INTRODUCTION

permanent magnet:. The permanent magnet is made of a material, such as steel or iron, that will remain magnetized for long periods of time without the need for an external source of energy.

Electromagnetism: magnetic effects induced by the flow of charge, or current .

MAGNETIC FIELDS In the region surrounding a permanent magnet there exists a magnetic field, which can be represented by **magnetic flux lines** . The strength of a magnetic field in a particular region is directly related to the density of flux lines in that region.If a nonmagnetic material, such as glass or copper, is placed in the flux paths surrounding a permanent magnet, there will be an almost unnoticeable change in the flux distribution (Fig. 1). However, if a magnetic material, such as soft iron, is placed in the flux path, the flux lines will pass through the soft iron rather than the surrounding air because flux lines pass with greater ease through magnetic materials than through air. This principle is put to use in the shielding of sensitive electrical elements and instruments that can be affected by stray magnetic

fields (Fig. 2).

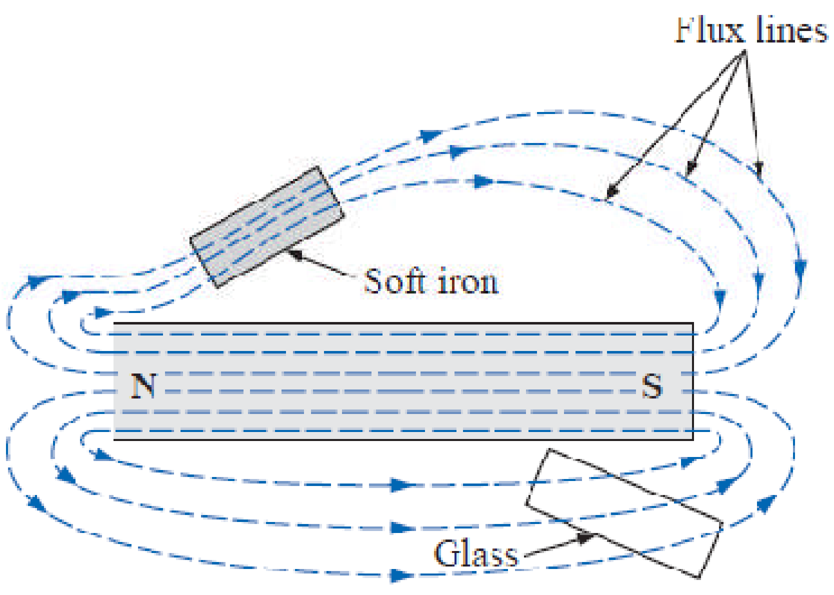
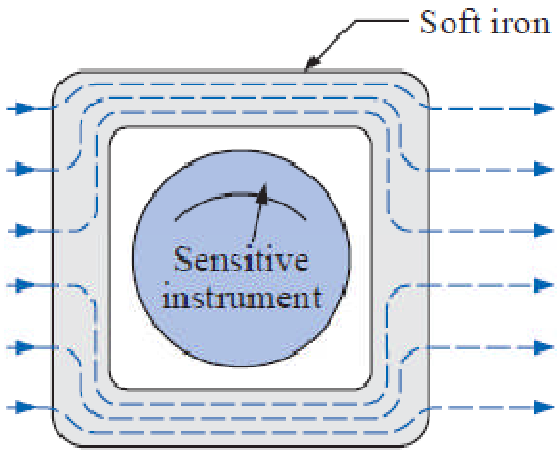
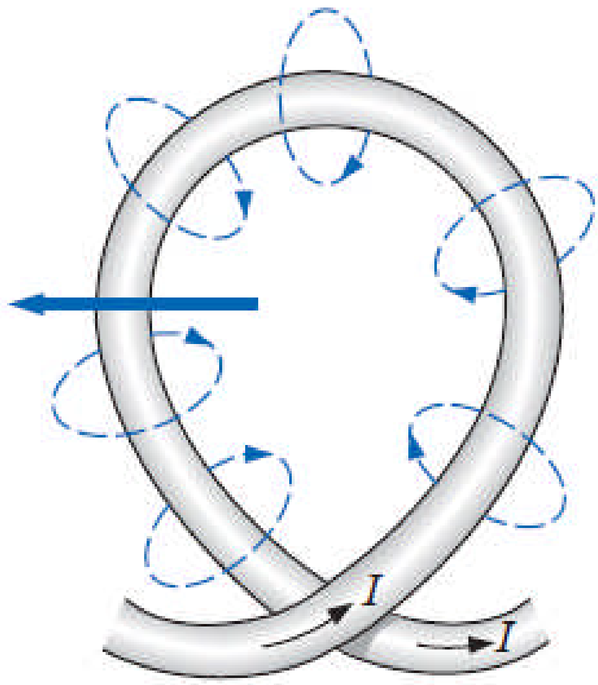


Fig (1)

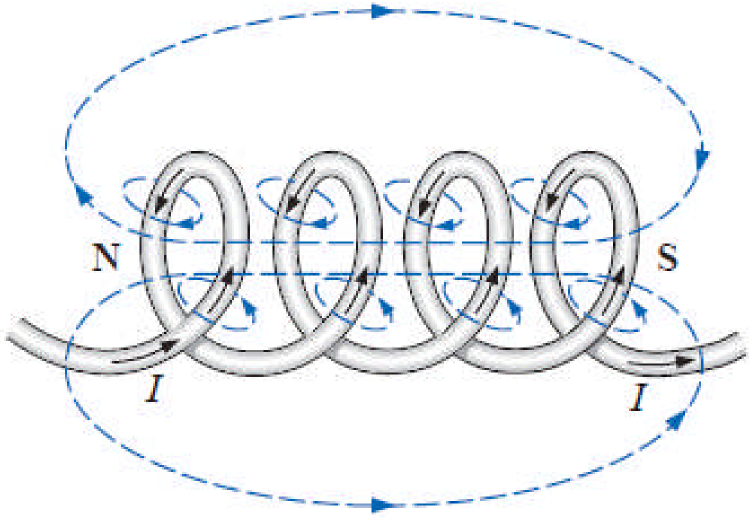


Fig(2)

The direction of the magnetic flux lines can be found simply by placing the thumb of the *right* hand in the
direction of *conventional* current flow and noting the direction of the fingers. (This method is commonly called the *right-hand rule*.) If the conductor is wound in a single-turn coil (Fig. 3), the resulting flux will flow in a common direction through the center of the coil. A coil of more than one turn would produce a magnetic field that would exist in a continuous path through and around the coil (Fig4).

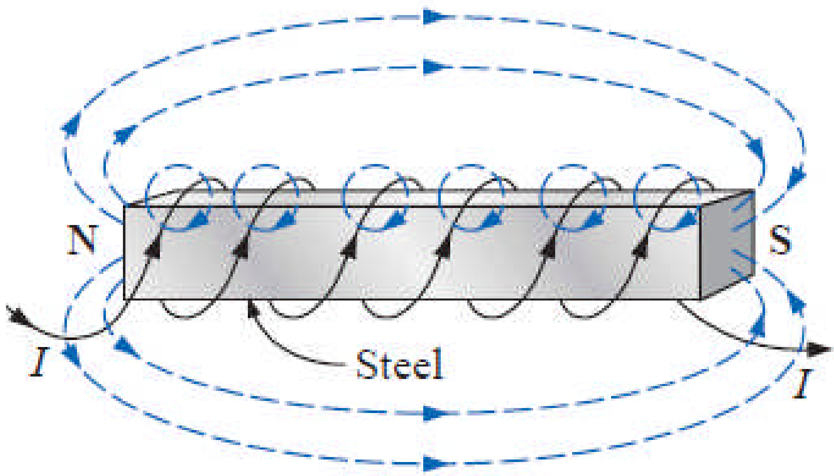


Fig(3)



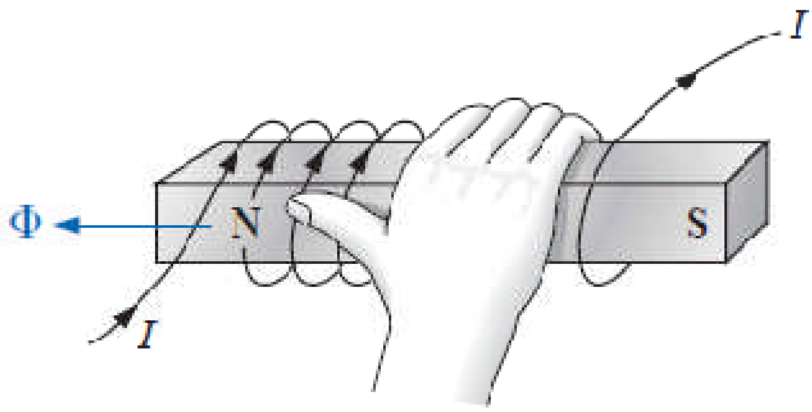
Fig(4)

The flux distribution of the coil is quite similar to that of the permanent magnet. The flux lines leaving the coil from the left and entering to the right simulate a north and a south pole, respectively. The principal difference between the two flux distributions is that the flux lines are more concentrated for the permanent magnet than for the coil. Also,
since the strength of a magnetic field is determined by the density of the flux lines, the coil has a weaker field strength. The field strength of the coil can be effectively increased by placing certain materials, such as
iron, steel, or cobalt, within the coil to increase the flux density (defined in the next section) within the coil. By increasing the field strength with the addition of the core, we have devised an *electromagnet* (Fig. 5)

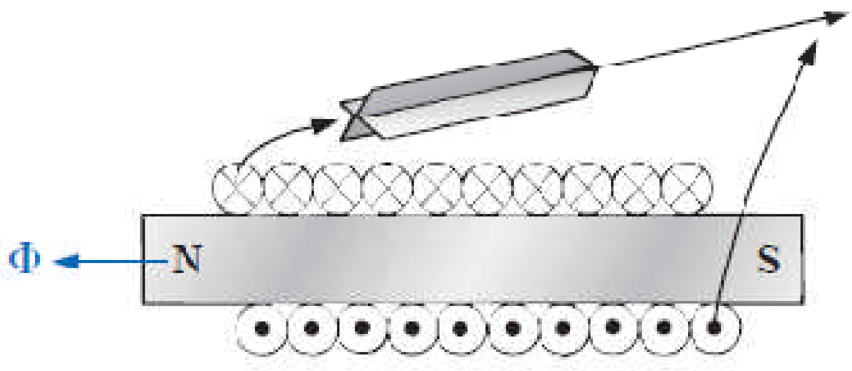


Fig(5)

The direction of flux lines can be determined for the electromagnet (or in any core with a wrapping of turns) by placing the fingers of the right hand in the direction of current flow around the core. The thumb will then point in the direction of the north pole of the induced magnetic flux, as demonstrated in Fig. 6(a). A cross section
of the same electromagnet is included as Fig. 6(b) to introduce the convention for directions perpendicular to the page. The cross and dot refer to the tail and head of the arrow



(a)



(b)

Fig(6)

FLUX DENSITY

In the SI system of units, magnetic flux is measured in ***webers*** and has the symbol Φ. The number of flux lines per unit area is called the **flux density *B*.**

$$\boxed{B = \frac{\Phi}{A}}$$

B = teslas (T)
Φ = webers (Wb)
A = square meters (m^2)

PERMEABILITY

The **permeability** (μ) of a material, therefore, is a measure of the ease with which magnetic flux lines can be established in the material. It is similar in many respects to conductivity in electric circuits. The permeability of free
space μ_o (vacuum) is :

$$\mu_o = 4\pi \times 10^{-7}\ \frac{\mathrm{Wb}}{\mathrm{A\cdot m}}$$

the permeability of all nonmagnetic materials, such as copper, aluminum, wood, glass, and air, is the same as that for free space. Materials that have permeabilities slightly less than that of free space are said to be **diamagnetic,** and those with permeabilities slightly greater than that of free space are said to be **paramagnetic.** Magnetic materials, such as iron, nickel, steel, cobalt, and alloys of these metals, have permeabilities hundreds and even thousands of times that of free space. Materials with these very high permeabilities are referred to as **ferromagnetic.**
The ratio of the permeability of a material to that of free space is called its **relative permeability;** that is,

$$\mu_r = —$$

RELUCTANCE

The reluctance, however, is inversely proportional to the permeability, while the resistance is directly proportional to the resistivity. The larger the μ or the smaller the ρ, the smaller the reluctance and resistance, respectively. Obviously, therefore, materials with high permeability, such as the ferromagnetics, have very small reluctances and will result in an increased measure of flux through the core.

$$\boxed{\mathscr{R} = \frac{l}{\mu A}} \qquad \text{(rels, or At/Wb)}$$

OHM’S LAW FOR MAGNETIC CIRCUITS

For magnetic circuits, the effect desired is the flux Φ The cause is the **magnetomotive force (mmf)** F, which is the external force (or “pressure”) required to set up the magnetic flux lines within the magnetic material. The opposition to the setting up of the flux Φ is the reluctance R. .
Substituting, we have :

$$\boxed{\Phi = \frac{\mathscr{F}}{\mathscr{R}}}$$

The magnetomotive force _ is proportional to the product of the number of turns around the core (in which the flux is to be established) and the current through the turns of wire (Fig.7). In equation form,

$$\boxed{\mathscr{F} = NI} \qquad \text{(ampere-turns, At)}$$

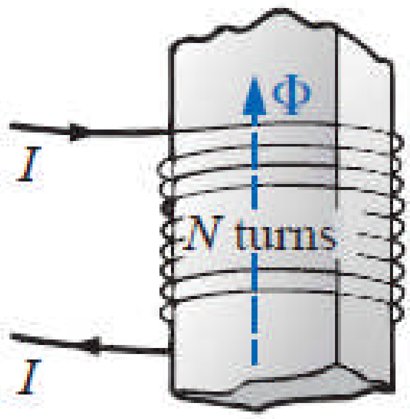


Fig (7)

Magnetic flux is established in the core through the alteration of the atomic structure of the core due to external pressure and is not a measure of the flow of some charged particles through the core.

MAGNETIZING FORCE

The magnetomotive force per unit length is called the **magnetizing force** (*H*). In equation form

$$\boxed{H = \frac{\mathscr{F}}{l}} \qquad \text{(At/m)}$$

Substituting for the magnetomotive force will result in

$$\boxed{H = \frac{NI}{l}} \qquad \text{(At/m)}$$

the magnetizing force is independent of the type of core material—it is determined solely by the number of turns, the current and the length of the core. As the magnetizing force increases, the permeability rises to a maximum and then drops to a minimum. The flux density and the magnetizing force are related by the following equation:

$$\boxed{B = \mu H}$$

AMPÈRE'S CIRCUITAL LAW

states that the algebraic sum of the rises and drops of the mmf around a closed loop of a agnetic circuit is equal to zero; that is, the sum of the rises in mmf equals the sum of the drops in mmf
around a closed loop. sources of mmf are expressed by the equation :

$$\boxed{\mathscr{F} = NI}$$

The equation for the mmf drop across a portion of a magnetic circuit:

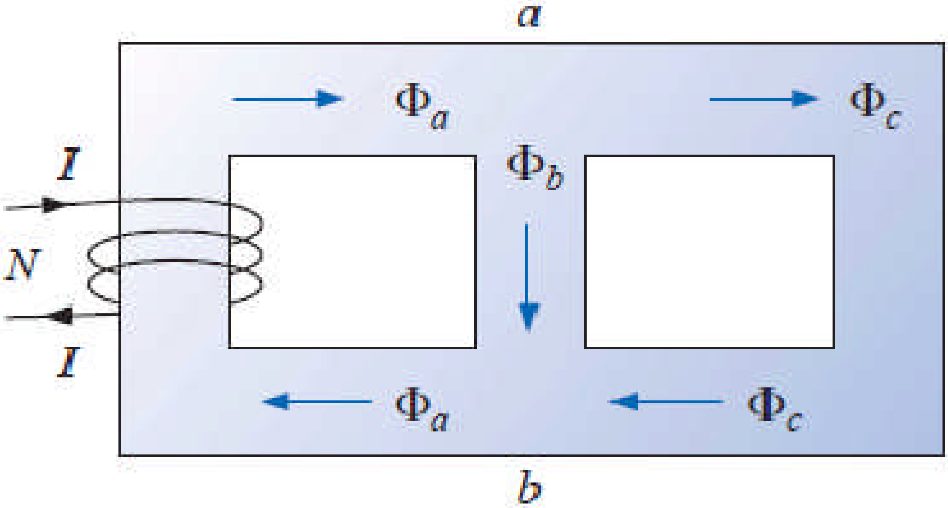
$$\boxed{\mathscr{F} = \Phi \mathscr{R}}$$

A more practical equation for the mmf drop is :

$$\boxed{\mathscr{F} = Hl}$$

THE FLUX Φ

the sum of the fluxes entering a junction is equal to the sum of the fluxes leaving a junction; that is, for the circuit of Fig. (8)



Fig(8)

$$\Phi_a = \Phi_b + \Phi_c \qquad \text{(at junction } a\text{)}$$

or

$$\Phi_b + \Phi_c = \Phi_a \qquad \text{(at junction } b\text{)}$$

both of which are equivalent.