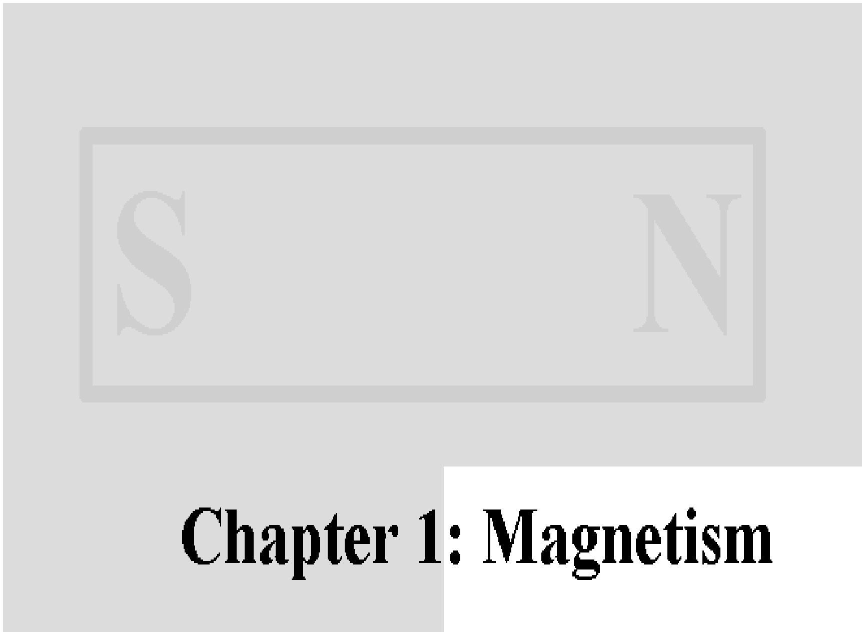


The Gauss Rifle:
A Magnetic Linear Accelerator

This very simple toy uses a magnetic chain reaction to launch a steel marble at a target at high speed. The toy is very simple to build, going together in minutes, and is very simple to understand and explain, and yet fascinating to watch and to use.

Click on image for ***animated*** view

The photo above shows six frames of video showing the gauss rifle in action. Each frame shows 1/30th of a second. In the first frame, a steel ball starts rolling towards a magnet taped to a wooden ruler. In the second frame, a second ball can be seen speeding between the rightmost two magnets. By the third frame, the accelerator has sped up so much that the ball that is seen leaving the left side of the device is just a blur as it smashes into the target. One ball, starting at rest, has caused another ball to leave the device at a very high speed.

Click on image for larger view

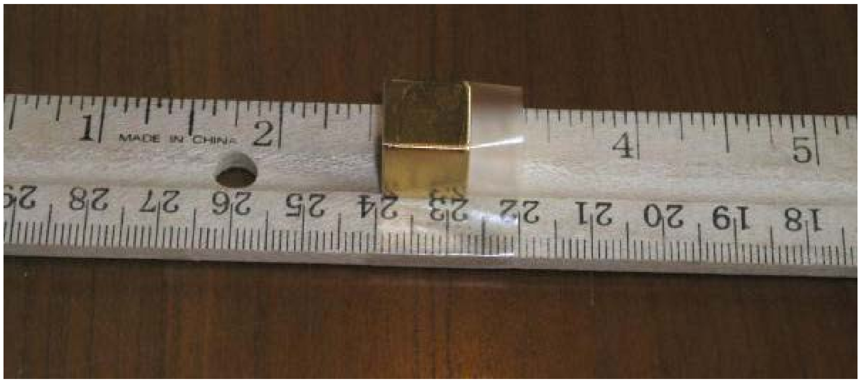
The materials are simple. We need a wooden ruler that has a groove in the top in which a steel ball can roll easily. Any piece of wood or aluminum or brass with a groove will work. We chose the ruler because they are easy to find around the house or at school or at a local stationery store.

We need some sticky tape. Again, almost any kind will do. Here we use Scotch brand transparent tape, but vinyl electrical tape works just as well.

We need four magnets. Most any type will do, but the stronger the magnets are, the faster the balls will go. Here we use the super strong gold-plated neodymium-iron-boron magnets we have made available in our catalog for the other projects. They work great.

We will also need nine steel balls, with a diameter that is a close match to the height of the magnets. We use 5/8 inch diameter nickel plated steel balls from our catalog.

The only tool we will need is a sharp knife for trimming the tape.



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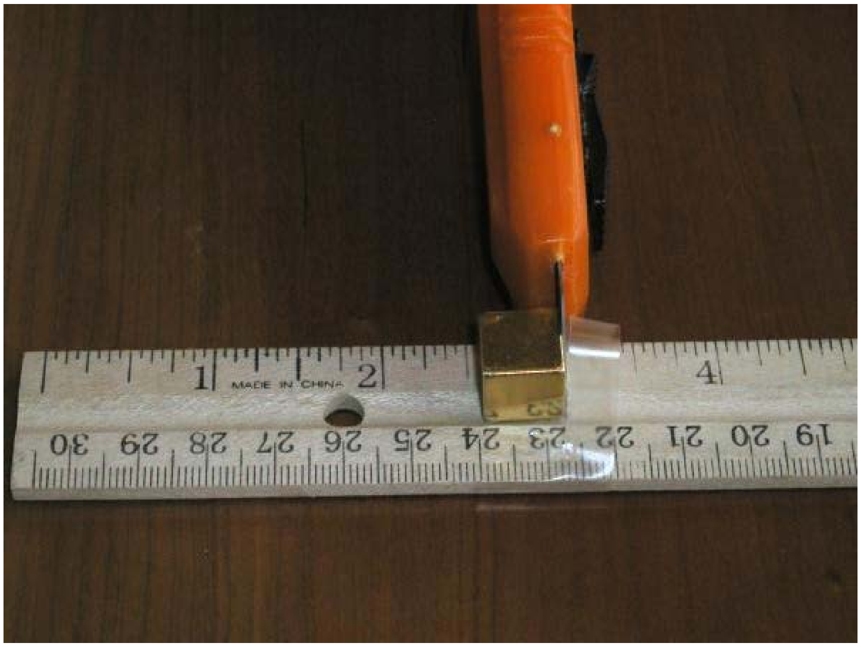
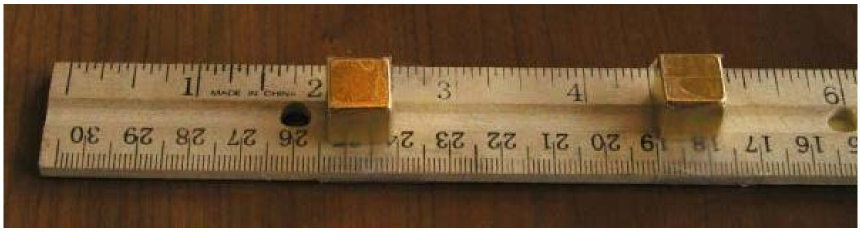
We start by taping the first magnet to the ruler at the 2.5 inch mark. The distance is somewhat arbitrary -- we wanted to get all four magnets on a one foot ruler. Feel free to experiment with the spacing later.



Click on image for larger view

With the sharp knife, trim off any excess tape. Be careful, since the knife will be strongly attracted to the magnet.

It is ***very important*** that you keep the magnets from jumping together. They are made of a brittle sintered material that shatters like a ceramic. Tape the ruler to the table temporarily, so that it doesn't jump up to the next magnet as you tape the second magnet to the ruler.



Click on image for larger view

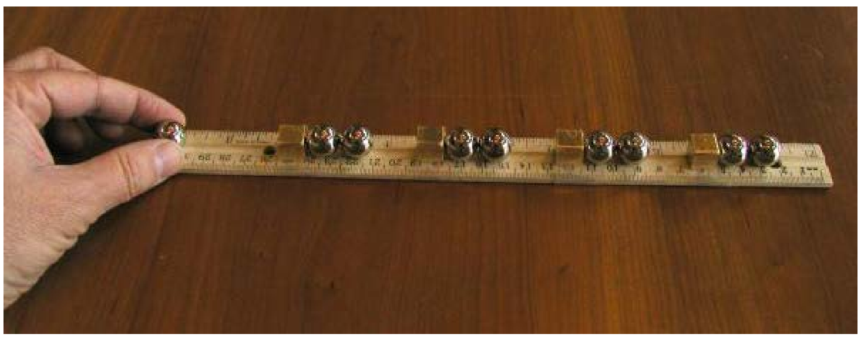
Continue taping the magnets to the ruler, leaving 2.5 inches between the magnets.

When all four magnets are taped to the ruler, it is time to load the gauss rifle with the balls.

Click on image for larger view

To the right of each magnet, place two steel balls. Arrange a target to the right of the device, so the ball does not roll down the street and get lost.

To fire the gauss rifle, set a steel ball in the groove to the left of the leftmost magnet. Let the ball go. If it is close enough to the magnet, it will start rolling by itself, and hit the magnet.



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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. Our one foot long version is designed so the speed is not enough to hurt someone, and you can use your hand or foot as a target.

How does it do that?

When you release the first ball, it is attracted to the first magnet. It hits the magnet with a respectable amount of force, and a kinetic energy we will call "1 unit".

The kinetic energy of the ball is transfered to the magnet, and then to the ball that is touching it on the right, and then to the ball that is touching that one. This transfer of kinetic energy is familiar to billiards players -- when the cue ball hits another ball, the cue ball stops and the other ball speeds off.

The third ball is now moving with a kinetic energy of 1 unit. But it is moving towards the second magnet. It picks up speed as the second magnet pulls it closer. When it hits the second magnet, it is moving nearly twice as fast as the first ball.

The third ball hits the magnet, and the fifth ball starts to move with a kinetic energy of 2 units. It speeds up as it nears the third magnet, and hits with of 3 units of kinetic energy. This causes the seventh ball to speed off towards the last magnet. As it gets drawn to the last magnet, it speeds up to 4 units of kinetic energy.

The kinetic energy is now transfered to the last ball, which speeds off at 4 units, to hit the target.

Another way of looking at the mechanism

When the device is all set up and ready to be triggered, we can see that 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. These second balls are not at the ground state. They are each 5/8ths of an inch from a magnet. They are easier to move than the balls that are touching the magnet.

If we were to take a ball that was touching a magnet, and pull it away from the magnet until it was 5/8ths of an inch away, we would be adding energy to the ball. The ball would be pulling towards the magnet with some considerable force. We could get the energy back 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 5/8ths of an inch from a magnet. That energy has gone into the last ball, which uses it to destroy the target.

Speed and kinetic energy

The kinetic energy of an object is defined as half its mass times the square of its velocity. 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 is 4, but the speed goes up as the square root of the kinetic energy. As we add more magnets, the speed goes up by a smaller amount each time. But the distance the ball will roll, and the damage it causes to what it hits, is a function of the kinetic energy, and thus a function of how many magnets we use.

We can keep scaling up the gun 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.

Why a circular track will not be a perpetual motion device

I have been getting a lot of mail asking what would happen if we made the track circular. Would we get free energy? Would the balls keep accelerating forever?

I have been tempted to reply with the famous quote: "There are two kinds of people in the world -- those who understand the second law of thermodynamics, and those who don't".

However, I am not the kind of person to leave an inquiring mind unsatisfied, and it is more productive (and kind) to explain in a little more depth what is going on.

Suppose you made a circular track, and put two balls after each magnet. When the last ball is released, it encounters a magnet that has two balls at the ground state. There is no energy to be had from this magnet. The ball just bounces back.

Now suppose you had placed three balls after each magnet. When the last ball is released, it hits a ball that is 5/8ths inch from the magnet. It has not gained much momentum, because most of the momentum gained is in the last half inch as the magnet pulls much stronger on things that are closer. But the ball has enough energy from previous accelerations to release the next ball. However, that ball has less energy than the ball that caused it to release. It may have enough energy to release another ball or two, but each ball that is released has less energy than before, and eventually the chain stops.

You can show by inductive logic that no matter how many balls you stack in front of each magnet, eventually the system stops.

To estimate the losses due to heating the balls as they compress when hit, consider a plastic tube standing upright on a table. Place one steel ball at the bottom of the tube. Now drop another ball into the tube, so it hits the ball at the bottom, and bounces back up.

Now measure how high the ball bounced. If it bounces halfway back up, the losses are 50%. Perform the experiment for yourself with the balls from the Gauss Rifle. How high does your ball bounce? Send me mail with your results.

Next: Electromagnetism

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