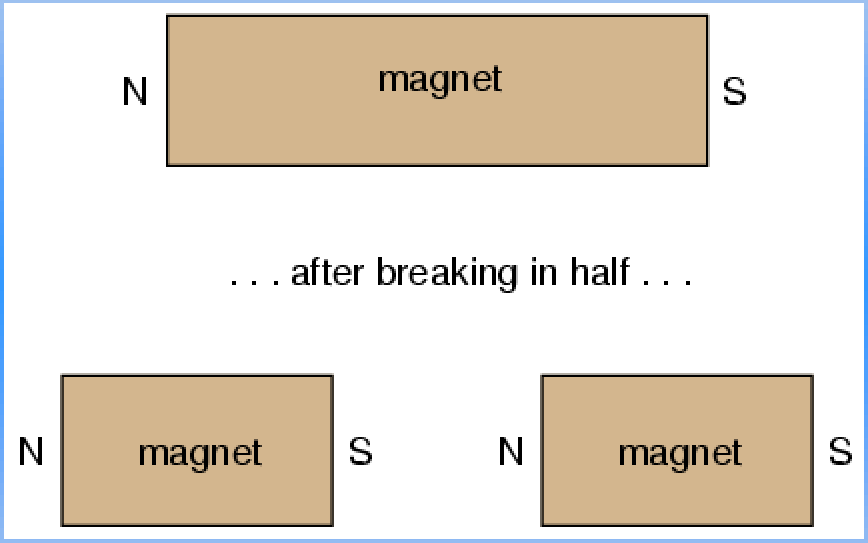
MAGNETISM

Permanent magnets

- Centuries ago, it was discovered that certain types of mineral rock possessed unusual properties of attraction to the metal iron. One particular mineral, called *lodestone*, or *magnetite*, is found mentioned in very old historical records (about 2500 years ago in Europe, and much earlier in the Far East) as a subject of curiosity. Later, it was employed in the aid of navigation, as it was found that a piece of this unusual rock would tend to orient itself in a north-south direction if left free to rotate (suspended on a string or on a float in water). A scientific study undertaken in 1269 by Peter Peregrinus revealed that steel could be similarly "charged" with this unusual property after being rubbed against one of the "poles" of a piece of lodestone.

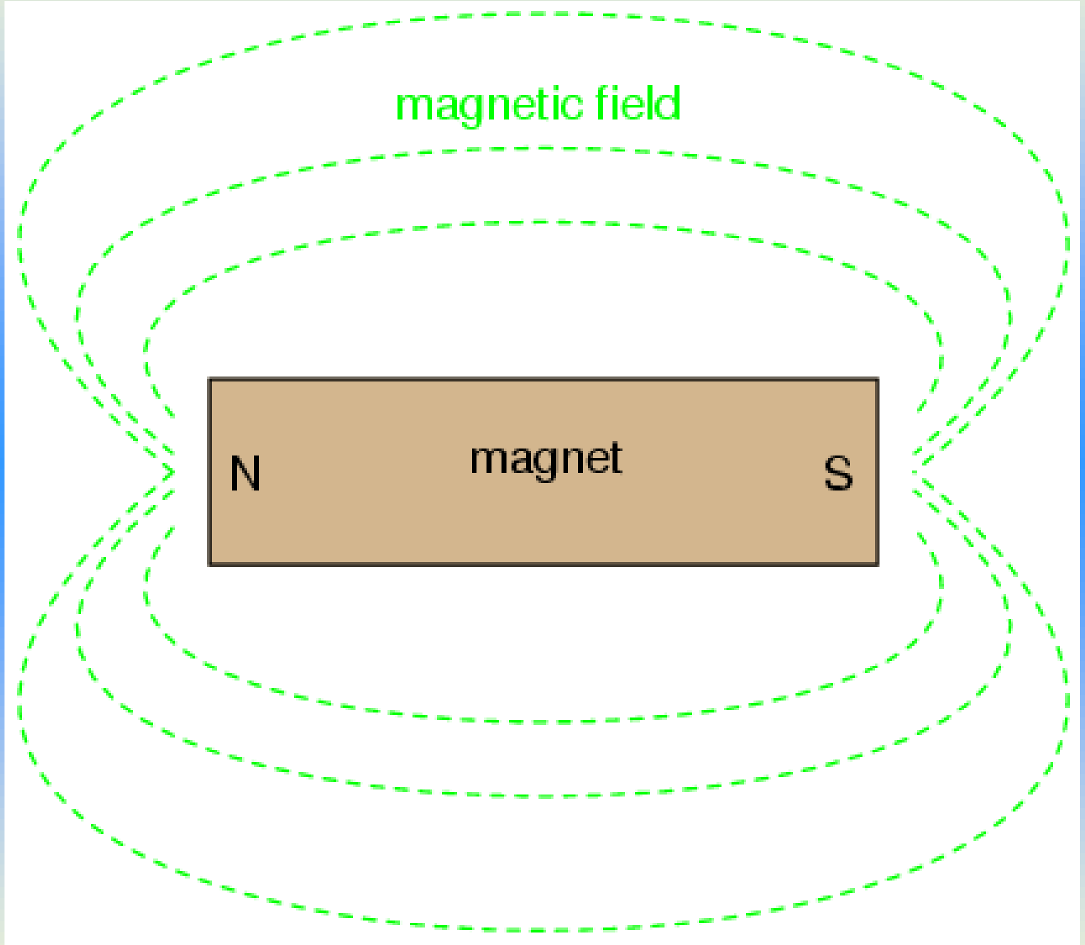
- Unlike electric charges (such as those observed when amber is rubbed against cloth), magnetic objects possessed two poles of opposite effect, denoted "north" and "south" after their self-orientation to the earth. As Peregrinus found, it was impossible to isolate one of these poles by itself by cutting a piece of lodestone in half: each resulting piece possessed its own pair of poles:


N
magnet
S
. . . after breaking in half . . .
N
magnet
S
N
magnet
S

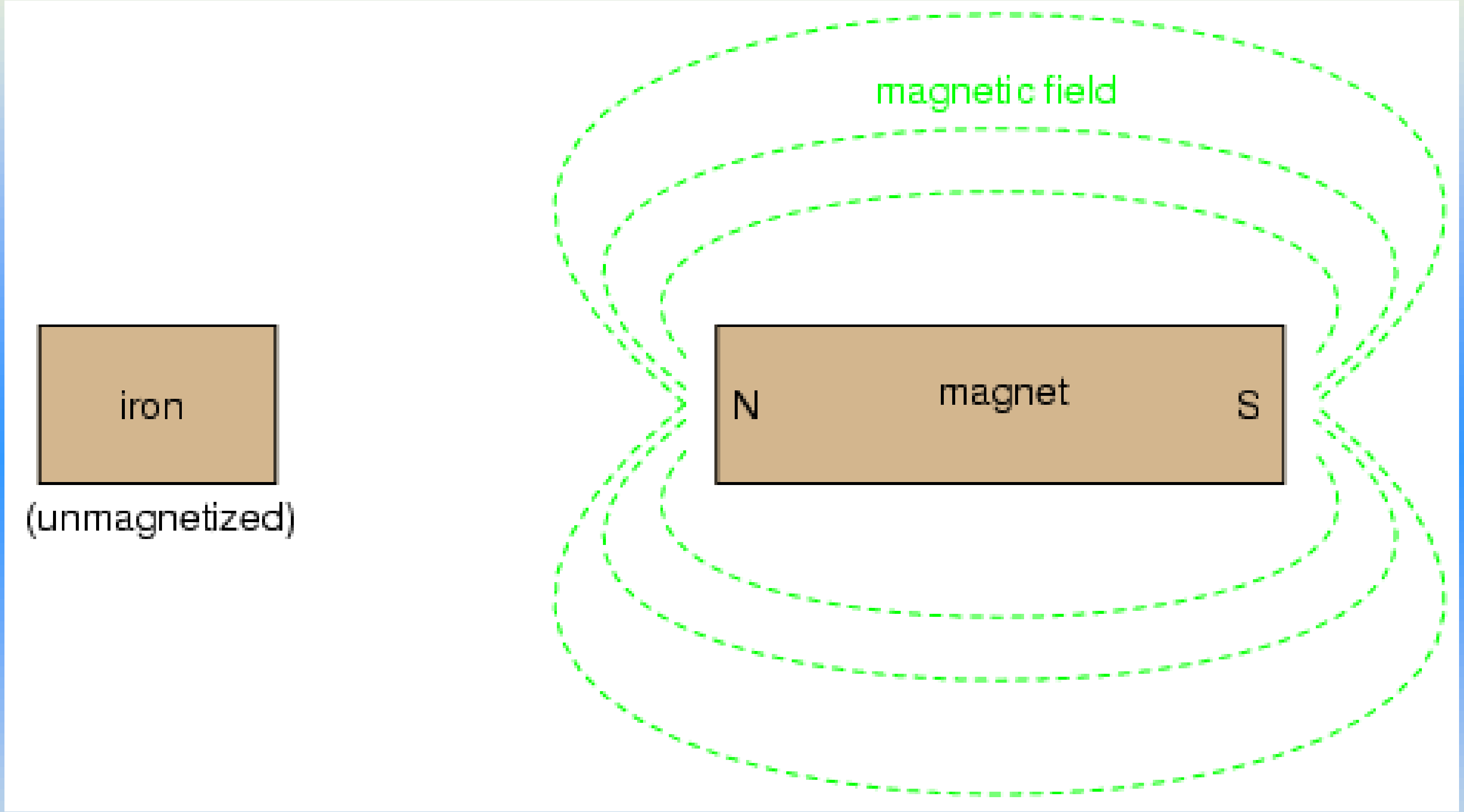
- Like electric charges, there were only two types of poles to be found: north and south (by analogy, positive and negative).

- Just as with electric charges, same poles repel one another, while opposite poles attract. This force, like that caused by static electricity, extended itself invisibly over space, and could even pass through objects such as paper and wood with little effect upon strength.

- The philosopher-scientist Rene Descartes noted that this invisible "field" could be mapped by placing a magnet underneath a flat piece of cloth or wood and sprinkling iron filings on top. The filings will align themselves with the magnetic field, "mapping" its shape. The result shows how the field continues unbroken from one pole of a magnet to the other:

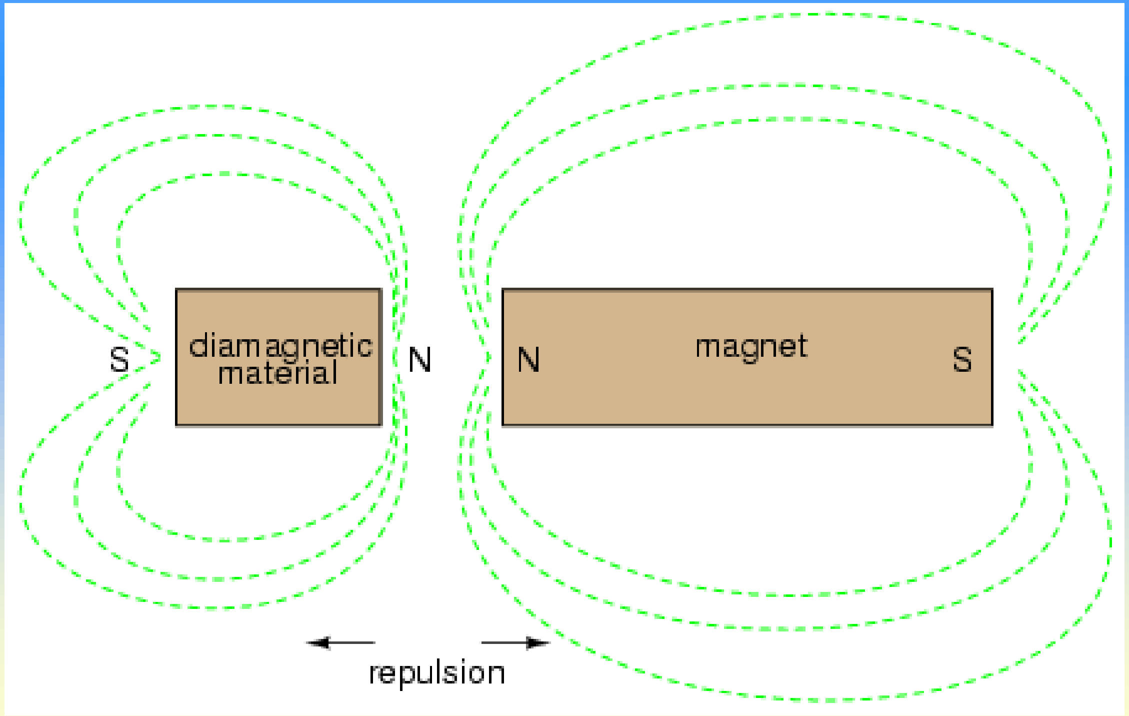

magnetic field
N
magnet
S

- As with any kind of field (electric, magnetic, gravitational), the total quantity, or effect, of the field is referred to as a *flux*, while the "push" causing the flux to form in space is called a *force*. Michael Faraday coined the term "tube" to refer to a string of magnetic flux in space (the term "line" is more commonly used now). Indeed, the measurement of magnetic field flux is often defined in terms of the number of flux lines, although it is doubtful that such fields exist in individual, discrete lines of constant value.
- ***Modern theories of magnetism maintain that a magnetic field is produced by an electric charge in motion, and thus it is theorized that the magnetic field of a so-called "permanent" magnets such as lodestone is the result of electrons within the atoms of iron spinning uniformly in the same direction.***
- Whether or not the electrons in a material's atoms are subject to this kind of uniform spinning is dictated by the atomic structure of the material (not unlike how electrical conductivity is dictated by the electron binding in a material's atoms). Thus, only certain types of substances react with magnetic fields, and even fewer have the ability to permanently sustain a magnetic field.
- Iron is one of those types of substances that readily magnetizes. If a piece of iron is brought near a permanent magnet, the electrons within the atoms in the iron orient their spins to match the magnetic field force produced by the permanent magnet, and the iron becomes "magnetized." The iron will magnetize in such a way as to incorporate the magnetic flux lines into its shape, which attracts it toward the permanent magnet, no matter which pole of the permanent magnet is offered to the iron:



magnetic field
iron
(unmagnetized)
N
magnet
S

- Referencing the natural magnetic properties of iron (Latin = "ferrum"), a *ferromagnetic* material is one that readily magnetizes (its constituent atoms easily orient their electron spins to conform to an external magnetic field force). All materials are magnetic to some degree, and those that are not considered ferromagnetic (easily magnetized) are classified as either *paramagnetic* (slightly magnetic) or *diamagnetic* (tend to exclude magnetic fields). Of the two, diamagnetic materials are the strangest. In the presence of an external magnetic field, they actually become slightly magnetized in the opposite direction, so as to repel the external field!



- If a ferromagnetic material tends to retain its magnetization after an external field is removed, it is said to have good *retentivity*. This, of course, is a necessary quality for a permanent magnet.

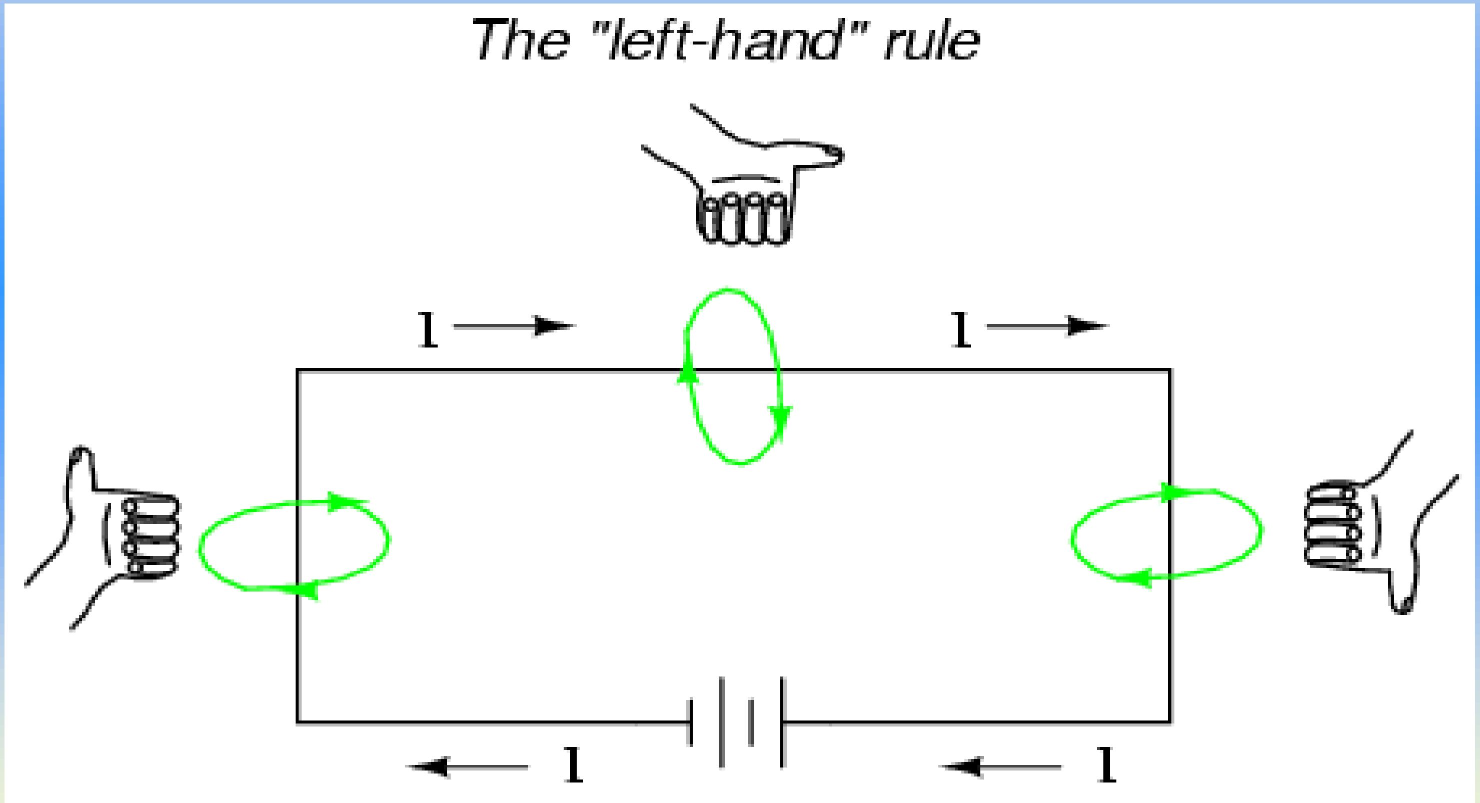
ELECTROMAGNTISM

Electromagnetism

- The discovery of the relationship between magnetism and electricity was, like so many other scientific discoveries, stumbled upon almost by accident. The Danish physicist Hans Christian Oersted was lecturing one day in 1820 on the *possibility* of electricity and magnetism being related to one another, and in the process demonstrated it conclusively by experiment in front of his whole class! By passing an electric current through a metal wire suspended above a magnetic compass, Oersted was able to produce a definite motion of the compass needle in response to the current. What began as conjecture at the start of the class session was confirmed as fact at the end. Needless to say, Oersted had to revise his lecture notes for future classes! His serendipitous discovery paved the way for a whole new branch of science:

ELECTROMAGNETICS.

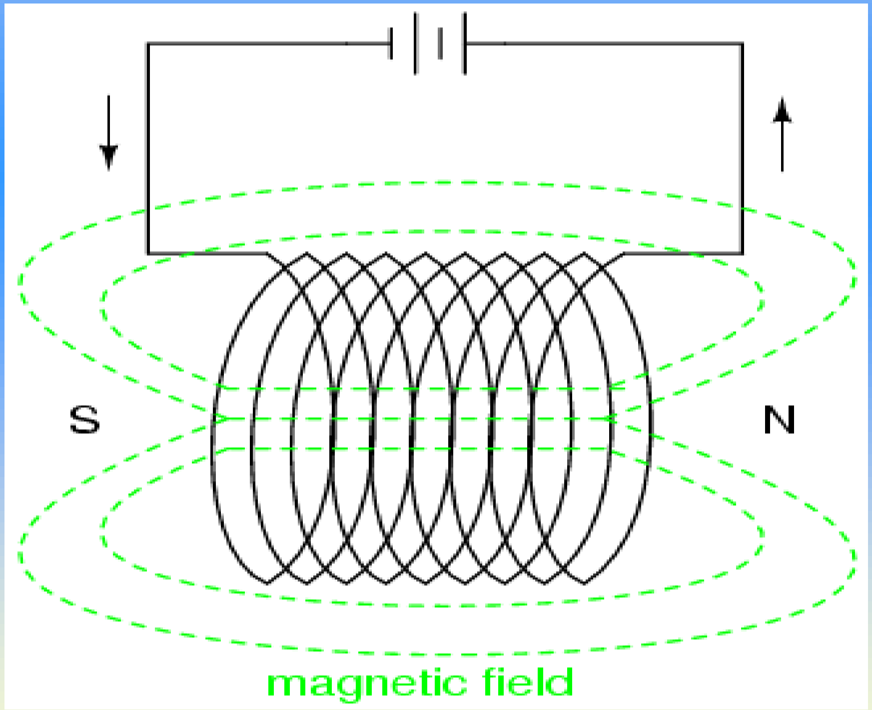
- Detailed experiments showed that the magnetic field produced by an electric current is always oriented perpendicular to the direction of flow. A simple method of showing this relationship is called the *left-hand rule*. Simply stated, the left-hand rule says that the magnetic flux lines produced by a current-carrying wire will be oriented the same direction as the curled fingers of a person's left hand (in the "hitchhiking" position), with the thumb pointing in the direction of electron flow:



The magnetic field encircles this straight piece of current-carrying wire, the magnetic flux lines having no definite "north" or "south' poles.

While the magnetic field surrounding a current-carrying wire is indeed interesting, it is quite weak for common amounts of current, able to deflect a compass needle and not much more. To create a stronger magnetic field force (and consequently, more field flux) with the same amount of electric current, we can wrap the wire into a coil shape, where the circling magnetic fields around the wire will join to create a larger field with a definite magnetic (north and south)

Polarity:



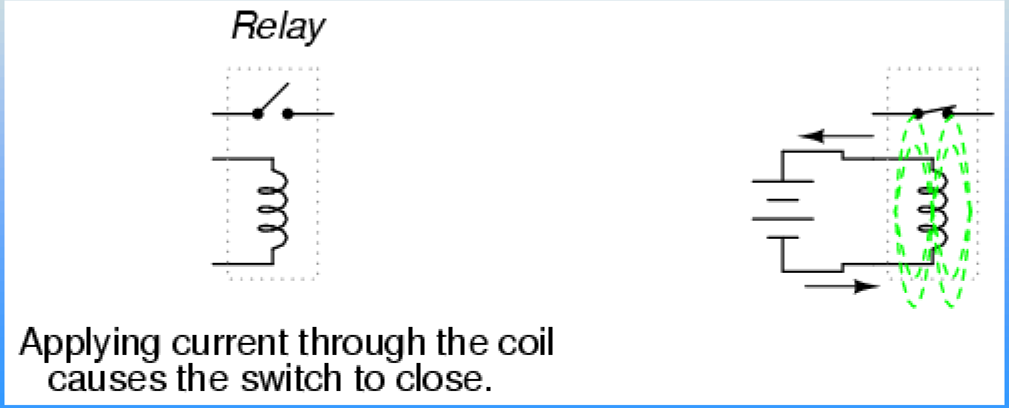
- The amount of magnetic field force generated by a coiled wire is proportional to the current through the wire multiplied by the number of "turns" or "wraps" of wire in the coil. This field force is called *magnetomotive force* (mmf), and is very much analogous to electromotive force (E) in an electric circuit.

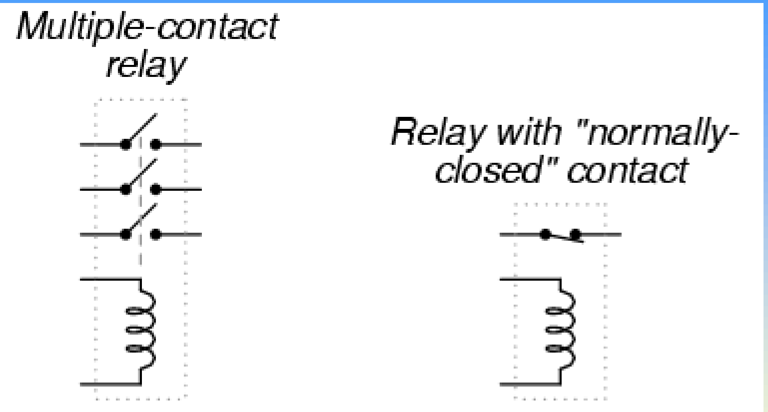
- An *electromagnet* is a piece of wire intended to generate a magnetic field with the passage of electric current through it. Though all current-carrying conductors produce magnetic fields, an electromagnet is usually constructed in such a way as to maximize the strength of the magnetic field it produces for a special purpose. Electromagnets find frequent application in research, industry, medical, and consumer products.

- As an electrically-controllable magnet, electromagnets find application in a wide variety of "electromechanical" devices: machines that effect mechanical force or motion through electrical power. Perhaps the most obvious example of such a machine is the *electric motor*.

- Another example is the *relay*, an electrically-controlled switch. If a switch contact mechanism is built so that it can be actuated (opened and closed) by the application of a magnetic field, and an electromagnet coil is placed in the near vicinity to produce that requisite field, it will be possible to open and close the switch by the application of a current through the coil. In effect, this gives us a device that enables elelctricity to control electricity:

- Relays can be constructed to actuate multiple switch contacts, or operate them in "reverse" (energizing the coil will *open* the switch contact, and unpowering the coil will allow it to spring closed again).





NEXT UP

HOW WE MAKE MAGNETICS

GENERATE POWER

without a battery