Bob's TechTalk #44
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Electromagnets:

Last month we talked about permanent magnets and ferromagnetic materials such as iron and cobalt. This month the discussion will begin on electromagnets.

Two months ago we learned that a wire carrying a current produces an electromagnetic field circularly around the wire as shown in figure 1.

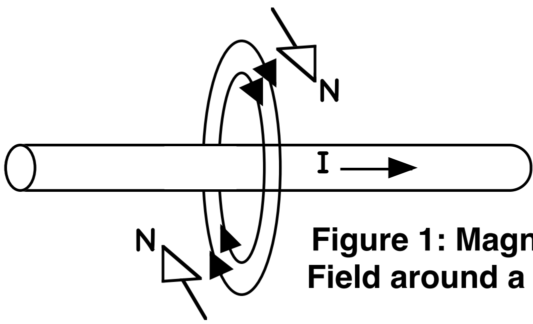


Figure 1: Magnetic Field around a wire

The direction the field travels can be seen by holding a compass near the wire examining the compass needle. The compass needle will point in the northward direction of the field. An easier way to determine the direction of the field is the **Right-hand Rule** (figure 2). It states:

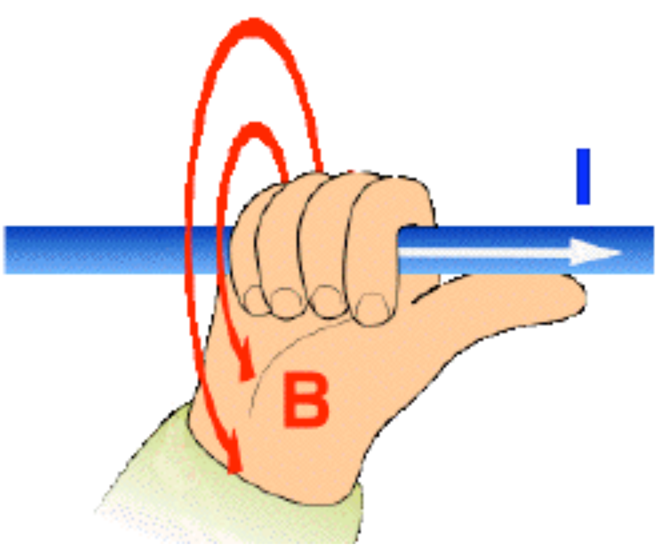


Figure 2: The Right-hand Rule

If the fingers of the right hand encircle a conductor with the thumb pointing in the direction of current flow, the encircling fingers will point in the direction of the magnetic field. *(Here current flow is defined as usual, positive to negative.)*

A wire may be wound as a solenoid resulting in a stronger field along the axis of the solenoid.

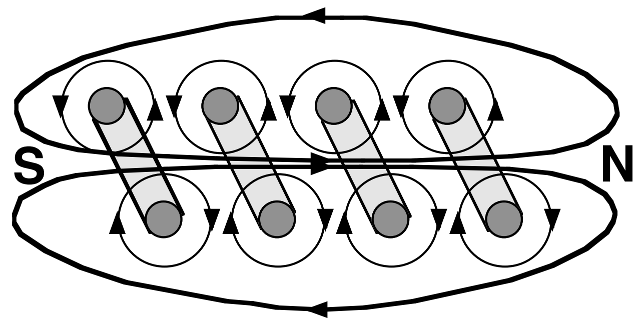
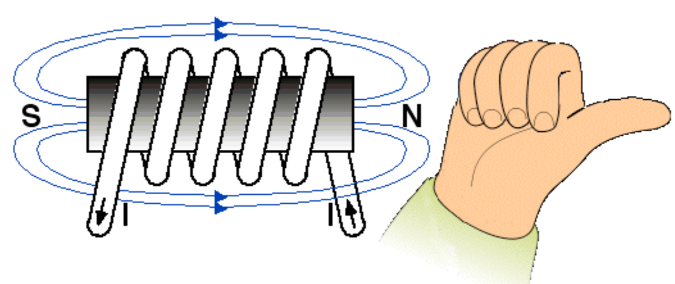


Figure 3: Magnetic field of a Solenoid Coil

Figure 3 shows the cross-section of a solenoid coil. The current is going in the lower sections of the coil and coming out the upper sections. A field is produced around the wire; note that in between wires the fields are in opposite directions canceling each other. A stronger field traveling through the center of the solenoid results.

If the core of the magnet is made of a ferromagnetic material the result is an electromagnet that acts just like a permanent magnet as long as current continues to flow through the coil. You may use the right hand rule around each turn of the wire to deter-



mine the direction of the field, or you can use a modified rule called the **Right-hand Rule of Solenoids**. It states:

If the right hand grasps a solenoid such that the fingers point in the direction of current flow in the coil, then the thumb points in the direction of the magnetic flux (the north magnetic pole).

Ohms Law of Magnetics

When a current 'I' is passed through a solenoid with 'N' number of turns it produces a magnetizing force depicted by a fancy $\Im$. This force is known as the magnetomotive force and is the magnetic equivalent of electromotive force, or emf (voltage). It is measured in ampere-turns abbreviated At.

$$\Im = NI$$

The magnetic flux, which is often depicted by the Greek character Φ, was discussed last month and is proportional to the magnetomotive force, just like the current is proportional to the voltage in an electrical circuit. In an electrical circuit the proportional constant is call the resistance. In a magnetic circuit the constant is called the reluctance and is depicted by a fancy $\Re$.

$$I = \frac{E}{R} \qquad \Phi = \frac{\Im}{\Re}$$

Actually Φ is a vector quantity and the right-hand rule is used to find the vector direction. Notice the similarity of equations!

The resistance of a bar or wire is just the length ℓ divided by the cross sectional area A, divided by the conductivity of the material σ. Thus for a given material the thicker the bar or wire the lower the resistance and the longer it is the higher the resistance.

$$R = \frac{\ell}{\sigma A}$$

Reluctance can be equated to magnetic resistance so:

$$\Re = \frac{\ell}{\mu A}$$

And μ can be thought as magnetic conductivity, but in real life μ is called the **permeability**.

The permeability is made up of μ_0 the permeability of free space multiplied by μ_r the relative permeability of the material:

$$\mu = \mu_r \mu_0$$

The permeability of free space μ_0 is:

$$\mu_0 = 4\pi \times 10^{-7}$$

The value of μ_r is very close to one for almost all materials that aren't ferromagnetic. For ferromagnetic materials μ_r can be quite large.

The permeability of ferromagnetic materials has some other interesting and important idiosyncrasies that are not evident in paramagnetic or diamagnetic materials.

Next month we'll cover permeability and hysteresis in electromagnets.

73, from AF6C

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