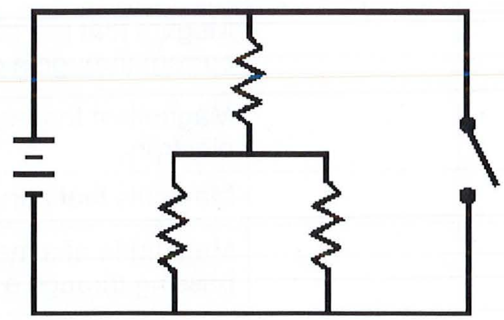
16) What would happen if the switch were closed?

Illustration 6



a) Battery would short out
b) Loads would be energized
c) Nothing would happen

4. Principles of basic magnetism and electromagnetism

Overview

Purpose

Gas technicians/fitters require knowledge of the principles of magnetism and electromagnetism to understand the operation of electric motors, solenoid switches, and valves and relay Units in control circuits.

Objectives

At the end of this Chapter, you will be able to:

- describe the principles of basic magnetism; and
- describe the principles of basic electromagnetism.

Terminology

Term	Abbreviation (symbol)	Definition
Electromagnet		Magnet that is a product of passing an electric current through a conductor
Electromagnetism		Magnetism that results from the movement of electrons
Ferromagnetic materials		Materials that attract other magnetic materials
Flux density		Magnitude of a magnetic, electric, or other flux passing through a Unit area
Lines of force or flux lines		Imaginary line that represents the strength and direction of a magnetic, gravitational, or electric field at any point
Magnetic field		Region around a magnetic material or a moving electric charge within which the force of magnetism acts
Permanent magnets		Magnets that retain their magnetic effects
Permeability		Ease with which a material accepts magnetic lines of force
Temporary magnets		Magnets that do not retain their magnetic effects

Principles of basic magnetism

Magnetic materials

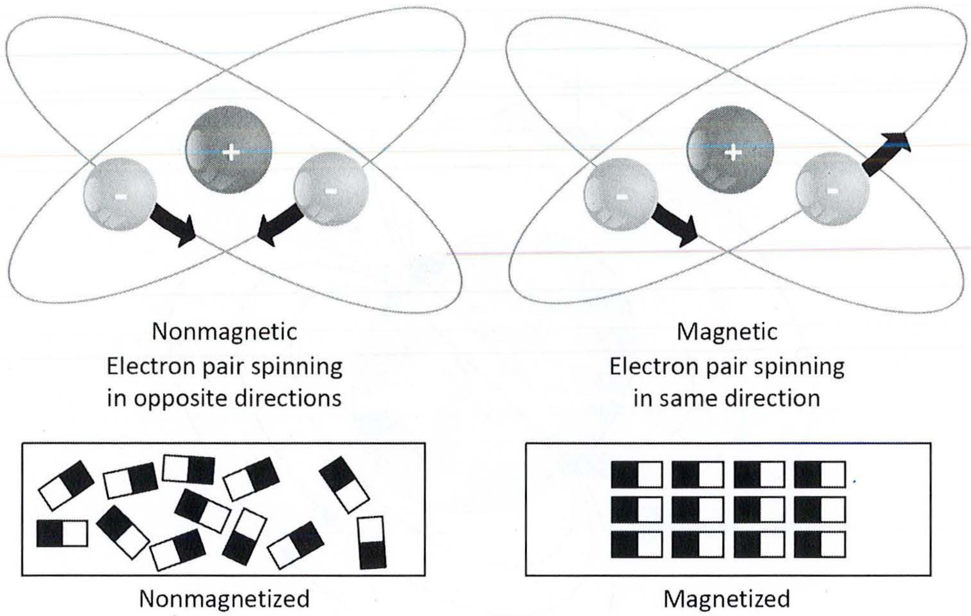
Magnetism is the property certain materials have that allows them to attract other magnetic materials. These are called *ferromagnetic* materials. Iron, nickel, and cobalt are the only naturally occurring ferromagnetic metals. (Steel is ferromagnetic but is made from iron.)

When a magnet strokes ferromagnetic materials across their surface, they also become magnets. Magnets that retain their magnetic effects are *permanent* magnets. Those that do not retain their magnetic effects are *temporary* magnets.

Electrons, molecules, and magnetism

Any conductor of electric current acts like a magnet. In fact, it is spinning electrons that cause magnetic forces. In most atoms, electrons tend to pair off in orbits that have spins in opposite directions. Each spin produces a tiny magnetic field and the magnetic fields of these pairs cancel each other. In a magnetic material, however, electrons with similar spins can pair off. Their magnetic fields add together and the molecules of the material have a net magnetic field. See Figure 4-1.

Figure 4-1
Molecular alignment in a magnet



When a ferromagnetic material is not magnetized, its molecules are randomly oriented. Their magnetic effects work in different directions and cancel each other. In a magnetized metal, the molecules are aligned with each other so that the magnetic effects of the molecules all work together. This produces a strong magnet. On the other hand, if a magnetic material is partially magnetized, only some of the molecules are aligned. This produces a weak magnet.

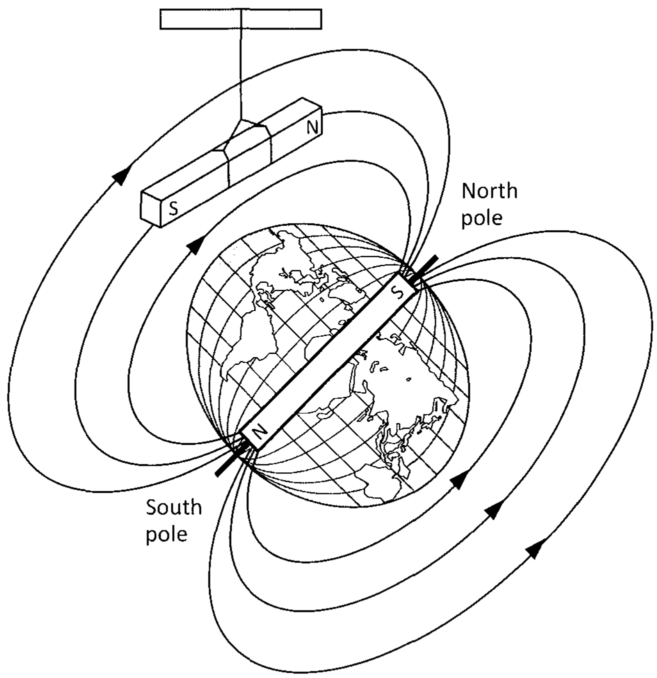
If the molecules of a magnet become misaligned again, the material loses its magnetism. This can gradually happen. It can also happen if the magnet becomes very hot or receives a strong physical shock.

Magnetic polarity

The magnetic field is strongest at each end of a magnet. These ends are what you call the *poles* of the magnet.

The Earth itself acts like a giant magnet and has a magnetic north pole and south pole. When you suspend a magnet (see Figure 4-2) so that it is free to move, it will turn so that one pole always points toward the Earth's North Pole. In the past, this was the north-seeking pole of the magnet and diagrams show this with an N. The other pole was the south-seeking pole and this comes with an S in diagrams.

Figure 4-2
Magnetic polarities



Compasses

The interaction of a magnet with the earth's magnetic effect is the operating principle of a compass. The needle of a compass is a small permanent magnet that indicates its north-seeking pole. Regardless of the direction towards which the compass turns, its needle always swivels to point north.

Attraction and repulsion

If the north poles of two magnets point toward each other, they repel each other. Two south poles also repel each other. On the other hand, a north and a south pole attract each other. This is the law of attraction and repulsion:

Like poles repel, unlike poles attract.

Magnetic fields

Magnetic lines of force

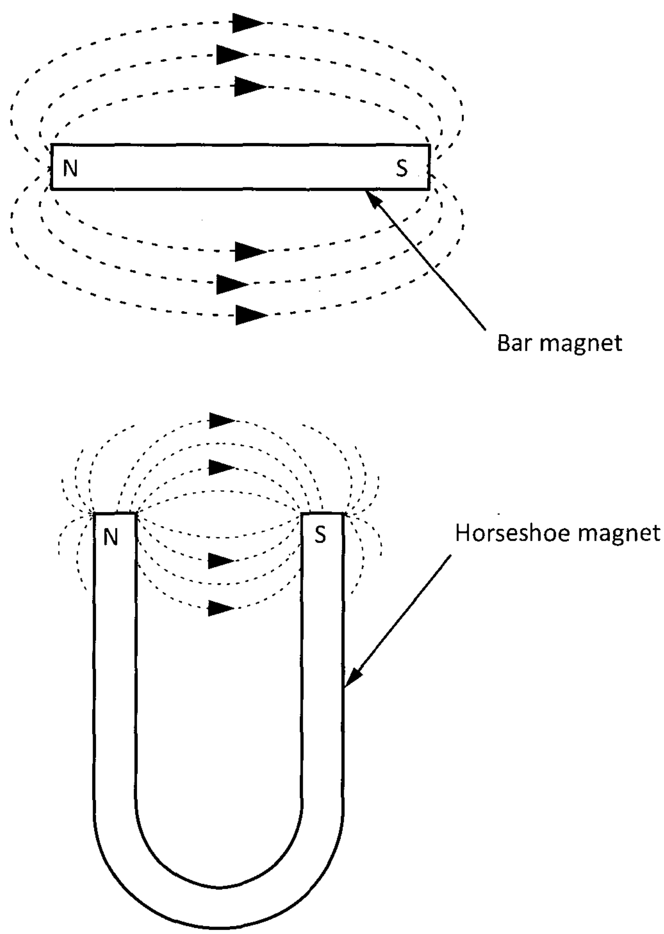
A magnetic field consists of lines of force that interact with magnetic substances. The most common magnetic substances are iron and steel. You can make iron magnetic but it will lose its magnetism quickly. Steel, on the other hand, remains magnetic for a longer period. Magnetized metal bars are what you call permanent magnets.

Figure 4-3 shows two types of permanent magnet:

- a bar magnet; and
- a horseshoe magnet.

Permanent magnets appear to be ordinary pieces of steel. Even close observation will not reveal any visible signs of magnetism. However, if you bring any iron or steel object close to the magnet, the invisible magnetic field will pull it toward the magnet. The magnetic field will only affect magnetic material such as iron, steel, nickel, and cobalt.

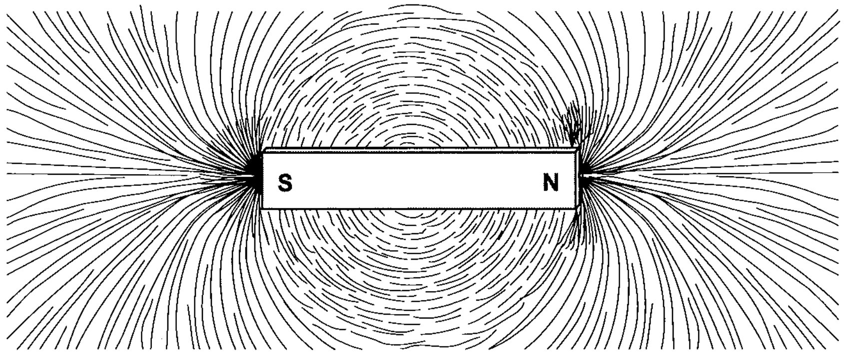
Figure 4-3
Magnetic fields



The magnetic force can act at a distance without contact. It can act in the *magnetic field*, the area that surrounds the magnet. In the magnetic field, the force acts in *lines of force* or *flux lines*.

Although flux lines are not visible, you can see if you place a small magnet under a sheet of paper and sprinkle iron filings over the top of it. When you tap the paper gently, the iron filings move slightly to align themselves along the flux lines. See Figure 4-4.

Figure 4-4
Iron filings aligning themselves along lines of force in a magnetic field



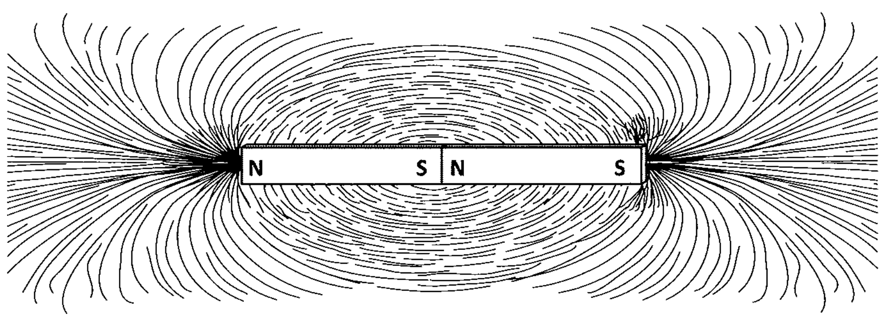
Notice that flux lines are:

- more concentrated at the two poles (the magnetic field and force is stronger here);
- farther apart at greater distances from the magnet (the magnetic field and force is weaker here); and
- curved and do not cross.

The ease with which a material accepts magnetic lines of force is what you call its *permeability.* Iron and steel have high permeability. Air, on the other hand, has low permeability.

When you bring together two magnets, their magnetic fields interact. You can clearly see the way the flux lines combine using iron filings. See Figure 4-5.

Figure 4-5
Combined flux line pattern when two magnets are brought together



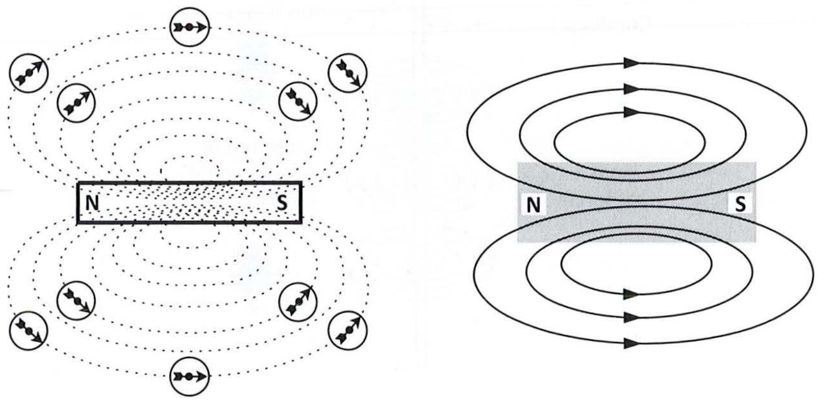
Magnets always have north and south poles. The magnetic lines of force extend from the north pole of a magnet to the south pole. The poles react with each other. If you bring two north or two south poles together, they will repel or push away each other. If a north pole and a south pole come together, however, they will attract and stick together (like poles repel and unlike poles attract). You use this magnetic field effect to operate electric motors, generators, and other devices.

Some magnets are stronger than others. A stronger magnet pulls harder and is harder to separate from a magnetic substance. If you place a stronger magnet under the iron filings in Figure 4-5, more lines of force will show. The stronger the magnet, the more lines of magnetic force produced. These lines are what you call *flux*, and their concentration is what you call *flux density*.

Direction of flux lines

Lines of force are considered to emerge from the magnet's north pole and move toward the south pole. Diagrams show the direction using arrows (see Figure 4-6). They travel from south to north within the magnet to form a closed loop. The direction of flux lines is the direction in which the north-seeking pole of a compass would point.

Figure 4-6
Direction of flux lines



Principles of basic electromagnetism

Electromagnetism

Electromagnetism is magnetism that results from the movement of electrons. Whenever current flows in a conductor, a magnetic field forms around the conductor. Also, if you move a conductor within a magnetic field, the movement will induce a voltage and current will flow in the conductor.

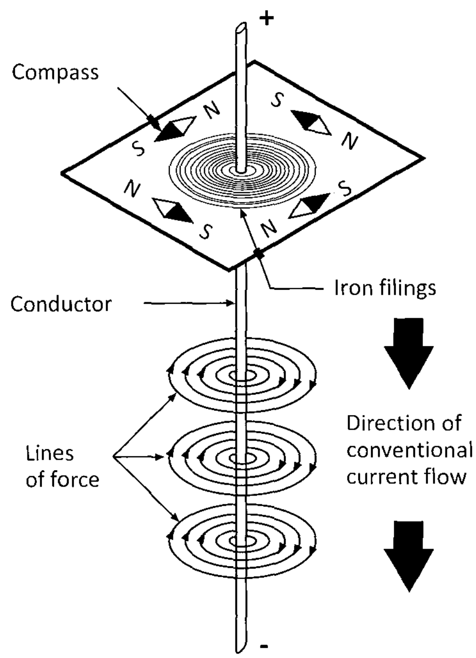
Electric currents and magnetic fields are inseparable. In the area where current flows, there are always magnetic fields.

Electromagnets depend upon current flow for their magnetism. If current flow decreases, so does the magnetism. The direction of current flow determines the polarity of the magnet. If the current is turned off, the electromagnet is no longer magnetic.

Electromagnetism in a straight wire

If you move around a compass near a straight wire conductor (see Figure 4-7), it shows the presence and direction of a magnetic field. The flux lines encircle the wire. If the direction of current flow changes, the direction of the magnetic field also changes.

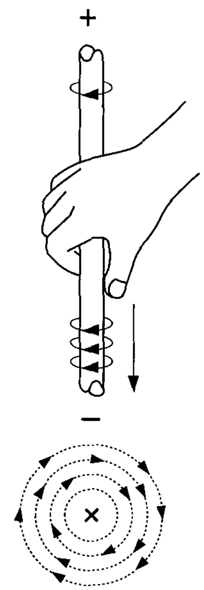
Figure 4-7
Using a compass near a conductor to show the presence of a magnetic field and its polarity



The right-hand rule

You use a simple rule to work out the direction of the magnetic lines of force around a wire. Imagine grasping the wire with your right hand (see Figure 4-8). If your thumb points in the direction of conventional current flow, your fingers wrap around the wire in the direction of the magnetic lines of force. This is what you call the *right-hand rule*.

Figure 4-8
The right-hand rule shows the direction of the magnetic field around a conductor

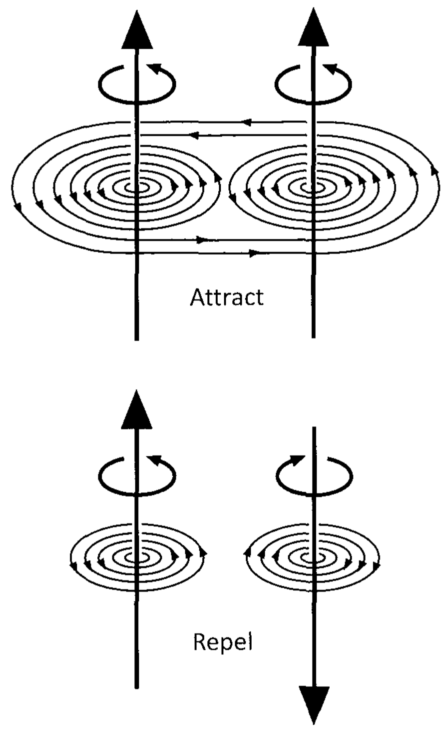


Magnetic forces between conductors

If you bring two wires in which current is flowing near each other, the magnetic fields around the wires would interact as follows:

If the current is flowing in the same direction, the magnetic lines of force around the wires would be in opposition and the two wires would attract each other. See Figure 4-9.

Figure 4-9
Forces of magnetic attraction and repulsion between conductors



If the current is flowing in opposite directions, the magnetic lines of force around the wires would be similar and the two wires would oppose each other.

When very large currents can flow through conductors, the resulting magnetic forces can damage the conductors.

Electromagnetism in a coil of wire

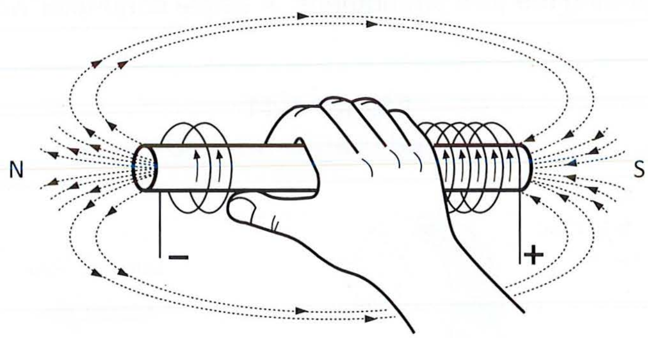
If a wire is coiled in a spiral (*helically*), the magnetic field is concentrated in the centre of the coil. If you have wound the wire around a steel bar, the resulting magnet can be very strong. The shape of the magnetic field of a coil is like a large bar magnet. The lines of force leave the north pole at one end of the coil and pass toward the south pole at the other end.

Direction of the electromagnetic field (right-hand rule)

You can use another right-hand rule to find the direction of the magnetic field of a coil. Imagine grasping the coil with your right hand (see Figure 4-10):

If the fingers wrap in the direction of conventional current flow around the coil, the thumb then points in the direction of the north pole of the coil.

Figure 4-10
Using a right-hand rule to find the polarity of coil's magnetic field



Strength of a coil's magnetic field

A closely wound coil creates a stronger magnetic field. Also, because the permeability of iron is much higher than air, permanently placing an iron or steel core inside the wire coil makes the magnetic field of a coil even stronger.

Making an electromagnet

Using an iron core in a coil is the basis for making an electromagnet. A coil is wound around a core of steel with a low carbon content (or iron). This has high permeability but does not retain much magnetism after the current stops flowing, removing the magnetic field.

You use various sizes of electromagnet in many ways in the home and in industry. You use them in:

- motors;
- generators;
- clocks;
- voltage testers;
- solenoid and relay Units in control circuits; and
- cranes for lifting scrap metal, etc.

Electricity and magnetism

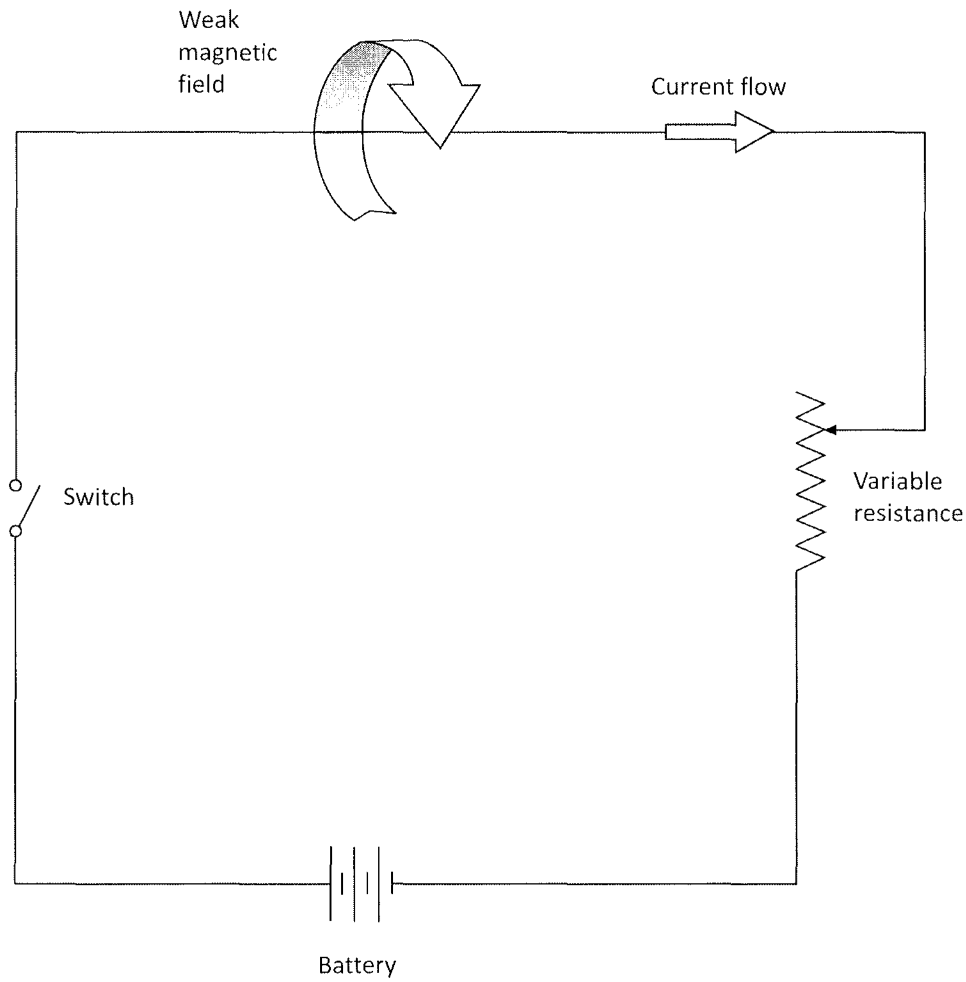
Magnetism and electric current are inseparable. The flow of current through a conductor (wire) produces a magnetic field around that conductor. If the electric current flow is constant, as with dc current, the magnetic field is constant, and the product is a magnet.

In Figure 4-11, a wire is connected to the terminals of a battery with a variable resistor and a switch. When the switch is closed, electric current flows through the wire in one direction. This current flow produces a weak magnetic field around the wire, and since the electric current flow is always in the same direction, the magnetic field is set up in one direction. If you switch the battery terminals, the current flow is reversed and the magnetic field is set up in the opposite direction.

When the switch is in open position, current flow stops. This causes the magnetic field to collapse. Although the field collapses very quickly, it does take time. The concept of an electric field taking a certain amount of time to collapse is an important point to remember for later discussion.

If the switch is closed and the variable resistance adjusted, the current flow will change. As the resistance lowers, the current flow increases and vice versa. When the current flow increases, the magnetic field surrounding the wire strengthens. A single conductor would produce a weak magnetic field.

Figure 4-11
Induced magnetic fields



Magnetic coils

If you wind the wire (see Figure 4-12) wound into a coil, it will form several conductors arranged side by side, with current flowing through each.

A magnet that is a product of passing an electric current through a conductor is an *electromagnet*. Electromagnets have major advantages compared with permanent magnets. They do not become weaker with use, and controlling the current flow can control the strength of the magnet.

Each wire in the coil carries the current flow through it. Therefore, each loop of the coil generates a small magnetic field around itself. Since the electric current flows in the same direction through each loop, the magnetic field around each wire extends in the same direction. These small magnetic fields combine to produce a single, larger field. The strength of the larger field depends on the number of loops in the coil.

You know that more current flow produces a stronger magnetic field. Therefore, you can strengthen a magnetic field by increasing the applied voltage. Increasing applied voltage will increase current flow and field strength. You can also increase the number of loops in the coil to strengthen the field.

If you place a magnetic plunger, such as a soft iron bar, inside a coil of wire in a dc circuit like the one in Figure 4-12, expect the formation of a *solenoid*. When the switch is closed, the magnetic field produced will attract the iron bar, pulling it to the centre of the coil. You use this action to operate many magnetic solenoid devices such as motor contactors, solenoid valves, and relays.

A magnetic field is a bit like an electric circuit. Magnetic lines pass through a *magnetic conductor* better than through a *magnetic insulator.* Air has a high *magnetic resistance*. For that reason, an air-filled coil will not produce as strong a magnet as a coil that is wrapped around an iron core. Iron is a better *conductor* of magnetism and is said to be more *permeable*.

Electric current flow through any conductor produces a magnetic field around the conductor. This is true for alternating current as well as for direct current. With alternating current, however, the magnetic field changes direction every time that the current flow changes direction. The rapid switching of magnetic fields can cause vibration in ac electric machines. This explains why some machines, such as transformers, sometimes hum as the iron parts vibrate.

Figure 4-12
Magnetic coils

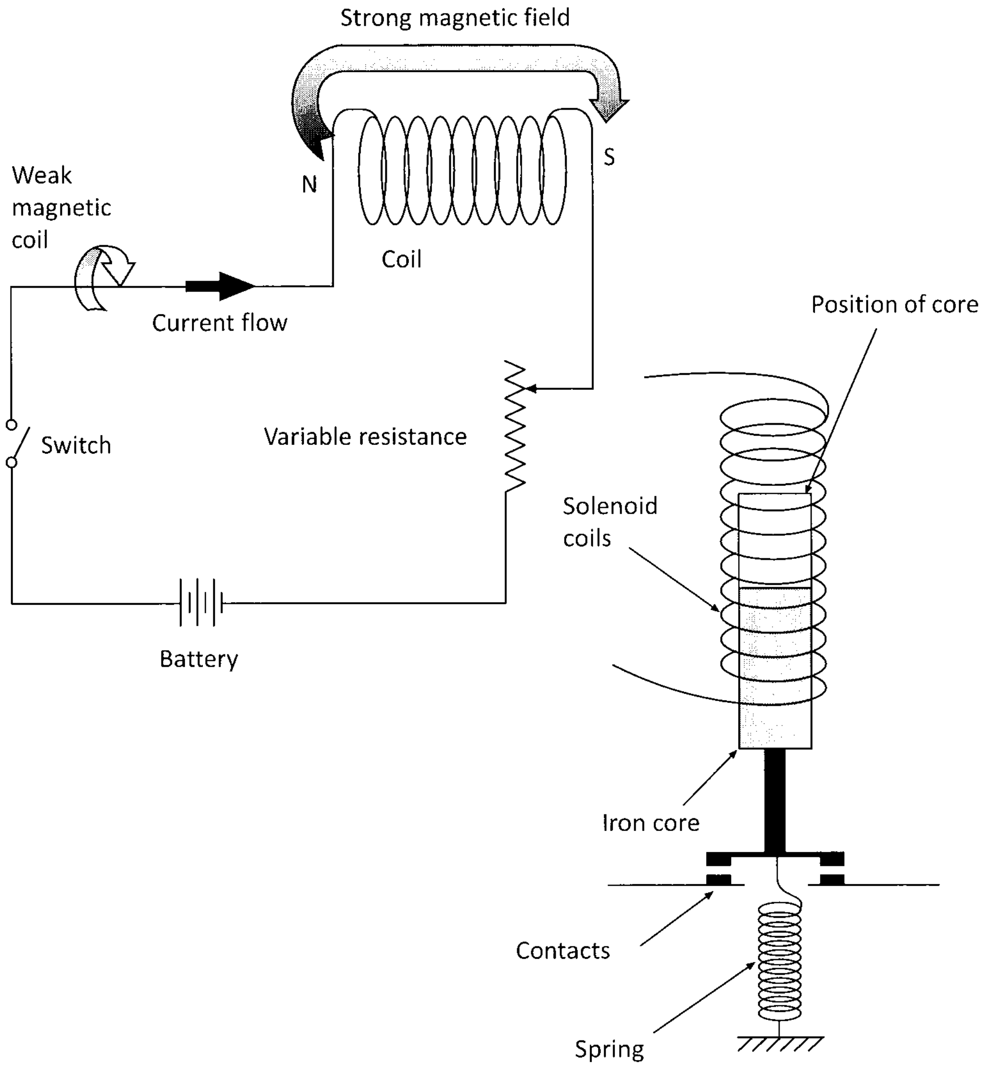
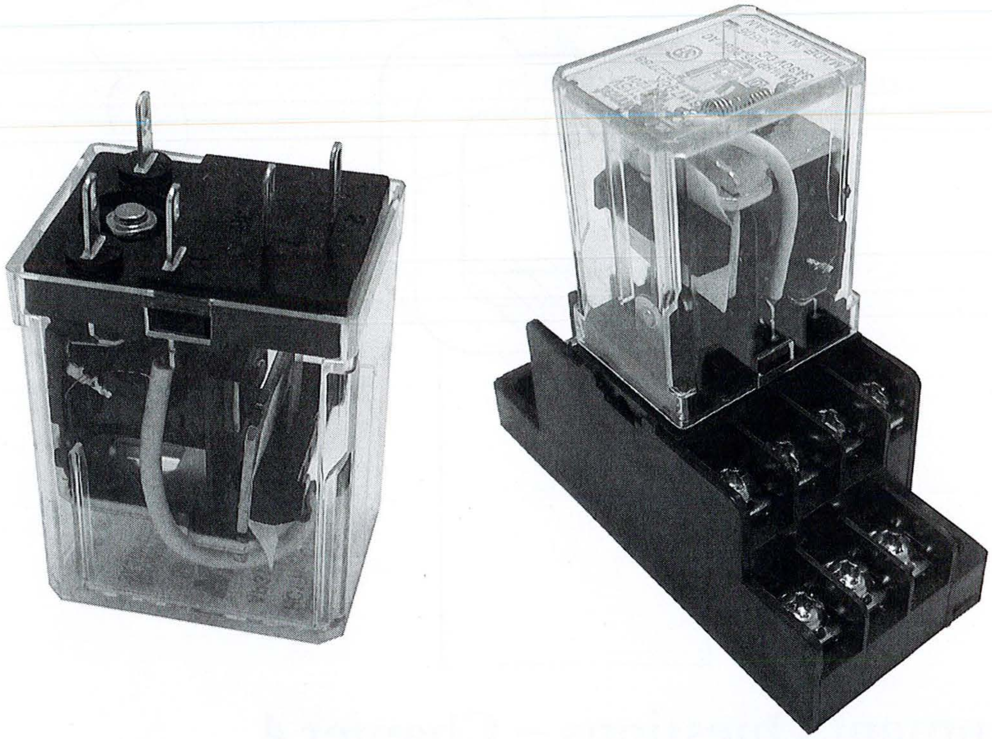


Figure 4-13
Magnetic relay
Image courtesy of Terry Bell



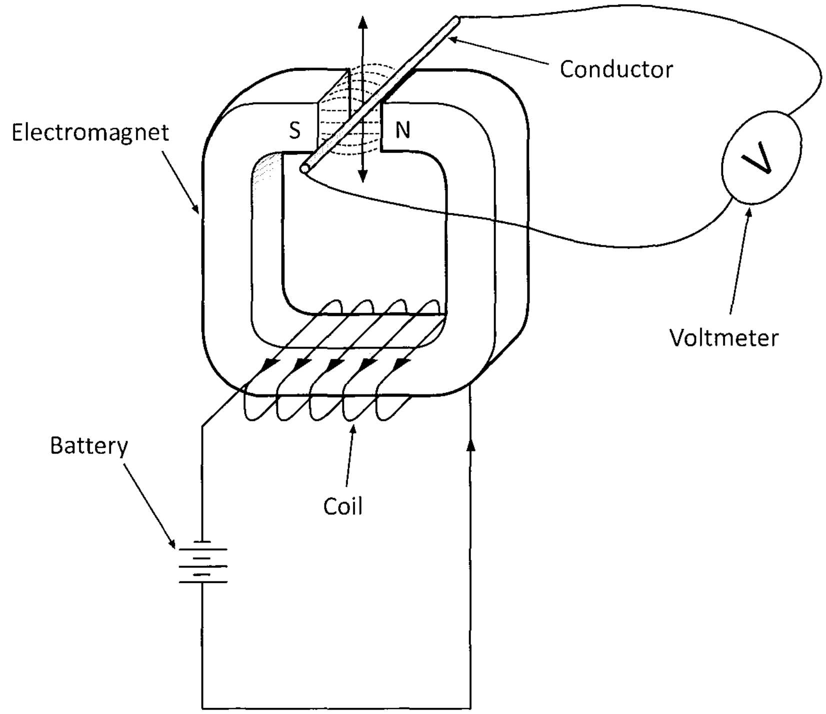
Electromagnetic induction

As mentioned previously, the flow of an electric current flows through a conductor produces a magnetic field around that conductor. It is also true that the movement of a magnetic field across a conductor generates voltage is generated in that conductor.

Figure 4-14 shows a u-shaped electromagnet. The supply of direct current to the coil around the iron core produces an electromagnet. Magnetic flux lines pass between the poles of the magnet through the opening in the core. These form north and south poles on the magnet. The movement of a conductor across the magnetic field, as indicated, generates voltage in that conductor. the voltmeter connected across the conductor shows this voltage.

The voltage generated is very small, but is measurable with a sensitive meter. The voltage generated depends on the number of lines of flux that the conductor cuts every second and on the angle at which the conductor cuts the flux. In this example, the conductor cuts few lines of flux because it moves slowly through a weak magnetic field. The faster the movement of the conductor, the greater the voltage produced. Also, increasing the concentration of magnetic flux lines (flux density) increases the induced voltage, with the conductor moving at a constant speed. You use the same principle to generate large amounts of electric energy in power stations.

Figure 4-14
Induced voltage



Assignment Questions – Chapter 4

1) Which of the follow is **not** a ferromagnetic metal?
   a) Copper
   b) Iron
   c) Nickel
   d) Cobalt

2) State the law of Attraction and Repulsion.
   a) Like poles attract, unlike poles repel
   b) Like poles repel, unlike poles attract

3) What is the term used to describe the ease with which a material accepts magnetic lines of force?
   a) Magnetism
   b) Density
   c) Permeability

4) How is the magnetism of an electromagnet increased?
   a) By decreasing current flow
   b) By increasing surface area
   c) By increasing current flow