Electricity and Magnets

• Initial explanations, rules, setup	5 min
• Turn a nail into a magnet	10 min
• Discussion – electromagnets/motor	10 min
• Use magnets to create an electric current	10 min
• Discussion – generators, cleanup	5 min

Setup, rules, etc.

- Have the kids split up into as many groups as the room can accommodate (we will see when we get there how many that is; our equipment should suffice for 10 groups if that can fit). We will have prepared a kit on each group's table. As they are settling in, ask them not to touch the stuff. In general, they are to handle the stuff in the kit only when and how they are told to do so.
- They have heard about magnets. See if they can come up with the concept of *poles* and the idea that opposite poles attract. If not, help them out.
- As a demonstration, place one of the two-colored magnets on the pivoting support. Show them how bringing the blue (or red) pole of another magnet near the blue (resp. red) pole of the supported magnet causes rotation away from the approaching magnet (*repulsion*) while bringing a red (blue) pole near a blue (resp. red) pole causes rotation towards the approaching magnet (*attraction*).
- You may want to mention the concept of a magnetic compass, using the Earth's magnetic field. They will be using compasses (show one) to discover, or *measure*, the presence of magnets. This is a far more sensitive measure than, say, picking up paper clips.
- If you do end up talking about Earth's magnetism, beware the sticky issue of Pole names. By convention, we call North the side of a magnet that is attracted to the North when the magnet aligns to Earth's field. The tricky part is that this means that if

we think of Earth as a magnet, the pole in the North is in fact a South pole!

- Today we will be talking about the close connections between magnets and *electricity*. They will (or have) heard more about the nature of electric currents in the other activity.

First Activity

- Have them take the compass out of the kit and place it on the table. Their first activity is a repeat of your demo with a colored magnet and their compass needle. This should go rather quickly, the idea to take away is that a nearby magnet influences the compass needle, and that the two poles of a magnet have opposite effects on the compass.
- Now, have them find the nail with wire wrapped around it. I will prepare nails with 100 wraps of wire on them, fixed with epoxy, to save time. They need to connect the ends of the wire to the two poles of the battery. They can use one crocodile wire to connect one end to the positive terminal, if they are careful. They will need to hold the other end in their hand, touching the negative (bottom) terminal. This is good, it will prevent them leaving the circuit closed and draining our batteries. The current in the coil generates a magnetic field, enhanced by the iron in the nail. So when they bring the nail near the compass,

they should discover that it's a magnet. The two ends of the nail are two opposite poles of the magnet.

- When they reverse the connections, they will find that the polarity of the magnet has been reversed as well – current flowing in the opposite direction leads to a reversed magnetic field.
- Some may notice that the nail continues to act as a magnet even when disconnected from the battery. This residual magnetism is in fact the way *permanent* magnets like the colored bars we used earlier are produced. In the nail it will relax to nothing over time, but in some materials the magnetization will persist. If you have a lot of time and things are going well you can talk about the microscopics of magnetism: atoms (usually electrons, but atoms is close enough) act like tiny, exceedingly weak, magnets. In a normal material, the microscopic magnets point in random directions so the net effect is a cancellation. An external magnetic field causes them to align, so all the North poles point in one direction, making the material magnetic (this is how a paper clip touching a magnet becomes itself a magnet). In iron, the little magnets remain aligned long after the external field is removed, in some types of iron essentially forever. Those are permanent magnets. You can demonstrate how hitting the nail hard against the edge of a desk demagnetizes it by jarring the little magnets out of alignment.
- They are then asked to wind the wire another 50 times around the nail. It is crucial that they do this in the same direction as the windings I have prepared, else

of course the fields will cancel. This should make the magnetic effects 50% more pronounced. If short on time, this can be skipped.

- If a group finishes early, have them try to hook up two batteries to the wires to increase the effect even more.
- Ask them to put all the equipment back and get their attention.

Discussion:

- With leading questions, get to a summary of what they have learned from their experiment. They will come up with lots of things, write them all on the board. The ones we need right now:
  1. An electric current flowing through a wire creates a magnetic field.
  2. The direction in which the current flows (determined by the way we connect the wires to the battery) determines the direction of the field.
  3. Adding more windings increases the effect. Essentially, each wrap acts as a magnet and their effects add.
  4. Increasing the current (hooking up two batteries) also increases the effect.

- What are the differences between permanent magnets and the *electromagnets* we have made here:

  1. These can be turned *on* and *off* by controlling the current.
  2. The intensity of the magnetic field can be controlled by varying the number of windings as well as the current. In particular, we can make electromagnets far more powerful than any permanent magnet.

- Talk about some applications of electromagnets:

  1. The classic crane in the junkyard – pick up metal and drop it.
  2. A *relay* is a switch that allows us to turn things on and off electrically. They are all over, the one most adults have heard of is the one in your car that turns your starter motor on and off when you touch the key. In a relay, the switch is connected to a permanent magnet, and a spring pulls it away from making contact. When current flows in the solenoid (the coil surrounding this) the coil becomes magnetic, causing a force on the permanent magnet defeating the spring, and the circuit is closed. When current to the solenoid stops, the magnetic force turns off and the spring opens the circuit.
  3. An audio speaker has a permanent magnet and a "voice coil" which is an electromagnet. The electric current flowing through the coil causes it to

become magnetic, and the attraction/repulsion to the fixed permanent magnet causes it to move. This moves the diaphragm connected to it, and makes sound.

4. An electric motor uses electromagnets. In the neat model we have with us, a large permanent magnet is positioned around an electromagnet free to swivel. When you turn the electromagnet on, it rotates to align with the external field. To make a (DC) motor, you need to keep it turning even after it has aligned. When you were using one magnet to turn another at the start, you had to keep moving the magnet in your hand to keep the rotation going. See if the kids can come up with a way to do this. In a motor, this is achieved by a neat device called the *commutator* – the split ring in our motor. As the motor rotates, this reverses the direction of the current through the coil, hence its magnetic poles. So as soon as the coil gets aligned to the permanent magnet it finds itself out of alignment again, and so keeps turning. In most electric motors, the permanent magnet is also replaced by electromagnets.

Second Activity

- We have seen how an electric current can be used to create a magnet. Now we will see how to do the opposite: use magnets to create an electric current.

- Ask them how, given a wire, they can find whether an electric current is flowing through it. There are many ways (connect it to a lightbulb, a motor, etc.) but one we have used today, which is in fact the way a common current-measuring device (*ammeter*) works is to run the current through a coil, and measure the resulting magnetic field. In our case, run the current through the wire on the nail and see if it can make the compass needle move!
- We saw that making more windings increases the effect. We will want to measure small currents here, so instead of our nail we will use a large coil with 3000 windings. It would take us too long to do that with the nails! We do not have enough large coils, so groups will need to pair up for this activity if we really have 10 groups in a classroom. Have them place the compass inside the large coil. The coil has plugs for banana plug wires. Connect these to a battery to see the compass needle move. If a group has a problem with this, they likely have the coil aligned to local magnetic North, so the needle is already aligned. Ask them to rotate the coil so the needle is not aligned along the axis when the current is off. This should lead to a quite satisfactory effect.
- Likewise, many windings of the coil will help a magnetic field create a larger current for us to detect, so we have another, smaller coil, with 3200 windings. Have them connect the two coils in a circuit (no battery). They will be putting magnets near the smaller coil, so we want this as far as possible from the

compass needle to avoid an effect on the needle from the magnet itself.

- When they put a magnet near the small coil they should see *nothing* happening. A steady magnetic field does not create a current.
- However, moving the permanent magnet near the coil, or moving the coil near a permanent magnet, will cause a current to flow through the coil, hence also through the larger coil, and the resulting magnetic field will cause the compass needle to jump. Point out that it is the *change* in the magnetic field that causes a current to flow.

Discussion

- The effect we saw – a changing magnetic field creates a current – is called *electromagnetic induction* and has a large variety of uses. One favorite is to read magnetic storage media. I might bring a cool demo with me: stick one of our little nail coils into a cassette player instead of the recording head. As the tape runs, the magnetic field created on the tape when it was recorded causes a current to flow through our coil. Connect this to a speaker and you can play the tape!
- Another important application of induction is the electric *generator*. This performs the opposite function of the electric motor, in that it converts *motion* to *electric current*. Ask them for ideas on a design for this. In fact, the motor we demonstrated before was an adapted generator. So we can now show them how to

use it for its original function. Disconnecting the power source, insert a lightbulb in the appropriate socket. Turning the handle causes the coil to rotate, so that it "sees" a changing magnetic field (we could turn the permanent magnet but that is too heavy). Once again, the changing field changes in different directions, so we use the commutator to extract a current that always flows in the same direction all the time.

- This is how power gets to our sockets. Generators at power plants are driven by various energy sources (usually oil, coal, or fission used to heat water to boiling and the steam pressure used to turn a turbine). The rotation of a generator much like ours creates a current which we use to power stuff. The only difference is they do *not* use a commutator, so that what is produced is an *alternating current.*