

# A downhill rolling race

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Everyday items like aluminum cans can teach us about physics. A filled can has more mass. It will roll differently than a can that is empty. Photo by: ziodanilo/Pixabay

Imagine rolling two identical cans down a slope, but one is empty and the other is full. Which one will reach the bottom first? You might have learned that when dropped straight down, all objects fall at the same rate regardless of how heavy they are (neglecting air resistance). Is the same true for objects rolling down a hill? Try this activity to find out.

## Background

When you lift an object up off the ground, it has potential energy due to gravity. The amount of potential energy depends on the object's mass, the strength of gravity and how high it is off the ground. When you drop the object, this potential energy is converted into kinetic energy, or the energy of motion. Kinetic energy depends on an object's mass and its speed. Ignoring frictional losses, the total amount of energy is conserved.

For a rolling object, kinetic energy is split into two types: translational (motion in a straight line) and rotational (spinning). So when you roll a ball down a ramp, it has the most potential energy when it is at the top, and this potential energy is converted to both translational and rotational

kinetic energy as it rolls down. This leads to the question: Will all rolling objects accelerate down the ramp at the same rate, regardless of their mass or diameter?

The answer depends on the objects' moment of inertia, or a measure of how spread out its mass is. If two cylinders have the same mass but different diameters, the one with a bigger diameter will have a bigger moment of inertia, because its mass is more spread out. Similarly, if two cylinders have the same mass and diameter, but one is hollow (so all its mass is concentrated around the outer edge), the hollow one will have a bigger moment of inertia. Does moment of inertia affect how fast an object will roll down a ramp? Give this activity a whirl to discover the surprising result!

### **Materials**

Two soup or bean or soda cans (You will be testing one empty and one full.)

A hollow sphere, such as an inflatable ball

A solid sphere, such as a marble (It does not need to be the same size as the hollow sphere.)

Cardboard box or stack of textbooks

Flat, rigid material to use as a ramp, such as a piece of foam-core poster board or wooden board. The longer the ramp, the easier it will be to see the results.

### **Preparation**

Empty, wash and dry one of the cans. (Don't waste food — store it in another container!) Prop up one end of your ramp on a box or stack of books so it forms about a 10- to 20-degree angle with the floor.

### **Procedure**

Hold both cans next to each other at the top of the ramp. Which one do you think will get to the bottom first?

Let go of both cans at the same time. Watch the cans closely. Which one reaches the bottom first? Repeat the race a few more times. Does the same can win each time?

Now try the race with your solid and hollow spheres. Which one do you predict will get to the bottom first? What happens when you race them?

Extra: Find more round objects (spheres or cylinders) that you can roll down the ramp. For example, rolls of tape, markers, plastic bottles, different types of balls, etcetera. Try racing different types of objects against each other. What seems to be the best predictor of which object will make it to the bottom of the ramp first?

Extra: Try the activity with cans of different diameters. What happens if you compare two full (or two empty) cans with different diameters? What about an empty small can versus a full large can or vice versa?

Extra: Try racing different combinations of cylinders and spheres against each other (hollow cylinder versus solid sphere, etcetera). Can you make an accurate prediction of which object will

reach the bottom first?

## Observations And Results

You should find that a solid object will always roll down the ramp faster than a hollow object of the same shape (sphere or cylinder) — regardless of their exact mass or diameter. This might come as a surprising or counterintuitive result! A classic physics textbook version of this problem asks what will happen if you roll two cylinders of the same mass and diameter — one solid and one hollow — down a ramp. The answer is that the solid one will reach the bottom first. In that specific case, it is true the solid cylinder has a lower moment of inertia than the hollow one does. Although they have the same mass, all the hollow cylinder's mass is concentrated around its outer edge so its moment of inertia is higher.

But it is incorrect to say, "The object with a lower moment of inertia will always roll down the ramp faster." It takes a bit of algebra to prove, but it turns out that the absolute mass and diameter of the cylinder do not matter when calculating how fast it will move down the ramp — only whether it is hollow or solid. So, in this activity you will find that a full can of beans rolls down the ramp faster than an empty can — even though it has a higher moment of inertia. It has the same diameter, but is much heavier than an empty aluminum can. Applying the same concept shows two cans of different diameters should roll down the ramp at the same speed, as long as they are both either empty or full. The same principles apply to spheres as well — a solid sphere, such as a marble, should roll faster than a hollow sphere, such as an air-filled ball, regardless of their respective diameters.

## Quiz

- 1 Which option BEST explains how potential energy interacts with kinetic energy?
- (A) Potential energy is based on an object's mass, and is converted to kinetic energy based on how the object is put into motion.
  - (B) Potential energy is based on an object's speed in motion, and is lost when kinetic energy begins to create friction with the object.
  - (C) Potential energy is the same for all objects, but kinetic energy can either be rotational or translational depending on shape.
  - (D) Potential energy is different based on objects' mass and weight, but kinetic energy is always the same for objects of every shape and size.

- 2 Which characterization accurately describes BOTH solid and hollow rolling objects?
- (A) Both have to be weighed and measured before beginning the experiment to see how much energy they lose.
  - (B) Both have most of their mass concentrated around their outer edges so the moment of inertia is high.
  - (C) Both will roll faster than an object with the same shape as long as they have a different mass and diameter.
  - (D) Both will roll at the same speed as objects with different diameters as long as they are both empty or both full.

- 3 Read the following paragraph from the section "Background."

*The answer depends on the objects' moment of inertia, or a measure of how spread out its mass is. If two cylinders have the same mass but different diameters, the one with a bigger diameter will have a bigger moment of inertia, because its mass is more spread out. Similarly, if two cylinders have the same mass and diameter, but one is hollow (so all its mass is concentrated around the outer edge), the hollow one will have a bigger moment of inertia. Does moment of inertia affect how fast an object will roll down a ramp? Give this activity a whirl to discover the surprising result!*

How does the final sentence contribute to the development of reasons for doing the rolling race experiment?

- (A) It demonstrates the effects of the experiment on different types of objects.
  - (B) It suggests that the outcome may be contrary to what the information in the paragraph would predict.
  - (C) It provides instructions for carrying out the experiment under different circumstances.
  - (D) It highlights a key problem with the accuracy of information in the rest of the paragraph.
- 4 A reader of the article suggested that the author included the section "Procedure" in order to show that the experiment can be carried out in various ways.
- Is this a reasonable claim? Which selection from the article supports your answer?
- (A) No: The materials of the experiment have no effect on the outcome and use of energy.
  - (B) No: The steps of the experiment are strict and it will only work if carried out in the listed order.
  - (C) Yes: Readers should try making stacks and ramps out of different types of materials.
  - (D) Yes: Readers should try creating and observing different combinations of shape, mass and diameter.