Linear Accelerator

Overview: Linear accelerators (also known as a ”linac”) use different methods to move particles to very high speeds. One way is through induction, which is basically a pulsed electromagnet. We’re going to use a slow input speed and super-strong magnets and multiply the effect to cause a ball bearing to shoot across the floor at high speed.

What to Learn: Today you’re going to do an award-winning project (yes, loads of students have used this experiment in science fairs and taken home first prize!) that will teach you how to measure, calculate, record data, and make steel ball bearings fly around the room using momentum and magnetism.

Materials

- Wood or plastic ruler with a groove down the center, 12” long
- Eight thick rubber bands or epoxy for a permanent mount
- Four super-strong magnets (try 12mm or ½” neodymium magnets)
- Nine steel ball bearings (1/2”, 5/8”, or other sizes)
- Measuring tape

Lab Time: This lab has two sections. Feel free to stop after the first part, or go on to the second. It’s really up to you. The first lab is fairly easy and straightforward without a lot of fuss, since you do not need rubber bands or epoxy, and you only need one magnet and the setup doesn’t need to be permanently mounted. The second part of the lab does require additional adult help to separate the magnets and get them under the stiff rubber bands. You can opt to make one of the advanced models

Construction note: If you plan on having a set of these to use for years, permanently stick the magnets to the ruler using epoxy or JB Weld. When you permanently mount the magnets, this experiment is safer to handle since the magnets can’t slip out from under the rubber band and squash fingers or break into pieces.

<u>Part 1: Single-magnet design:</u>

1. Place the ruler on the table.
2. Put a magnet at the 6” mark on the ruler. If you’ve found a strong neodymium magnet, you only need one magnet, not the four as shown in the video.
3. Add four ball bearings in the groove on the ruler in a line, with one end touching the magnet. The balls should extend past the 7” mark.
4. Prop up the 0” mark slightly with a thin book or block (or just lift it a bit with your finger).
5. Place a fifth ball bearing on the 0” mark and let go. What happened?
6. Complete the data table.

Simple Linear Accelerator Data Table

You'll want to prop up your ruler at the same height for all the data you measure, or you'll have to record the ruler angle as well with each trial run. Also, note how far the initial ball has to travel. If your magnet is at 6" and you let go at the 2" mark, then it travels 4". So you'd write 4" in the "Distance Initial Ball Traveled".

Trial #	**Distance Initial Ball Traveled**	**Distance Breakaway Ball Traveled**
	(inches)	Circle one: (inches or feet)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Part 2: Multiple-magnet design:

1. Take your ruler and find the 11" mark. Wrap your first rubber band strongly around the ruler at this mark.
2. Wrap a second rubber band at the 8" mark.
3. Wrap the third at the 5" mark.
4. Wrap the fourth at the 2" mark.
5. Carefully stack your magnets. Be very careful because if they snap together, they will break.
6. Take the first off the stack, keeping the orientation exactly the same as it was in the stack. We are going to separate the magnets from the stack but keep them in exactly the same direction they are in. If you mix up the north-south pole orientation, your linac (linear accelerator) won't work.
7. Slide the magnet under the first rubber band. Have the magnet straddle the 11" mark. This will be important later when we take measurements.
8. Slide the second magnet under the second rubber band. Keep the magnets facing the same way as you work!
9. Slide the third magnet under the third rubber band. Do the same with the fourth.
10. Add a second rubber band to each magnet to secure it into place.
11. Carefully place two ball bearings on one side of each magnet in a line in the groove of the ruler. Your last ball bearing should be at the 12" mark.
12. Look at your ruler. You should have a magnet at the 2" mark, followed by two ball bearings in the groove. Then you should have another magnet with two more ball bearings, a third magnet with another two ball bearings, and a fourth magnet with the last two ball bearings ending at the edge of the ruler.
13. Prop up the 0" mark on the ruler with a thin book, block, or your finger.
14. Take your very last, ninth ball bearing. Place it at the 0" mark, and let go. What happened? Write it here:

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15. Draw what your ruler looks like before impact:

16. Draw what your ruler looks like after impact (where are the ball bearings now?):

17. Complete the data table.

Advanced Linear Accelerator Data Table

Note that we're measuring two things for the breakaway ball: how long it takes for the ball to travel six feet, which is measured in seconds, and also how far it goes until it stops on its own, measured in distance. Assign one person to each measurement task: distance or time.

For the time measurement, you'll want to use your tape measure to mark how far six feet is before you start, and then place the end of your ruler at the start line. As soon as the breakaway ball leaves the ruler, start timing. When it crosses the finish line six feet away, stop timing and record this number in the third column: 'Time Breakaway Ball Traveled 6 Feet'.

To figure out how fast your ball is going, divide 6 feet by the time you recorded. If it took your ball two seconds to go six feet, then the speed is 3 feet per second.

You'll want to prop up your ruler at the same height for all the data you measure, or you'll have to record the ruler angle as well with each trial run. Also note how far the initial ball has to travel. If your first magnet is at 2" and you let go at the 0.5" mark, then it travels 1.5". So you'd write 1.5" in the "Distance Initial Ball Traveled".

Trial #	**Distance Initial Ball Traveled**	**Time Breakaway Ball Traveled 6 feet**	**Total Distance Breakaway Ball Traveled**	**Calculated Average Speed: Speed = 6 feet / Time**
	(inches)	(seconds)	Circle one: (feet or inches)	(feet per second)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Reading

There are several different types of magnets. Permanent magnets are materials that stay magnetized, no matter what you do to them… even if you whack them on the floor (which you can do with a magnetized nail to demagnetize it). You can temporarily magnetize certain materials, such as iron, nickel, and cobalt. And an electromagnet is basically a magnet that you can switch on and off and reverse the north and south poles.

The strength of a magnetic field is measured in "Gauss." The Earth's magnetic field measures 0.5 Gauss. Typical refrigerator magnets are 50 Gauss. Neodymium magnets (like the ones we're going to use in this project) measure at 2,000 Gauss. The largest magnetic fields have been found around distant magnetars (neutron stars with extremely powerful magnetic fields), measuring at 10 trillion Gauss. (A neutron star is what's left over from certain types of supernovae, and typically the size of Manhattan.)

In this experiment, the metal ball bearing is seriously attracted to your magnets, and this pull intensifies the closer the ball gets to the magnet (inverse-square law). When the ball smacks into the magnet, the energy wave from the impact zips through the magnet and attached ball bearings until it knocks the furthest ball free, which has the least magnetic pull on it because it's furthest from the magnet. If it wasn't, it would be slowed down and possibly reattached to the magnet it just broke away from.

With each impact, there's an increase in velocity. Imagine if you had a hundred of these things lined up… how fast could you get that last ball bearing going?

After each firing, you have to reset your system, and chances are it takes a bit of effort to pull the ball bearings from the magnets! You are providing the energy that gets released during each collision and adds to the velocity of the ball bearings.

Exercises

1. Does it really matter where you start the first ball bearing? If so, does it matter *much*?
2. Why does only the last ball go flying away? Why don't the others break away as well?
3. What happens if you try this experiment without the magnets?
4. How many inches did the first initial ball (the one you let go of) travel?
5. How many inches did the last ball (the one that detached from the magnet) travel?
6. Why did we use four magnets in the second lab? What did that do?

Answers to Exercises : Linear Accelerator

1. Does it really matter where you start the first ball bearing? If so, does it matter *much*? (Refer to your data table.)
2. Why does only the last ball go flying away? Why don't the others break away as well? (Have you ever shot a billiard ball toward another on a pool table and watched the first one stop while the second goes flying? This has to do with a concept known as momentum. The ball furthest from the magnet breaks free because it has enough momentum (which is directly related to speed) to escape the magnetic field of the strong magnet.)
3. What happens if you try this experiment without the magnets? Can you get one ball bearing to transfer all its momentum to a second one? (It works, but the ball doesn't travel as far. The magnets provide extra energy (speed) to the incoming ball, which is transferred to the breakaway ball on impact.)
4. How many inches did the first initial ball (the one you let go of) travel? (Refer to data table.)
5. How many inches did the last ball (the one that detached from the magnet) travel? (Refer to data table.)
6. Why did we use four magnets in the second lab? What did that do? (With each impact, there's an increase in speed. The advanced model is like lining up four of the simple models all in a row.)