Magnetic Linear Accelerator

Physics Demonstration

Introduction

Create a simple magnetic linear accelerator using magnets and steel ball bearings! Demonstrate magnetism, the conservation of energy and momentum, and projectile motion.

Concepts

- Potential vs. kinetic energy
- Conservation of energy and momentum
- Magnetic potential energy

Materials

Angled metal track, 75 cm	Steel ball bearings, ⅝″ dia., 10
Neodymium magnets, 6	Support feet, wood, 2″ × 3″ × 1″, 2

Safety Precautions

Use caution when handling the neodymium magnets. These magnets are very strong and may quickly snap together and pinch skin. The magnets are fragile and may shatter if dropped or if they hit another object too hard. Wear safety glasses when performing this demonstration.

Preparation

1. Place two neodymium magnets together in each of the three locations along the angled track, starting 10 cm from one end and spacing them 20 cm apart (see Figure 1). Make sure the north (or south) poles of the magnets point in the same direction along the track. The magnets will "stick" to the metal track and remain in place.

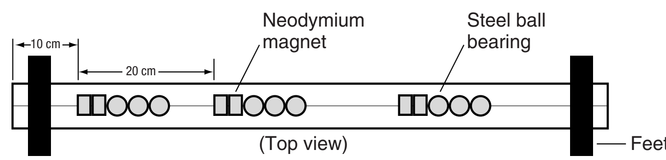

Figure 1.

2. Slide the support feet onto the metal track so that the angled metal track is in a V-position with the V pointing down (Figure 2).
3. Place three ⅝″ diameter steel ball bearings to the right of each magnet set.

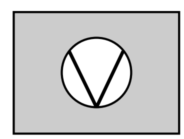

Figure 2.

Procedure

1. Position the last steel ball bearing to the left of the first set of magnets.
2. Slowly push the single ball toward the first magnet set. Once the ball is close enough to the magnet, it will be pulled towards the magnet.
3. Observe the "chain reaction" collision of the ball bearings as the small motion of the first ball is translated and enhanced in each successive collision.
4. The last ball in the chain will launch off the end of the track at a surprisingly fast speed. How far does the ball travel? Does it appear to be moving faster than the ball that initiated the collision?

Disposal

The materials can be reused indefinitely and should be saved for future use.

Tips

- The more ball bearings there are between the magnet and the launched ball, the more kinetic energy the launched ball will acquire. However, three to four balls seem to work the most efficiently. The fifth or sixth ball added to the system will not be attracted to the magnet significantly, and the overall dipole magnetism will no longer simply be proportional to $1/r^3$. The potential energy that the incoming ball gains as it travels from "infinity" to the surface of the magnet will be less, and thereby the resulting kinetic energy will be less.

- Neodymium magnets are strong and it may be difficult to separate the ball from the magnet. It may be easier to slide the steel ball bearings off the magnets, instead of pulling them directly.
- Keep neodymium magnets away from computer disks or other magnetic strips such as credit cards. They will quickly erase the magnetized data.

Extensions

- Experiment with the number of magnets at each location, the number of steel ball bearings at each location, and the separation between the magnet systems. Attempt to arrange the components to create the "most powerful" linear accelerator.

Optional Student Questions

➢ How does the spacing between the magnets affect the speed of the last steel ball bearing?

➢ Does the apparatus still "work" when only one ball bearing is placed next to the magnets, instead of three? Does the accelarator "work" when two ball bearings are next to the magnets? If so, do the launching ball bearings move faster or slower?

Discussion

This demonstration may appear to break the laws of physics, especially the laws of conservation of energy and momentum, because the ball bearings appear to gain free energy after each collision. In reality, however, no laws have been violated. This is not a free-energy generator or perpetual motion machine. The key to this demonstration is the potential energy of the invisible magnetic fields. Magnetic fields store potential energy the same way that a spring does when stretched or that a ball does when it is held above the ground.

When the magnetizable metal ball is far away from the magnet (at "infinity"), the ball has a small amount of magnetic potential energy. This is similar to the gravitational potential of a ball held at a great distance above the Earth—the farther away from Earth, the lower its potential energy (where gravitational potential is proportional to the inverse of the distance between the objects). As the steel ball bearing is pulled toward the magnet, the ball bearing's speed increases tremendously over the short distance it travels. The ball then hits the magnet and comes to a stop. Since energy and momentum must be conserved in an elastic collision, the energy must be transferred through the solid magnetic system. The energy is transferred to the last ball at the end of the system of magnets and balls. The last ball in each magnet system is already a great distance away from the magnet so it does not require much energy to "break away" from the magnet's potential energy. The difference between the work done by the magnet on the incoming ball and the work necessary to break the final ball away from the magnet determines the amount of kinetic energy (and therefore speed) of the final ball in the sequence. A large amount of work is done on the incoming ball, and only a small amount of work is needed to break the launching ball away. Therefore, the kinetic energy of the final ball in each sequence will be very high and the ball shoots off with a high speed.

The same pattern repeats itself at the other magnet systems along the accelerator. However, the incoming ball at each subsequent magnet system already has a high initial speed. The final speed of the ball as it hits the magnet will be much higher than the speed of the original initiating ball. So, the second leaving ball will travel faster than the first leaving ball. The third leaving ball in the three-magnet system will travel even faster.

Potential energy can be calculated (using calculus) to be proportional to $1/r^2$. [Again, for comparison, gravitational potential energy is proportional to $1/r$.]

Materials for *Magnetic Linear Accelerator—Physics Demonstration* are available from Flinn Scientific Canada Inc.

Catalogue No.	Description
AP6838	Magnetic Linear Accelerator—Physics Demonstration Kit
AP5666	Neodymium Magnet
AP5820	Steel Ball, ⅝″, Solid

Consult www.flinnsci.ca or your *Flinn Scientific Canada Catalogue/Reference Manual* for current prices.