Build a Gauss Rifle!

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Experimental Procedure

Safety Notes about Neodymium Magnets:

- *Handle magnets carefully.* Neodymium magnets (used in this science project) are strongly attracted and snap together quickly. Keep fingers and other body parts clear to avoid getting severely pinched.
- *Keep magnets away from electronics.* The strong magnetic fields of neodymium magnets can erase magnetic media like credit cards, magnetic I.D. cards, and video tapes. It can also damage electronics like TVs, VCRs, computer monitors, and other CRT displays.
- *Keep magnets away from young children and pets.* These small magnets pose a choking hazard and can cause internal damage if swallowed.
- *Avoid use around people with pacemakers.* The strong magnetic field of neodymium magnets can disrupt the operation of pacemakers and similar medical devices. Never use neodymium magnets near persons with these devices.
- *Use the magnets gently.* Neodymium magnets are more brittle than other types of magnets and can crack or chip. Do not try to machine (cut) them. To reduce the chance of chipping, avoid slamming them together. Eye protection should be worn if you are snapping them together at high speeds, as small shards may be launched at high speeds. Do not burn them; burning will create toxic fumes.
- *Be patient when separating the magnets.* If you need to separate neodymium magnets, they can usually be separated by hand, one at a time, by sliding the end magnet off the stack. If you cannot separate them this way, try using the edge of a table or a countertop. Place the magnets on a tabletop with one of the magnets hanging over the edge. Then, using your body weight, hold the stack of magnets on the table and push down with the palm of your hand on the magnet hanging over the edge. With a little work and practice, you should be able to slide the magnets apart. Just be careful that they do not snap back together, pinching you, once you have separated them.
- *Wear eye protection.* Neodymium magnets are brittle and may crack or shatter if they slam together, possibly launching magnet fragments at high speeds.

Building the Slide for the Rifle

1. You are going to use the two wooden dowels to make a slide on which the magnets and balls will sit on and move down.
2. Place the dowels evenly next to each other and make sure the ends are flush (lined up). Use clear tape to tape the dowels together at both ends. The tape will temporarily hold them together.
3. Place the taped dowels on the table and then carefully glue them together with wood glue. Try to prevent the glue from leaking through to the other side.
4. Let the glue dry (this may take a few hours, depending on the humidity) and then take the pieces of tape off.

Setting Up the Experiment

1. Place the wood slide on the table with the glued side down. Put one neodymium magnet on the slide, toward one end. Place two ball bearings on one side of the magnets such that the last ball is at the end of slide. See Figure 1. This step is represented by the magnet and ball bearings on right edge of the table in the figure.

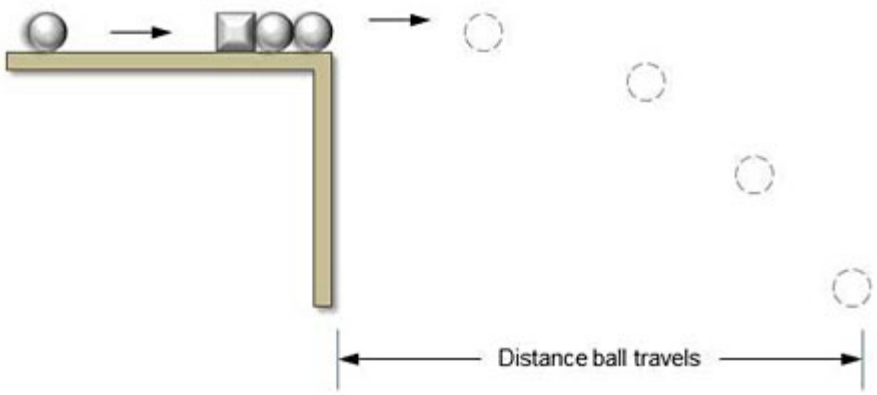

Figure 1. A one-magnet stage Gauss rifle.

2. Now wrap a piece of tape around the magnet so that the ends of the tape wrap around the wood slide. Remove the ball bearings.
    a. *Troubleshooting Tip:* If you have problems with the magnet pulling out from the tape or with the tape breaking, then add a second layer of tape for reinforcement.
3. Place the wood slide on the table so that the end of the slide is flush with the end of the table. See Figure 1.
4. Place two ball bearings on one side of the magnet, at the end of the slide (where they were located in step 1).
5. Pour the sand in the plastic box and smooth it out so that the sand is approximately level. Place the box on the floor a couple of feet away from the edge of the table.
6. Place one ball bearing on the other side of the magnet, about 5 centimeters (cm) from the magnet. This is the *starter* ball. See Figure 2.

Figure 2. A one-stage Gauss rifle. Note the two ball bearings touching the magnet stage at the end of the slide (as described in step 4) and the single ball bearing (the starter ball) 5 cm behind the magnet stage (as described in step 6).

7. Measure the height of the table, in meters (m), on which the Gauss rifle is sitting. Record this value in your lab notebook.

Launching the One Magnet Stage Gauss Rifle

1. Practice launching the Gauss rifle so that you can place the plastic box at the correct distance for accurate measurements, as follows. Your experiment will look something like Figure 1.
    a. Lift the slide just a little to get the starter ball rolling toward the magnet. Keep an eye on the last ball and watch where it lands so that you know where to place the plastic box. Caution: Be sure there is nothing breakable and nobody in front of the setup before you begin testing.
    b. Place the box so that the ball will land approximately in the middle of the plastic box.
2. Now make a data table, like the one below, in your lab notebook so you can record the data that you get from your experiments.

Height of table (m)= _____

Number of Magnet Stages	Trial	Distance the Ball Traveled (m)
1	1	
	2	
	3	
	4	
	5	
2	1	
	2	
	3	
	4	
	5	
3	1	
	2	
	3	
	4	
	5	
4	1	
	2	
	3	
	4	
	5	

3. Replace the correct number of balls on either side of the magnet.
    a. *Troubleshooting Tip:* You may find it helpful to stabilize the magnet with one hand while repositioning the ball

bearings. This keeps the tape holding the magnet to the wooden dowels from stretching or breaking as you reset the launcher. It is often easier to reset the launcher by sliding the ball bearings around the magnets instead of trying to pull them off the magnets.

4. Now lift the slide just a little to get the starter ball rolling toward the magnet. After the launched ball lands, take the tape measure and measure the horizontal distance from the edge of the table to the spot where the ball first landed in the box. Record this distance in meters (m) in the data table in your lab notebook.
    a. *Troubleshooting Tip:* Sometimes the ball bearing will roll or bounce after it first hits the sand. You want to measure the distance from the edge of the table to where the ball first hit the sand, not the distance from the edge of the table to where the ball finally comes to rest. See Figure 3.

Figure 3. In this case, the launched ball bearing landed in the crater at left, then bounced and slid to where it finally stopped at the right side of the box. The tape measure is positioned to start measuring from the circular crater at left—the place where the ball bearing first hit the sand.

5. Retrieve the ball from the box, smooth the sand, and replace the ball in its original position on the slide.
6. Repeat steps 4-5 four more times for a total of five trials. It is a good idea to repeat your experiments to make sure that your data is reproducible and accurate.

Launching a Multiple Stage Gauss Rifle

1. You now have data for a one-magnet stage Gauss rifle. But what happens when you have more than one magnet stage?
2. Build a two-magnet stage Gauss rifle. Remove the ball bearings from the launcher. Place the second magnet stage 10 cm to the left of the first magnet stage (as measured from the front of the first magnet stage to the front of the second magnet stage) and tape it to the wood slide. Cut off any excess tape, if needed. See Figure 4.
    a. *Troubleshooting Tip:* Depending on the strength of your magnets, 10 cm between stages may not be enough space. If you have problems with the magnet stages pulling together (instead of staying separated) due to their magnetic attraction, simply increase the spacing between magnet stages. If you do change the spacing, be sure to use the same spacing between all of the magnet stages in your Gauss rifle.

Figure 4. The magnet stages are spaced 10 cm apart, as measured from the front of the first magnet stage (at right) and the front of the second magnet stage (at left).

3. Now place two ball bearings on one side of each magnet stage. Place the starter ball 5 cm to the left of the second magnet. Figure 5 shows how to arrange the magnets and ball bearings.

Figure 5. A four-stage Gauss rifle with the "starter" ball bearing 5 cm to the left of the fourth stage. A two-stage launcher has two magnet stages, with the "starter" ball bearing 5 cm from the second stage. Similarly, a three-stage launcher has three magnet stages, with the "starter" ball bearing 5 cm from the third stage. In each case, the magnet stages are 10 cm apart from one another.

4. Practice launching the Gauss rifle so that you can place the plastic box at the correct distance for accurate measurements.
    a. Lift the slide just a little to get the starter ball rolling toward the magnet. Keep an eye on the launched ball and watch where it lands so you know where to place the plastic box.
    b. Place the box so that the launched ball will land approximately in the middle of the box.
5. Retrieve the ball from the box, smooth the sand, reset the launcher, and replace the launched ball in its original position on the slide.
6. Lift the slide a tiny amount to get the starter ball rolling toward the magnet. After the launched ball lands, take the tape measure and measure the horizontal distance from the edge of the table to the spot where the ball first landed in the box. Record this distance in meters (m) in the data table in your lab notebook.
7. Repeat steps 5-6 four more times for a total of five trials. It is important to repeat your experiments to make sure that your data is reproducible and accurate.
8. Repeat steps 2-7 for a three-magnet stage Gauss rifle. Remember to record all data in your data table in your lab notebook.
9. Repeat steps 2-7 for a four-magnet stage Gauss rifle. Remember to record all data in your data table in your lab notebook.

Analyzing the Data

1. Now review the data you collected in the previous two sections.
2. Create a plot showing the relationship between *distance traveled* and the *number of magnet stages*.
3. Now use Equation 1 to calculate the velocity at which the ball was launched from the wood slide (the Gauss rifle). Record your results in a table, like the one shown below.
    a. *Troubleshooting Tip:* Make sure that you use consistent units in your calculations. If you measured the table height and distance traveled in units other than meters, you will need to convert those measurements to meters.

Equation 1:

Velocity (m/s) = Horizontal distance between the table and the ball (m) X **Square root** of (gravitational acceleration (m/s^2) divided by [2 X height of the table (m)])

$$V = D\left(\sqrt{\frac{g}{2h}}\right)$$

- V = Velocity of ball ejected from launcher, in meters/second (m/s)
- D = Horizontal distance between the edge of the table and where the ball landed, in meters (m)
- g = Gravitational acceleration which is 9.8 meters/[second squared] (m/s^2)
- h = Height of table, in meters (m).

Number of Magnet Stages	Trial	Distance the Ball Traveled (m)	Velocity of the Ejected Ball (m/s)
1	1		
	2		
	3		
	4		
	5		
2	1		
	2		
	3		
	4		
	5		
3	1		
	2		
	3		
	4		
	5		
4	1		
	2		
	3		
	4		
	5		

4. Average the data from the table above. Average the velocity for each magnet stage (1, 2, 3, or 4) over the five trials. Record your data in a table like the one shown below.

Number of Magnet Stages	Average Velocity of the Ejected Ball (m/s)
1	
2	
3	
4	

5. Now make a plot of the average velocity dependent upon the number of magnet stages. Label the x-axis *Magnet Stages* and the y-axis *Average Velocity.*
6. What do the plots that you made tell you? How is velocity affected by the increase in magnet stages?

Frequently Asked Questions (FAQ)

FAQ for this Project Idea available online at https://www.sciencebuddies.org/science-fair-projects/project-ideas/Phys_p081/physics/gauss-rifle#help.