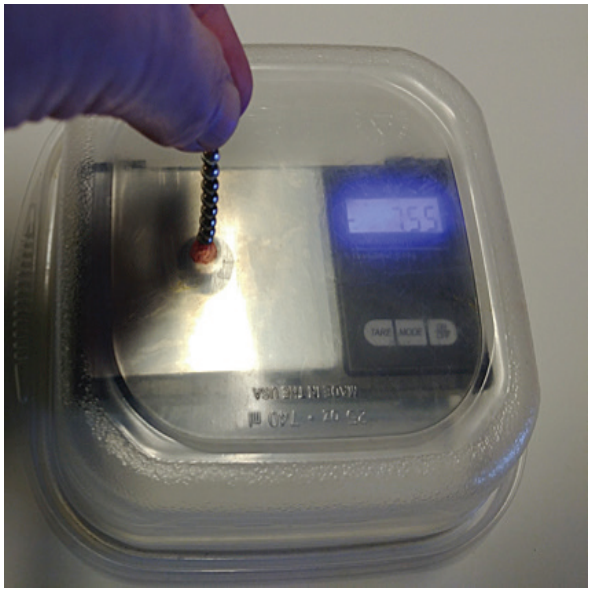


# Magnetic Chain Gang

**For magnets, strength isn't necessarily in numbers.**

Using a digital scale, measure the magnetic force of chains of spherical magnets. You'll discover that it's not how many magnets, but how they're arranged, that makes all the difference.

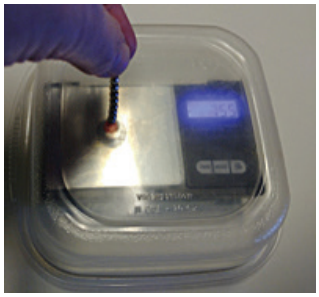
## Tools and Materials

- Digital scale that measures to the 0.1 grams or smaller
- Rare earth magnetic spheres (about 30 spheres in total; the 5-mm size works well)
- Small ceramic disk or ring magnet
- Transparent tape
- Clear plastic container (such as Tupperware) large enough to just fit over the scale
- Post-It Notes or other paper notepads to raise the height of the scale as necessary
- Marker, such as a Sharpie or VIs-a-Vis

## Assembly

1. Tape the disk magnet to the weighing plate of the scale.

2. Place the scale under the clear plastic container, making a clear cover for the scale.
3. Use pads of paper to raise the height of the scale so that the magnet is approximately 1 cm below the cover.
4. Looking straight down on the scale, mark on the plastic container the spot that is directly above the magnet.



## To Do and Notice

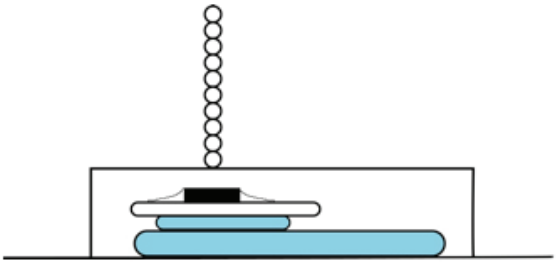
Tare (zero) the scale.

Take approximately 10 rare earth magnet spheres and assemble them into a chain. Hold the chain vertically over the disk magnet that is taped to the scale.

Bring the chain of magnets towards the scale.

You'll notice that one side of the chain is attracted to the magnet on the scale, and the other side of the chain is repelled. Since most scales won't properly measure negative values, you'll get better measurements if you hold the chain of magnets so that they repel the magnet on the scale. You'll probably need two hands to hold the chain straight, as it will try to veer away. (And if it happens that your digital scale is okay with negative values, you can use either side up.)

Hold the chain vertically over the disk magnet taped to the scale. Look at the reading on the scale as the chain is moved towards and away from the scale.

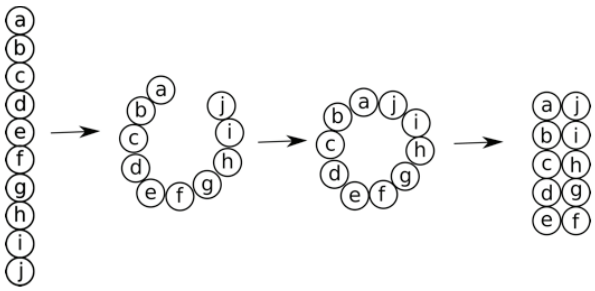


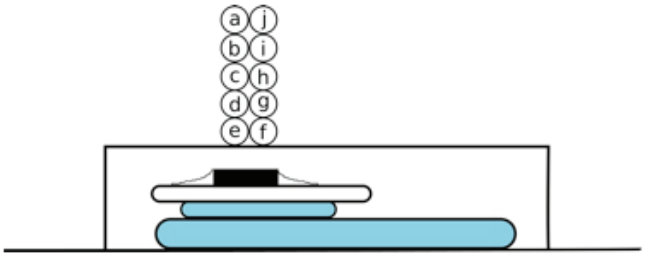
Since the reading varies with distance, you'll want to have the chain the same distance over the scale to make comparisons with other arrangements. So for consistency, place the chain so that it just touches the marked spot on the plastic container.

Hold the chain in place and record the reading on the scale.

Pull the chain apart so that it is only half as many spheres. Record the reading on the scale. (Surprised? The new reading isn't half the original reading.) Play with the length of the chain. What do you notice?

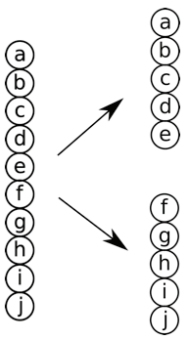
Rebuild the chain so that it is 10 spheres long. Fold the chain in half. It might spontaneously become a circle; if so, just squash the chain flat so that it forms a double line 5 spheres long and 2 spheres wide. Bring this near the scale and record the reading.  Are you surprised by the result?



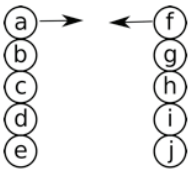


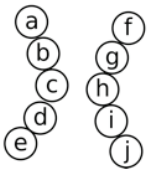
To better figure out what is going on, you might want to make a drawing of the arrangement of the spheres, marking their poles.

Let's try something that is similar but not quite the same. Make the 10-sphere chain again and then split it into two 5-sphere chains.



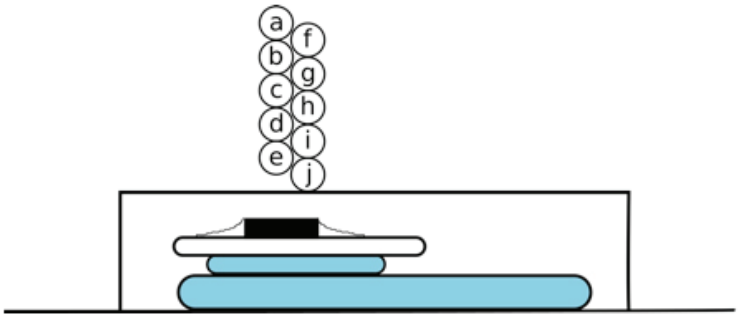
Bring the A to E chain towards the F to J chain so that the sphere A is near sphere F. As the chains get closer, you'll see them bend away from each other.






Keep bringing the chains together. Once the two chains are close enough, you'll be able to see them snap into place, with one chain is offset from the other chain.

Bring this pair of chains near the scale. Record the reading. How does this compare to the folded-over chain? How are these two chains different?



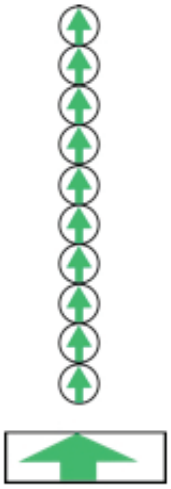

## What's Going On?

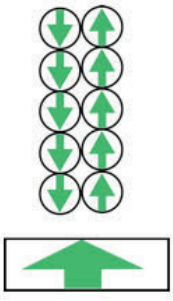
Each sphere is a magnet with a north and south magnetic pole. When you let them form a chain, they align so that the north pole of one sphere touches the south pole of the next.

While each additional sphere increases the total strength of the magnet, you may have been surprised to find that a chain twice as long isn't twice as strong.

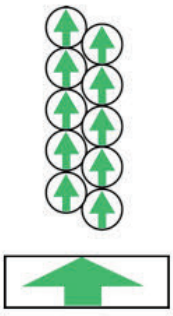
The magnetic force between two magnets is highly sensitive to the distance between them. The result is that the addition of extra spheres to chain at the far end of the chain makes less of an impact than you might expect; a 5-sphere chain results in a measured force only slightly less than a 10-sphere change.

When you fold the chain over, each sphere is paired with a sphere whose poles point in the opposite direction. Each sphere's force is canceled out by the one next to it, and the overall force on the scale drops to near zero.





When you allow the magnets to form in staggered rows, their poles can add together instead of canceling, making a stronger overall force.



## Going Further

Try attaching additional strands in the staggered fashion. You'll notice that the force increases with each strand. You'll also notice that the spheres will start to splay away from each other, and that it's difficult to keep the strands together. This is why extremely strong magnets are often also very fragile; repulsive forces within them make them ready to tear themselves apart.

## Teaching Tips

Students can start with one sphere and measure the force, then add another sphere to make two, and measure the force again. Continue sphere by sphere. Graph the 10 spheres. At first, each sphere seems to increase the force the same amount, but you'll notice that the effect gets smaller with each sphere.