Rolling Race

Introduction

It's a race! Investigate the properties of the moment of inertia by rolling differently shaped objects, such as a solid disc, ring, and sphere, down an incline. Discover why the sphere always wins!

Concepts

- Moment of inertia
- Newton's laws of motion
- Kinetic energy
- Potential energy

Materials

Cylinders, Solid disks, Spheres } of relatively the same mass

Balance, 0.1-g precision

Inclined plane or thin wood board, 1 m long

Ruler

Stopwatch

Safety Precautions

Be careful of rolling objects flying out of control. Wear safety glasses when performing this demonstration and have students stand at least 10 feet away. Follow all laboratory safety guidelines.

Preparation

Prepare an inclined plane by elevating one end of a commercial inclined plane or a thin wood board (about one meter long) with a block of wood or a textbook. Raise to a height of 5–10 centimeters from the floor or table top. Make sure the inclined plane or board has no sideways tilt. You may want to practice rolling the objects down the plane to ensure they will roll all the way down.

Procedure

1. Select three objects—a solid disk, a sphere, and a ring of approximately the same mass. Mass the objects in front of the students.
2. Place a ruler flat at the top of the inclined plane. Make sure it does not slide down the ramp.
3. Position the "rollers" behind the ruler so that they will roll straight down the inclined plane (see Figure 1). Adjust the ruler, if necessary, so that the centers of the rollers are at the same starting position on the inclined plane (i.e., the points on the solid disk, sphere, and ring in contact with the inclined plane are at the same height).

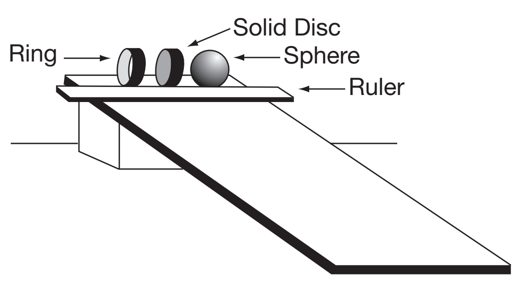

Figure 1.

4. Ask students to make a prediction about which object will reach the bottom of the inclined plane first. (Most students will predict that the ring will reach the bottom first.)
5. Quickly remove the ruler or meter stick from the base of the rollers so they simultaneously begin to roll down the inclined plane.
6. Discuss the results. *(The sphere will reach the bottom of the inclined plane first.)*
7. Repeat the experiment by using rollers of the same approximate radius.
8. Repeat the experiment with any combination of rollers, challenging students to predict and explain the results.

NGSS Alignment

This laboratory activity relates to the following Next Generation Science Standards (2013):

Disciplinary Core Ideas: Middle School
- MS-PS2 Motion and Stability: Forces and Interactions
  - PS2.A: Forces and Motion
  - PS2.B: Types of Interactions
- MS-PS3 Energy
  - PS3.A: Definitions of Energy
  - PS3.B: Conservation of Energy and Energy Transfer
  - PS3.C: Relationship between Energy and Forces

Disciplinary Core Ideas: High School
- HS-PS2 Motion and Stability: Forces and Interactions
  - PS2.A: Forces and Motion
  - PS2.B: Types of Interactions
- HS-PS3 Energy
  - PS3.A: Definitions of Energy
  - PS3.B: Conservation of Energy and Energy Transfer
  - PS3.C: Relationship between Energy and Forces

Science and Engineering Practices
- Developing and using models
- Constructing explanations and designing solutions

Crosscutting Concepts
- Patterns
- Cause and effect
- Systems and system models
- Stability and change
- Energy and matter

Tips

- Have students try the activity using various other rolling objects. Have students make predictions on how the objects will perform based on their moments of inertia.
- In the equations, (see *Discussion* section) students will find that mass cancels out. Demonstrate by choosing a few of the same type of rollers of different masses, and racing them to see which gets to the bottom first.
- For best results, make sure the ramp is long enough that the difference between the velocities will be apparent. A short ramp will only allow the sphere to gain a small lead. Inclined planes one meter long or longer are optimal.
- As an interesting twist, find a hollow sphere and race it with the ring and solid disk. Without knowing the sphere is hollow, students will be stunned to see it always loses to the solid disk! Challenge them to explain it. (A hollow sphere has a moment of inertia of $I = \frac{2}{3} mr^2$.)
- Use objects, such as wooden disks, metallic rings, and steel ball bearings, that have smooth edges and are relatively massive so that air resistance is negligible. Thin cardboard tubes and Styrofoam® spheres will give poor performance.
- Instead of propping up one end of the inclined plane or wood board with a block of wood or a book, lay the inclined plane or wood board flat on the tabletop. Position rollers near one of the ends of the inclined plane or board so that they are at rest and their contact points with the inclined plane are the same distance away from the end. To start the objects rolling along the inclined plane at the same time, slightly lift the end of the inclined plane where the rollers are positioned. The end only needs to be lifted a few centimeters and it should be held at this height until the race is finished.
- Do not raise the inclined plane up to a large angle because this may cause the rollers to slip down the inclined plane rather than roll, which would skew the results for the rolling objects.
- A towel or other soft barricade can be placed at the end of the inclined plane to stop the rollers once they finish the race.

Discussion

When an object, such as a rock on a cliff or a ball being bounced, starts at a certain height and falls, it transfers its potential energy into kinetic energy. Since energy must be conserved, the equation relating the two energies is fairly simple.

$$PE_{\text{initial}} = KE_{\text{final}} \qquad \textit{Equation 1}$$

$$PE = mgh$$

$$KE = \tfrac{1}{2}mv^2$$

where

m = mass
g = acceleration due to gravity
h = height of object's fall
v = velocity of object

and, all together,

$$mgh = \tfrac{1}{2}mv^2 \qquad \textit{Equation 2}$$

In the case of an object rolling down a ramp, the equation gets a little more complicated. The kinetic energy usually means just translational velocity, or how fast the object is moving forward. But in this case, some of the consumed potential energy is taken up into rolling the object—how much depends on the object's *moment of inertia*.

Moment of inertia is an object's resistance to being spun. It is calculated by taking the sum, ∑ of every little particle of mass multiplied by the square of the distance from the axis of rotation, as shown in Equation 3.

$$I = \sum m_i r_i^2 \qquad \textit{Equation 3}$$

where

I_{axis} = moment of inertia about a particular axis of rotation
m = infinitely small point of mass in the object
r = distance from axis of rotation

This can be fairly complicated to do in some cases. Most physics textbooks will provide a chart, allowing students to look up the values for various shapes (See Table 1). The addition of rotational kinetic energy turns Equation 2 into Equation 4:

$$mgh = \tfrac{1}{2}mv^2 + \tfrac{1}{2}I\omega^2 \qquad \textit{Equation 4}$$

I = moment of inertia
ω = angular velocity

Shape	Moment of Inertia
Ring	mr^2
Solid disk	$\frac{1}{2} mr^2$
Sphere	$\frac{2}{5} mr^2$

Table 1. Moment of Inertia

Since the rolling kinetic energy of the sphere will be the lowest of the three objects in this activity, most of its energy will be changed into translational velocity—giving it the edge to win the race.

Materials for *Rolling Race* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP4634	Ring and Disks
AP4535	Inclined Plane, Economy Choice

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.