Online Radio & Electronics Course

Reading 8

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MAGNETISM

There are no questions in either the NAOCP or AOCP exam about magnetism. You are justified then in asking why we are doing this subject. Well, although there are not any questions in the exam, later on in this course we do have to cover topics like:

Inductance
Mutual Inductance
Alternating Current

It is really impossible to gain an understanding of these subjects without a basic understanding of magnetism. I will try to keep the topic as brief as possible bearing in mind what has to be learnt, and more to the point 'understood' later on.

Magnetism is a very large subject, however I will cut it down into what you really need to know to help with your understanding of other topics later on.

I think it is a deficiency in the Amateur Radio syllabus that questions are not asked on magnetism.

MAGNETISM AND ELECTRICITY

Any wire carrying a current of electrons is surrounded by an unseen area of force called a magnetic field. For this reason, any study of electricity or electronics must consider magnetism.

Almost everyone has had experiences with magnets or with pocket compasses at one time or another. A magnet attracts pieces of iron but has little affect on practically everything else. Why does it single out the iron? A compass, when laid on a table, swings back and forth, finally coming to rest pointing toward the North Pole of the world. Why does it always point in the same direction?

These and other questions about magnetism have puzzled scientists for hundreds of years. It is only relatively recently that theories seeming to answer many of the perplexing questions that arise when magnetism is investigated have been developed.

Radio and electronic apparatus such as relays, circuit breakers, earphones, loudspeakers, transformers, chokes, magnetron tubes, television tubes, phonograph pickups, tape and disk recorders, microphones, meters, motors, and generators depend on magnetic effects to make them function.

Every coil (inductance) in a radio receiver or transmitter is utilising the magnetic field that surrounds it when current is flowing through it. But what is meant by the term magnetic field?

THE MAGNETIC FIELD

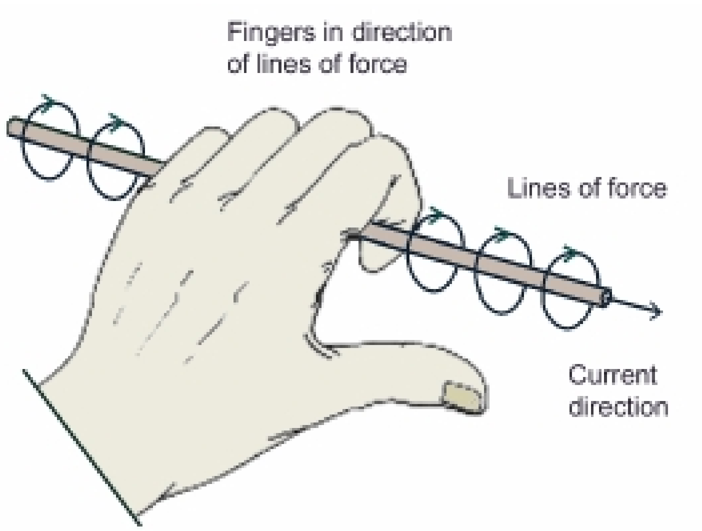
An electron at rest has a negative electrostatic field of force surrounding it. When energy is imparted to an electron to make it move, a new type of field develops around it, at right angles to its electrostatic field. Whereas negative electrostatic lines of force are considered as radiating outward from an electron, the electromagnetic field of force develops as a ring around a moving electron, at right angles to the path taken, around the wire.

An interesting difference between a magnetic field and an electrostatic field is that an electrostatic field can exist about a single stationary charge such as an electron or a proton. This is not the case with magnetism. A north 'monopole' does not exist any more than a south 'monopole' exists. With magnetism you always have two poles.

Electrons orbiting around the nucleus of an atom or a molecule produce electromagnetic fields around their paths of motion. In most cases, these magnetic fields are either balanced or neutralised by the magnetic effect of any proton movement in the nucleus, or the movement of one orbital electron is counteracted by another orbital electron whirling in an opposite direction. In almost all substances the net result is little or no external magnetic field.

In the case of an electric conductor carrying current, the concerted movement of electrons along the wire produces a magnetic field around the conductor. The greater the current, the more intense the magnetic field.

Figure 1.



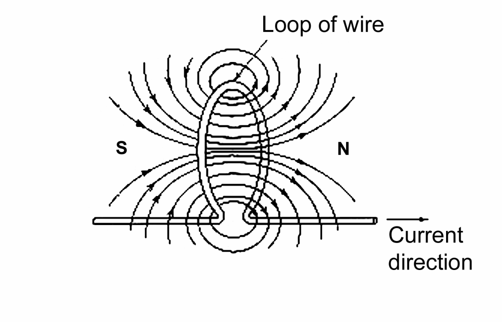
The diagram in figure 1 shows a method of determining the direction of the magnetic field around a current carrying conductor.

If you place a compass next to a conductor and then pass a current through the conductor the compass needle will move indicating the presence of a magnetic field.

Under normal circumstances, the field strength around a current-carrying conductor varies inversely as the distance from the conductor. At twice the distance from the conductor the magnetic-field strength is one-half as much, at five times the distance the field strength is one-fifth and so on. At a relatively short distance from the conductor the field strength may be quite weak.

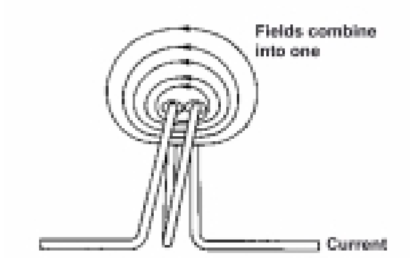
When the current in a conductor is increased, more electrons flow, the magnetic-field strength increases, and the whole field extends further outward.

Figure 2.



By looping a conductor, as shown in figure 2, magnetic lines of force are concentrated in the central core area of the loop.

Figure 3.



When several turns of wire are formed into a coil, as shown in figure 3, the lines of force from each turn add to the fields of the other turns and a more concentrated magnetic field is produced in the core of the coil.

By forming a coil with several loops, the field is concentrated and an electromagnet is produced.

AN EXPERIMENT TO TRY

Normally in face-to-face classes I would demonstrate many things by experiment. This makes learning more interesting. We don't have that luxury, however, I will mention these experiments from time to time and perhaps you can try them yourself. If you have never made an electromagnet I really encourage you to do so as it can be a lot of fun and fascinating to do so. Just get an iron rod about 75mm long. A bolt with a head and a nut screwed on to one end is ideal. Wind as many turns of wire onto it as you can. I use single telephone wire, however any small diameter wire will do the job. The more turns the better. Connect the ends of the coil you have made to a 6 volt lantern battery and you will have yourself an electromagnet. Which, by the way, you can use in other experiments down the track. Besides just playing with your electromagnet you can use it to magnetise some tools such as screwdrivers etc. Don't leave it connected to the battery for very long as it draws a heavy current from it. Do not use a car battery as the coil will overheat and melt. The coil (inductor) is a very low resistance, however current is limited by using a 6 volt lantern battery, which can only supply 3-4 amps. If you want to use a car battery you need to limit the current flow through the electromagnet. You could do this by connecting a 12 volt automotive light bulb in series with the magnet.

Figure 4.

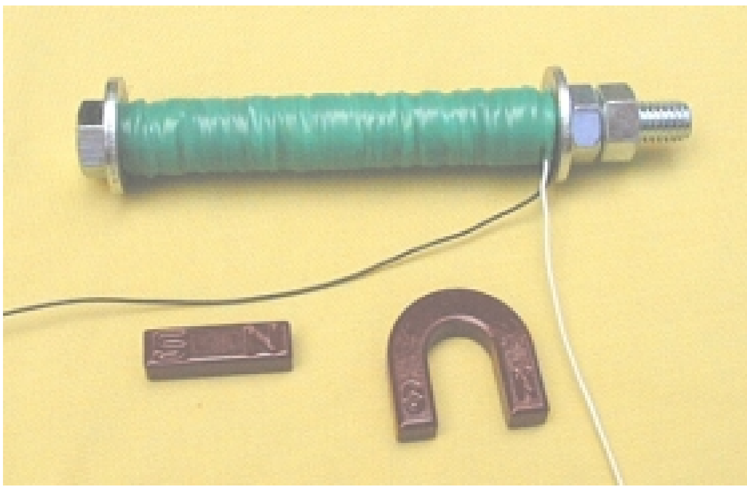


Figure 4 shows an electromagnet made from a bolt and some scrap wire; a permanent bar and horseshoe magnet.

The direction of the field of force (north and south pole) can be reversed by reversing the current direction or by reversing the winding direction.

At one end of the coil the field lines are leaving, and at the other end they are entering. When a coil or piece of metal has lines of force leaving one end of it, that end is said to have a north pole. The end with the lines entering is the south pole.

The terms "north" and "south" indicate magnetic polarity, just as "negative" and "positive" indicate electrostatic polarity. They should not be used interchangeably. The negative end of a coil is the end connected to the negative terminal of the source and does not refer to the north or south magnetic polarity of the coil.

All magnetic lines of force are complete loops and may be considered somewhat similar in their action to stretched rubber bands. They will contract back into the circuit from which they came as soon as the force that produced them ceases to exist.

Magnetic lines of force never cross each other. When two lines have the same direction, they will oppose mechanically if brought near each other.

PERMEABILITY

When a coil of wire is wound with air as the core, a certain flux density will be developed in the core for a given value of current. If an iron core is slipped into the coil a very much greater flux and flux density will exist in the iron core than was present when the core was air, although the current value and the number of turns have not changed.

With an air-core coil the air surrounding the turns of the coil may be thought of as pushing against the lines of force and tending to hold them close to the turns. With an iron core, however, the lines of force find a medium in which they can exist much more easily than in air. As a result, lines that were held close to the turns in the air-core coil are free to expand into the highly receptive area afforded by the iron. This allows lines of force that would have been close to the surface of the wire to expand into the iron core. Thus, the iron core produces a greater flux density, although no more magnetising force (NI). In other words for the same number of turns and current, a coil will have a stronger magnetic field if an iron core is inserted. The iron core merely brings the lines of force out where they can be more readily used and concentrates them.

The ability of a material to concentrate lines of force is called permeability.

The permeability of most substances is very close to that of air, which may be considered as having a value of 1. A few materials, such as iron, nickel, and cobalt, are highly permeable, with permeability's of several hundred to several thousand times that of air. (Note that the word "permeability" is a derivation of the word "permeate," meaning "to pervade or saturate" and is not related to the word "permanent.")

Permeability is represented by the Greek letter μ (mu, pronounced mew).

Alloying iron makes it possible to produce a wide range of permeability's. A cast iron can be made that has almost unity (1) permeability. Most stainless steels exhibit practically no magnetic effect, although some may be magnetic.

Any substance that is not affected by magnetic lines of force and is reluctant to support a magnetic field is said to have the property of reluctance. Air, vacuum, and most substances have unity reluctance, while iron has a very low reluctance.

In electric circuits the reciprocal of resistance is called conductance. In magnetic circuits the reciprocal of reluctance is called permeance. "Permeability" is used when discussing how magnetic materials behave.

THE ATOMIC THEORY OF MAGNETISM

The discussion here will be a considerably condensed version of the atomic theory of magnetism.

From atomic theory it is known that an atom is made up of a nucleus of protons surrounded by one or more electrons encircling it. The rotation of electrons and protons in most atoms is such that the magnetic forces cancel each other. Atoms or molecules of the elements iron, nickel, and cobalt arrange themselves into magnetic entities called domains. Each domain is a complete miniature magnet.

Groups of domains form crystals of the magnetic material. The crystals may or may not be magnetic, depending on the arrangement of the domains in them. Investigation shows that while any single domain is fully magnetised, the external resultant of all the domains in a crystal may be a neutral field.

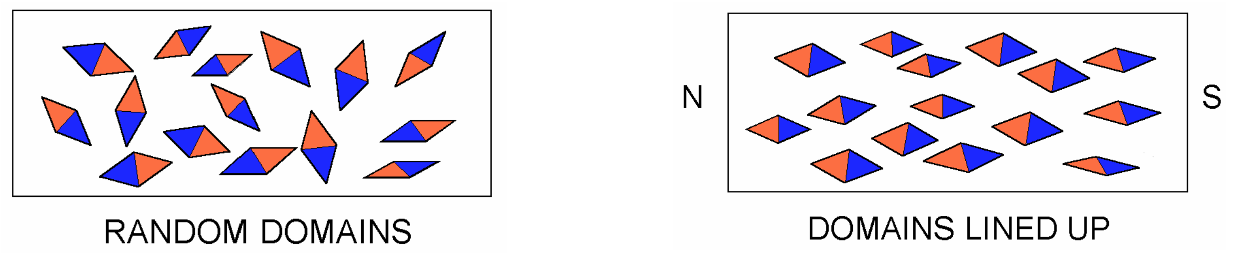


Figure 5.

Each domain has three directions of magnetisation: easy magnetisation, semi-hard magnetisation, and hard magnetisation. If an iron crystal is placed in a weak field of force, the domains begin to line up in the easy direction. As the magnetising force is increased, the domains begin to roll over and start to align themselves in the semi-hard direction. Finally, as the magnetising force is increased still more, the domains are lined up in the hard direction. When all the domains have been lined up in the hard direction, the iron is said to be saturated. An increase in magnetising force will then produce no more magnetic change in the material.

FERROMAGNETISM

Substances that can be made to form domains are said to be ferromagnetic, which means "iron magnetic." The ferromagnetic elements are iron, nickel, and cobalt, but it is possible to combine some non-magnetic elements and form a ferromagnetic substance. For example, in the proper proportions, copper, manganese, and aluminium, each by itself being non-magnetic, produce an alloy which is similar to iron magnetically.
Materials made up of nonferromagnetic atoms, when placed in a magnetic field may weakly attempt either to line up in the field or to turn at right angles to it. If they line themselves in the direction of the magnetic field, they are said to be paramagnetic. If they try to turn from the direction of the field, they are called diamagnetic. There are only a few diamagnetic materials. Some of the more common are gold, silver, copper, zinc, and mercury. All materials which do not fall in the ferromagnetic or diamagnetic categories are paramagnetic. The greatest percentage of substances are paramagnetic.

Ferromagnetic substances will resist being magnetised by an external magnetic field to a certain extent. It takes some energy to rearrange even the easy-to-move domains. Once magnetised, however, ferromagnetic substances may also tend to oppose being demagnetised. They are said to have retentivity, or remanence, the ability to retain magnetism when an external field is removed.

As soon as the magnetising force is released from a magnetised ferromagnetic substance, it tends to return at least part way back to its original non-magnetised state, but it will always retain some magnetism. This remaining magnetism is residual magnetism. Paramagnetic and diamagnetic materials always become completely non-magnetic when the external magnetising force is removed from them.

PERMANENT AND TEMPORARY MAGNETS

Ferromagnetic substances that hold magnetic-domain alignment well (have a high value of retentivity) are used to make permanent magnets. One of the strongest permanent magnets is made of a combination of iron, aluminium, nickel, and cobalt called Alnico. It is used in horseshoe magnets, electric meters, headphones, loudspeakers, radar transmitting tubes, and many other applications. Some magnetically hard, or permanent magnetic materials, are cobalt steel, nickel-aluminium steels, and special steels.

Figure 6 below shows the magnetic field surrounding permanent magnets. This picture was made by placing a piece of paper over the magnets and sprinkling iron filings on to the paper.

You can actually see the lines of force attracting when a north and a south pole are brought near to each other and repelling when two north poles are brought near to each other.

Remember:

Unlike poles attract and like poles repel.

Figure 6 captures the magnetic field, shown by iron filings around a magnet.

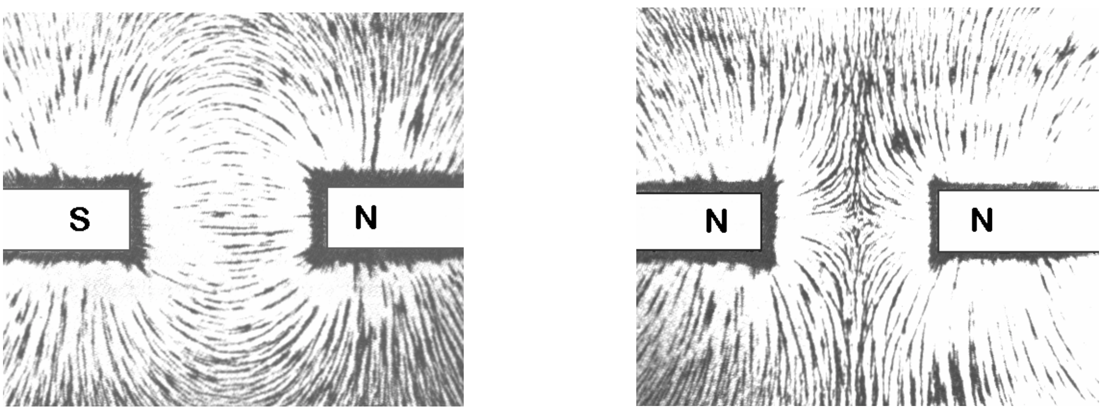


Figure 6.

Ferromagnetic metals that lose magnetism easily (have a low value of retentivity) make temporary magnets. They find use in transformers, chokes, relays, and circuit breakers.

Pure iron and Permalloys (perm derived from "permeable," not from "permanent") are examples of magnetically soft, temporary-magnet materials. Finely powdered iron, held together with a non-conductive binder, is used for cores in many applications. These are called ferrite cores.

MAGNETISING AND DEMAGNETISING

There are two simple methods of magnetising a ferromagnetic material. One is to wrap a coil of wire around the material and force a direct current through the coil. If the ferromagnetic material has a high value of retentivity, it will become a permanent magnet.

If the material being magnetised is heated and allowed to cool while subjected to the magnetising force, a greater number of domains will be swung into alignment and a greater permanent flux density may result. Hammering or jarring the material while under the magnetising force also tends to increase the number of domains that will be affected.

A less effective method of magnetising is to stroke a high-retentivity material with a permanent magnet. Have you ever magnetised a screwdriver using this method? This will align some of the domains of the material and induce a relatively weak permanent magnetism.

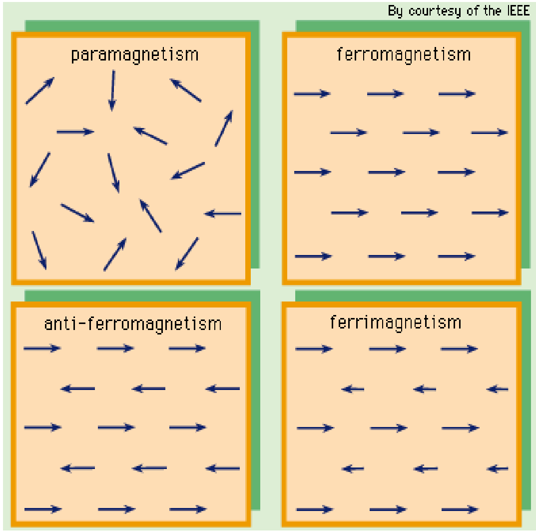


Figure 7.

If a permanent magnet is hammered, many of its domains will be jarred out of alignment and the flux density will be lessened. If heated, it will lose its magnetism because of an increase in molecular movement that upsets the domain structure. Strong opposing magnetic fields brought near a permanent magnet may also decrease its magnetism. It is important that equipment containing permanent magnets be treated with care. The magnets must be protected from physical shocks, excessive temperatures, and strong alternating or other magnetic fields.

When heated, permanent magnets lose their magnetism quickly, and also at a certain temperature. The temperature at which a magnet loses its magnetism is called the Curie temperature.

When tools or objects such as screwdrivers or watches become permanently magnetised, it is possible to demagnetise them by slowly moving them into and out of the core area of a many-turn coil in which a relatively strong alternating current (AC) is flowing. The AC produces a continually alternating magnetising force. As the object is placed into the core area, it is alternately magnetised in one direction and then the other. As it is pulled farther away, the alternating magnetising forces become weaker. When it is finally out of the field completely, the residual magnetism will usually be so low as to be of no consequence.

PERMANENT-MAGNET FIELDS

When a piece of magnetically hard material it subjected to a strong magnetising force the domains are aligned in the same direction. When the magnetising force is removed, many of the domains remain in the aligned position and a permanent magnet results. A north pole is anywhere the direction of the magnetic lines of force move outward from the magnet. A south pole is any place where the direction of the lines of force are inward.

If a magnet is completely encased in a magnetically soft iron box, all its lines of force remain in the walls of the box and there is no external field. This is known as magnetic shielding. Shielding may be used in the opposite manner. An object completely surrounded by an iron shield will have no external magnetic fields affecting it, as all such lines of force will remain in the permeable shield.

THE MAGNETISM OF THE EARTH

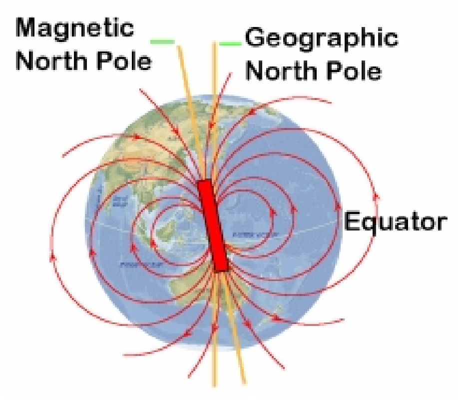


Figure 8.

Sufficient quantity of the ferromagnetic materials making up the earth have domains aligned in such a way that the earth appears to be a huge permanent magnet. The direction taken by the lines of force surrounding the surface of the earth is inward at a point near what is commonly known to be the North Pole of the world and outward near the earth's South Pole.

The familiar magnetic navigational compass consists of a small permanent magnet balanced on a pivot point. The magnetic field of the compass needle lines itself up in the earth's lines of force. As a result, the magnetic north end of the compass needle is pulled toward the earth's South Magnetic Pole, since unlike poles attract each other. This means that when the "north-pointing end" is pointing toward geographical north, this end (a magnetic north pole) is actually pointing toward a magnetic south pole

RELAYS

A relay is a relatively simple magnetic device that normally consists of a coil, a ferromagnetic core, and a movable armature on which make and break contacts are fastened. A simple relay may be used to close a circuit when the coil is energised. This type of relay is known as single-pole single-throw (SPST), normally open (NO), or "make-contact" relay.

The core, the U-shaped body of the relay, and the straight armature bar are all made of magnetically soft ferromagnetic materials having high permeability and little retentivity. One of the relay contacts is attached by an insulating strip to the armature, and the other to the relay body with an insulating material. The contacts are electrically separated from the operational parts of this particular relay. A spring holds the armature up and the contacts open.

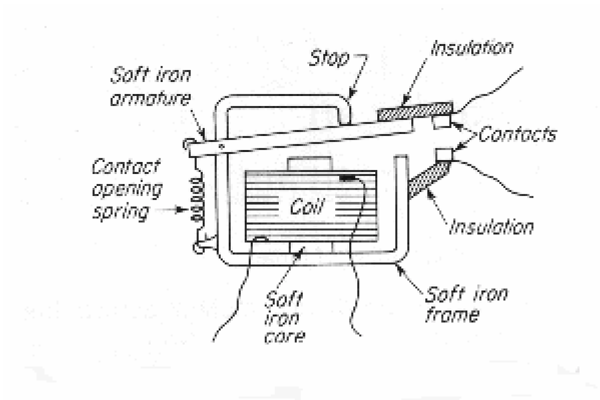


Figure 9.

When current flows in the coil, the core is magnetised and lines of force develop in the core and through the armature and the body of the relay. The gap between the core and the armature is filled with magnetic loops trying to contract. These contracting lines of force overcome the tension of the spring and pull the armature toward the core, closing the relay contacts. When the current in the coil is stopped, the magnetic circuit loses its magnetism and the spring pulls the armature up, opening the contacts.

Relays are useful in remote closing and opening of high-voltage or high-current circuits with relatively little voltage or current flow in the coil.

Relay contacts are usually made of silver or tungsten. Silver oxidises but can be cleaned by using a very fine abrasive paper or a piece of ordinary letterhead paper rubbed between the contacts. If the contacts are pitted by heavy currents, they may be smoothed with a fine file, but the original shape of the contacts should be retained to allow a wiping action during closing to keep them clean.

When I started out in electronics, relays were pretty big components. These days relays for switching small currents can be made very small and look no bigger than a medium sized integrated circuit.

End of Reading 8.
Last revision: November 2001

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