SCOPE,
SEQUENCE,
and
COORDINATION

A National Curriculum Project for High School Science Education

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Student Materials

Learning Sequence Item:

1035

Magnetic Induction

January 1997
Adapted by: Stephen Druger

Contents

Lab Activities

Readings

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This micro-unit was adapted by **Stephen Druger** (Northwestern University, Evanston, Ill.)

Science as Inquiry/
History and Nature of Science

A Discovery on Both Sides of the Atlantic

Electric currents can produce magnetism, but can magnetism produce electric currents?

Overview:

In earlier units, you saw that when electrical current flows through an insulated wire wound many times around an iron bar, the bar becomes magnetized for at least as long as the current flows, as shown by its ability to attract small iron objects such as paper clips. Often, instead of merely regarding the magnet as attracting objects through empty space, it proves more meaningful to regard the magnet as producing a magnetic field in the space around it, with the magnetic field then exerting forces on objects such as a small compass needle placed in the field.

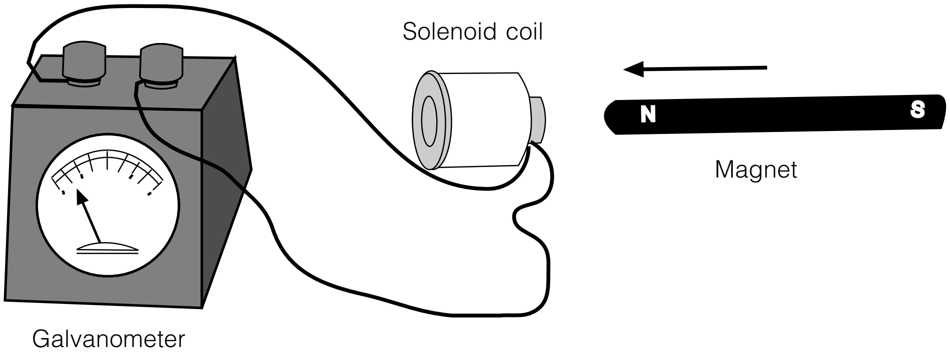
Michael Faraday (1791–1867) and many others of his time suspected that if electric currents can produce magnetic fields, then the reverse might also be true, that a magnet might perhaps produce an electric current. But exactly how that would happen, if at all, was unclear. There are, after all, not only similarities between how electric charges and magnets behave, but there are also differences.

Faraday in England and the American physicist (and high school teacher!) Joseph Henry independently discovered how and when a magnetic field could produce an electric current, with Henry making the discovery earlier but publishing it later. Because of their work, we now know how to observe the important effect they discovered.

Procedure:

Hook up the coil of wire wound around a hollow spool to the galvanometer. Then test the bar magnet by bringing it near paper clips and other objects to confirm that it is indeed magnetized.

Now holding the coil as shown in the figure, hold the magnet stationary a few inches in front of the center of the coil, not moving it at all. Note how the galvanometer behaves. Watch the galvanometer as you move the magnet into the coil and note the response if any. Then hold the magnet fixed in position



within the coil and note the response. Next pull the magnet away, observing how the galvanometer behaves while moving the magnet. Repeat any parts as needed to verify the observed behavior. Be sure that you have noted not only which cases cause the galvanometer to respond, but also in which direction the galvanometer needle moved whenever it did respond.

Next, try this with the north and south poles of the bar magnet interchanged.

Now compare the galvanometer response when the magnet is moved away slowly with that when it is moved away rapidly.

Finally, try moving the bar magnet toward and then away from the side of the coil, with the magnet pointed perpendicular to the side of the coil at its midpoint. Note how the response of the galvanometer compares with the previous results. You will probably get the most meaningful results by moving the bar magnet only to within about 5 cm (2 inches) of the side of the coil, not right up against the coil, and by comparing the response with that received from moving the magnet with about the same speed and through about the same range of distance toward or away from the front of the coil.

Questions:

1. Was a current produced by the magnet when it was held fixed in position inside the coil? How about when it was held in position outside the coil?

2. Was a current produced while the magnet was being moved into the coil? How about when it was being moved away from the coil?

3. How did the directions of the current compare in those cases when there was a current induced by the magnet?

4. Is the effect of the magnet at any point (basically, its magnetic field) stronger close to the magnet or farther away?

5. Was the magnetic field inside the coil increasing, decreasing, or staying the same when (a) the magnet was inside the coil and held stationary, (b) when the magnet was moving away, (c) when the magnet was moving closer, and (d) when the magnet was outside the coil and stationary?

6. In what ways were the results the same and in what ways were they different when you repeated the experiment with the magnet turned around so that its north and south poles were interchanged?

7. Based on your observations, what general rules apply for how the value of the magnetic field, and the way it changes, determine the current that is induced to flow in the coil?

8. How did the results change when you tested for the current by moving the bar magnet toward the side of the coil rather then toward the cross-sectional area of the coil?

9. What do your observations suggest about how the current induced by the magnetic field (and/or by changes in magnetic field) depends on the relative orientation of the coil and the magnet?

Student Sheet

Science as Inquiry

Getting an Angle on Electromagnetism

Is it because the magnet moved?

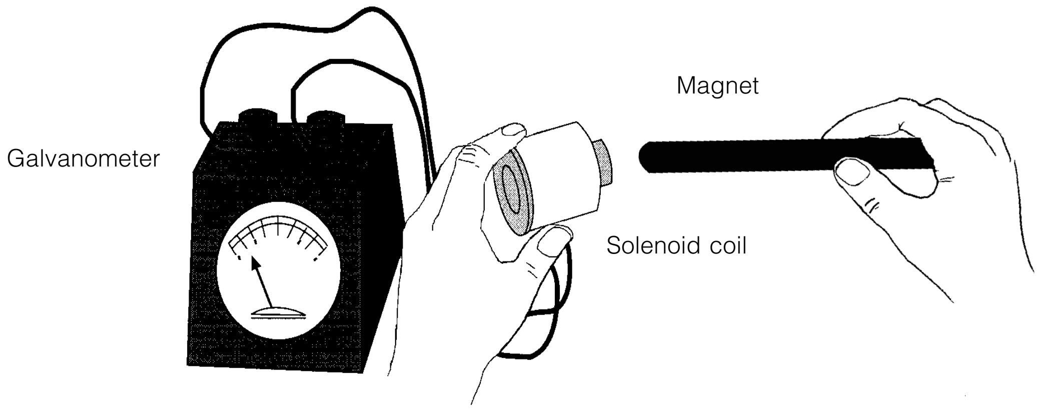
Overview:

Moving the magnet toward the coil had an effect on the galvanometer. But suppose that we hold the magnet still and move the coil instead. The physics of this situation might appear different, but in this activity we test whether or not the result is the same. We also try some other ways of moving the coil and the magnet around, with results that will later help in understanding some very important practical applications.

Procedure:

Connect the galvanometer to the coil as before. Now, however, with the help of another student who holds the bar magnet fixed in position, move the coil onto and off of the magnet with the magnet held at rest. Note what response you observe, including the direction of deflection of the galvanometer needle when there is a deflection.

Now hold the magnet in front of the center of the coil, and rotate the coil from having its circular area facing the magnet to having the side of the coil facing the magnet, with the magnet held fixed in position. Try not to change the distance from the center of the coil to the magnet while doing this. Rotate it back in the other direction and again observe the galvanometer readings. Again note not only which cases produce a galvanometer response, but also the direction of the response when there is one, and therefore the relative direction of the current. Compare with the galvanometer response if any while holding the coil and magnet fixed in position in each of the two orientations.



Questions:

1. What did the galvanometer readings indicate about a current being produced in the coil when the coil and magnet were both held still in each of the two orientations?

2. What did the galvanometer response show about any similarities and/or differences in trying to produce a current by moving the coil toward and away from the magnet compared with moving the magnet and holding the coil in position?

3. What did the behavior of the galvanometer show about the current being produced in the coil when it was being rotated from one orientation to the other?

4. How did this compare with when it was being rotated back in the opposite direction?

5. Compare the effect of changing the orientation of the coil at a fixed average distance from the magnet to the effect of changing the distance between the magnet and the coil.

6. What conclusions can you reach about the various kinds of changes that can cause a magnet to produce an electric current in a circuit? What general patterns, if any, do you see in these observations?

Science as Inquiry

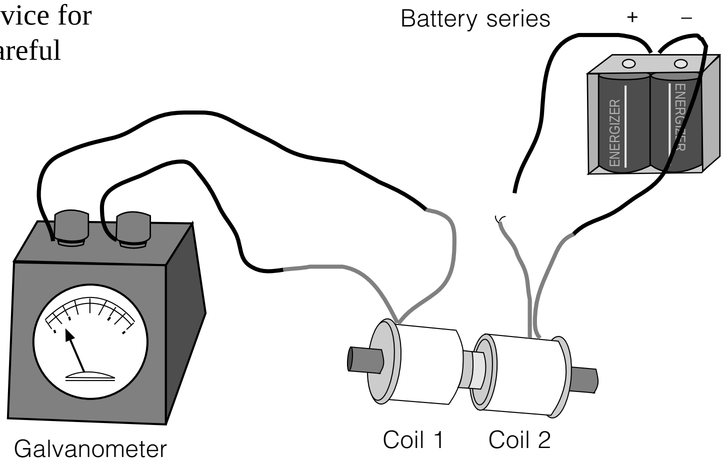
Turning on an Electromagnet

Is it because the magnet moved?

Overview:

The previous activity showed that a current can be produced when a magnet is brought inside a coil of wire. But does this result only by changing the distance between the bar magnet and coil or does it result by changing the magnetic field inside the coil regardless of the method used to change it? Fortunately, it is easy to turn a magnet on and off and test whether that can cause a current to flow in a coil connected to a galvanometer. We need only use as a magnet an iron rod temporarily magnetized by the current flowing in a coil around it. This is the kind of electromagnet examined in earlier activities.

Procedure:



The galvanometer is a very sensitive device for measuring small electric currents, so be careful to connect the galvanometer only to the coil *not containing* the battery.

Connect one coil (coil 1) to a galvanometer and the second coil (coil 2) only to the battery, but for now leave one contact to the battery unconnected so the current can be turned on and off easily by touching the wire to the remaining battery terminal.

Place the battery-connected coil alone on the iron bar and complete the connection to the battery. Test the ability of the rod to act as a magnet by attracting small iron objects, such as paper clips, with and without the current flowing. Compare this with the effectiveness of an aluminum rod used similarly to attract the same objects.

Now, place both coils together on the iron rod. Turn the current on in the battery-connected coil (coil 2) by touching the remaining wire to the battery terminal, allowing the current to flow for a second or two. Then abruptly disconnect the wire. Note any galvanometer needle deflection indicating current in the galvanometer-connected coil (coil 1) when (a) a steady current flows in coil 2, (b) when the current in coil 2 is zero, and (c) immediately after the current in coil 2 changes by being turned on or off. Be careful to note the *direction* of the galvanometer response in each case where a response is observed.

Repeat the procedure while holding the coils against each other without the iron rod, again recording the results to compare with the first experiment.

Questions:

1. When the battery drives an electric current through the coil so as to produce a magnetic field, is the magnetic field (including the effects of magnetized material) stronger or weaker for the same current flowing with the iron bar inside? How do you know this in terms of what you observed?

2. When both coils were placed on the iron rod, was there an observable current in the coil connected to the galvanometer when the battery-connected coil had a steady nonzero electric current?

3. Was the iron rod magnetized in this case, and was its magnetization changing? What leads you to that conclusion?

4. Was there an observable current in the coil connected to the galvanometer immediately after the current in the other coil had been changed by connecting and disconnecting it from the battery? How about when a steady current flowed from the battery through the coil connected to it? What leads you to these conclusions?

5. Was the magnetic field inside the coil increasing or decreasing when the current was turned on? When the current was turned off? How did the directions of the galvanometer needle deflection compare in the two cases? What does this mean about the directions of any currents produced?

6. How did the effect you observed when the iron rod was present inside the two solenoids compare with the effect observed when the solenoids were simply held together without the iron rod? How can you explain this?

7. What general conclusions can you reach about how these results are related to the results of the activity in which the magnet was brought closer to a coil or pulled away from it? What features do the results of the two activities share in terms of how magnetic fields and changes in magnetic fields can induce electric currents to flow?

Science as Inquiry/
Science and Technology

The Electric Generator

Rotating a coil of wire between magnetic poles

Overview:

We examine here how the relative motion of magnets and coils of wire can be used to generate electricity, in the sense usually meant of producing a current that flows through a wire, that can be used for such purposes as lighting an electric bulb. This can be seen to be an application of the principles in the previous activities. That electricity can be generated by a magnet was discovered at about the same time by Michael Faraday in England and American physicist Joseph Henry. Faraday, in fact, used it to build a small electric generator of the kind you will see here.

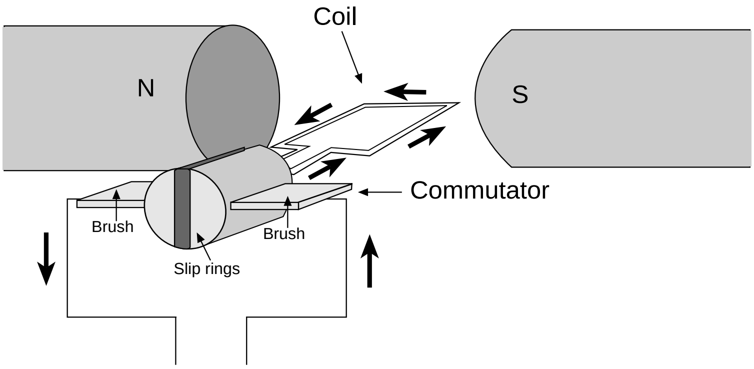
The practical uses that such a device would have are obvious to us now, considering how strongly dependent we are these days on electrical power. But things were different then. It is said that the Prime Minister of England visited Michael Faraday to see how electricity could be generated in this way and asked Faraday what practical application electricity might have. Faraday replied that he did not know of any practical use, but that he was sure nevertheless that the Prime Minister would one day place a tax on it!

Procedure:

Examine the hand-cranked generator to see how it is constructed. With the generator connected to the bulb, try turning it. Note the amount of effort it takes to light the bulb and the way that the light bulb is affected as the rate of rotation is increased.

Now carefully examine the construction of the hand-cranked generator. Note in particular how the contacts of the rotating coil are constructed in order to answer the questions below about how the generator operates.

Hand-cranked generator



Questions:

1. How was the rotation rate of turning the generator related to the brightness of the bulb? What does this tell you about how the voltage produced by the generator depends on the rate at which it is turned?

2. Based on your examination of the construction of the generator, describe how, in terms of the other activities in this unit, the generator produces an electric current.

3. If you examined the generator carefully, you saw that the contacts connecting the rotating coil to the wires leading away from the generator are arranged in an unusual way. When the coil rotates through 180 degrees, it interchanges which wire on the coil is connected to each wire leading away. Why would this have the effect of producing a current that always flows in the same direction through the wires leading away from the generator?

4. What would happen if the generator was arranged so that each wire outside the generator always made contact with the same end wire of the rotating coil? Explain why this would happen, using a diagram if desired.

Science as Inquiry

An Old-Fashioned Practical Application

Faraday's law in the movies

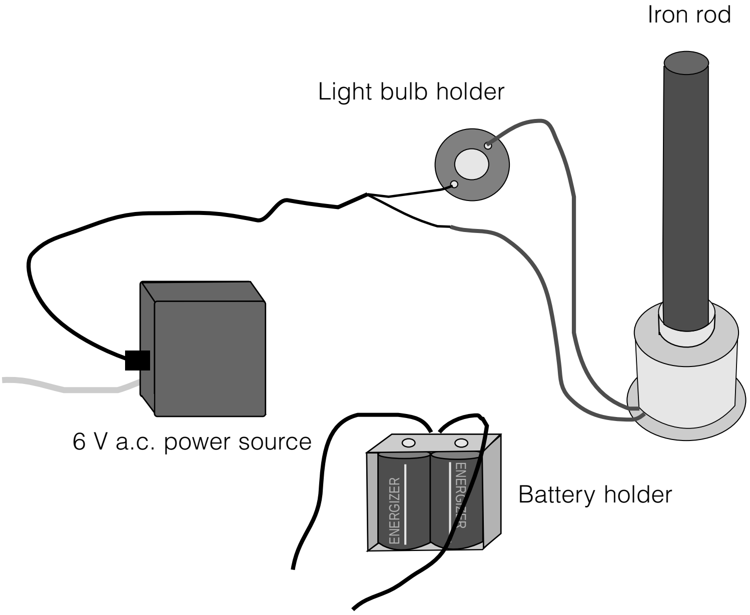
Overview:

By now you have observed that an electric current flowing along a wire produces a magnetic field, and that the changing magnetic field perpendicular to a circular loop of wire produces a current. We examine here what would happen if the current flowing through the wire is changing its direction of flow rapidly many times per second, as is true of the 60-cycle household current supplied from a wall socket by your local electric utility. In this activity, you will observe an unusual effect, which can be understood in terms of the other activities in this and other units.

Procedure:

We use a 6 V a.c. power supply connected to a magnet coil with an iron bar inserted in it. In series with the magnet coil is a flashlight bulb mounted in a bulb socket unit. Plug in the transformer to light the bulb. Observe what happens as you pull the iron bar out of the coil of magnet wire and as you reinsert it.

With the rod in the coil, hold a small paper clip near the end of the rod, almost touching it. Note the sensation you feel and whether the magnetic attraction feels constant or appears to vary in any way.



Now connect the magnet coil to a 3–6 V battery power source. (Use of a battery holder to wire the AA, C, or D cells is series in recommended.) Again note whether the sensation of holding a paper clip by hand very close to the magnet suggests a constant or varying magnetic field.

Questions:

1. How did the bulb behave when the iron rod was removed from the coil and when it was reinserted?

2. Was the magnetic field constant or changing when connected to the a.c. transformer as a power source? How did this compare with the iron rod magnetized by the d.c. battery power source? Justify your conclusions in terms of what you observed.

3. How do you explain whether the magnetization of the rod was constant or changing in terms of the nature of the power sources used?

4. Would you expect the magnetic field inside the coil with the iron rod inserted to be greater or smaller than when the iron rod is removed? Why?

5. Would the *changes* in magnetization occurring rapidly in time be greater or smaller with the iron rod inserted? Why, in terms of your previous answer?

6. What effect would the changes in magnetization have in tending to produce a current in a coil wound around the iron rod? Would this be greater or smaller with the rod inserted? Why?

7. Now suppose that your answer to the previous question about inducing a current to flow applies to any coil around the iron rod, including the coil that is magnetizing it. If the changing current in the coil produced a changing magnetic field whose effect was to *enhance* the changing current that was producing all this, what effect would this have on the light bulb and why? Is it consistent with what you observed? Why or why not?

8. What can you conclude about whether the induced voltage (or “induced electromotive force”) in response to the changing voltage opposes or enhances the change that produced it?