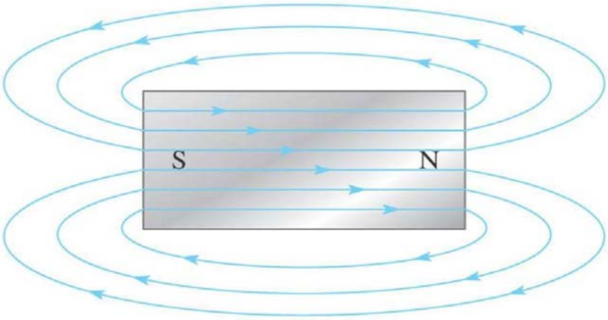
Chapter One

Electro magnetization

1.1 Introduction

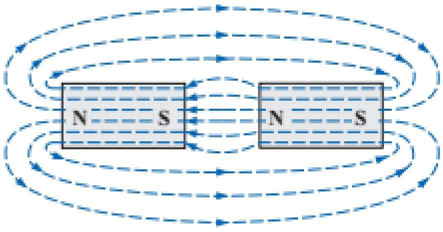
Magnetism plays an integral part in almost every electrical device used today in industry, research, or the home. Generators, motors, trans formers, circuit breakers, televisions, computers, tape recorders, and telephones all employ magnetic effects to perform a variety of important tasks.

The sources of magnetic field are electrical currents and a permanent magnets. In the region surrounding a permanent magnet there exists a magnetic field, which can be represented by **magnetic flux lines**. A unit N-pole is supposed to radiate out a flux of one weber. Its symbol is ϕ, then the flux coming out of N-pole of m weber is ϕ=mwb.

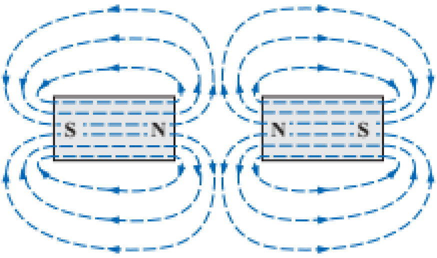


Notes

- The strength of a magnetic field in a particular region is directly related to the density of flux lines in the region.
- If unlike poles of two permanent magnets are brought together, the magnets will attract. If like poles are brought together, the magnets will repel, as shown in figure below.

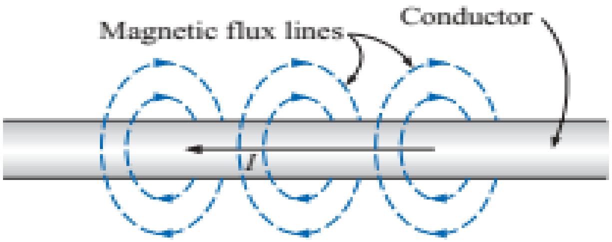


Attract

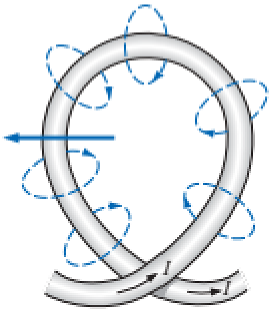


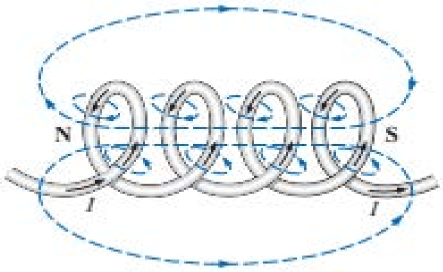
Repel

The magnetic field (flux) is produced due to the flow of current in a wire, and the direction of flux is determined by "R.H.R".



If the conductor is wound in a single-turn coil, 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





The resulting flux will flow in a common direction through the center of the coil.

1.2 Flux Density

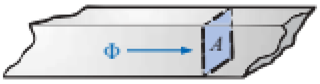
The number of flux lines per unit area is called the **flux density,** is denoted by the capital letter *B*,and is measured in ***teslas***.

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

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

B=wb/m^2*=Tesla*

For example,



$\Phi = 6 \times 10^{-5}$ Wb
$A = 1.2 \times 10^{-3}\ m^2$

$B = 6*10^{-5}/1.2*10^{-2} = 5*10^{-2}$ T

The magnetomotive force (m.m.f) is the ability of a coil to produce magnetic flux.

m.m.f.=F=N.I (ampere –turns) or [AT].

1.3 Magnetizing Force

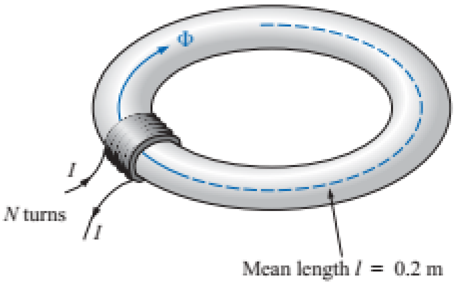
The magnetomotive force per unit length along the path is called magnetic field intensity or magnetizing force [H].

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

Substituting for the magnetomotive force will result in

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

L: is the mean or average path length of the magnetizing flux in m.



If magnetimotive force (m.m.f.)=40AT then the magnetzing force:

H=N.I / l = 40/0.2 = 200 [AT/m]

1.4 Reluctance

The relation between the m.m.f. and the flux is governed by the system reluctance R or S

m.m.f =R.ϕ

The **reluctance** of a material to the setting up of magnetic flux lines in the material is determined by the following equation:

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

where is the reluctance, l is the length of the magnetic path, and A is the cross-sectional area. The t in the units At/Wb is the number of turns of the applied winding.

Note:

$$\beta = \frac{\emptyset}{A} = \frac{m.m.f./R}{A}$$

$$m.m.f = H.l$$

$$R = \frac{l}{\mu A}$$

$$\beta = \frac{\frac{Hl}{L}}{\frac{\mu A}{A}} = \frac{Hl}{A}.\frac{\mu A}{l} = \mu H$$

1.5 Permeability

The phenomena of magnetisim and electromagnetisim are dependent upon a certain property of the meduim called its permeability.

Every meduim is supposed to posses two permeability:

i) Absolute (μ).
ii) Relative permeability (μ_r).

Vaccum or free space is chosen as the reference meduim and it is alloted on absolute permeabilityof $\mu_o=4\pi*10^{-7}$ [H/m] or [wb/Am].

The permeability of all nonmagnetic materials, such as copper, is the same as that for free space.[$\mu=\mu_o$]. Materials that have permeabilities slightly less than that of free space are said to be diamagnetic [$\mu<\mu_o$]. and those with permeabilities slightly greater than that of free space are said to be paramagnetic [$\mu>\mu_o$]. 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.

$$\mu_r = \frac{\mu}{\mu_o} = \frac{permeability\ of\ a\ material}{permeability\ of\ free\ space}$$

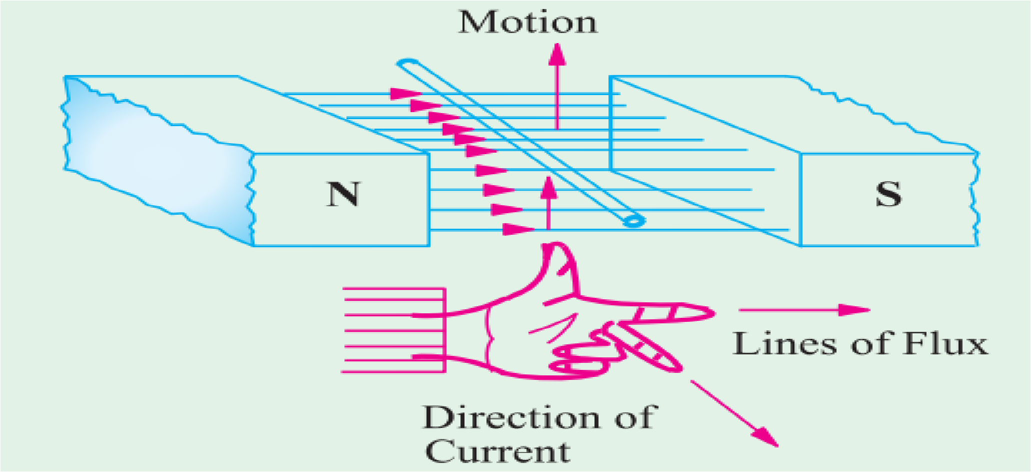
$$\mu_r = 1\ for\ nonmagnrtic$$

$$\mu_r < 1\ for\ diamagnrtic$$

$$\mu_r > 1\ for\ paramagnrtic$$

1.6 Force on a current –carrying conductor

Consider a conductor of length l placed between the poles of magnet. Let the conductor carry a current I and be at right angles to the magnetic flux lines. It is found experimentally that the conductor experiences a force F, The direction of this force may be easily found by Fleming’s left-hand rule "L.H.R".



and the magnitude is given by:

$$F = \beta\, l\, I$$

Where $\beta = flux\ density \left(\frac{wb}{m^2}\right)$.

$l = conductor\ length (m)$

$I = current\ (A)$

Or

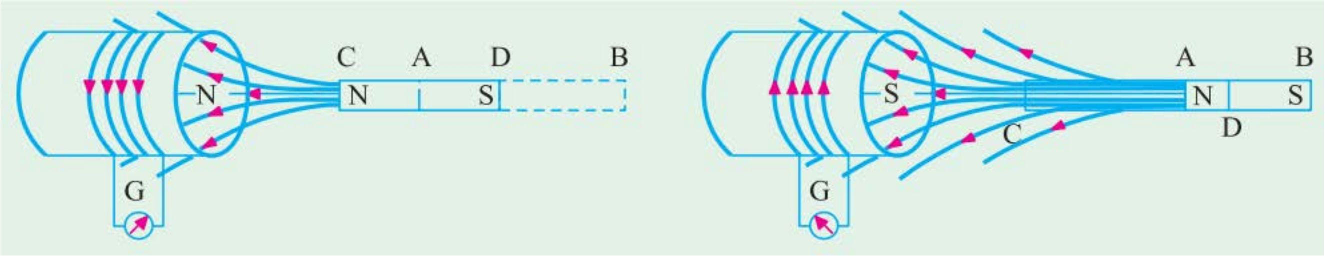
$$F = \beta\, l\, I\, \mathbf{\sin\theta}$$

This force is depends upon :

1- The flux density of the field,β tesla.
2- The strength of the current I, amperes.
3- The length of the conductor perpendicular to the magnetic field, l meters.
4- The directions of the field and the current.

1.7 Faraday's Law

In Figure shown below, an insulated coil whose terminals are connected to a sensitive galvanometer G. It is placed close to a stationary bar magnet initially at position AB (shown dotted). As seen, some flux from the N-pole of the magnet is linked with or threads through the coil:



First law. It states:

"Whenever the magnetic flux linked with a circuit changes, an e.m.f. is always induced in it".

or Whenever a conductor cuts magnetic flux, an e.m.f. is induced in that conductor. **Second Law**. It states : The magnitude of the induced e.m.f. is equal to the rate of change of flux-linkages.

Explanation. Suppose a coil has N turns and flux through it changes from an initial value of Φ_1 webers to the final value of Φ_2 webers in time t seconds. Then, remembering that by flux-linkages mean the product of number of turns and the flux linked with the coil, we have:

$$Initial\ flux\ linkage = N\emptyset_1$$

$$Final\ flux\ linkage = N\emptyset_2$$

$$induced\ e.m.f. = \frac{N\emptyset_2 - N\emptyset_1}{t} \quad weber/s \text{ or volts}$$

$$induced\ e.m.f. = N\frac{\emptyset_2 - \emptyset_1}{t} \quad \frac{weber}{s} or\ volts$$

Putting the above expression in its differential form, we get:

$$e = \frac{d}{dt}(N\emptyset) = N\frac{d\emptyset}{dt}\ volts$$

The negative sign indicates that the induced current is such that the magnetic field due to it opposes the magnetic flux producing it.

$$e = -N \frac{d\Phi}{dt} \text{ volt}$$

Principle of operation of a single d.c. motor and generator

A rectangular coil which is free to rotate about a fixed axis is shown placed inside a magnetic field produced by permanent magnets. A direct current is fed into the coil via carbon brushes bearing on a commutator, which consists of a metal ring split into two halves separated by insulation. This caused a torque and the coil rotates anticlochwise.

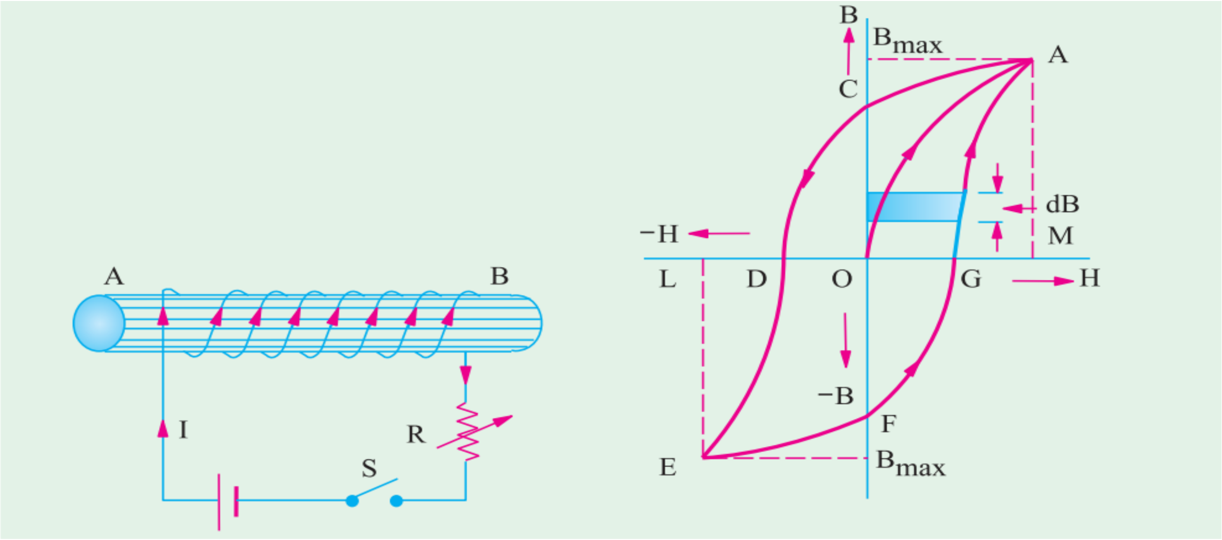
(motor takes electrical energy and converts into mechanical energy).

Core loss (Iron Losses)

There are two types of losses that are present in the iron core of any transformer or rotating machines, namely hysteresis and eddy current losses.

1- Hysteresis Losses

It may be defined as the lagging of magnetisation or induction flux density (B) behind the magnetising force (H). Alternatively, it may be defined as that quality of a magnetic substance, due to which energy is dissipated in it, on the reversal of its magnetism.



Let us take an unmagnetised bar of iron AB and magnetise it by placing it within the field of a solenoid. The field H (= NI/l) produced by the solenoid is called the magnetizing force. The value of H can be increased or decreased by increasing or decreasing current through the coil. Let H be increased in steps from zero up to a certain maximum value and the corresponding values of flux density (B) be noted. If we plot the relation between H and B, a curve like OA, as shown in Fig. below, is obtained. The material becomes magnetically saturated for H = OM and has at that time a maximum flux density of B_{max} established through it.

If H is now decreased gradually (by decreasing solenoid current), flux density B will not decrease along AO, as might be expected, but will decrease less rapidly along AC. When H is zero, B is not but has a definite value B r = OC. It means that on removing the magnetizing force H, the iron bar is not completely demagnetised. This value of B (=OC) measures the retentivity or remanence of the material and is called the remanent or residual flux density Br. To demagnetise the iron bar, we have to apply the magnetising force in the reverse direction. When H is reversed (by reversing current through the solenoid), then B is reduced to zero at point D where H = OD. This value of H required to wipe off residual magnetism is known as coercive force (Hc) and is a measure of the coercivity of the material i.e. its ‘tenacity’ with which it holds on to its magnetism. If, after the magnetisation has been reduced to zero, value of H is further increased in the ‘negative’ i.e. reversed direction, the iron bar again reaches a state of magnetic saturation, represented by point L. By taking H back from its value corresponding to negative saturation, (=OL) to its value for positive saturation (= OM), a similar curve EFGA is obtained. If we again start from G, the same curve GACDEFG is obtained once again.

هناك عاملين يؤثران على شكل وحجم دائرة الهسترة:

1- المادة / المواد سهلة التمغنط/ضيقة الحلقة
/المواد التي لا تتمغنط بسهولة/عريضة الحلقة
2- المواد التي لها نقاط تشبع مختلفة تؤثر على ارتفاع الهسترة.

2- Eddy Current

Suppose a coil carrying an a.c. current that produces an a.c. flux in iron core. So, the iron core is cuts a magnetic flux lines, and an e.m.f. will be induced in the core, and circulate the current called eddy current.

Eddy current resulting =heat up=I^2R

Discussions

Example (1): A coil of resistance 100 Ω is placed in a magnetic field of 1 mWb. The coil has 100 turns and a galvanometer of 400 Ω resistance is connected in series with it. Find the average e.m.f. and the current if the coil is moved in 1/10th second from the given field to a field of 0.2 mWb.

Solution. Induced e.m.f. $= N \cdot \dfrac{d\Phi}{dt}$ volt

Here $d\Phi = 1 - 0.2 = 0.8 \text{ mWb} = 0.8 \times 10^{-3} \text{ Wb}$

$dt = 1/10 = 0.1 \text{ second}\ ;\ N = 100$

$e = 100 \times 0.8 \times 10^{-3}/0.1 = \mathbf{0.8\ V}$

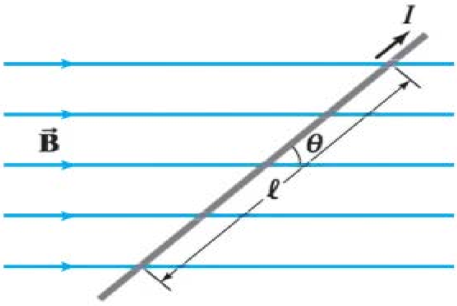
Total circuit resistance $= 100 + 400 = 500\ \Omega$

$\therefore$ Current induced $= 0.8/500 = 1.6 \times 10^{-3} \text{ A} = \mathbf{1.6\ mA}$

Example: Magnetic force on a current-carrying wire. A wire carrying a 30-A current has a length £=12cm between the pole faces of a magnet at an angle $\theta = 60^o$. The magnetic field is approximately uniform at 0.90 T. We ignore the field beyond the pole pieces.

1- What is the magnitude of the force on the wire?

2- What is the force on the wire if the wire is perpendicular to the magnetic field.



The force F on the 12-cm length of wire within the uniform field B is

$$F = I\ell B\sin\theta = (30\,\mathrm{A})(0.12\,\mathrm{m})(0.90\,\mathrm{T})(0.866) = 2.8\,\mathrm{N}.$$

If the wire is perpendicular to the field:

$$F = BLI\ \sin\theta$$

$$F = 30 * 0.12 * 0.9 = 3.24N$$

EXERCISE D A straight power line carries 30 A and is perpendicular to the Earth's magnetic field of 0.50×10^{-4} T. What magnitude force is exerted on 100 m of this power line?

A coil consists of 200 turns of wire. Each turn is a square of side 18 cm, and a uniform magnetic field directed perpendicular to the plane of the coil is turned on. If the field changes linearly from 0 to 0.50 T in 0.80 s, what is the magnitude of the induced emf in the coil while the field is changing?

Solution The area of one turn of the coil is $(0.18\text{ m})^2 = 0.0324\text{ m}^2$. The magnetic flux through the coil at $t = 0$ is zero because $B = 0$ at that time. At $t = 0.80$ s, the magnetic flux through one turn is $\Phi_B = BA = (0.50\text{ T})(0.0324\text{ m}^2) = 0.0162\ \text{T}\cdot\text{m}^2$. Therefore, the magnitude of the induced emf is, from Equation 31.2,

$$|\mathcal{E}| = N\frac{\Delta\Phi_B}{\Delta t} = 200\ \frac{(0.0162\text{ T}\cdot\text{m}^2 - 0)}{0.80\text{ s}}$$

$$= 4.1\text{ T}\cdot\text{m}^2/\text{s} = \boxed{4.1\text{ V}}$$

Quick Quiz 29.1 The north-pole end of a bar magnet is held near a positively charged piece of plastic. Is the plastic (a) attracted, (b) repelled, or (c) unaffected by the magnet?

Quick Quiz 29.2 A charged particle moves with velocity **v** in a magnetic field **B**. The magnetic force on the particle is a maximum when **v** is (a) parallel to **B**, (b) perpendicular to **B**, (c) zero.

Quick Quiz 29.3 An electron moves in the plane of this paper toward the top of the page. A magnetic field is also in the plane of the page and directed toward the right. The direction of the magnetic force on the electron is (a) toward the top of the page, (b) toward the bottom of the page, (c) toward the left edge of the page, (d) toward the right edge of the page, (e) upward out of the page, (f) downward into the page.

Quick Quiz 29.5 A wire carries current in the plane of this paper toward the top of the page. The wire experiences a magnetic force toward the right edge of the page. The direction of the magnetic field causing this force is (a) in the plane of the page and toward the left edge, (b) in the plane of the page and toward the bottom edge, (c) upward out of the page, (d) downward into the page.

Quick Quiz 29.4 The four wires shown in Figure 29.11 all carry the same current from point *A* to point *B* through the same magnetic field. In all four parts of the figure, the points *A* and *B* are 10 cm apart. Rank the wires according to the magnitude of the magnetic force exerted on them, from greatest to least.

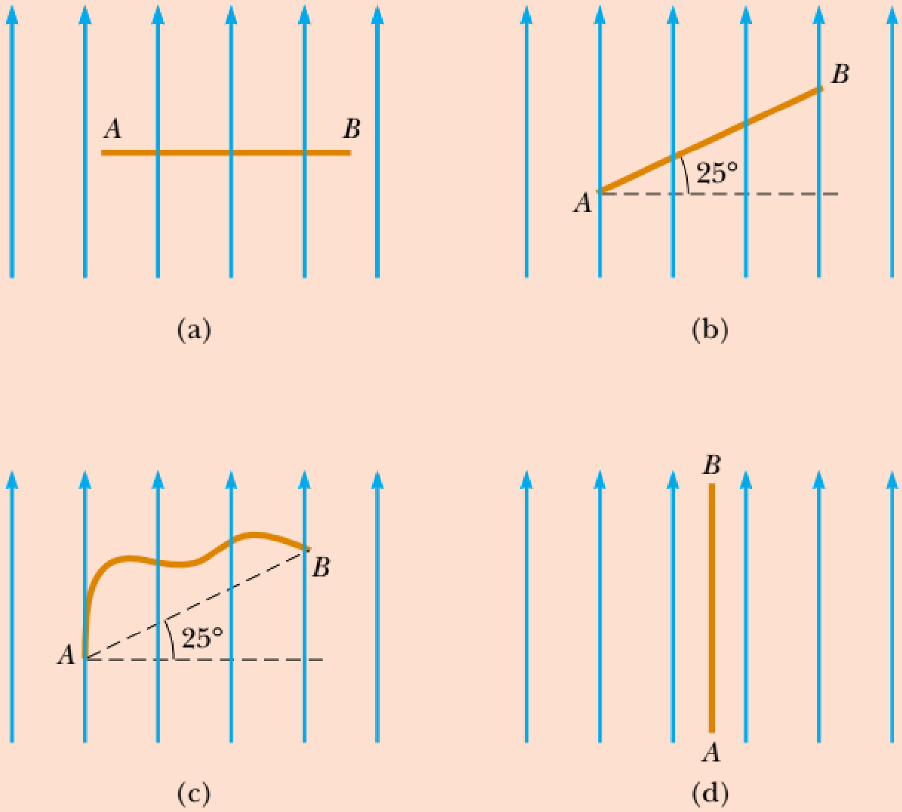


Figure 29.11 (Quick Quiz 29.4) Which wire experiences the greatest magnetic force?

Quick Quiz 29.5 A wire carries current in the plane of this paper toward the top of the page. The wire experiences a magnetic force toward the right edge of the page. The direction of the magnetic field causing this force is (a) in the plane of the page and toward the left edge, (b) in the plane of the page and toward the bottom edge, (c) upward out of the page, (d) downward into the page.

A wire 2.80 m in length carries a current of 5.00 A in a region where a uniform magnetic field has a magnitude of 0.390 T. Calculate the magnitude of the magnetic force on the wire assuming the angle between the magnetic field and the current is (a) 60.0°, (b) 90.0°, (c) 120°.