Electromagnetism

Northwestern University MRSEC
Lesson Plan for Middle School Students
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Lesson Goals:

1) Learn that electric current produces magnetic field
2) Magnetic field direction can be measured with a compass
3) Magnetic field is perpendicular to current-carrying wire
4) Magnetic field is axial inside a solenoid
5) Magnetic field direction depends on direction of current flow
6) How electromagnets are made and how they are used
7) Laboratory skill:
    a. Recording qualitative observations by drawing figures
    b. Independently exploring fields due to various configurations of wires
    c. Synthesizing multiple local observations into a continuous concept of magnetic field lines

Target Age Group:
This lesson has been used in after-school science club settings at middle schools.

Lesson Duration:
45-60 minutes

Preparation:
About 1 hour to make solenoids for 4-5 groups. For all wires handed to students, strip off the insulation at the ends. If using varnish-coated wires, use a razor-blade to strip the insulation. Do not ask students to strip their own wires.

Beginning Discussion:
Electricity: Depending on students' background with electronics, review the concept of current flowing in a wire when a battery is connected. Current is a consequence of the movement of electrons. Electrons move from the negative side of the battery to the positive side. Convention states that "current" flows from the positive side to the negative side.
Magnetism: What does a compass do? Why does it point north? ("Earth's magnetic field") Compass shows you the direction of magnetic field lines. Remind students to always hold the compass horizontal, that's the only configuration in which it works well. (Can do brief exercise with permanent magnets and compass if students don't feel confident about using the compass to map the magnetic field direction.)

Hands-On Activity 1:

Students should work in groups of 2-4. Connect a loop of insulated wire to a D battery (or two D batteries in series) with alligator-clip-terminated jumper wires. (The insulation should be stripped from the ends of the wire where the alligator clip is attached.) We used thick-gauge varnish-insulated magnet wire, but any wire that holds its shape will work. What direction does the compass point when it's above the loop? Below the loop? (Should be perpendicular to the wire and have opposite directions above vs. below the wire.) Students should be asked to draw their results in their notebooks. Now switch the wires connecting to the battery so the current flows in the opposite direction. What happens now? Again, students should draw the result in their notebooks. Now bend the wire such that it is vertical. Go around it with the compass. What direction does it the compass point? (Students generally won't know the term "tangential" so just use the term "perpendicular".) Ask students to try to draw the magnetic field lines in their notebooks.

Discussion:

Session leader should draw on board the direction of the magnetic field that students should have observed. Current makes magnetic field that's perpendicular to the wire. Direction of the magnetic field reverses when the current flow is reversed.

Hands-on Activity 2:

Hand out solenoids that were earlier prepared. Use cardboard tube with diameter around 3-5 inches. Wind wire around it several times but leave free ends sticking out. Free ends should have insulation removed. (We did about 20-50 windings to create a strong field.) Use single-strand insulated copper wire, not braided wire because the braided wire will not hold its shape. We used thick-gauge copper magnet wire and that worked well. Only use insulated wire; we used varnish-insulated wire which holds its shape well. You can hold down the loops with masking tape if necessary. Students can make their own solenoids if there is time or session leader can prepare them ahead of time. We found that students tended to tangle the long pieces of wire so we felt that making them ahead of time worked better. Students should hold the solenoid such that the plane of the loop is vertical (ie: the central axis is horizontal). Connect the two free ends of the cylindrical solenoid to two D batteries in series using alligator-clip-terminated jumper wires. Place the compass in the middle of the solenoid. What direction does the compass point? (Should be axial.) Draw results in notebook. Can you explain why the compass points in that direction? Note: if the solenoid is lying down with the axis of the cylinder vertical, the compass will not be able to show that the magnetic field is axial in the middle. Students need to "turn the solenoid sideways" so the axis is horizontal.

Discussion:

Magnetic field is always perpendicular to the wire. Session leader should draw the magnetic field lines around a loop on the board, then add more loops to show how the field will be axial in the middle of a cylindrical solenoid.

Hands-on Activity 3:

Making an electromagnet. Students should wind wire on an iron nail. Again, use non-braided wire that holds its shape. The winding doesn't have to be particularly nice as long as the students don't reverse the direction of the winding. Connect uninsulated ends of wire to two D batteries in series and add a switch into the circuit in series as well. When the switch is closed, the electromagnet can be used to pick up paperclips. When the switch is open, the paperclips should fall down. After a while the paperclips will not fall when the switch is open because the field from the solenoid actually permanently magnetized the nail. You can try to switch the battery leads to reverse the current direction, but it usually won't get rid of the magnetization.

Discussion:
Electromagnets are used to move cars in the junk yard. You can also use this method to create permanent magnets by taking iron-rich materials and putting them inside a solenoid to set the field direction.

Materials:
big iron nails (4-inch long, several millimeter diameter), varnish-insulated copper magnet wire (1 foot for the loop exercise, 20 feet for the solenoid, 4 feet for electromagnet per group), D batteries, D battery holders, wires with alligator clip ends, compasses, paper clips, cardboard tube, knife switches

Note on materials: you can't actually get iron nails because typical hardware stores only sell steel nails. Bring a magnet with you to the store and any nail that is attracted to the magnet will work fine. The exercise will drain the batteries, but we have found that all three activities can be completed with the same two D batteries in series. After the exercises, session leader can use a multi-meter to determine if the batteries can be used in the future for other experiments.