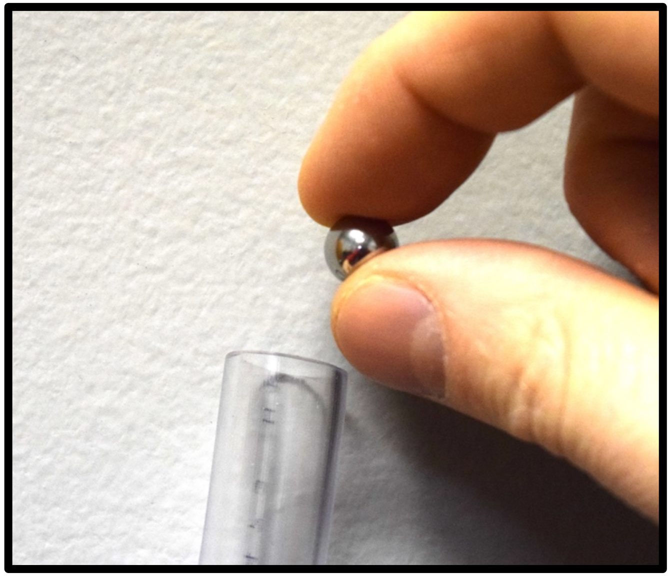
GARAGE PHYSICS
by eisco



Ball Bearing Roller-Coaster Kit
GP00017

Guide for Educators

Loop de loops, corkscrews and dives can be made with this simple kit exploring gravitational potential energy, and translational and rotational kinetic energy. Send a steel ball bearing careening through a 20 foot long transparent tube to explore the interplay between these forms of energy. Stick the hooks to your wall to create a roller-coaster work of art! Compete with other teams to implement the most loop de loops, shortest transit time, and maximum final velocity. Or try the much more difficult challenge of achieving the longest transit time and minimum final velocity. The quest is up to you!

NGSS Standards

Motion and Stability: Forces and Interactions
MS-PS2-2

Contents of Kit

20 ft long 5/8“ diameter FDA approved vinyl tube, Removable small wire hooks (9 per package), 1 package of twisty ties with included clipper, 4 steel ball bearings 3/8“ diameter, 3 rubbing alcohol pads.

Required but not included

A piece of scratch paper (US Letter or A4 size is sufficient) and a pair of sissors.
Tape (just about any kind will do)
2 tin cans per class (any size will do)

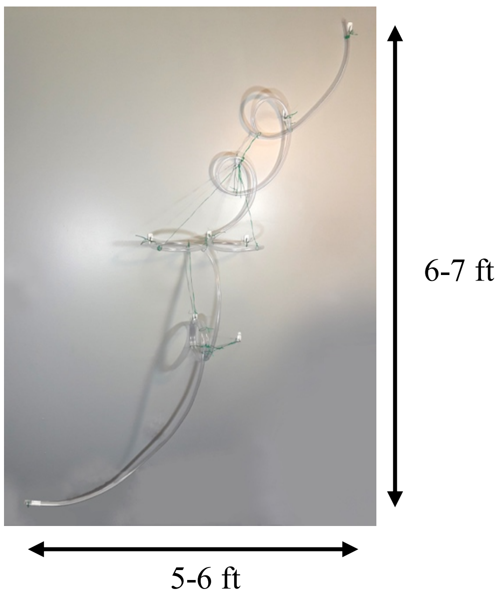
Optional Equipment

Visual Scientifics Photogate Sensor (Eisco model PTPGS)

Pedagogical Guide

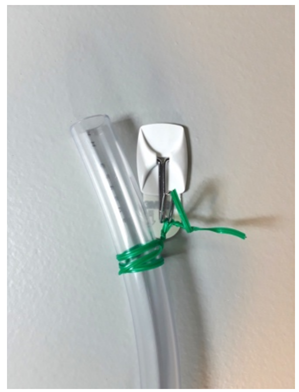
Assembly

1) Follow the instructions on the Command Small Wire Hooks to apply two of the hooks to the wall at the starting and ending positions. Use the alcohol wipes to clean the application site for each hook. In a classroom setting your teacher will indicate where these should be located. For home use, a typical starting position might be 6-7 feet high. A typical ending position might be 5-6 feet away at floor height.

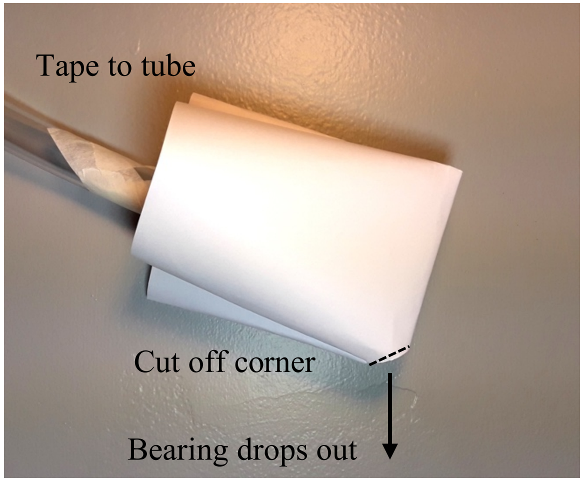


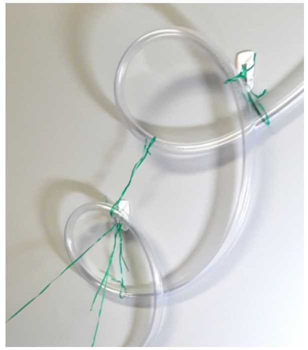
If applied and removed according to the Command Small Wire Hooks application and removal instructions, the adhesive backs should remove cleanly without damaging paint.

2) Use the included twisty ties to secure the tube to the top hook. You may have to wrap the wire tie around the tube a few times before securing it to the hook to ensure the tube doesn't slide.



3) Roll a piece of paper into a loose tube (roughly 2" diameter), fold in half to make a pocket, and secure it to the end of the vinyl tube with a piece of tape. Cut off one corner so the bearing can drop out. This will help ensure you don't lose your bearings when they exit the tube!





Consecutive loop de loops

4) Work with your partner(s) to explore various tube configurations including loop de loops, figure eights, corkscrews, and increasing and decreasing spirals. It's best at this stage to avoid using the additional hooks (even though they're used in the pictures below). Instead you can attach the tube to chairs, tables – anything that will allow you to explore.

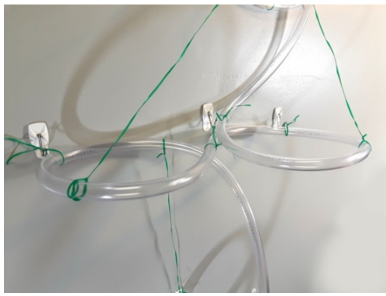
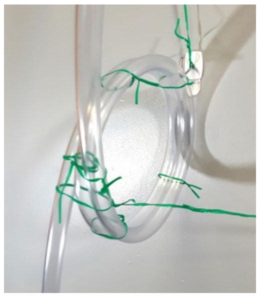



Figure 8 and Double loop de loop

5) Devise a strategy for your roller-coaster based on one of the following challenges.

- Shortest/longest transit time
- Most number of loop de loops
- Maximum/minimum exit velocity

Using some scratch paper, draw pictures showing where you will put your loop de loops. Test your ideas by holding the tube with your partners. Plan carefully because once you place a hook, it can be difficult to move it!

6) Once you've come up with a plan, attach the hooks to the wall and secure the tube to the hooks to match your plan.

7) If in a classroom setting, you can challenge other teams according to the class challenge.

Comprehension and Analysis

8) Calculate the volume of the ball bearing in cubic millimeters, mm^3, using the formula for the volume of a sphere,

$$V = \frac{4}{3}\pi r^3,$$

where r is the radius of the bearing. Be sure to use units of mm. You can approximate π as $\pi = 3.1416$. [$V = 452.5\ \mathrm{mm}^3$.]

9) Calculate the mass of the ball bearing using the density of Carbon Steel, $0.00785\ \mathrm{g/mm}^3$,

$$m = V \times .00785\ \frac{\mathrm{g}}{\mathrm{mm}^3}$$

[$m\ =\ 3.552$ g or 0.003552 kg.]

10) Where does the energy of the rolling ball come from? [Gravitational potential energy.]

11) What is the total gravitational potential energy available to be converted into kinetic energy,

$$U = mg\Delta h,$$

where $g = 9.8\ m/s$, and Δh is the difference in height between the starting position and the lowest point in the tube.

12) What forms of kinetic energy are present in the rolling ball? [Translational and rotational kinetic energy.]

Now we'll compare the amount of energy in these two forms of energy.

13) Suppose the ball is traveling at $v = 1\ \mathrm{m}/s$ at a particular spot in the tube. What is the translational kinetic energy of the ball? Be sure to use units of kg for the mass.

$$KE_{\mathrm{translational}} = \frac{1}{2}mv^2$$

[$KE_{\mathrm{translational}} = 1.776\ \mathrm{mJ}.$]

Now we'll calculate the rotational kinetic energy.

14) First, calculate the angular rotation rate of a bearing traveling with $v = 1 \text{ m/s}$,

$$\omega = \frac{v}{r}.$$

Be sure to use units of meters for the radius. [$\omega = 210.0$ radians per second.]

15) Then calculate the moment of inertia of the bearing using the formula for a sphere,

$$I = \frac{2}{5}mr^2.$$

Be sure to use units of kg and m. [$I = 3.223 \times 10^{-8} \text{ kg m}^2$.]

16) Finally, calculate rotational kinetic energy,

$$KE_{\text{rotational}} = \frac{1}{2}I\omega^2.$$

[$KE_{\text{rotational}} = 0.7104 \text{ mJ}$.]

17) What percentage of the total kinetic energy comes takes the form of rotational kinetic energy?

$$\%_{\text{rotational}} = \frac{KE_{\text{rotational}}}{KE_{\text{translational}} + KE_{\text{rotational}}}.$$

[$\%_{\text{rotational}} = 28.6\%$]

18) Suppose the path in the tube requires the rotation direction of the ball to change and go the other direction. Is energy required to make that change? [Yes.] Where can that energy come from? [It has to come from gravitational potential energy and translational kinetic energy. This is why consecutive loops in opposite directions slows the bearing compared to consecutive loops in the same direction.]

19) **(Challenge question)** Is the percentage of rotational kinetic energy you found valid for all rolling spheres? [Yes.] Can you prove it using the formulas above?

20) **(Challenge question)** What is the maximum achievable translational kinetic energy in your tube? What is the maximum achievable speed in your tube?

Teacher Preparation for use in a classroom setting.

Decide ahead of time challenge type, parameters, and measurement criteria.

- Type of challenge
  - Shortest/longest transit time
  - Most number of loop de loops
  - Maximum/minimum exit velocity
- Challenge parameters
  - Maximum/minimum starting height?
  - Maximum/minimum horizontal distance between starting and ending positions?
  - Use of auxiliary structures such as chairs and table legs allowed?
- Measurement criteria
  - Photogate measurement?
  - Audio measurement technique (see below)?

Devise a measurement technique for the challenge. If you have a photogate system you can measure the travel time and velocities precisely. The Visual Scientifics Photogate Sensor is able to detect the bearing through the vinyl tube. This makes it very convenient to measure the bearing's speed at any position in the tube, or delay between two points of the tube.

If you don't have a photogate system, you can use tin cans to compare the transit time in two tubes. This is done by putting the tin can at the end of the tube so the bearing makes a loud noise when it gets to the bottom. To make sure the teams start at the same time you can have a monitors from the opposing team observe the release of the bearing. You can also put together a competition bracket to determine the winner.

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