Magnets and electromagnets have many uses, every electric motor, generator or transformer requires a magnetic field for it's operation. With the exception of a few special types, all use electromagnets. The magnets mounted on large cranes are used to lift heavy loads. Magnetism makes the generator supplying the electricity to your home work and the radio, telephone and most other electrical gadgets work.

The properties of Magnetism were known to the Greeks as early as 700 B.C. It was found that a certain type of ore had the power to attract pieces of iron which were in it's vicinity. The discovery was made in a province called Magnesia, and the ore was given the name Magnetite after its place of discovery. The type of magnetite which exhibits magnetic properties is commonly known as Lodestone. Any material which exhibits these magnetic properties is called a Magnet.

The first uses of magnetism were recorded by the Chinese, who are believed to have used suspended pieces of magnetite as compasses nearly 2000 years ago. Compasses were also used by the European navigators, but not until about 1200 A.D. Christopher Columbus was interested in the properties of magnetic compasses, and he made some important observations on the accuracy of compasses during his voyage to America in 1492. However, the first true study of magnetic properties was not attempted until 1600, when William Gilbert, an English physician, published a report on his experiments with magnets.

A careful and through study of magnets and their actions shows that all materials are affected to some extent when brought close to a strong magnet. By testing all the known substances, it has been found that iron and steel are affected very strongly, cobalt and nickel are affected to some extent, while all other materials are only slightly affected. Iron and steel are called magnetic, or ferromagnetic, substances, the prefix "ferro" being taken from the Latin word "ferrum", which means iron. The magnetic effect on iron is much greater than on other materials, but certain combinations or alloys of iron, nickel and cobalt are in common use today.

A magnet found in a natural state is known as a Natural Magnet. deposits of magnetic ore (magnetite) have been discovered at various places one of these being Labrador. Pieces of this material are called natural magnets because they exhibit the properties of magnetism without any special treatment. The earth is considered to be a huge natural magnet because it possesses the same properties as smaller magnets. Due to irregularities in size, shape and strength, natural magnets have little commercial value. However, when placed in a magnetic field, a piece of steel becomes a magnet. By proper treatment called ageing, it can be made to keep it's magnetism almost indefinitly. When properly magnetized and treated, a piece of steel is called a permanent magnet.

Almost any kind of steel and certain types of ceramics can be made into a permanent magnet, but some alloys can be more strongly magnetized than ordinary steel. The most popular magnetic alloys for permanent magnets are alloys of pure iron, aluminum, nickel and cobalt, called Alnico. By combining different percentages of these metals, various magnetic qualities are set up in the alloys when they are processed in a magnetic field.

Permanent magnets made of alnico are used commonly in television, radar and other electronic instruments. Ceramic magnets are also used to a wide extent in these instruments.

When in contact with a permanent magnet, a piece of iron becomes magnetized as strongly as a piece of steel. However, when the permanent magnet is removed, the iron loses practically all of it's magnetism. Therefore a piece of iron, especially soft iron, is called a Temporary Magnet. Because they do not occur in a natural state, all forms of magnetized steel and iron are considered as Artificial Magnets.

Magnetic Poles

When a bar magnet is suspended, it rotates to a generally north and south direction, with the same end always pointing to the north. No matter which way it is pointed, when released, the magnet comes to rest pointing approximately north and south. At each end of the bar magnet, there is a concentration of magnetic force. This concentration of force is known as a Magnetic Pole. The presence of the poles can be demonstrated by dipping the ends of a magnet into a pile of iron filings, when withdrawn filings cling to each end demonstrating the concentration of force at each end. The poles of a bar magnet are named after the direction in which they point when the magnet is suspended. The end that points northward is the North Pole and the that points south is the South Pole.

Magnetic Fields

A magnet produces some surprising effects. When placed close to one end of a strong magnet, a small piece of iron actually jumps to reach the magnet. The fact that the iron jumps shows clearly that the magnetic force extends for some distance around the magnet. This area of influence in the space around the magnet is known as the Magnetic Field. The unknown force that causes the field is referred to as the Magnetomotive force (mmf) of the magnet.

For convenience, a magnetic field is considered as being made up of manetic lines of force, or simply Magnetic Lines. However, the single line of force is seldom considered in analyzing magnetic fields. Instead, it is more common to use the term Magnetic Flux, which refers to the total number of magnetic lines that make up a magnetic field.

A simple but effective method of making a magnetic field "visible" is to place a piece of glass over a bar magnet and then sprinkle iron filings on the glass. The glass offers no opposition to the field, even though it is not a good conductor of magnetic lines. Thus, the filings are affected by the field, and align themselves in a pattern like that of the field around the magnet.

In addition to providing a convenient means of explaining the action of a magnetic field, the theoretical lines of force also provide a means of measurement. In practicle work, magnetic fields have a comparatively large number of lines and are of all shapes and sizes. Therefore, they usually are described as having a certain number of lines per square centimeter, which means the number of lines that pass through each square centimeter of a surface that is placed squarely across the magnetic field.

Because a given number of lines of force may be spread over a large field or compressed into a relatively small field, it is necessary to know both the number of lines that make up the flux and the size of the area through which the lines of force pass. The number of lines passing through a given area is known as the density of the field or the Flux Density.

The standard unit of measurement of the number of magnetic lines of force or magnetic flux is the Weber, abbreviated Wb. One weber is equal to 100,000,000 or 10 to the 8th power lines of force. The symbol used to represent magnetic flux is the Greek letter Phi. As previously mentioned, the lines of force passing through a given area is also important. The standard unit of measurement of the lines of force for a given area of the flux density is the Tesla. A tesla is equal to a weber per square meter; that is, 10 to the 8th power magnetic lines of force passing through an area one meter by one meter. The capitol letter B is often used to represent flux density.

Attraction and Repulsion
The earlier suspended bar magnet can be used to demonstrate theattraction and repulsion of the magnet. Suspend a bar magnet by a string and end marked N will point to the north. Take another bar magnet with the ends marked N (north) and S (south), hold the north end of this magnet near the north end of the suspended magnet and the suspended magnet will move away, place the south end near the north end and they will be attracted to each other. Like magnetic poles Repel; Unlike magnetic poles Attract

Magnetic Induction
Certain materials can be magnetized while under the influence of a magnetic field, but lose their magnetism as soon as the field is removed. Materials of this type are temporary magnets, and one of the materials most commonly used in temporary magnets is iron. Ordinary tacks can become temporary magnets if they are brought under the influence of a magnetic field. A tack placed at the end of a magnet becomes at magnet itself, and another tack placed at the end of it becomes another magnet and a third, each tack with it's own north and south pole, north connected to south to north to south all down the line of tacks. This process of setting up magnetism in an object that is under the influence of a magnetic field is called Magnetic Induction. If the original magnet is taken away from the first tack, the magnetic poles at the end of each tack disappear, and there is no longer a force to hold them together, the entire string falls apart.

The reason for magnetic induction is best explained by the molecular theory. The molecules that make up the tack material are easily turned from a random state of alignment, all the N's and S's pointed in random directions, to an organized state of alignment, all the N's northward of the material and all the S's southward of the material. In this organized state the material is considered to be a magnet. However, these molecules turn back to their original state of a random organization as soon as the original magnet is removed. This characteristic distinguishes the temporary magnet from the permanent magnets. In a material such as hardened steel, the molecules require a great deal of force to bring them into alignment, but once this alignment occurs, the steel tends to maintain it's magnetism indefinitly.

Reluctance and Permeability

Because most of the molecules of soft iron turn quite easily under the influence of a magnitizing force, the overall effect is quite strong. In some other materials, very few or none of the molecules turn because of the rigid structure of the material. In other materials, the magnetic field for each molecule is quite small, the total magnetic effect is very weak.

Although magnetic lines of force pass through all substances under normal conditions, some materials do not carry them as readily as others. This opposition which a substance offers to the passage of magnetic lines is known as it's Reluctance.

Reluctance is a property of every material. Just as there is no perfect electric conductor, under normal conditions, there is no perfect magnetic conductor. However, soft iron has a very low reluctance and is a good conductor of magnetic lines in comparison with most other materials. Reluctance describes the opposition offered to magnetic lines of force. The term Permeability describes the ease of passage of magnetic lines of force. Thus, a material with a high permeability has a low reluctance, and vice versa.

Measurement of permeability are taken with air as the reference. Air has a permeability of one. Iron, for example has a permeability several thousand times that of air. The Greek letter Mu is often used to represent permeability.

Magnetic Circuits The paths taken by magnetic lines of force can be thought of in much the same way as the current paths in an electric circuit. In an electric circuit, pressure or voltage overcomes the resistance of the conducting path and sets up a current flow. In a magnetic circuit, similar conditions exist, but instead of voltage or electromotive force (emf), there is a: Magnetomotive Force(mmf) which causes magnetic lines throughout the circuit.

The opposition which the magnetic circuit offers to this flux is known as reluctance. Electrically, nearly all materials have different resistance characteristics, some offering little and others offering high opposition to an electric current. However, with the exception of the magnetic metals, most substances offer nearly equal reluctance. Air and some other nonmagnetic materials have high reluctance.

To further compare the magnetic circuit with an electric circuit: there is an mmf instead of voltage; line of force, or flux lines, instead of current; and reluctance instead of resistance. The relationship between mmf flux and reluctance in the magnetic circuit is very similar to the relation ship between voltage, current and resistance in the electric circuit. Just as current is equal to voltage divided by resistance, flux is equal to magnetomotive force divided by reluctance.

Electromagnetism

It has been found that an electric current sets up a magnetic field similar to that produced by a permanent magnet. This action is known as Electromagnetism and is very important in many devices. A desirable feature of electromagnetism is that it is possible to control the strength and polarity of the magnetic field. When current exists in a coil, the coil has all the magnetic qualities of a permanent magnet and is called an Electromagnet. If this electromagnet is brought near a permanent magnet or another electromagnet, the like and unlike poles react exactly as explained for the permanent magnets. Moreover, an increase of current in the coil increases the strength of the magnetic field, and a decrease of current weakens the field.

Ampere-Turns

When the number of loops or turns of the coil is increased and the current remains the same, the strength of the magnetic field increases. Each loop or turn of the coil sets up it's own magnetic field, which unites with the fields of the other loops to produce the field around the entire coil. The more loops, the more magnetic fields unite and reinforce each other and, as a result, the total magnetic field becomes stronger.

To compare the magnetic strength of different coils, and to obtain a basis for measuring the magnetomotive force of an electromagnet, the number of turns of wire is multiplied by the number of amperes of current carried by the wire and the result is called Ampere-Turns (NI). The ampere-turn is the unit for measuring the magnetomotive force of a current-carrying coil. In a formula, the magnetomotive force in ampere-turns can be expressed as:

**Code:** $F = NI$  $F$ = magnetomotive force in ampere-turns  $N$ = number of turns  $I$ = current in amperes

For example:

A coil with 10 turns and a current of 10 amperes has an F of 100 ampere-turns.

Effect of an iron core

Earlier it was stated that iron and steel have low reluctance and carry magnetic lines of force much more readily than air and certain other materials. To increase the magnetic field of a coil, it is common practice to insert a piece of iron through the center of the coil. This piece of iron is called the core, and it's low reluctance permits passage of many more magnetic lines of force through it than the surrounding air will carry. It tends to concentrate the coil's magnetic field.

The magnetic behavior of a coil carrying electric current can be summed up in the following three statements:

Whenever current is present in a coil of wire, a magnetic field is set up in and around the coil, which then exibits all of the properties of a magnet.

The strength of the magnetic field varies with the number of turns and the current. With no current, there is no magnetism.