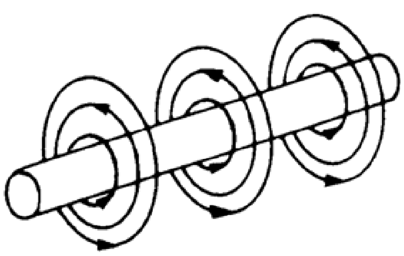
Lesson 1
Electromagnetism

Electromagnetism refers to the relationship between electricity and magnetism.

Hans Christian Oersted spent much time trying to link electricity and magnetism. He was demonstrating the heating effects of electric current in a wire to some friends and students. He had some compasses nearby and noticed that they deflected when he closed the circuit. In this way, Oersted accidentally discovered that since the compass needle was deflected under a current carrying wire, then a magnetic field was created around the wire.

Magnetic Field Around a Straight Wire:

A magnetic field is created around a current-carrying wire as shown below.

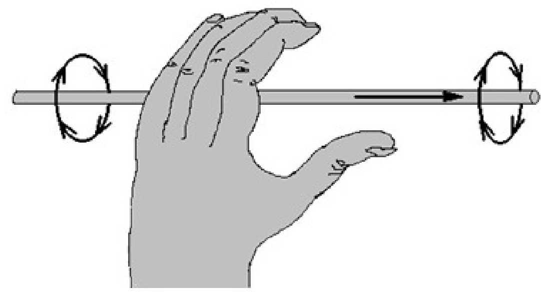


The shape of the magnetic field is concentric circular rings around the conductor.

The direction of the magnetic field is given by the left hand rule for a straight conductor (see p. 634).

Thumb = direction of current flow.

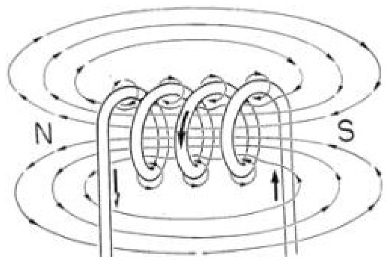
Fingers wrap around the wire in the direction of the magnetic field.

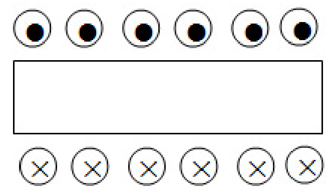


Note: Since we deal with electron current we use the left hand rule. When dealing with conventional current you would use the right hand.

The magnetic field around a straight conductor is actually quite weak. We can increase the magnetic field strength by using a coiled conductor (a helix). Even stronger is a bunch of loops or coils called a solenoid. Using a solenoid however also changes the shape of the magnetic field produced.

Magnetic Field Around a Solenoid:





The direction of the magnetic field is given by the left hand rule for a coiled conductor (p. 636).

Fingers curl in the direction of current flow.

Thumb points in the direction of the North pole of the magnetic field.

Parallel Current Carrying Wires:

Current in same direction in each wire:

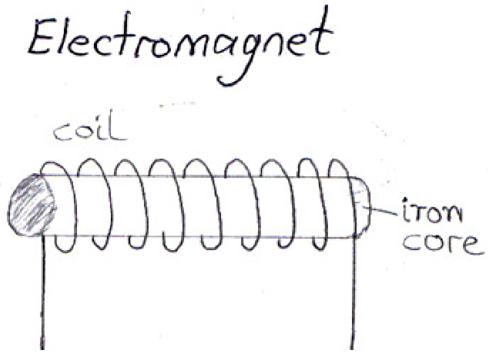
Wires are pushed together because magnetic field is weaker between the wires.

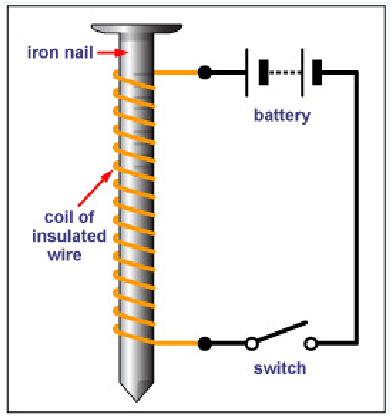
Current in opposite directions in each wire:

Wires are pushed apart because magnetic field is stronger between the wires.

Electromagnet:

A current carrying coiled conductor (solenoid) with a solid core made of a magnetic material like iron. The core itself becomes a magnet because of the magnetic field created by the coil.





It is possible to make very strong electromagnets. Strength is governed by four factors (p. 636):

1. The amount of current in the coil. The greater the current flow the greater the magnetic field strength. Strength is proportional to current.
2. The number of loops in the coil. The greater the number of coils, the greater the field strength. If the current is constant, strength is proportional to the number of coils.
3. The size of the coil. The smaller the diameter of the coil, the stronger the magnetic field.

4. The type of material in the coil's center. The more ferromagnetic the material, the greater the strength of the electromagnet (eg. iron). A measure of the ferromagnetic properties of the core material is called magnetic permeability (μ).

$$\text{Magnetic permeability} = \frac{\text{Magnetic field strength of electromagnet with the core}}{\text{Magnetic field strength of electromagnet without the core}}$$

Since iron has a magnetic permeability of about 6100, it is usually the material of choice.

Note:
You would think that for a core of given material, all you have to do is increase current and the number of turns to create a really strong electromagnet. Practically it is not quite so simple. As you increase the number of turns, you also increase the resistance (RαL). For a fixed voltage, doubling the number of coils doubles the resistance and halves the current. The result is no increase in the strength of the magnet. One solution is to use heavier wire. However, given the size of the magnet, using heavier wire means you cannot put as many turns around the magnet. Also heavier wire increases the mass of the coil and the cost of making it.

Increasing the voltage to increase the current, similarly results in an increase in power and the cost to operate the magnet. Increasing the current also means an increase in energy converted to heat by the coils. Finding the most efficient design for electromagnets is a challenge.
If very strong magnetic fields are required, the magnets must be supercooled to the point where the coils become superconductors. At that point the coils lose their resistance and large currents can flow through them. (used in MRI machines, MAGLEV trains, and particle accelerators)

Applications of Electromagnets: (see p. 637)

- Lifting electromagnet

- Relay
- Electric Bell