**Experiment No : ** EM6

Experiment Name: Current Balance / Force acting on a current-carrying conductor

Objective: To observe the force acting on the current-carrying loops with various sizes and shapes in a uniform magnetic field and to determine which parameters that the Lorentz force depends on.

Keywords: Lorentz force, magnetic force, magnetic field, moving charges, current, right-hand rule.

Theoretical Information:

The force on a current-carrying conductor can be calculated starting with the magnetic force $\vec{F}_B = q\vec{v} \times \vec{B}$ on a single moving charge.

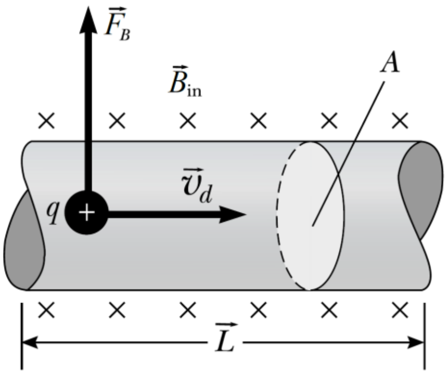

Figure 6.1: A segment of a current-carrying wire in a magnetic field B.

Figure 6.1 shows a straight segment of a conducting wire, with length L and cross-sectional area A, the current is from left to right. The wire is in a uniform magnetic field $\vec{B}$, perpendicular to the plane of the diagram and directed *into* the plane.

The drift velocity $\vec{v}_d$ is to the right and perpendicular to $\vec{B}$. The average force on each charge is $\vec{F}_B = q\vec{v}_d \times \vec{B}$ directed to the up as shown in Figure 6.1; since $\vec{v}_d$ and $\vec{B}$.are perpendicular, the magnitude of the force is

$$F_B = qvBsin\phi = qvB_{\perp} \qquad 6.1$$

where ϕ is the smaller angle between $\vec{v}$ and $\vec{B}$.

From Equation 6.1 the *units* of B must be the same as the units of Fq/v. Therefore, the SI unit of B is equivalent to $1\text{N}\cdot\text{s/C}\cdot\text{m}$ or, since one ampere is one coulomb per second $(1\text{A}=1\text{C/s})$, $1\text{N/A}\cdot\text{m}$. This unit is called the Tesla (abbreviated T), in honor of Nikola Tesla (1856–1943), the prominent Serbian-American scientist and inventor:

$$1 \text{ Tesla} = 1\text{T} = 1\ \frac{\text{N}}{\text{C}\cdot \text{m/s}} = 1\ \frac{\text{N}}{\text{A}\cdot\text{m}}$$

We can derive an expression for the total force on all the moving charges in a length L of conductor with cross-sectional area A. The number of charges per unit volume is n; a segment of conductor with length L has volume AL and contains a number of charges equal to nAL. The total force $\vec{F}_B$ on *all* the moving charges in this segment has magnitude

$$F = (nAL)(qv_dB) = (nqv_dA)(LB) \quad 6.2$$

The current density J is

$$J = \frac{I}{A} = n|q|v_d \quad 6.3$$

Therefore, from Equation 6.3, the product JA is the total current I so we can rewrite Equation 6.2 as

$$F = ILB \quad 6.4$$

If the field $\vec{B}$ is not perpendicular to the wire but makes an angle ϕ with it, only the component of $\vec{B}$ perpendicular to the wire (and to the drift velocities of the charges) exerts a force; this component is $B_\perp = Bsin\phi$. The magnetic force on the wire segment is then

$$F = ILB_\perp = ILBsin\phi \quad 6.5$$

The force is always perpendicular to both the conductor and the field, with the direction determined by the *right-hand rule*. Hence this force can be expressed as a vector product, just like the force on a single moving charge. We represent the segment of wire with a vector $\vec{L}$ along the wire in the direction of the current I, and has a magnitude equal to the length L of the segment; then the force $\vec{F}$ on this segment is

$$\vec{F}_B = I\vec{L} \times \vec{B} \quad 6.6$$

Note that this expression applies only to a straight segment of wire in a uniform magnetic field. If the conductor is not straight, we can divide it into infinitesimal segments $d\vec{s}$. The force $d\vec{F}$ on each segment is

$$d\vec{F}_B = Id\vec{s} \times \vec{B} \quad 6.7$$

Then we can integrate this expression along the wire to find the total force on a conductor of any shape.

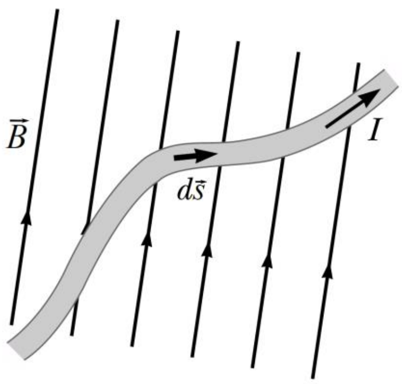

Figure 6.2: A wire segment of arbitrary shape carrying a current I in a magnetic field B experiences a magnetic force.

To calculate the total force $\vec{F}_B$ acting on the wire shown in Figure 6.2, we integrate Equation 6.7 over the length of the wire:

$$\vec{F}_B = I\int_a^b d\vec{s} \times \vec{B} \qquad 6.8$$

where a and b represent the end points of the wire. When this integration is carried out, the magnitude of the magnetic field and the direction the field makes with the vector $d\vec{s}$ may differ at different points.

The direction of the magnetic force on current carrying wire is defined by *right-hand rule*. Figure 6.3 reviews two right-hand rules for determining the direction of the cross product $\vec{L} \times \vec{B}$ and the direction of the magnetic force $\vec{F}_B = I\vec{L} \times \vec{B}$ acting on a wire with current I with a length $\vec{L}$ in a magnetic field $\vec{B}$. The rule in Figure 6.3(a) depends on right-hand rule for the cross product. The fingers point in the direction of $\vec{L}$, where $\vec{L}$ is a vector that points in the direction of the current I, with $\vec{B}$ coming out of your palm, so that you can curl your fingers in the direction of $\vec{B}$. The direction of $\vec{L} \times \vec{B}$, and the force on the wire, is the direction in which the thumb points. An alternative rule is shown in Figure 6.3(b). In this rule, the vector $\vec{L}$ is in the direction of your thumb and $\vec{B}$ in the direction of your fingers. The force $\vec{F}_B$ on the wire is in the direction of your palm, as if you are pushing the wire with your hand.

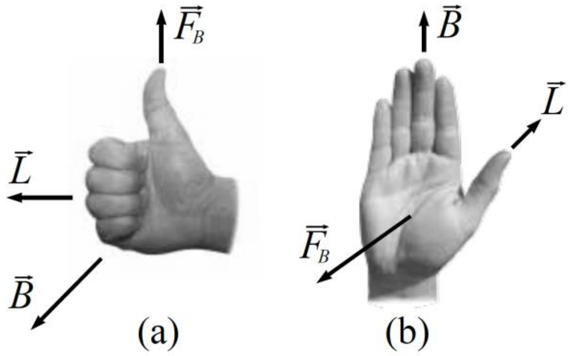

Figure 6.3: Illustrations of the right-hand rules.

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[1] Hugh D. Young, Roger A. Freedman, A. Lewis Ford, Francis Weston Sears, Sears and Zemansky's University Physics with Modern Physics, 13th ed., Pearson (2014).

[2] Raymond A. Serway, John W. Jewett, Physics for Scientists and Engineers, 6th ed., Thomson Brooks/Cole (2004).