RAFT IDEAS

Topics: Potential & Kinetic Energy, Viscosity, Moment of Inertia

Materials List

- ✓ 10 Clear, hollow hemispheres that can be joined to make 5 spheres
- ✓ Water
- ✓ Viscous liquid (e.g., detergent or syrup)
- ✓ Large marble
- ✓ Sand
- ✓ Optional: Paint or permanent marker
- ✓ Ramps, 2 - see Assembly step 2 for suggestions
- ✓ Books, blocks, &/or other materials

This activity can be used to teach:
Next Generation Science Standards:

- Forces & Motion (Physical Science, Grade K, 2-1, 2-2; Grade 3, 2-1, 2-2; Middle School, 2-2; High School, 2-1)
- Kinetic and Potential Energy (Physical Science, Grade 4, 3-1; Middle School, 3-2, 3-5)
- Gravity (Grade 5, Physical Science 2-1)
- Science & Engineering Practices (Grades K-12)

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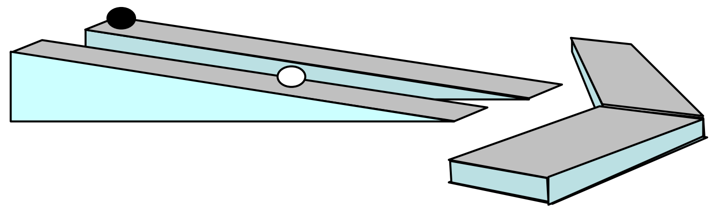
Inertia Ball

Create spheres that seem to defy gravity!



Students commonly think that heavy balls will always roll down a ramp faster than light ones! Explore this misconception by filling hollow balls with different substances and make surprising observations. Set inquiring minds to work to figure out what is going on!

Assembly

1. Use 10 hollow hemispheres to create 5 spheres - each with a different filling. Suggested fillings:
   a. Air
   b. Sand, fill each hemisphere and then assemble so the sphere is full of sand
   c. Water, assemble under water so the sphere is completely filled with water
   d. Detergent or syrup, add enough to fill 1/3 of the sphere
   e. Same amount of detergent or syrup as listed above then add a large marble before assembling the sphere
2. Create 2 ramps at least 1 m (~1 yd) long from a tube cut in half lengthwise, a cardboard strip folded into a "v" or "w" shape, or tubes set side by side.
3. Use books or equal to raise one end of each ramp the same amount, ~10 cm (4").
4. Use 2 books, or other materials, positioned in a V-shape to stop the spheres at the bottom of the ramp, as shown in the illustration at the top of the page.

To Do and Notice

Optional Discrepant Event presentation: Note this activity may be presented as a discrepant event demonstration. Paint or cover the spheres so that students can not see what is inside. Have students roll each painted sphere down the ramp and then ask the students to figure out what is inside the spheres that is causing the different rolling speeds. Having a second set of clear filled spheres where the students can see what is inside will be helpful.

Clear Sphere presentation: Alternately the students could be given clear spheres and asked to investigate the spheres different properties as outlined in the steps below:

1. Let the air-filled sphere roll down the ramp several times; note the rolling speed.
2. Race the air-filled sphere against the sand filled ball by using 2 ramps. Which sphere is the fastest?
3. Race the winner of step 2 against the water-filled sphere. Which sphere is the fastest?
4. Race the air-filled sphere against the sphere filled with the detergent or syrup. What is observed? Were the results surprising?
5. Race the spheres filled with detergent or syrup against the sphere containing the large marble. What is observed? The sphere with the syrup and the large marble may be appropriately nicknamed "Inertia Ball". What is the reason behind the name?

Written by Gus Liu (RAFT)

The Science Behind the Activity

A hollow sphere's mass is concentrated along the outer surface while a solid sphere has the mass evenly distributed from the center to the outside. The moment of inertia for mass that is nearer the center of a solid sphere will be less than for the mass that is located farther from the center. In fact, if rolling friction and air resistance could be eliminated, any solid sphere will roll down faster (or "beat") any hollow sphere regardless of size or mass differences! A practical example of is seen when figure skaters pull in outstretched arms creating a reduced moment of inertia, becoming more "solid", and thus spinning faster.

The moment of inertia can be defined as the amount of resistance to change in rotational velocity. The following formulas show that the moment of inertia is quite different between a hollow and a solid sphere:

Moment of inertia for hollow spheres: $I_{hollow} = 2/3\ mr^2$

Moment of inertia for solid spheres: $I_{solid} = 2/5\ mr^2$

Where m = mass of the sphere and r = radius of the sphere

The formula used to calculate the velocity of an object rolling down a ramp (an inclined plane) states that the potential energy of the object at the top of the ramp is equal to the linear (translational) kinetic energy plus the rotational kinetic energy that the object will have at the bottom of the ramp. In calculating the velocity at the bottom of the ramp the mass and radius of the object on each side of the equation will cancel out so that the velocity (**v**), for an object with a specific moment of inertia, is dependent only on the height (**h**) of the ramp and gravity (**g**). With the masses and radiuses cancelling out the velocity will vary inversely with the object's moment of inertia. A smaller moment of inertia means a faster velocity for the solid sphere than for any hollow sphere when both are released from the same height, regardless of the size or mass difference between the two!

	Potential Energy	=	Linear Kinetic Energy	+	Rotational Kinetic Energy
Hollow sphere:	$m \cdot g \cdot h$	=	$\frac{1}{2} \cdot m \cdot v^2_{hollow}$	+	$\frac{1}{2} \cdot I_{hollow} \cdot \omega^2$
	$m \cdot g \cdot h$	=	$\frac{1}{2} \cdot m \cdot v^2_{hollow}$	+	$\frac{1}{2} \cdot (2/3\ mr^2) \cdot \frac{(v_{hollow})^2}{r^2}$
	$g \cdot h$	=	$\frac{1}{2} \cdot v^2_{hollow}$	+	$1/3 \cdot v^2_{hollow}$
	v_{hollow}	=	$(6/5 \cdot g \cdot h)^{1/2}$ = square root $(6/5 \cdot g \cdot h)$		
Solid sphere:	$m \cdot g \cdot h$	=	$\frac{1}{2} \cdot m \cdot v^2_{solid}$	+	$\frac{1}{2} \cdot I_{solid} \cdot \omega^2$
	$m \cdot g \cdot h$	=	$\frac{1}{2} \cdot m \cdot v^2_{solid}$	+	$\frac{1}{2} \cdot (2/5\ mr^2) \cdot \frac{(v_{solid})^2}{r^2}$
	$g \cdot h$	=	$\frac{1}{2} \cdot v^2_{solid}$	+	$1/5 \cdot v^2_{solid}$
	v_{solid}	=	$(10/7 \cdot g \cdot h)^{1/2}$		

Since 10/7 is bigger than 6/5, v_{solid} will always be larger than v_{hollow}!

ω = angular velocity

Viscosity describes a fluid's internal resistance to movement or flow and may be thought of as a measure of fluid friction. At room temperature, water has a viscosity of 1 cP (centipoise). Olive oil's viscosity is about 100 times higher at 100cP while corn syrup is really thick at almost 1400cP!

The sphere filled with the detergent or syrup, both viscous liquids, will roll down the ramp much slower than the air-filled sphere, because the liquid is "sticking" to the wall, increasing the moment of inertia for the sphere.

Finally the sphere containing a viscous liquid and the marble will "crawl" down the ramp because the marble inside the sphere is "sticking" to the interior wall, increasing the sphere's moment of inertia even more.

Taking it Further

- Experiment with corn syrup or some other very high viscosity ("thick") liquid.
- Race a sphere, and a hollow cardboard tube of the same diameter as the sphere, down the ramps. Stuff a tube with cloth material and observe whether or not a stuffed tube rolls faster down the ramp.

Web Resources (Visit www.raft.net/raft-idea?isid=584 for more resources!)

- For information on measure viscosity - http://hyperphysics.phy-astr.gsu.edu/hbase/pfric.html#vi
- Viscosity values for various liquids - http://www.science.uwaterloo.ca/~cchieh/cact/c123/liquid.html