Labatorial 4: Centripetal Force[4]
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Pre-Reading:
- *Physics for Scientists and Engineers* by Serway and Jewett (10th ed.), Section:
    - 4.4 – A.M. : Particle in Uniform Circular Motion
    - 6.1 – Extending the Particle in Uniform Circular Motion Model (see in particular Examples 6.1 and 6.3)

Equipment: Ruler, fixed-length string, mass, photogate timer, PASCO force sensor, caliper

Learning Goals:
- Understanding the relationship between centripetal force, radius, and velocity
- Understanding the nature of the centripetal force in a simple pendulum
- Understanding some applications of centripetal force in the real world

Activity 1: The Merry-Go-Round (30-40 min.)

Problem: We wish to model the physics of a merry-go-round to understand what kind of forces act on the riders from the perspective of an observer on the ground. If a ladybug happens to be on board when the merry-go-round starts, they will also be in for quite the ride.

Question 1:
Suppose the bug is on the merry-go-round and moves around to various locations. Assume it is turning counter clockwise.

a. Draw what you think the **velocity** and **acceleration** vectors would look like at the locations shown in Figures 1 and 2. Indicate higher velocity and acceleration with longer arrows.

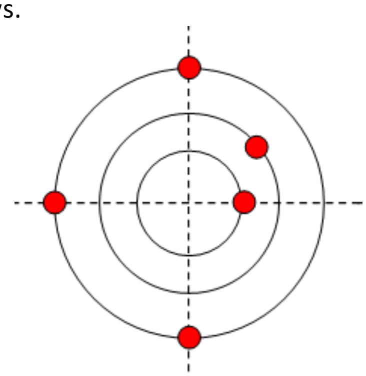

Figure 1 – Velocity vectors (expectations).

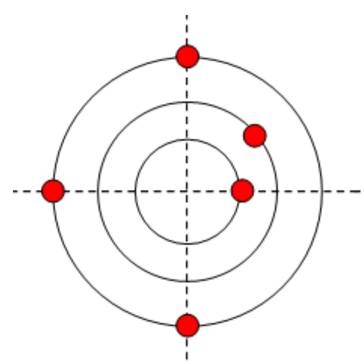

Figure 2 – Acceleration vectors (expectations).

b. Using the **Ladybug Revolution** simulation (rotation_en.jar) to check your ideas and make corrections on Figure 3 and 4. Start the simulation by clicking on the plate and spinning it or setting an angular velocity. If there were any discrepancies with your expectations, discuss why you think your intuition went wrong.

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[4] Questions 1 and 2 and Activity 2 of this labatorial have been adapted from the 2014-2015 lab manual for the course "PHYS 1201: Classical Physics I" at Mount Royal University.

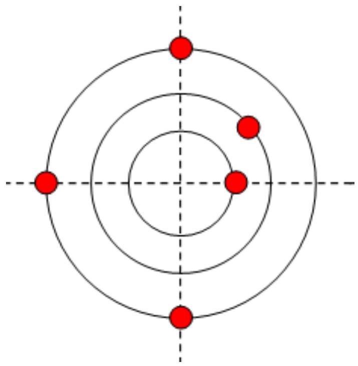

Figure 3 – Velocity vectors from the simulation.

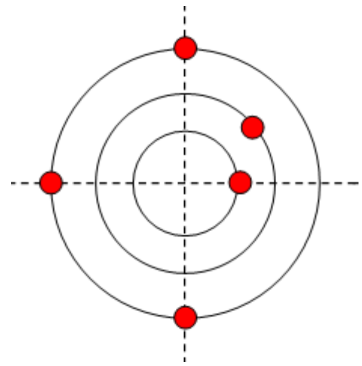

Figure 4 – Acceleration vectors from the simulation.

Question 2:
What is the nature of the centripetal force that keeps the ladybug from sliding off the merry-go-round? Draw a free-body-diagram of all the forces in the plane of rotation acting on the bug shown below. Now assume that the ladybug has a mass of 2 g and that air resistance can be ignored. By playing with the simulation, determine the maximum possible magnitude of this force. (Hint: The ladybug will get flung off if moving too quickly.)

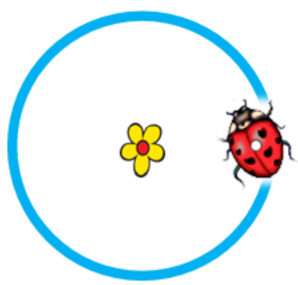

Figure 5 – Ladybug free-body diagram.

Question 3:
We know from our intuition (and the fact that the ladybug gets flung off the merry-go-round if spinning too quickly) that the ladybug would feel as though it is being pushed outward as the merry-go-round spins, just like we feel ourselves pushed toward the right in a car as it turns left around a bank. But from the free-body diagram, there should be no forces acting outward in centripetal motion according to an observer on the ground. Then why do you think we feel that outward push?

Checkpoint 1: Before moving on to the next part, have your instructor check the results you obtained so far.

Activity 2: The Simple Pendulum (70-80 min.)

Question 4:
In this part of the experiment we will have a cylinder hanging from a string tied to a force sensor (Figure 6). The cylinder will move like a pendulum. There is a photogate that measures the velocity of the cylinder at the lowest point of the swing.

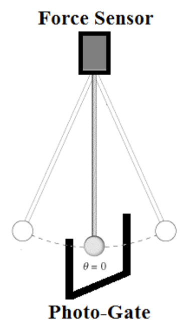

Figure 6 – An object hanging from a string exhibiting periodic motion.

a. Draw a free-body diagram for the hanging cylinder when it is not moving.

b. If the cylinder were moving, what would the free-body diagram look like at the lowest point?

Checkpoint 2: Before moving on to the next part, have your instructor check the results you obtained so far.

c. Make sure photogate is directly below the hanging cylinder. Connect the photogate to the PASCO black box (Digital Input 1). Open PASCO Capstone and click on "Hardware Setup". An image of the PASCO black box will appear. Click on Channel 1 and choose the "Photogate" option. Click on "Hardware Setup" to make the PASCO black box image disappear. Use the caliper to measure the diameter of the cylinder. Click on the "Timer Setup" tab and click "Next" until step 3. At this step, select the type "One Photogate (Single Flag)" option and click "Next". At step 4, ensure that "Speed" is selected and then select "Next". At step 5, enter the measured diameter of the cylinder as the "Flag Width", and then click on "Next" and "Finish". Now you can click on the "Timer Setup" to close the setup window.

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d. Connect the force sensor to Port 1. On PASCO Capstone, click on "Hardware Setup". An image of the PASCO black box will appear. The "Force Sensor" icon should have appeared in Port 1. Click on "Hardware Setup" again to make the PASCO black box image disappear.

e. Remove the pendulum mass from the force sensor, hit "Record", and drag "Digits" from the icons on the right hand side to the main page. Click on "Select Measurement" and choose the "Force (N)" option. When there is nothing attached to the force sensor (not including the string), it should read zero. To set the reading to zero, press the "ZERO" button on the force sensor. When the force sensor shows zero, stop recording data and delete the digits box by right-clicking it and selecting "Delete".

f. Choose the "Two Displays" option and select the "Graph" options in the middle icon on both displays to create speed-versus-time and force-versus-time graphs. Add a coordinates tool (which is the approximately "+" shaped icon 8th from the left on the toolbar above each display) on each graph. Then for each graph, right-click the icon that appears and select "Tool Properties." Open the drop down menu for "Numerical Format" and then "Vertical Coordinate". Select "Override default number format" and set the number of decimal places to 3. Select "OK" to close the window.

g. Re-attach the pendulum. Start the cylinder swinging and hit the "Record" button on the PASCO Capstone software. Record about 15 seconds of data. Choose seven speed data points from the bottom of the motion and note the force at those data points. Enter your data into Table 1. (You may play with different starting angles if you want.)

h. Measure the length of the pendulum from the pivot point of the pendulum to the center of the cylinder.

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i. What type of force does the force sensor measure in this experiment?

j. Calculate the net force for each speed and record your data in Table 1. Show a sample calculation below.

Table 1 – Measured and calculated data for the circular motion experiment.

	Speed of the Cylinder $(\boldsymbol{m/s})$	**Force Sensor Force** $(\boldsymbol{N})$	**Calculated Net Force** $(\boldsymbol{N})$
Point #1			
Point #2			
Point #3			
Point #4			
Point #5			
Point #6			
Point #7			

k. If you wanted to repeat the experiment again, what could you do to get better results?

l. How does the net force you have calculated compare with the force that the force sensor has measured?

m. Try to come up with a possible explanation if your calculated values are far from your experimental results. Call your lab instructor.

STOP CHECK POINT **Checkpoint 3: Before moving on to the next part, have your instructor check the results you obtained so far.**

Activity 3: Centrifuges (20-30 min.)

Question 5:
The idea of centripetal force has numerous applications, two of which are two types of centrifuge (i.e. a spinning chamber). Scientists can use large centrifuges to create artificial gravity for astronauts inside in order to prepare them for the high *g* forces experienced during a rocket launch. They can also use smaller ones to separate a heterogeneous fluid in a flask into its constituents, such as separating the plasma and red blood cells from a blood sample, or oil and water; in the centrifuge shown in the image shown in Figure 7, the denser fluid will end up at the bottom of the flask, and the less dense fluid on top. Using what you have learned so far (in particular, your answer to Question 3), try to explain how these applications work. Feel free to draw any free body diagrams if it helps with your explanation. (Hint for the fluid centrifuge part: Think about what causes oil and water in an upright flask to separate. How does rapid spinning accentuate this process?)

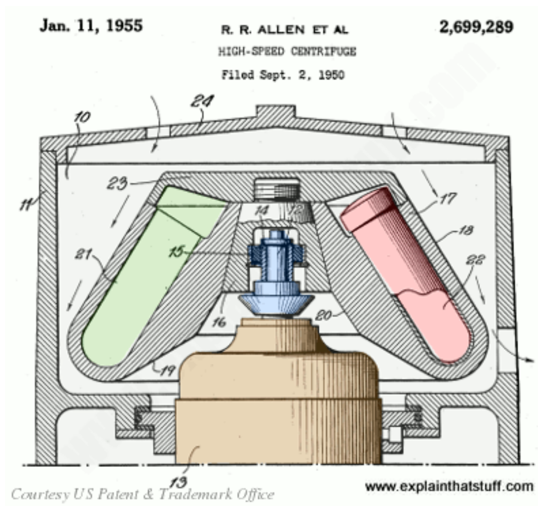

Figure 7 – A diagram of a fluid centrifuge.

Checkpoint 4: Put the equipment away and have your instructor check your work before leaving the lab.

Component	**Explanations**	**Points**	**Mark**
Worksheet	• If you finish all checkpoints, you will get 4 points.	4	
Group	• All students must be engaged in the lab activity. • All students must work, discuss, and share their information in the lab. • Interaction with group members and TA is mandatory. • All students must obtain answers to the questions that are the same as the other group members.	3	
Individual	• All appropriate data must be collected. • Data must be well organized and neatly displayed, including graphs. • The results of calculations must be presented with appropriate units. • Related physics concepts must be stated correctly.	3	

Please note that:

- Not properly cleaning the worktable or not putting away equipment that was taken out will result in a 1-point deduction from the "group" component of all members' grades.
- As of Labatorial 2 onward, not bringing your labatorial manual (in which case, a separately printed worksheet will be provided) or pre-reading summary to the lab will result in a 1-point deduction from the "individual" component of your grade.
- Progressing as a group is critical to the success of the labatorial, and so being more than 15 minutes late will result in a 1-point deduction from the "individual" component of your grade. Being more than 20 minutes late means you cannot perform the labatorial and you will receive a 0.