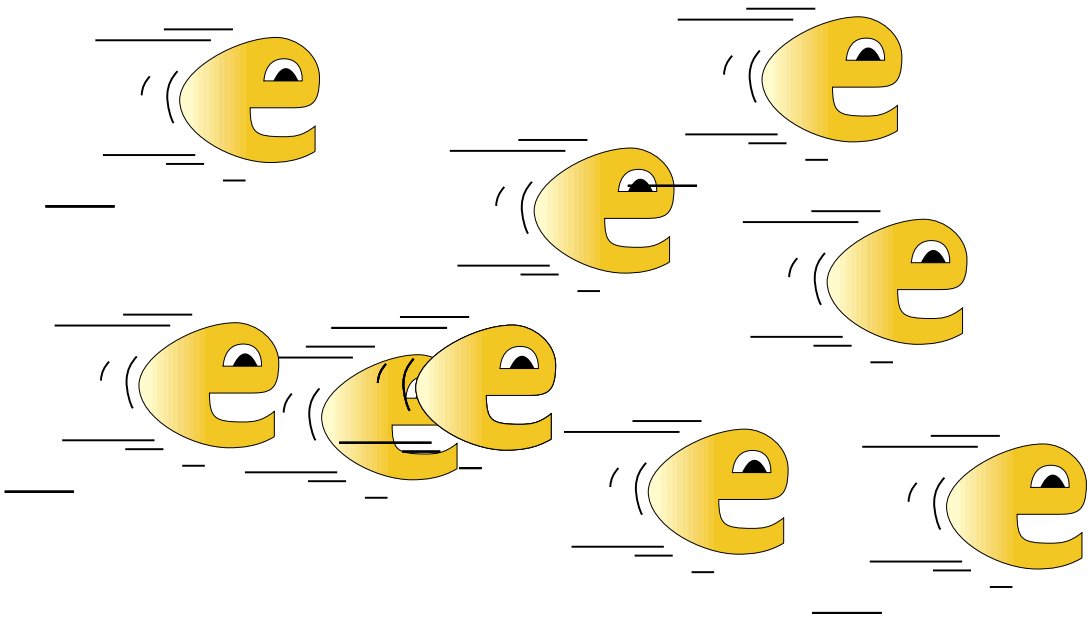
Moving Electrons

(Grades 4-12)



The Advanced Light Source (ALS) is a particle accelerator that moves electrons in a big way to produce extremely bright light for many types of scientific experiments. The ALS moves the electrons using electromagnets (in the linear accelerator, booster ring, and storage ring) and permanent magnets (in the undulators and wigglers). This unit gives students the chance to move electrons and explore the relationship between electricity and magnetism by making a simple electromagnet and building the world's simplest electric motor.

Although the Advanced Light Source's size and complexity can make it seem beyond students' understanding, actually it operates on the same principles used in objects as familiar as a television, quartz clock, and door bell. This curriculum unit can help make the ALS more accessible to students by building on the concepts presented in the "Inside the ALS" poster and by providing classroom activities to prepare students for a tour to the ALS.

The Advanced Light Source is a national user facility funded by the Department of Energy and located at Lawrence Berkeley National Laboratory, University of California. Scientists from around the world use the ALS to do a variety of scientific experiments that take advantage of the unique qualities of the light it produces.

This curriculum unit is part of a presentation package created for a teacher workshop given by the Advanced Light Source in March 1996. Other materials available include

- Puzzling Polarizers - a hands-on activity unit
- “Inside the ALS” poster - a resource for teachers and students with a handout on suggestions for using it in the classroom
- Top Ten Questions People Ask about the ALS (a fun trivia sheet of cool facts)
- Mass, Energy, The Speed of Light—It’s Not Intuitive!
- A Day in the Life of an ALS Electron - a lighter look at what an electron does at the ALS
- "The Electromagnetic Spectrum" poster - a great classroom resource for exploring the range of electromagnetic radiation from radio waves to gamma rays

For copies of "Inside the ALS" and "The Electromagnetic Spectrum" posters , contact the ALS User Office [(510) 486-7745]. All other curriculum materials are available on the web at: http://www.lbl.gov/MicroWorlds/

For more information about the ALS, contact Elizabeth Moxon [(510) 486-5760 or ejmoxon@lbl.gov].

Comments Welcome!

We welcome your criticisms, suggestions, helpful hints, and any other information that will help us improve these curriculum ideas. Please send your comments to:
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Developers
These curriculum materials were developed by the Advanced Light Source and Kirsten Daehler, a science educator, in cooperation with local teachers.

Millions of moving electrons + an iron core = The World's Simplest Electromagnet

What you need

- a large steel nail or bolt (i.e., containing iron)
- some insulated electrical wire (about 25 cm)
- a "D" size battery
- batteries smaller than "D" size (optional)
- two small pieces of duct tape or a thick rubber band
- any type of permanent magnet such as a refrigerator magnet
- different items that may or may not be attracted to a magnet
- (e.g., staples, small nails, pencils, metal spoons, scissors, etc.)

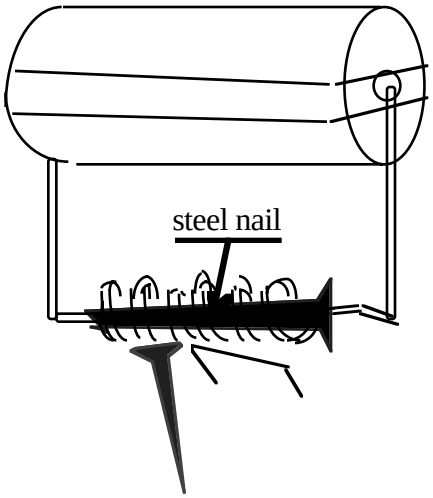
Where to get it

All of these materials are readily available in any hardware store or general-purpose department store. Be sure that your nail is made of steel. (It should be attracted to a magnet.) Plain refrigerator magnets are good permanent magnets. Alternatively, a variety of magnets can be ordered from any science supply company for less than $1.00 each. In addition, some water districts, gas and electric companies, or other businesses give away flat refrigerator magnets.

How to build it

Remove about 5 mm of the insulation from both ends of your electrical wire. Then wrap the electrical wire around your large steel nail or bolt.

Attach the ends of the electrical wire to each end of the battery. Hold the wires in place with a little tape or a rubber band.



Try it and see

Once you have built your electromagnet, see what kinds of things it is attracted to. Is the electromagnet attracted to everything? Is it attracted to all metal things? Is it attracted to other magnets? See how many paper clips or staples you can pick up. What happens if you build another electromagnet using a different size battery? How many paper clips will this new electromagnet pick up? What happens to the electromagnet if you disconnect one of the wires from the battery?

How many turns of the wire does it take to pick up a paper clip? Are more turns better? Does using a different size battery ("A" versus "C") make a difference?

What things are attracted to a permanent magnet, such as a refrigerator magnet? Are these the same things that are attracted to the electromagnet? Are there any differences between what the permanent magnet and the electromagnet can do?

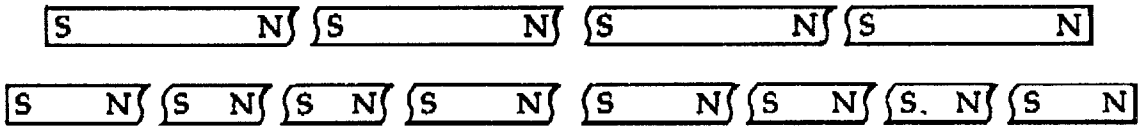
After using the electromagnet, remove the iron nail or bolt. Can the nail still pick things up? How many paper clips or staples can it pick up? Try dropping the nail or bolt a couple of times on the floor. How does this affect whether or not you can pick up any paper clips or staples? How many paper clips or staples can the nail or bolt pick up after being dropped?

Be sure to disconnect your electromagnet when it is not in use. Leaving the wires connected will drain your battery.

What is going on?

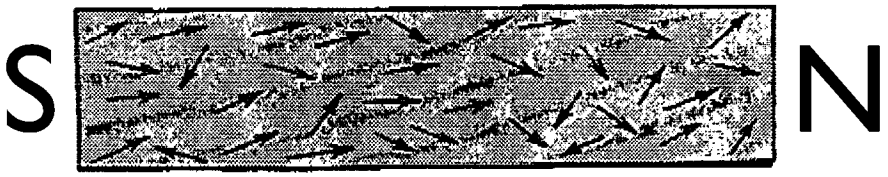
Moving electrons and magnetism are intimately linked. As soon as electrons start to move along a wire, they create a magnetic field around them. Whether it comes from moving electrons or from a naturally magnetic material, you can't see magnetism. So how is it that the Greeks experimented with natural magnets perhaps as early as the sixth century B.C.? As the Greeks did, to study magnetism you have to look at the effects a magnet has on other things. By exploration you can "see" or feel that there is an area around a magnet—known as a magnetic field—that affects certain other things; it can attract or repel another magnet or turn the needle on a compass. A magnetic field becomes weaker as the distance from the magnet increases. The poles of a magnet, the areas with the strongest magnetic fields, are called the north (or north-seeking) pole and the south (or south-seeking) pole. These names are given because a magnet hung from a string will rotate so that its north pole faces toward the Earth's magnetic north pole.

One interesting thing about magnets is that, if you break a magnet in half, you will have two magnets, each with a north and south pole. Many of the properties of magnets can be understood if you imagine continuing to break this magnet into smaller and smaller pieces.

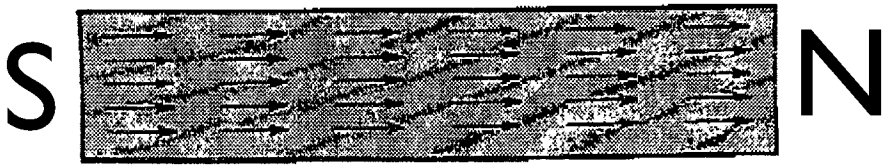


A random arrangement of molecule-sized pieces of magnetic material will result in a canceling out of their magnetic poles. In materials that can be attracted to a magnet, such as iron, the atoms can become aligned in clusters known as magnetic domains. If the magnetic domains are randomly oriented, the material will not be magnetized. Place this material in the presence of another magnet, however, and the domains can be coaxed to align with the north and south poles of the magnet. To weaken or demagnetize a magnet, you can use heat or repeated hammering or dropping to realign the magnetic domains in a random way so that they again cancel each other out.

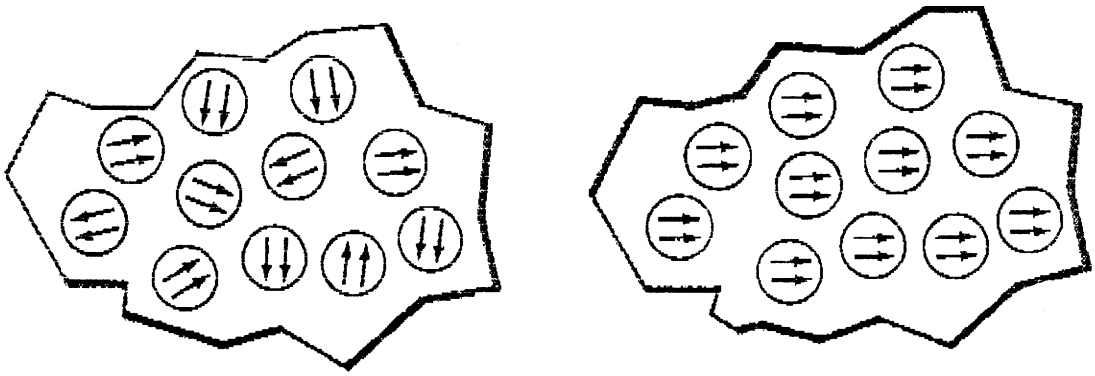
Unmagnetized iron



Slightly magnetized iron



Strongly magnetized iron



In an electromagnet, the movement of electrons in a wire creates the magnetic field. An electromagnet and a permanent magnet both have magnetic fields that can attract the same kinds of materials. If the current to an electromagnet is turned off, however, it will no longer behave like a magnet. A permanent magnet retains its magnetism after the force that originally magnetized it is taken away. What do you suppose is the purpose of the nail or bolt in the middle of the wire coils? The iron in a nail or bolt has moveable magnetic domains. These domains can be aligned by an external magnetic field such as the one created by the movement of electrons in a wire. The result of the nail or bolt becoming magnetized is an overall amplification of the magnetic field around the current-carrying wire.

Make your best guess

If you were to make an electromagnet by using a straight wire (without loops), how would it be different from the coiled electromagnet you made?

A cassette tape can lose its sound quality when it is left in a hot car or when the tape becomes stretched with wear. Why is the sound quality affected? How can you design an experiment to test your idea?

Imagine you are on a hike that takes you near a horse pen with a fence around it. As you get close to the fence you notice that there is an electric wire running all around the pen to keep the horses in. Describe one way you could find out if there is current passing through the electric wire before you try to climb over the fence.

Do you think there is any truth in the saying, “Once a magnet falls off the refrigerator door it will fall off more and more often”? How could you design an experiment to test this idea?

Sometimes a credit card will not work when you try to make a purchase. The credit card company may tell you that your card has been demagnetized. Describe what this means and give a couple of reasons for how this demagnetization could happen.

In 1831, an American physicist named Joseph Henry was able to make an electromagnet that could lift more than a ton. Use your imagination: what could an electromagnet of this power be used for? How could it benefit people?

Going further

Make a compass from a dish of water, a cork, a needle, and a permanent magnet. Use the compass to locate magnets in items around the house, such as wrist watches; electrical appliances that are turned on; and iron or steel objects like lamps, food cans, or radiators.

You can also use the compass to “look” at how magnetic fields around differently shaped permanent magnets differ.

How do cassette tapes store sounds through magnetism? See if you can realign the magnetic domains of a cassette tape. To do this, cut a short (3-cm) section of tape and staple or tape it to a 3×5 note card. Then stroke a permanent magnet over the strip of cassette tape several times in the same direction. Now see if the permanent magnet attracts or repels the strip of cassette tape. What happens if you stroke the strip of tape in the opposite direction?

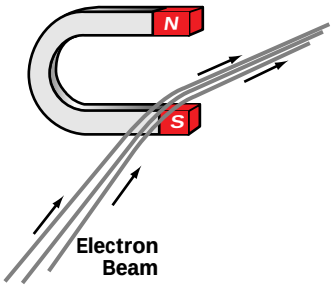
See if you can separate out the particles of magnetic sand from a bucket of sand from the beach. Design a machine or device that will do this efficiently.

Why is the earth a magnet? What are some visible effects of the earth’s magnetic field? Where are the magnetic north and south poles of the earth?

What causes batteries to go dead? How can you recharge them?

In an electromagnet, the movement of electrons in a wire creates a magnetic field. Do you think the opposite is possible—could a moving magnet make electrons move?

How do we make the “moving electrons” in the Advanced Light Source (ALS) do things? If you want a moving electron to change direction, use a magnet; for instance, if you place a magnet with its north pole above and its south pole below the electron’s path, the electron will curve to the right. This effect is used in bend magnets, undulators, and focusing magnets at the ALS. Can you think of some other machines that use magnets to move electrons?



Trillions of moving electrons + 1 magnet = The World's Simplest Motor

What you need

- a "D" size 1.5-volt battery
- 2 large safety pins (~ 3–4 cm long)
- an emery board, sandpaper, or a fine-grain file
- a small disk-shaped (or rectangular) magnet (nickel to quarter size in diameter)
- at least 60 cm of solid wire with varnish coating (22-gauge magnet wire works well)
- several centimeters of duct tape or one very thick rubber band

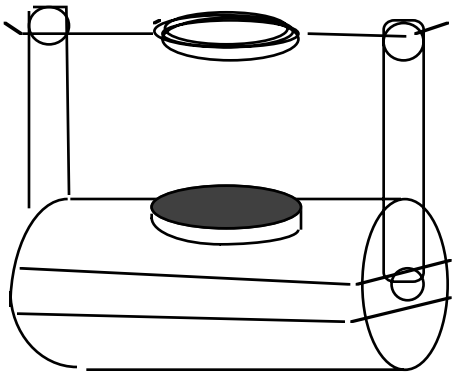
Where to get it

All of these materials are readily available at any hardware store or general-purpose department store. Small ceramic disk-shaped magnets can be ordered from any science supply company for around $0.60 each. Varnish-coated, solderable 22-gauge magnet wire works well and is available at many electronics stores. It can also be ordered from Newark Electronics, Palo Alto (415) 812-6300 at a cost of approximately $20 per 250 ft.

How to build it

Leaving a couple of centimeters of straight wire on each end, coil your piece of wire so that it has at least 10 loops that are about the diameter of a nickel or quarter. When finished, the entire length of your wire needs to be a bit longer than your "D" size battery.

Using an emery board or sandpaper, scrape the varnish off the bottom half (or underside) of the two wire ends.



Form supports for your coiled wire by using either duct tape or a thick rubber band to attach the “head” of a safety pin to each end of your “D” size battery.

Place your magnet on top of the battery between the two safety pins and insert the wire into the loops of the safety pins. Give the coils a little spin and see what happens. Hint: if nothing happens you may need to make little adjustments to straighten your wire or move the magnet slightly.

Try it and See

Once you get your motor running, see if there is anything that you can do to make the motor spin slower or faster. Can you get it to spin in both directions? Does it make a difference which side of the magnet is facing up? What happens if you use a wire that has a different number of loops? What happens if you make the coils smaller? or larger? What happens when you use more than one magnet? What happens if the magnet is on its side?

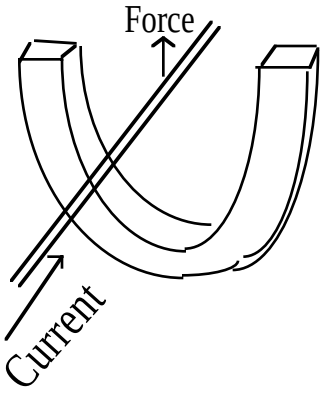
What is going on?

Making a motor is all about using the movement of electrons in a wire (electrical current) to create a magnetic field (an electromagnet)--this magnetic field is in turn repelled from another permanent magnet, causing rotation of the coiled wire.

When you made a connection from one end of your battery to the other—through the two safety pins and coiled wire—this allowed the battery to provide energy to “push” loose electrons from one atom to another in the wire, creating an electrical current. Whenever electrons are moving, a magnetic field is created. On your motor, the magnetic field around the coil of wires was then attracted to and repelled from the magnet sitting on top of the battery. The result was a conversion of the energy stored in the battery (electrical potential energy) to the movement of the coiled wire (kinetic energy).

To better understand the relationship between electrical current, magnets, and movement, try the following question:*

When current flows in a wire that is placed in the magnetic field shown to the right, the wire is forced upward.



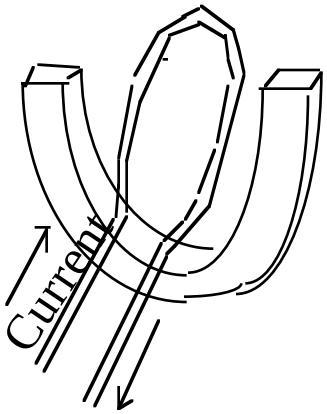
*Source: Paul G. Hewitt and Helen Yan, *Conceptual Physics: Next-Time Questions*, Addison-Wesley publishing Company, Menlo Park, CA (1986) pg. 36-2.

If the wire is made to form a loop as shown below, the loop will tend to

a) rotate clockwise

b) rotate counter-clockwise

c) remain at rest



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—the left side is forced up while the right side is forced down.

What happens after the loop rotates around one half turn? How will the magnetic forces want to push the loop now? To keep the loop continuing to rotate, many motors use a split ring, or commutator, to change the direction of the current every half turn. In the simple motor you made, the varnish works to momentarily break the flow of electrons. To continue rotating, the coiled wire must have enough inertia to carry it around the second half of the rotation until the wire is again attracted to the magnet. For this reason, the motor often requires a little push to get started.

Make your best guess

What different things could happen if you leave the wire touching the two safety pins for a while? (Be careful; don't burn your fingers!)

Your younger sister or brother (Pretend you have one.) wants to know what makes the wire in your motor continue to go around and around and whether it will ever stop. How would you explain this to her or him?

Trace the transfer of energy from the inside of a battery to the spinning of the coiled wire in the motor.

Making a motor is all about the movement of electrons to produce a magnetic field. Do you think the opposite is possible: could a moving magnet make electrons move? How could you try this out?

The battery provides direct current (DC) resulting from the movement of electrons in one direction. Would it be possible to make this same kind of motor by using alternating current (AC)—current that causes electrons to quickly move back and forth? Why or why not?

With the dream of some day powering a space station, NASA recently attempted an experiment to create electricity by dragging a wire through the Earth's magnetic field behind a satellite. Explain how this process is the reverse of what a motor does.

Going further

Walk around your house and look for as many different things containing motors as you can find. Make a class list of the different things found. How are the items on the list similar? How are they different?

Find a watch or clock that is “see through” and try to find the battery, the magnet, and the coils of wire. (If you can’t find someone who has a watch with a clear back, try the watch counter at a store.)

Find an old speaker that you won’t ever be using again. (Try an electronic repair shop or garage sale for old discarded equipment.) Dissect the speaker by cutting it open and carefully removing the small disk from the center of the speaker diaphragm. Look inside for a coil of wire and a permanent magnet. Can you figure out how an electromagnet and a permanent magnet work together in a speaker to make sound?

Resources

Burnie, David. Eyewitness Science: Light. Dorling Kindersley, Inc., New York, 1992. A strongly graphical presentation of the physics of light in historical context. Explains concepts and their development over time in nontechnical terms.

The Exploratorium Science Snackbook. The Exploratorium, 3601 Lyon Street, San Francisco, California, 94123 (Tel: 800-359-9899 or 415-561-0393), 1991. Lists a dazzling variety of science demonstrations, with full descriptions of how to make them and brief explanations of what is going on in each.

Falk, David, Dieter Brill, and David Stork. Seeing the Light: Optics in Nature, Photography, Color, Vision, and Holography. John Wiley and Sons, New York, 1986. An excellent and thorough reference source for light, its properties, and how we use it written at the high school or college level. Lots of good diagrams and pictures.

Gamow, George. Mr. Tompkins in Paperback. (Containing "Mr. Tompkins in Wonderland" and "Mr. Tompkins Explores the Atom.") Cambridge University Press, New York, 1965. An excellent, enjoyable presentation of quantum physics in the form of extended metaphors, as seen through the eyes of the curious everyman, Mr. Tompkins.

Gonick, Larry and Arthur Huffman. The Cartoon Guide to Physics. HarperCollins, New York, 1991. A humorous (and accurate) comic-book approach to basic physics concepts, this book brings abstractions down to earth. Helpful for beginning students.

Hewitt, Paul G. Conceptual Physics, 7th ed. Scott, Foresman and Company; Glenview, Illinois; 1993. This college physics text (also available in a high-school version) uses mathematics chiefly as a supplement to accessible, intuitive explanations, keeping the everyday world at center stage.

Morrison, Philip, Phylis Morrison, and the Office of Charles and Ray Eames. Powers of Ten: A Book About the Relative Size of Things in the Universe and the Effect of Adding Another Zero. Scientific American Library, New York, 1982.

Macaulay, David. The Way Things Work. Houghton Mifflin, Boston, 1988. A pictorial book for a lay audience brimming with details about the machinery of our world.

Nye, Bill. Bill Nye The Science Guy's Big Blast of Science. Addison-Wesley Publishing Company, New York, 1993. A fun and slightly irreverent approach to exploring science from "molecules to the Milky Way." A wide variety of easy-to-do activities and experiments with explanations that everyone can understand.

Walker, Jearl. The Flying Circus of Physics with Answers. John Wiley and Sons, New York, 1977. A book full of provocative questions, addressing virtually everything you ever wondered about that relates to physics in everyday life. A valuable section of brief answers has been added to this edition.