

**Magnetism:** In 2010 & 2020 so far we've seen 2 fundamental forces of nature: gravity and electrical forces. Electrical force depends on the existence of charge – charges *make* E fields, and then E fields in turn exert forces on other charges,  $F = qE$ . There is another kind of force in the world, called **magnetism** (attracting “rocks” were found in Magnesia > 2,000 years ago). You've surely played with kitchen magnets. They stick to some materials but not others. E.g. magnets don't stick to aluminum. *Magnetism is not equal to Electricity!* They are different forces!

E.g.: Hold a magnet near the electroscope (which is very sensitive to even tiny amounts of electric charge). Nothing happens!

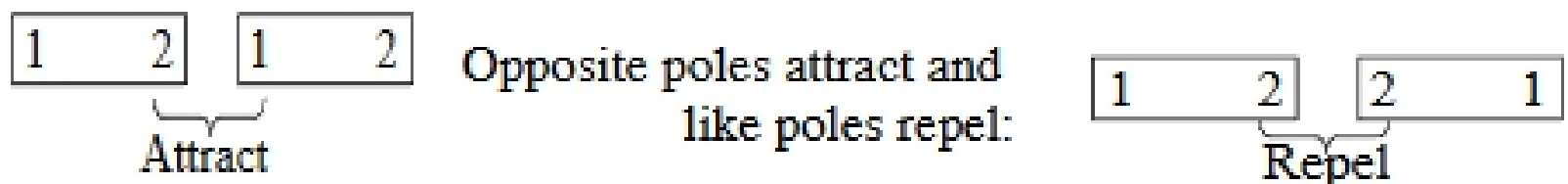
E.g.: Hold a magnet near those electric dipole seeds we used to demo E-fields. You'll see nothing.

E.g.: Charge up a balloon, hold a magnet near it. Nothing!!

Magnetic forces are new, a different force than electrostatics.

**Phenomenology of Magnets:**

Play with magnets a little! Some attract, and some repel. 1                      2  
 In fact, all magnets seem to have 2 “sides” or “poles”.  
 Once you've labeled the poles, you'll notice they act like this:



This is a bit like electricity, where we also had two charges: opposites attracted while likes repelled. But this is not electrical! So let's avoid naming the magnetic “charges” + and -. Here's another name: “N” and “S” (North and South). We'll label one (arbitrarily) and then we can figure out all the others in the world.

Unlike electricity, you'll never see: N                      (impossible)                      N

You always have N                      S called a “**dipole**” magnet, because it has two (different) poles.

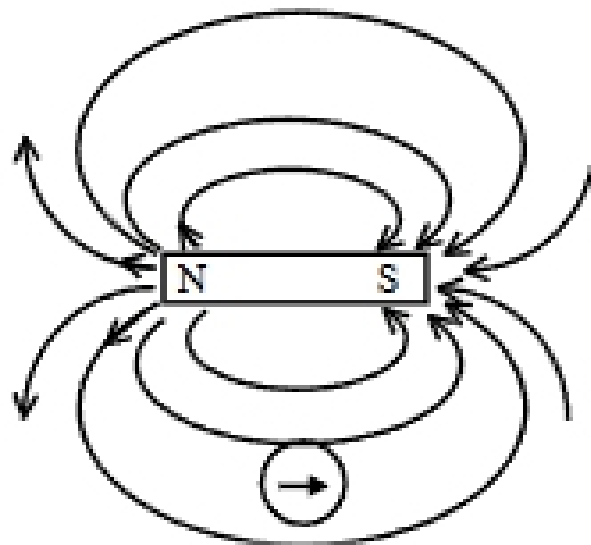
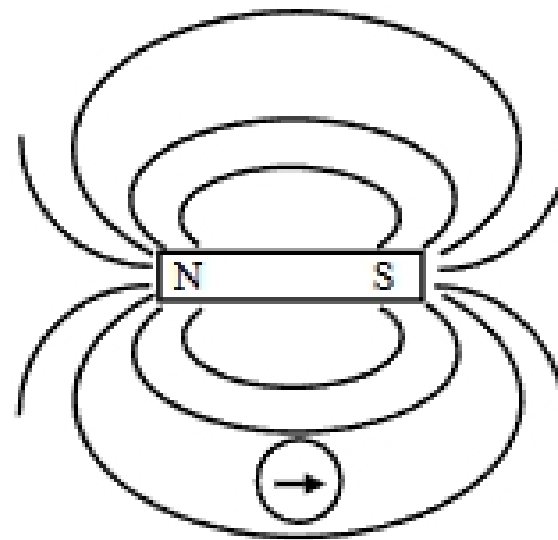
If you break a magnet, you **DON'T** get one “N-only” and one “S-only” magnets, instead you simply get two smaller dipole magnets! N                      S / N                      S

There is a *magnetic field* which (like E-fields) extends through space. It exerts a force on other magnetic objects. (It's a vector associated with every point in space)

We can use little "test magnets" to map out a B field (just like little "test charges" mapped E-fields for us.)

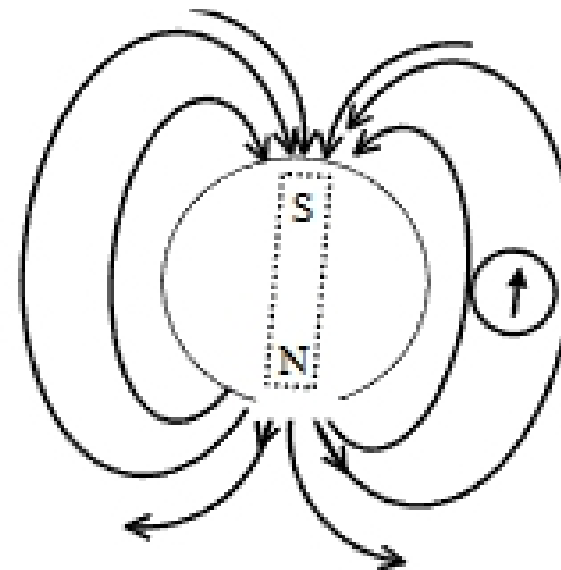
E.g. Iron filings, or a small compass, near a magnet.

The compass can define the direction of those lines. We can draw arrows on field lines (pointing where the compass does). (Looks rather like an electric dipole E-field pattern!)



Remember, opposites attract, and a compass needle's tip is (*by definition*) "N", so the compass points towards (is attracted to) the "S" pole of other magnets.

The Earth is a giant magnet:  
A compass points towards the geographic "North" of the planet, so the magnetic "S" pole (of the giant hidden magnet) sits up near the planet's geographic N pole!  
(It's a little strange, think about this picture until you understand the conventions)



Some key questions to ask now:

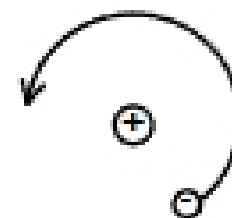
- What makes/causes magnetic fields (call them B-fields)?
- Can we quantify the strength of B-fields?
- Can we quantify the effects of B-fields?

Lots of experiments were done (1800's) to figure this out. E.g.:

- 1) (Oersted discovered) B-fields are always created by currents, i.e. by moving electrical charges! (So although B-fields and E-fields are very different, they are also related too)
- 2) B-fields always *exert forces* on any other currents.

So what about regular magnets? (Where's the *current* in a kitchen magnet? You don't need to buy batteries for them, right?!)

Answer: All atoms have tiny currents around them, all of the time! (Just the electrons in orbit.)



But normally, atoms are randomly oriented, so there's no net effect. (Magnetic fields of *different atoms* cancel)

But if the atomic currents all line up (which happens only in unusual and special materials, like ferromagnets!) then they act magnetic.

This happens in E.g. iron (Fe), Nickel, Cr, not too much else.