Centripetal Force

Educator Notes

Learning Objectives

- Students demonstrate their knowledge through listing examples of centripetal forces.
- Students make observations about circular motion.
- Students examine the effect of each variable on centripetal force.

Safety

- All students need to wear impact-resistant safety glasses for the bucket demonstration and lab investigation.

Introduce the Investigation

Ask

- Before performing this demonstration with a class, prepare enough small buckets of water for each group of students to have one bucket demonstration apparatus. To create the bucket demonstration apparatus, fill each bucket with approximately 1 inch of water. Securely tie a 1-meter-long piece of rope to the top of each of the bucket handles. Create an additional two bucket apparatuses without water for students to practice with.
- Place students in groups of three or four and handout one bucket demonstration apparatus to each group. Find an open space outdoors where the demonstration can take place.
- First demonstrate centripetal force by carefully swinging one of the buckets in a circle, horizontal to the ground and complete one full revolution. Show students how the water remains in the bucket and does not pour out as some may think.
- Next instruct each group to keep a safe distance from all other students and demonstrate the same horizontal swing.
- Now challenge each group to swing the bucket of water in a circle, vertical to the ground so the bucket of water is fully inverted at its maximum height. Have students practice this trick using the empty buckets and remind students to maintain a constant angular velocity. You may need to define constant angular velocity to your students as whirling the bucket at the same rate of speed. Maintaining a constant angular velocity is key to achieving zero water spillage. Next, have students pick up their group's buckets containing 1 inch of water. Instruct them to start by swinging the bucket back and forth. When they feel ready, students carefully swing the bucket vertical to the ground and complete a few revolutions. The goal of this demonstration is to not spill the water despite the inverted bucket.
- Fill each bucket with approximately 3 inches of water and have students again carefully swing the bucket, so it is fully inverted without spilling the water. Ask students to swing the bucket at approximately the same, constant angular velocity as before and focus on the difference in force required to swing a bucket filled with more water.

Grades 9 to 12

Suggested Pacing

60 minutes total

- Ask–25 min
- Watch Centripetal Force STEMonstration Video–5 min
- Test–20 min
- Share–10 min

Materials

This list of materials supports one group of students.

- ☐ Centripetal Force Student Worksheet (one per student)
- ☐ Acrylic or glass tube (an empty, plastic pen tube works)
- ☐ Five small washers
- ☐ Thin nylon string
- ☐ Calculator
- ☐ Small rubber stopper with a hole
- ☐ Tape measure/meter stick
- ☐ Marker
- ☐ Stopwatch
- ☐ Thin rope
- ☐ Water
- ☐ Masking tape
- ☐ Paperclip
- ☐ Small bucket

National STEM Standards

- HS-PS2-1
- HS-PS2-2

Centripetal Force

- Bring students back into the classroom and have each group think about the demonstration. Pose the following questions to students for a quick group discussion:
  - How were we able to swing the bucket of water and complete a full revolution?
  - Why didn't the water pour out of the bucket when the bucket was fully inverted?
  - What forces are involved in this demonstration?
- Handout the Centripetal Force Student Worksheet to each student. Give students a few minutes to write down their answers to the first few questions about the bucket of water demonstration.

Watch STEMonstration Video

- Watch the Centripetal Force STEMonstration video found at https://www.nasa.gov/stemonstrations.
- Write down the following centripetal force equations on the board and ask your students to copy these equations on their Centripetal Force Student Worksheet where space is provided.
  - Address each one of the variables, stating the measurement and its corresponding S.I. unit.

$$F_c = ma_c$$

$$a_c = \frac{V^2}{r}$$

$$F_c = \frac{m\,V^2}{r}$$

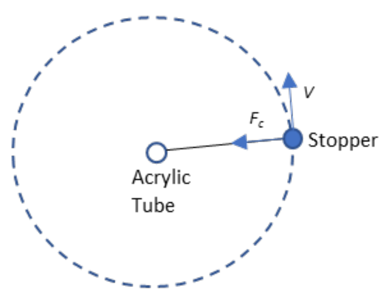
F_c = Centripetal Force (N)
m = Swinging Mass (kg)
a_c = Centripetal Acceleration (m/s^2)
V = Tangential Velocity (m/s)
r = Radius of Swing (m)

- Students work on the STEMonstration video activity portion of the worksheet. Walk around the classroom to ensure this is completed appropriately and clear up any misconceptions about centripetal forces.

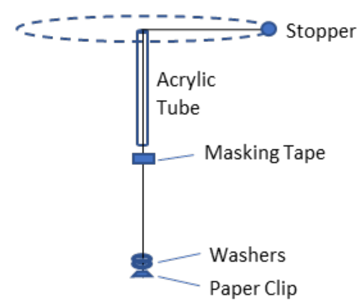
Centripetal Force Investigation

Test

- Each group of students needs one centripetal force apparatus. These should be assembled in advance of this activity.
  - Securely tie the string through the hole of a small rubber stopper. The string length from the stopper to the acrylic tube should measure a radius of 30 cm. With a marker, mark the location of 30 cm on the string. Make the mark large enough for students to see it inside the acrylic tube.
  - Feed the string through the acrylic tube. Place a piece of masking tape on the string, 2 cm below the acrylic tube. Make sure the 30 cm mark on the string is at the edge of the top end of the acrylic tube before measuring the 2-cm placement for the masking tape.



Top View



Side View

  - Measure the average mass of each washer ahead of time and provide the value to your class. For now, secure one washer from falling by attaching a paperclip to the bottom of the string as the diagram illustrates. Have students remove the paperclip to attach additional washers as instructed.
- As a class, discuss how the centripetal force apparatus works and go over the procedures with your students. Provide sample calculations, and a demonstration as you see fit.
  - Students swing their stopper at a radius smaller than the 30 cm, and then slowly increase their angular velocity until the stopper is revolving with a 30 cm radius. Students can hold onto and control the string from below the acrylic tube until they can successfully swing the stopper with a constant angular speed at a radius of 30 cm.
  - Remind students the stopper should move at a constant angular speed, where the 30 cm mark remains at the top edge of the acrylic tube. Students should not start timing revolutions until this is achieved.
- Students follow the lab procedures and fill out the data table with their measurements and calculations.

Share

- Students answer the post-lab questions within their groups. Once finished, students share and explain their answers to the class. Use the centripetal force apparatus to discuss and clear up misconceptions students may have.

Extensions

- Explain to your class how the calculated centripetal force should be equal to the total weight of the hanging washers. Allow students time to calculate the weight of the washers in Newtons and compare their calculated centripetal force to their experimental centripetal force. Students perform a percent error calculation and identify possible sources of error in the lab experiment.
- Use the Centripetal Force apparatus to perform an investigation where you alter the radius of the revolution and examine the tangential speed and/or the centripetal force.

Centripetal Force Student Worksheet

Bucket of Water Demonstration Questions

- In which direction were you applying a force to the rope to maintain the bucket's circular path around your hand?
- Did you require more force, less force, or the same force to keep the heavier bucket of water moving at roughly the same angular speed?
- Think about when the bucket of water swung perpendicular to the ground. Examine the forces exerted on the bucket of water when it was at its highest point, and when it was at its lowest point. Are the forces exerted on the bucket the same at these two locations? Why or why not? Draw free body diagrams to help you formulate your response.

Centripetal Force Equations

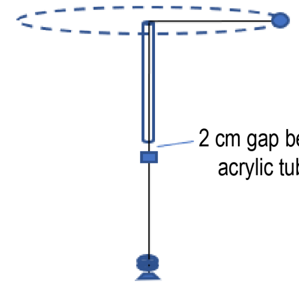
STEMonstration Video Activity

Centripetal force is not a force itself, rather the name given to any center-seeking force which keeps an object moving along a circular path. The STEMonstration video gave you examples of some centripetal forces. Determine the centripetal force for the two listed examples. Provide an additional two examples of centripetal forces and identify the centripetal force at work.

Example	Centripetal Force
The Moon orbiting Earth	
A runner rounding the bend of a track	

Lab Procedures

- If the stopper has a radius of 30 cm, calculate the circumference of a full revolution and write it in the blank above your data table. $C = 2\,\pi\,r$
- Add the number of washers to your centripetal force apparatus as indicated by each row of the data table and use the paperclip to secure the washers in place. Knowing the approximate mass of each washer, calculate the total washer mass and record it in your data table.
- Holding onto the acrylic tube, swing the stopper so it is moving at a constant angular speed, where the 30 cm mark remains at the top edge of the acrylic tube. Initially it helps to hold on to the string while you get the stopper moving, but once the stopper is swinging let go of the string and maintain a constant angular speed. You should only be holding the acrylic tube before taking any measurements. Once you have consistently met these parameters, a partner should time how long it takes for the stopper to complete ten revolutions using a stopwatch. Write down this time in your data table.



- Calculate how long it took your stopper to complete one full revolution knowing the time it took to complete ten revolutions.
- Calculate the translational speed of the stopper knowing $V_T = \frac{2\pi r}{t}$.
- Use the centripetal force equation to calculate the force of tension. Write down this answer in your data table.
- Continue to use these procedures to fill in the entire data table for the indicated number of washers.

Data

Approximate mass of each washer: _______________

Calculated circumference of circular path: ___________________

Number of washers	Total washer mass (kg)	Time to complete 10 revolutions (s)	Time to complete 1 revolution (s)	Translational speed of the stopper (m/s)	Force of tension (N)
1					
2					
3					
4					
5					

Post-Lab Questions

- Name the centripetal force in this lab investigation.
- As the centripetal force increased, what happened to the translational speed of the stopper?
- Look at the centripetal force equation.
  - What would happen to the centripetal force if we used a string with a shorter radius?
  - What would happen to the centripetal force if we were to replace the small stopper with a larger, more massive stopper?
- Think back to your bucket of water demonstration. What happened to the centripetal force when more water, or mass was added to the bucket?