The Gauss Rifle
A Magnetic Linear Accelerator

This simple device uses a magnetic chain reaction to launch a steel marble at a target at high speed. The device is relatively simple to build, is simple to understand and explain, and yet fascinating to watch and to use.

Materials:

Metric ruler or custom cut wood strip
Four powerful, one cubic centimeter magnets made of Neodymium-Iron-Boron alloy
Nine 1.5-cm (5/8-inch) diameter, nickel-plated steel balls each with a mass of 16 grams
The magnets and steel balls are available as a kit for $31.54 from Simon Quellen Field at Science Toys (e-mail: sfield@scitoys.com).

Set-Up:

Photos of the set-up recommended by Science Toys are shown below in Figure 1.

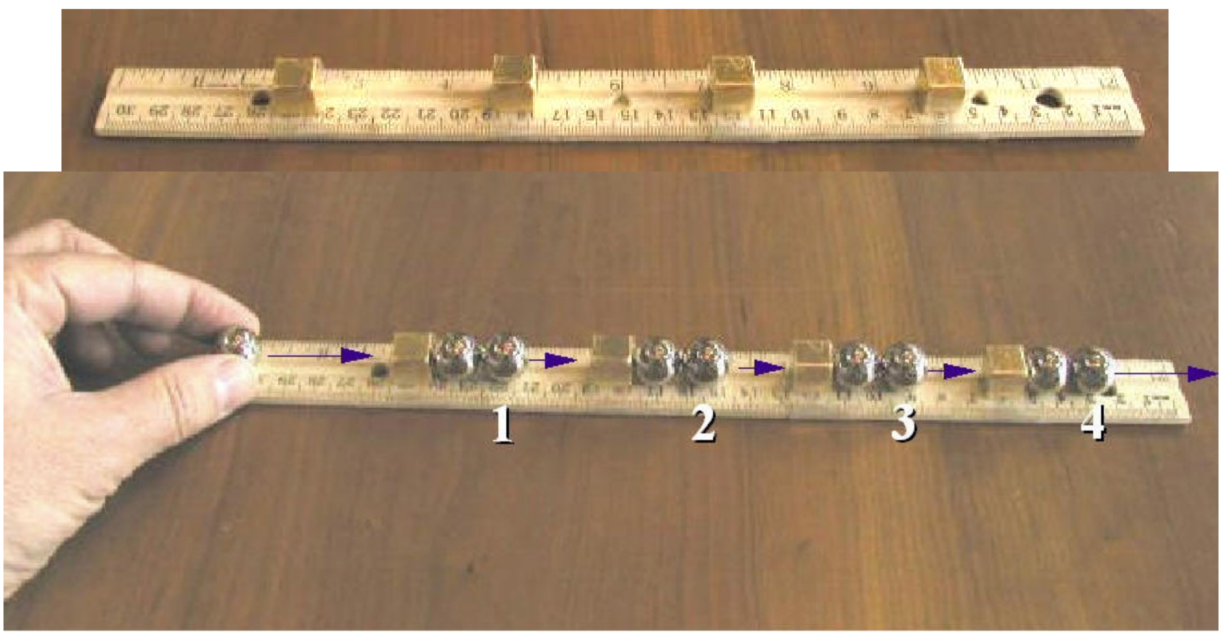

Figure 1. Gauss Rifle set-up recommended by Science Toys.

Science Toys recommends use of a wooden ruler that has a groove in the top in which a steel ball can roll easily. Rulers are easy to find around the house, at school or at a local stationery store. With this method Scotch brand transparent tape is used to hold down Science Toys' super strong gold-plated, neodymium-iron-boron magnets. The four magnets are spaced about 7 cm apart from each other. **One must be very careful to keep the magnets separated at a distance of at least 30 cm so they don't jump together. They are very hard to separate once they are attracted to each**

other. Also, the material is brittle like a ceramic and can shatter. Nine 1.5-cm (5/8-inch) diameter, nickel-plated steel balls are also required and are part of the Gauss Rifle Kit from Science Toys. After a number of runs, the tape can come loose and the magnets will move, causing erratic results.

An alternate method is to replace the ruler with a piece of wood (fir or poplar) that is 356 mm (14-inches) long x 38 mm (1.5-inches) wide x 19 mm (0.75-inches) thick and with a channel that is 7 mm wide and 3 mm deep running across the length of the wood at its center. This channel is wide enough to allow the steel balls to move easily along its length. Four pilot holes are drilled 7 cm (2.5-inches) apart and four flat-head steel wood screws (12 mm diameter head x 12 mm long) are fastened to the wood through these holes. A magnet is then placed on the head of each screw. The strong magnets will be firmly held to the screw heads as shown in Figure 2.

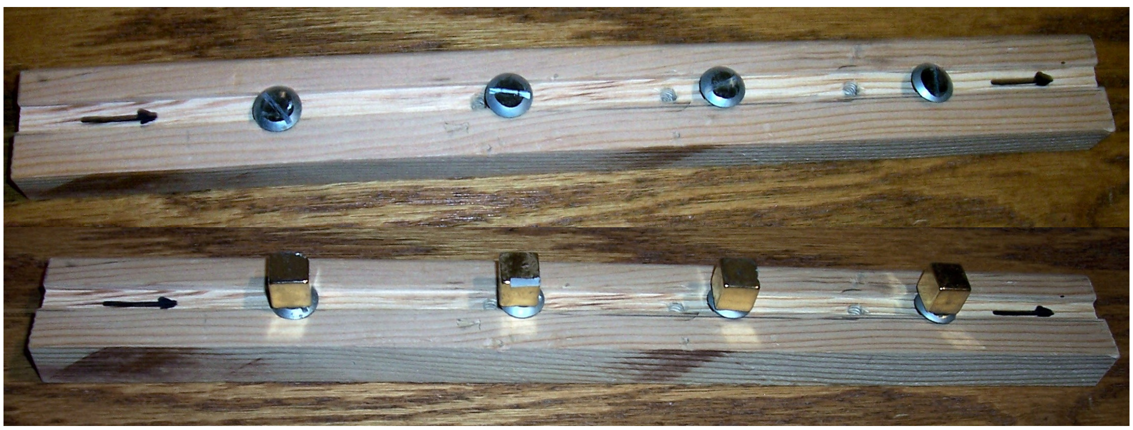

Figure 2. Alternate method of building the Gauss Rifle.

Procedure:

Two steel balls are placed to the right of each magnet. Arrange a target to the right of the device, so the ball does not roll away and get lost. To fire the gauss rifle, set a steel ball in the groove to the left of the first magnet. Let the ball go. If it is close enough to the magnet, it will start rolling by itself and hit the magnet. When the gauss rifle fires, it will happen too fast to see. The ball on the right will shoot away from the gun, and hit the target with considerable force. This device is designed so the speed is not enough to hurt someone, and you can use your hand or foot as a target.

Why and How it works:

The Gauss Rifle works as follows. When you release the first ball, it is attracted to the first magnet. It hits the magnet with a respectable amount of force, and with a certain kinetic energy. The kinetic energy of an object is defined in classical mechanics as one-half of the product of its mass times the square of its velocity.

$$\mathbf{E_k = mv^2/2}$$

When the device is all set up and ready to be triggered, there are four balls that are touching their magnets. These balls are at what physicists call the "ground state." It takes energy to move them away from the magnets. But each of these balls has another ball touching it and these second balls are not at the ground state. Since they are each 1.5 cm from a magnet, they are easier to move than the balls that are touching the magnet because energy was added to pull the ball 1.5 cm away from the magnet. These balls would be pulling towards the magnet with some considerable force. This energy is released by letting the ball go. After the gauss rifle has fired, the situation is different. Now each of the balls is touching a magnet. There is one ball on each side of each magnet. Each ball is in its ground state, and has given up the energy that was stored by being 1.5 cm from a magnet. That energy has gone into the last ball, which uses it to hit the target.

In an experiment to prove this, the initial velocity of a 16 gram ball was measured at 65 cm/sec to the right, resulting in a kinetic energy of 33,800 ergs (3.38×10^{-3} joules). The kinetic energy of the ball was transferred to the magnet and to the ball that touched it on the right, and then to the ball that was touching the second ball (Ball # 1 in **Figure 1**). (This transfer of kinetic energy is familiar to billiard players -- when a cue ball hits another ball, the cue ball stops and the other ball speeds off.) Ball #1 was now moving with a kinetic energy of 33,800 ergs, but it was moving towards the second magnet so it picked up speed as the second magnet pulled it closer. When Ball #1 hit the second magnet, its kinetic energy doubled to 67,600 ergs as it transferred its energy to Ball # 2. According to the equation above, Ball #2 was moving at a velocity of nearly 92 cm/sec to the right when it hit the third magnet.

$$\mathbf{67{,}600 = 16v^2/2 \text{ or } 67{,}600/8 = v^2 \text{ or } v = \sqrt{8450} = 92 \text{ cm/sec}}$$

Ball # 3 then moved with a kinetic energy 101,400 ergs and a velocity of 113 cm/sec to the right as it struck the fourth magnet. Ball #4, with a kinetic energy of 135,000 ergs, then sped off to the target on the far right at a velocity of 130 cm/sec, twice the velocity of the initial ball.

As each magnet pulls on a ball, it adds kinetic energy to the ball linearly. But the speed does not add up linearly. If we have 4 magnets, the kinetic energy of Ball #4 is 4 times that of Ball #1, but the speed goes up as the square root of the kinetic energy. As more magnets are added, the speed goes up by a smaller amount each time. But the distance the ball will roll and the force with which it hits the target is a function of the kinetic energy, and thus a function of how many magnets are used. It's possible to scale up the rifle until the kinetic energy gets so high that the last magnet is shattered by the impact. After that, adding more magnets will not do much good.

References:

1. http://www.all-science-fair-projects.com/science_fair_projects/29/372/2a3570ed70d249b93d61e9b46cd66c39.html

2. "Gonzo Gizmos," Simon Quellen Field, Chicago Review Press, Chicago, IL, p. 29, 2002 (ISBN: 978-1-55652-520-9).