (s)		
$\delta T = \sigma(\overline{T}) = \frac{\sigma(T)}{\sqrt{N}}$		
Relative Error in T		

Observation: What happens to the period when you change the spring from weak to strong?