National Aeronautics and Space Administration

Moment of Inertia

Educator Notes

Learning Objectives

- Describe the relationship between mass distribution and ease of rotation for a cylinder, hollow hoop, and sphere.
- Calculate moment of inertia and identify the relationship between the calculation and ease of rotation.
- Use the moment of inertia equations to determine how each variable effects the ease of rotation for a hollow hoop, solid cylinder, and sphere.

- Hot glue guns are required for this activity. Students should never touch the hot components of a hot glue gun. Review hot glue gun safety with your students prior to this activity.

Introduce the Challenge

STEMonstration Video

- Students watch the Moment of Inertia STEMonstration video found at https://www.nasa.gov/stemonstrations.
- Pose the following questions to students and facilitate a class discussion about each one.
  - Which position caused the astronaut to spin at a faster rate? Why?
  - Which position caused the astronaut to spin at a slower rate? Why?
  - What is moment of inertia and what does it tell us about a particular object?

Astronaut Megan McArthur is photographed floating in the U.S. lab with astronaut Thomas Pesquet in the background.

Facilitate the Challenge

Test

- Set up six ramps total in pairs of two throughout the room for groups to share during the lab investigation. More ramp pairs should be set up if available. Each ramp should be angled at approximately 10° with the floor. Ramps with varying lengths other than 2 meters can be used to complete this lab. Longer ramps tend to produce better results.
- Create groups consisting of three to four students.

Grades 9 to 12 Suggested Pacing

50 minutes total

- STEMonstration video – 10 min
- Test – 30 min
- Share – 10 min

Materials

All materials should be provided one per group unless otherwise stated.

- ☐ 2 snack size (2.5 oz) cylindrical chip containers with lids
- ☐ 2 additional cylindrical chip container lids
- ☐ 40 cotton balls
- ☐ Duct tape
- ☐ Scale/balance
- ☐ Calculator
- ☐ Hot glue gun with hot glue sticks (groups can share)
- ☐ 2-meter-long ramps, 6 total (per class)
- ☐ Moment of Inertia Equation Sheet
- ☐ 1 permanent marker (groups can share)
- ☐ Moment of Inertia Student Worksheet (1 per student)

Next Generation Science Standard

- HS-PS2-1

- Pass out two empty 2.5 oz snack-sized cylindrical chip containers with lids, an additional two chip container lids, 40 cotton balls, a roll of duct tape, and one calculator to each group. Groups can share the hot glue guns, hot glue sticks, and duct tape if there are not enough to give one to each group.
- Pass out the Moment of Inertia Student Worksheet to each student.
- Explain to the class how each group is going to conduct an experiment to determine how mass distribution affects the chip container's ease of rotation, and therefore speed, rolling down a ramp. To do this experiment, students must first ensure all other parameters are kept the same except for the distribution of the mass. Instruct students how both chip containers must have the same mass, but different distribution of mass, before they start the experiment. Students apply strips of duct tape on the outside of one chip container to demonstrate a rotating hoop and use cotton balls to fill another chip container to demonstrate a rotating solid cylinder.
- Students first prepare their solid cylinder chip container by placing 40 cotton balls inside one of the chip containers and closing the top by clipping on one of the lids. To ensure the chip container rolls straight, hot glue another lid to the bottom of the solid cylinder chip container. The result should be a solid cylinder chip container with two lids, one clipped on top and another glued on the bottom. Students use a marker to write "solid cylinder" on the top lid of this chip container.
- Next, students use a scale to determine the mass of their solid cylinder chip container and write this down on their student worksheet where indicated. Students should round measurements to the nearest gram.
- Students prepare their hoop chip container by first hot gluing a lid to the bottom of the empty chip container. Snap the lid onto the top of the container without using hot glue. Students use a marker to write "hoop" on the top lid of this chip container.
- Students must now measure the mass of their hoop container and then calculate the difference in mass between the solid cylinder and hoop containers. Record this number in the student worksheet where indicated.
- Instruct students to use the duct tape to add more weight to the inside or outside of the curved surface of the hoop container. Students should not add duct tape to either the top or bottom lid.
  - You can measure the mass of a 20 cm strip of duct tape ahead of time and write this mass on the board for students to calculate approximately how much length of tape is needed for their hoop container.
  - Students should evenly distribute the strips of tape inside and/or outside their hoop container.
- After students add the approximate mass of duct tape to their hoop container, ask students once again to measure the mass of both chip containers to ensure both have the same mass. Students should alter the amount of duct tape on their hoop container until both containers have the same mass. Measurements should be rounded to the nearest gram.
- When both containers have equivalent masses, they are ready to proceed with rolling their chip containers down the ramp. Monitor student progress.
  - As students are collecting data, ensure both containers are aligned straight at the top of the ramp so they both roll down the ramp without veering right or left.
  - Ensure both containers begin from the same height at the top of the ramp.
  - Ask students to write down any notes about each trial. Students should make note of anytime the containers veer in a direction other than straight down the ramp, or if either of the containers rolls off the side of the ramp. If this happens, remind students to carefully align the containers at the top of the ramp so they both roll down the ramp along a straight path.
- Instruct students to complete the post-lab questions following their data collection.

Share

- When students finish their data collection and post-lab questions, briefly hold a class discussion about each of the post-lab questions to clear up any misunderstanding students may have.

Extensions

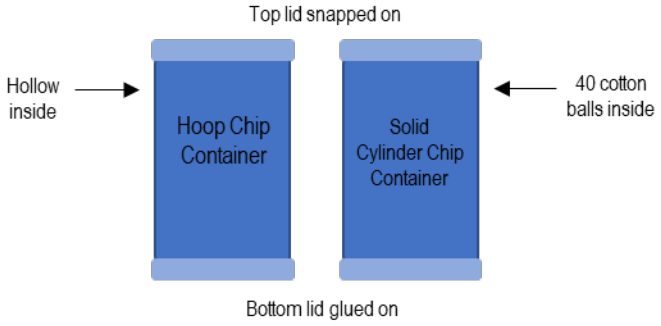
- Provide an assortment of materials with various masses for students to use in addition to scissors, hot glue guns, and hot glue sticks. Give each group plenty of time to redesign their solid cylinder container and have groups race their modified containers. Students can safely modify their container in any way they see fit using the provided class materials.
- Students design and build a car that runs solely on the energy stored within the spring of a single mouse trap. Students must use their knowledge of moment of inertia to design the wheels.

Moment of Inertia Student Worksheet

Laboratory Investigation Procedures

- Prepare your solid cylinder chip container according to Figure 1 by placing 40 cotton balls inside one chip container and close the top by clipping on one of the lids. Hot glue an additional lid to the bottom of the solid cylinder chip container. The result should be a solid cylinder chip container with two lids, one clipped on top and another hot glued to the bottom. Use a marker to write "solid cylinder" on the top lid of this chip container.
- Next use a scale to determine the mass of your solid cylinder chip container and write it down in the data section of this worksheet. Round your measurement to the nearest gram.
- Prepare your hoop chip container according to Figure 1 by first hot gluing a lid to the bottom of the empty chip container. Snap another lid on the top of this empty chip container without using hot glue. Use a marker to write "hoop" on the top lid of this chip container.
- Determine the mass of your hoop container and write it down in the data section of this worksheet. Round your measurement to the nearest gram.
- Calculate how much more mass the hoop container needs to have a mass equivalent to the solid cylinder container. Record this calculation in the data section of this worksheet.

Figure 1: Chip Container Assembly



- Apply strips of duct tape to the inside or outside curved surface of the hoop container until both containers have the same mass. Do not add duct tape to either the top or bottom lid. Be sure to evenly distribute the strips of tape inside and/or outside the container.
- When your group has added the approximate mass of duct tape to the hoop container, use a scale to measure the mass of both containers to ensure both have the same mass. Round measurements to the nearest gram. Adjust duct tape if necessary, until both containers have the same mass. Record the final masses of the two containers in the data section of this worksheet.
- When both containers have equivalent masses, you are ready to race your two containers down the pair of ramps provided by your teacher. Share your ramps with other groups if supplies are limited. Write down your results for each trial in the Group Data Table.
  - Make sure both containers are equally aligned at the top of the ramp, so they roll down following a straight path.
  - Make sure both containers are released at the same time and from the same height.
  - Make note of any trial where containers veer off to the side or roll off the ramp in the data table where indicated.
- Once all eight trials are performed and the data table has been filled in, answer the post-lab questions.

Data

Chip Container Masses (grams)

Beginning mass of the solid cylinder container: _____

Beginning mass of the hoop container: _____

Mass difference between containers: _____

Final mass of the solid cylinder container: _____

Final mass of the hoop container: _____

Group Data Table

Trial	Write down the name of the first container to reach the bottom of the ramp for each trial. (Solid Cylinder or Hoop)	Notes
1		
2		
3		
4		
5		
6		
7		
8		

Post-Lab Questions

1. How are the two containers similar and different?

2. Use the Moment of Inertia Equation Sheet to calculate the moment of inertia for each container. For the hoop container, assume the lid and bottom mass is negligible and your hoop container is a hollow hoop.

   a. Solid Cylinder: _____

   b. Hoop: _____

3. Which container has the largest moment of inertia? What does this calculation tell us in relationship to the smallest moment of inertia calculation?

4. Looking at the Group Data Table, which container rolled down the ramp the fastest?

5. Would you expect a solid sphere of equivalent mass and radius to roll down the ramp faster or slower than your solid cylinder and hoop containers? Use the Moment of Inertia Equation Sheet to explain your answer.

6. If the solid cylinder container was modified to have a smaller radius, but equivalent mass, how would you expect the speed of this modified container to compare to your original two containers? Use the Moment of Inertia Equation Sheet to explain your answer.

7. If the solid cylinder container was modified to have the same radius, but larger mass, how would you expect the speed of this modified container to compare to your original containers? Use the Moment of Inertia Equation Sheet to explain your answer.

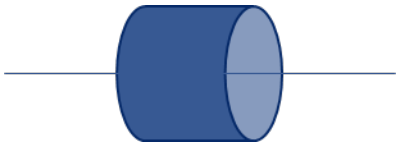
Moment of Inertia Equation Sheet

I = Moment of Inertia (kg·m^2)

M = Mass (kg)

R = Radius (m)

Solid Cylinder

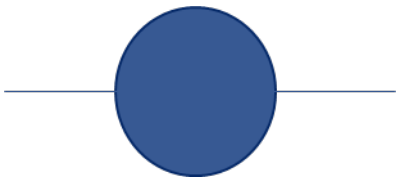


$$I = \frac{1}{2}MR^2$$

Hollow Hoop

$$I = MR^2$$

Solid Sphere



$$I = \frac{2}{5}MR^2$$