Lesson C-19

Electricity III: Electric Current and Magnetic Fields: The Basis of Electromagnets, Solenoids, Speakers, Motors, and Generators

Overview:

Through making direct observations, students will discover that a magnetic field is invariably associated with the flow of an electric current and, conversely, passing a wire through a magnetic field induces an electric current. They will apply this understanding to constructing electromagnets and solenoids and observe how these devices are used in many common electrical appliances. They will discover a further application in observing how speakers and microphones work. Lastly, they will apply the principle to understanding how motors and generators work.

Time Required:

Part 1. Electric Current and Magnetic Fields (hands-on activities, observation and interpretation, 40-60 minutes)
Part 2. Electromagnets and Solenoids (hands-on activity, analysis, interpretation, and application, 1-2 hours)
Part 3. Speakers and Microphones (examination and interpretation of how they work, 50-60 minutes)
Part 4. Motors and Generators (examination and interpretation of how they work, 50-60 minutes)

Outcomes: Through this exercise, students will be able to:

1. Use a flashlight battery, compass, and wire to demonstrate that an electric current creates a magnetic field. State how this effect is reversible, i.e., passing a wire through a magnetic field causes current to flow in the wire.

2. Build, demonstrate and explain the action of a simple electromagnet.

3. Cite similarities and differences between an electromagnet and a permanent magnet.

4. Demonstrate how reversing the direction of current-flow reverses the poles of an electromagnet.

5. Construct and demonstrate the action of a solenoid. Point out how/where solenoids are used in many appliances in and around the home.

6. Diagram the basic design of a loudspeaker and explain how it works to produce sound.

7. Explain the principle behind the operation of an electric motor. Point out how/where electric motors are used in many appliances in and around the home.

8. Explain the principle behind the operation of an electric generator.

9. Cite the major hurdle that must be overcome in the production of electrical power.

Required Background:

Lesson A-5A, Magnets and Magnetic Fields
Lesson D-3A, North, East, South, and West
Lesson C-2, Sound and Vibrations
Lessons C-13, C-13A, C-14: Electricity I, IA, and II

Materials:

Part 1. Electric Current and Magnetic Fields
For class demonstration:
Directional compass
2 feet or so of light-weight copper wire (insulated or uninsulated)
Flashlight battery
For each student or group:
Same as above if possible (otherwise the class demonstration will suffice)

Part 2. Electromagnets and Solenoids
In addition to the above, a thin plastic straw is needed. The straw should be such that a small sewing needle will drop through but not with much space to spare. A coffee stirring straw works well.
A small sewing needle

Part 3. Speakers and Microphones
A discarded stereo or radio speaker (One may often be obtained free from a musical instrument store. An in-use speaker may also be used as it is only to allow students to examine the back side.)

Part 4. Motors and Generators

A discarded motor that students can disassemble (Such motors can be obtained free from any appliance repair shop.)

A discarded generator (Such generators can usually be obtained free from an auto repair shop or an auto parts recycling center, i.e., junk yard.)

A hand-crank generator (This is very useful for demonstration, but hardly worth the purchase price if it is just for one student/class. See if one can be purchased for the school or group and shared.)

Teachable Moments:

Hold a flashlight battery in one hand and a magnet in the other; ask students to ponder the two and think of how the two may be related. After a bit of reflection, ask them to crowd around and observe the demonstration described in the first section of Part 1.

Methods and Procedures:

Part 1. Electric Current and Magnetic Fields

With a flashlight battery, directional compass, and copper wire (roughly a foot) in hand, invite students to crowd around to observe the following demonstration. The compass needle will be pointing north. Place the wire under the compass in a direction parallel to the needle and connect one end of the wire to the negative pole (bottom) of the battery. Then, have students watch the behavior of the compass needle as you briefly connect (a touch will do) and disconnect the other end of the wire to the positive pole of the battery. (Note that contacts effectively short-circuit the battery and will quickly drain its power. Therefore, keep contacts brief.)

As a contact is made, students will observe that the compass needle abruptly reorients itself to a position perpendicular to the wire. It holds that position as long as current is flowing through the wire. When the contact is broken, the needle returns to its north-south orientation. Students will want to try this themselves. So far as practical, facilitate their doing so, and encourage them to try variations in the process. Variations may include passing the wire over the top of the compass rather than under it, and reversing the poles of the battery. They should diagram each variation in their notebooks and record the results. In diagrams, it will be significant to indicate both the direction of current flow —it flows from negative to positive—and whether the needle points east or west as a result of the current flow.

After a period of experimentation, bring students together to discuss and analyze their results. You may have to begin with a review and re-emphasis of the fact that a compass needle is really a small magnet balanced on a pivot. Second, the Earth itself also acts as a giant but weak magnet with its poles corresponding roughly to the geographic North and

South Poles.[1] Recall how like poles of a magnet repel and unlike poles attract. Thus, the compass needle, barring other influences, orients itself according to the magnetic field of the Earth.

Students may offer various novel ideas to explain the results. The only one that will hold up to scrutiny, however, is that the electric current (electrons) flowing through the wire creates a magnetic field. Close to the wire, this field is stronger than the Earth's magnetic field. Thus, the compass needle orients itself according to the magnetic field formed by current flowing through the wire.

The various tests that students have done, i.e., placing the wire over rather than under the compass and reversing the flow of current (by reversing poles on the battery), show that the magnetic field created by current flow has a very specific orientation. It is not random. For example, when current is flowing south under the compass—the compass and wire oriented and connected so that the current is flowing geographically south under the compass—the needle always points to the east. If current flows north under the compass, the needle always points west. (Placing wire over the top of the compass gives the reverse effect.)

In cases where students come up with causes for results other than the electric current creating a magnetic field, don't reject them outright. Instead, subject them to "If that, then what?" questioning. Students will discover that their erroneous explanations are wanting.

Some students will invariably ask why an electric current should produce a magnetic field. Tell them that the answer is for future scientists to explain. For now, we can only say that this is what is observed. It is part of the nature of electricity. Electricity and magnetic fields are always like the two sides of a coin. Each is an aspect of the other. Further, while we don't have an answer as to why, we can and do use this phenomenon in all sorts of devices from doorbells to computers. We will investigate some of these in the following parts.

> Note: A number of students will probably want to test if an in-use power cord, which obviously is conducting current, will likewise affect a compass. Allow students to try it. Despite the logic that leads them to predict that it should work, it doesn't. Current through a power cord has no effect on the compass. Why not? There are two reasons.

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[1] Magnetic north (the direction a compass needle points) may vary by as much as 15 degrees to the east or west of true north depending on your location. Navigators must make adjustments for this factor, which is known as magnetic declination. Maps used for navigation are continually updated to show magnetic declination for any given area (Google: magnetic declination).

First, household/commercial power is alternating current (AC); it switches direction back and forth 60 times each second. The compass simply cannot adjust to these rapid switches. Second, the two wires of the circuit are always carrying current in opposite directions. Since the magnetic field depends on the direction of current, the fields around the two wires effectively neutralize one another.

Converse of Electric Current Producing a Magnetic Field

Let students reflect for a few minutes on what they have just discovered, i.e., the fact that an electric current produces a magnetic field. Then ask: Do you think this phenomenon works backwards as well? That is: Does a magnetic field passing across a wire produce an electric current? Let students make guesses and give any reasons for their answers that they may but also expect them to respond that this is an idea that needs to be tested.

Unfortunately, it is not so easy to demonstrate that an electrical current is produced by a magnetic field acting on a piece of wire. One needs a very sensitive amp meter. If one has this, one can show that sweeping a magnetic field across a wire (sweep one pole of a permanent bar magnet across the wire close to but not touching the wire) one will see the amp meter register a “blip” of current. In the absence of this hands-on demonstration, however, animations may be used; (Google: how electric generators work animation). Also, the principle will become more clear through the hands-on experience gained in observing the operation of actual generators (see Part 4).

Part 2. Electromagnets and Solenoids

Electromagnets

Invite students to reflect on the relative strength of the magnetic field produced by the battery current flowing through the wire, which they have just demonstrated. It is strong enough to influence a compass needle, but will it pick up a small nail or paper clip? Allow students to conduct the test. They will discover that the answer is, “No.” Ask: Can they conceive of a way to amplify the magnetic field produced by current flowing through a wire—a way that does not involve changing the kind of wire used, or the size or voltage of the battery(ies) used?

Give students think-time to ponder the problem. If necessary, give them a hint by asking: What will happen if you wind the wire into a coil, keeping the loops separate of course? Students may reason that the magnetic field formed by the electric current going around one loop should add to and reinforce the magnetic field formed by its going around the next loop, and so on. Therefore, a coil of wire may be expected to produce a stronger magnetic field than a single strand of wire by itself. Invite student to test if this idea actually works.

The test may be done by simply wrapping fine, insulated copper wire 10-20 turns around a nail (iron), such that you will have a foot or so of wire free at both ends. Uninsulated copper wire will also work if you first put a strip of plastic tape around the nail to insulate it from the wire, and wrap the wire carefully so that the turns of wire are close but not touching. Connecting the wire to the poles of a battery, students can test and note that the core nail now behaves as a magnet capable of picking up small nails, paper clips, and other small iron items. (Note that the wire connected to the battery is effectively a short circuit; therefore, the draw on power is great and batteries will be drained rapidly. Therefore, advise students to make tests brief and disconnect the battery every time the magnet is not in active use.)

Students may test the relative strength of their electromagnet by observing how many small tacks or paper clips it will pick up at one time. Then, they may make variations in their electromagnets and test the results for each. Variations may include using differently sized nails as the core, increasing or decreasing the number of times the wire is wrapped around the nail, and adding additional batteries (not more than three for safety reasons) to the circuit. They should diagram each variation and record the results in their notebooks.

A test that all students should make with one or more of their electromagnets is to bring the point of the electromagnet nail close to a compass. One end of the compass needle will be drawn to the nail. Then bring the head end of the electromagnet nail up to the compass; they will observe that the opposite end of the needle is drawn to the nail. Then have students reverse the connections of the wire to the battery to reverse the flow of current and repeat. They will discover that effect will be the same in principle, but it will be the opposite end of the compass needle that is drawn to the point or head of the electromagnet nail. Bring students to discuss and summarize the properties of their electromagnets: How are they like other magnets with which they are familiar? How are they different? Primary conclusions that they should derive are:

- Electromagnets have two poles just like other magnets. As in other magnets, like poles repel and unlike poles attract as observed in Lesson A-5.
- The poles of an electromagnet are reversed when the flow of current through the wire is reversed.
- The primary difference is that the electromagnet field may be turned on and off and/ or poles may be reversed with the electric current. Familiar magnets remain constant. Thus, the common magnets we are familiar with are known as PERMANENT MAGNETS, as opposed to electromagnets.

Students may test how the nail-points of two electromagnets shift from attraction to repulsion as the connections to the battery of one of the electromagnets is reversed, thus reversing the poles of the electromagnet.

Describing the way the north-seeking and south-seeking poles of the electromagnet correspond to the direction the current is flowing can be confusing, but there is a simple way of doing it. It is called the right-hand rule: If the coil is grasped by the right hand so that the fingers point in the direction the current is flowing (negative to positive), the thumb (sticking out from the fist) will point in the direction of the north-seeking pole. The opposite end will be the south-seeking pole. Have students test this with a compass. The north-seeking pole of the electromagnet will attract the south end of the compass needle.

Solenoids

Review the basic principles regarding electric current and magnetic fields uncovered thus far:

- An electric current flowing through a wire creates a magnetic field around it.
- If the wire is wrapped around an iron core, the magnetic field produced by the flow of current makes the iron core act as a magnet.

Next, pose the question: Does the iron core (the nail) have to be present in order for the coil to act as a magnet? Invite students to test this idea by making a coil of wire (in the same manner as above) around a thin plastic straw (see materials). (Drinking straws don't work because there is too much distance between the electrical wire and the center of the straw.) Position the coils around the straw such that a needle (effectively an iron rod) placed in the straw may have one end hanging out while the other end sticks up to where the wire is coiled.

When students turn the current on (connect the battery), they will see the needle jerked up into the straw to where it is centered within the coil of wire. When the current is tuned off, it will drop out of the straw again. From this activity, students should conclude that the answer to the question is: Yes, current passing through the coil creates a magnet-like field that will pull an iron "rod" into its center. Thus we see that a coil of wire can be used to move an iron core when an electric current is applied. Only add that such a device is called a SOLENOID.

Continue by having students note that if we had something attached to the end of the needle (rod), it could be lifted or, considering the other end, it could be pushed. A spring at the opposite end could return the rod to its original position so that it need not depend on gravity. Alternatively, one solenoid could pull and tip a lever one way; a second solenoid could be installed to pull the lever the other way.

Have students brainstorm the possible ways that solenoids might be used. (Add that solenoids can be built in virtually any size, so their applications can range from micro to macro.) One can't predict the novel ideas that kids may come up with, but all will be worthy of reflection.

In fact, solenoids are commonly used in opening and closing locks, valves, and switches. For example, have students reflect on their experience with an automatic dishwasher or laundry machine. The click they hear preceding water flowing into the machine is a solenoid opening a water valve. A remotely activated car-door lock is another example. The signal from the "clicker" activates (causes current to be sent to) a solenoid in the lock. That solenoid pulls the lever that actually locks/unlocks the door. Remotes for TV sets work similarly. Ringers and buzzers also utilize solenoids. The clapper is drawn to the bell by a solenoid. However, as the clapper hits the bell it also disconnects the circuit so that it falls back and reconnects the circuit. Thus the ring/buzz. If students can disassemble a bell and observe its workings, so much the better.
(For additional examples, Google: solenoids various applications.)

Part 3. Speakers and Microphones

Ask students to consider a variation on the theme of solenoids. Review: In the solenoid, they have seen how the electric current moving through the coil creates a magnetic field that pulls an iron rod into the core. What would happen if we held the iron rod stationary and allowed the coil to slide up and down? (Think time.) Students will reason that the general effect is the same; only the coil, rather than the rod, will move back and forth as current is applied. If something was attached to the coil that would move as well.

Guide students to take this idea one step further. Suppose we make a coil of many loops of wire spread out in the shape of a disc. Suppose that we mount a permanent magnet so that one of its poles—let's say the north pole—is over the top of the coil "disc." Further yet, suppose that the magnet is held stationary and the coil, and whatever may be attached to it, is free to move up or down. (You may help students visualize the arrangement by diagramming it on the board as you proceed.) Next, have students analyze what will happen as current is applied to the coil in one direction and then the other. Guide students in reasoning:

- When the current flow is in the opposite direction such that the top of the coil becomes the north pole, the coil will be repelled away from the permanent magnet (like poles repel).
- When current flows in the direction such that the top of the coil becomes a south pole, there will be an attraction (unlike poles attract); the coil will be drawn toward the permanent magnet.
- Furthermore, the relative attraction and repulsion will be proportional to the amount of current applied.

Thus, bring students to conclude that the coil, and anything attached to it, may be pulled back and forth, by adjusting the force (voltage) and direction of the current applied to the coil.

But hasten to add that this conclusion is just a "theory" or supposition derived from what we understand from our observations concerning the behavior of electromagnets, and the interaction between two magnets. Therefore, have students move on to examine the construction of a speaker from an old TV, stereo, or radio. (This process need not damage the speaker. You may simply take the cover off a working speaker to examine its back side.) Instruct students to gently touch the central metal portion with a screwdriver or other metal tool. They will discover that it is a strong permanent magnet. Within the magnet structure, they will see a coil of wire. (It may be wrapped so that individual wires are not discernible, but try to show students that a coil of fine wire is at the core of the speaker.) The coil, in turn, is attached to the diaphragm of the speaker.

Ask: How does this arrangement of permanent magnet and coil correspond to the "theory" derived above? Students should see that it corresponds exactly. Ask: How then does the speaker produce sound? Guide students in reasoning, in their own words: An electric current modulated (adjusted very rapidly in force and direction) through the coil causes the coil, and hence the attached diaphragm, to move back and forth. The changes in electric current can be brought up to vibration speeds. Thus the diaphragm "pumps out" sound waves. Those sound waves impacting our eardrums give us the sensation of hearing.

As students grasp this understanding, they are likely to ask: How is the electric current to the speaker coil modulated? In answer, the key point to emphasize, again, is that the electromagnetic effect works backwards as well as forwards. That is, current through the wire produces a magnetic field. Movement of a coil of wire within a magnetic field causes electrons (current) to flow within the wire. Thus, a microphone contains an arrangement of diaphragm, coil, and magnet similar to the speaker. Here, the process is reversed: Sound waves hitting the microphone diaphragm cause it to vibrate. A coil of wire, which is attached to the diaphragm and within the field of a permanent magnet, vibrates and produces an electric current that is modulated accordingly.

Of course, between the microphone and the final speaker there are electronic devices for amplifying the electric current, sending it over wires or broadcasting it as radio/TV waves, recording and replay devices, and so on. Any and all of these are for independent studies and/or future courses. (Information concerning any particular device may be found by Googling: how stuff works/ and entering the desired item. In many cases you will be able to find animations by including the word, animation.)

Note: If you Google "how microphones work," you will find that in addition to the type described above there are some that work on another principle known as capacitance. The concept of capacitance was described in Lesson C-13A, Electricity IA, Static Electricity, Sparks, and Lightning.

Part 4. Motors and Generators

Motors

Note: The words "motor" and "engine" are commonly, but erroneously, used interchangeably. In correct usage, "motor" refers exclusively to an electric motor, which uses electric power to turn a shaft. "Engine" refers to the fuel-consuming device under the hood of your car and in all other vehicles (except those that run on electrical power). To avoid confusion, it will be well to clarify this distinction at the outset and correct any misusage as you go.

Ask students to reflect on electromagnets, perhaps the ones they have constructed and say, "Hmmm, I wonder if we can use the principle of electromagnets to turn a shaft and keep it turning?" Students may recognize that you are essentially asking them to contemplate an electric motor, but it will create an enhanced learning experience if you have them wrestle with and create possible designs rather than just looking up how motors work. Encourage them to work in groups and allow them as much time as they may desire to exercise their creativity.

At the outset, students only need to recognize what they have learned above: an electromagnet can be switched on and off and/or its poles may be reversed by changing the direction of current flow. Yes, they may incorporate more than one electromagnet into their design and also include any number of iron "posts" and/or permanent magnets. You may also remind them that household current is AC, which is alternating current. It reverses direction and will consequently reverse the poles of an electromagnet at a rate of 60 cycles per second.

Some students may be stumped by the challenge. Let them know that is okay. It took many inventors many years to come up with workable designs. Insofar as students do come up with proposed designs, let them share and explain them to the rest of the class and receive comments and suggestions as to their workability. Some designs may be so complex that they defy simple analysis. Have students keep these in their notebooks for later reflection and examination by someone with more expertise.

After this challenge, invite students to disassemble an electric motor to observe its insides and also watch animations of how electric motors work (Google: how electric motors work animations). From hands-on observation, students will see that the innards of any motor consist of coils of wire around iron "posts." Wow! Electromagnets. There may be permanent magnets as well. Then animations will show that there is a mechanism that switches the current from one electromagnet to the next. Without getting into great detail, students will derive the understanding that all electric motors utilize the principle of electromagnets to pull the shaft around by magnetic attraction/repulsion plus a switching mechanism (or AC current) to activate one electromagnet after the next to maintain rotation.

While all electric motors operate on the principle of electromagnets, there are many variations on the theme. Therefore, if their own creative designs do not correspond to the actual motor(s) or diagrams that they see, it does not mean that their concept is in error. It may be perfectly workable, just a different variation on the theme. Professional engineers are continually working to design and build motors with greater efficiency, i.e., giving more movement energy output with less electrical energy input.

Generators

Long before now, students have probably asked where electricity comes from or how it is produced. Therefore, the essence of this section may be brought up much earlier in studies. I put it here simply as a matter of writing and because generators, which produce electrical power, are closely allied with motors. In fact, generators are effectively motors in reverse.

Facilitate students in disassembling and examining the innards of a generator. Again they will find coils of wire wrapped around iron “posts” (and perhaps permanent magnets as well) indistinguishable from those found in a motor. What is going on? Reemphasize to students that there are two sides to the electric-current-magnetic-field phenomenon. One side of the “coin” is that an electric current passing through a wire creates a magnetic field. The other side of the “coin” is that passing a wire through a magnetic field causes current to flow in the wire (assuming it is connected into a circuit).

From here, ask students to speculate on how the generator produces electric current. They may be expected to reason (correctly) that turning a generator amounts to passing one or more coils of wire through magnetic fields. The result is an output of electrical power. You may confirm their reasoning by showing them animations of how generators work (Google: how generators work animation). This sounds quite simple and in principle it is. The big hurdle, inform students, is the power source to turn the generator.

Cranking the generator sounds easy. However, the problem arises in that there is a conflict between the two sides of that “coin” noted above. Passing the wire through the magnetic field causes current to flow in the wire, but as that current flows it creates another magnetic field of its own. The two magnetic fields are in conflict; the magnetic field produced by current flowing through the wire is such that it resists the passage of the wire through the magnetic field.

Again, guide students to observe that nature does not give us something for nothing. Review how in previous lessons they have observed that they cannot get more energy out of a system than they put in. For example, they cannot slide down a slide without putting in the energy required to climb up. They cannot get the snap out of a rubber band without putting in the energy to stretch it, and so on. Students may cite additional examples. Thus, the same is true in the case of a generator. The experience is that we can't get more electrical energy out of a generator than the equivalent amount of movement energy we put in to turn the generator.

There is no simple hands-on way to demonstrate this other than having students crank a generator connected to a small light bulb. Students readily find that they can work up quite a sweat producing current to keep the bulb lit only dimly.

Thus, the problem of producing the vast amounts of electrical power needed/desired by today's civilization is not with the concept of generators; they can be built in any size desired. It is with power sources to turn the generators. This takes us into the next lesson, Lesson C-20, Electricity IV.

Historical Perspective

Discovery of electrical phenomena and the development of electrical devices has a long and fascinating history involving many discoveries along the way. Take students into this history of inventions and biographies of inventors at your discretion.

Questions/Discussion/Activities to Review, Reinforce, Expand, and Assess Learning:

In their science notebooks, students should record, using diagrams as appropriate:

a) how to demonstrate the fact that an electric current creates a magnetic field
b) how to make a simple electromagnet and how its poles shift with the direction of current
c) how to make a solenoid, what the solenoid will do, and a list of common applications
d) how speakers work
e) the principle behind electric motors and electric generators

Set up an activity center where students can make and experiment further with electromagnets and solenoids, and spend further time examining speakers, motors, and generators.

Design games or contests that will challenge students to list things in and around their homes that utilize the electromagnetic principle. Be specific. For example, solenoids in the automatic dishwasher open/close valves to turn water on/off, etc. Their lists may also include electric motors.

Design games or contests that will challenge students to list things in and around their homes that utilize electric motors. (The list will include refrigerators, air conditioners, dishwashers, fans, mixers, power tools, electric razors, and more.)

Create games or contests that challenge students to match a specific device/appliance with a specific electrical feature.

What is the similarity between an electric motor, a solenoid-operated switch or valve, and a stereo speaker? What are the differences?

How is electrical power produced? Do generators give us a source of free energy? Why not?

In small groups pose and discuss questions such as:

How will a battery current through a wire affect a compass?
Why does the current through the wire have this effect on a compass?
How can you build an electromagnet? … a solenoid?
Aliens are searching for solenoids and motors to repair their spaceship. Where might they find them? (What common appliances/devices use solenoids? … motors?)
A cord to a lamp does not affect a compass even when the light is on. Why not?
How does an electric motor work?
How does an electric generator work?
Do electric generators give us "free" energy? Why not?

To Parents and Others Providing Support:

Facilitate children demonstrating how an electric current from a flashlight battery affects a compass. Guide them in expressing why/how this effect occurs.

Facilitate children building and experimenting with electromagnets and solenoids (powered by no more than three batteries).

Facilitate children disassembling and examining discarded bells, buzzers, speakers, and motors. Discuss with them how each device works.

Invite children to search and make a list of where electric motors reside (in various appliances) in your home. Do the same for solenoids.

Kits for building electric motors are available. Consider this option for children who express such a desire.

Show or have a mechanic show children the generator under the hood of a car. Discuss why every car must have a generator to keep the battery charged. Show children how the generator is turned by the car's engine. With the engine idling, switch the headlights on and off while listening carefully to the engine. Children will hear the engine change pitch as it must work harder to turn the generator as it supplies current for the lights.

Note: A mechanic may tell you that it is an alternator, not a generator. An alternator is simply a generator of different design. The principle of operation, inducing current flow by having coils of wire pass through magnetic fields, is the same.

Connections to Other Topics and Follow-up to Higher Levels:

Generation of electrical power and respective resource and environmental problems
Mathematical relationship of volts, amps, resistance, and watts
Further investigations into how various electrical devices (including computers) work. (They all utilize the basic principles revealed in this and previous lessons.)
Chemistry of batteries/electrochemistry

Books for Correlated Reading:

Gifford, Clive. *How the Future Began: Machines*. Kingfisher, 1999.

Hakim, Joy. *The Story of Science: Newton at the Center*. Smithsonian Books, 2005. (See especially Chapters 32 and 33.)

Hartman, Eve. *Magnetism and Electromagnets*. Raintree, 2009.

Parker, Steve. *Eyewitness: Electricity.* DK, 2005.
__________. *Fully Charged: Electricity* (Everyday Science). Heinemann-Raintree, 2005.

Somervill, Barbara. *Electricity and Electrical Circuits.* Raintree, 2009.