UNIT 6 MAGNETISM

Structure

6.1 INTRODUCTION

In Unit 5, you studied electricity and came to know that the electric charges exert force on each other and flow of charge in a conductor constitute electric current. You also learnt how the flow of current in electrical circuits can be used to design and develop variety of appliances for our day-to-day use as well as for the industry. It is, however, important to mention that the numerous applications of electricity has become possible because of the fact that electric current produces magnetic effects. In the present unit, you will learn about magnetism.

The magnetism or the magnetic properties of materials are known since ancient times. It was discovered that some materials such as lodestone or mineral magnetite (an oxide of iron) attracted small pieces of iron. Further, magnetic compass (a tiny bar magnet) has been used for navigation since long. In Section 6.2, you will study the magnetic field produced by magnets and discover that it can be described in terms of magnetic lines of forces (which is almost similar to electric lines of force description of the electric field).

In the early nineteenth century, it was discovered by Oersted that an electric current in a wire deflected a compass needle. This phenomenon led to the understanding of electrical origin of magnetism. In Section 6.3, you will study the relation between the magnetic field and electric current in the form of Biot-Savart's law. You will also learn that a current carrying loop is equivalent to a tiny bar magnet in all respect. Since electric current exerts force on magnets, Newton's third law suggests that magnet should also exert a force on moving charges. It is indeed true and you will study about this in Section 6.4. This effect has been used to develop some basic electrical instruments like galvanometer, ammeter and voltmeter which are also discussed in this section. In Section 6.5, you will learn the behaviour of a moving charged particle subjected to the electric and magnetic fields simultaneously. And, lastly, in Section 6.6, we discuss the broad classification of magnetic materials and their properties.

Objectives

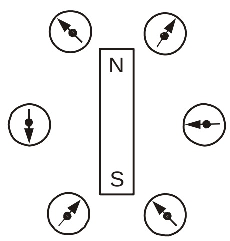
After studying this unit, you should be able to

- explain the concept of magnetic field,
- state Biot-Savart's law and use it to determine magnetic field due to current in a wire,
- derive an expression for the force exerted by magnetic field on a current carrying conductor,
- explain the working of a moving coil galvanometer, a ammeter and a voltmeter,
- describe the working of a cyclotron,
- define physical parameters related to magnetism of materials, and
- classify the magnetic materials.

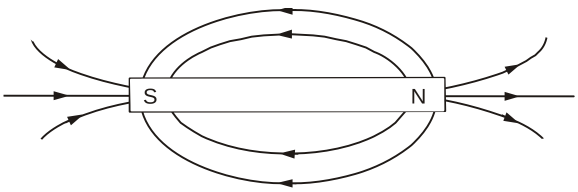
6.2 MAGNETIC FIELD

In Unit 5, you studied that an electric charge produced electric field everywhere in the space. In terms of electric field (E), the magnitude of the electric force experienced by an electron at any point in space is given as $F = e\,E$, where e is the electronic charge.

The effect of magnets can similarly be described in terms of magnetic field B. (Note that, like electric field E, the magnetic field B is also a vector quantity characterised by magnitude and direction.) The magnitude and direction of the magnetic field due to a permanent magnet (such as a bar magnet) can be determined using a compass, as shown in Figure 6.1(a). At a given point around the bar magnet, the equilibrium orientation of the compass needle gives the direction of magnetic field. And the torque, that is, the force experienced by the compass needle gives the magnitude of the magnetic field.



(a)



(b)

Figure 6.1 : (a) Magnetic Field Experienced by a Compass Needle due to a Bar Magnet; and (b) Magnetic Lines of Forces of a Bar Magnet

Similar to the electric lines of forces, we can draw the magnetic lines of forces to depict the spatial distribution of the magnetic field. Refer to Figure 6.1(b) which shows the magnetic lines of forces due to a bar magnet. Some of the characteristics of these lines of forces are given below :

- Conventionally, outside the magnet, the magnetic lines of forces always originate from the north pole and terminate at the south pole.
- The direction of magnetic field B at any point is along the tangent to the line of force at the point.
- The magnitude of the magnetic field is represented by the number of field lines per unit cross-sectional area at the point under consideration; near the north or the south pole of the magnet, the lines are close together indicating larger value of the magnetic field at these points compared to the far off points where separation between lines are larger.

Now, before proceeding further, you may argue : **Even when there are no permanent magnets around, why does the compass needle show deflection when we go from one place to another**? The compass needle is affected by the magnetic field of the earth because (the earth) it behaves like a big bar magnet as shown in Figure 6.2. Note that the magnetic south pole of the earth is located near its geographical north pole and *vice-versa*. The geographical north pole of the earth is called so because it attracts the north pole of the compass needle.

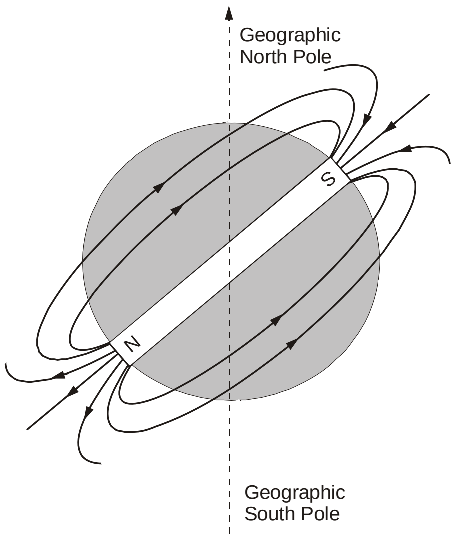


Figure 6.2 : Magnetic Field Lines of the Earth

For a long time, magnetism was considered a bulk property of the materials and there was no explanation as to why some materials exhibited magnetism and others did not. The early clue to understand the cause of magnetism was provided by Oersted who discovered that a current flowing in a wire deflected a compass needle just like a permanent magnet. This was a clear indication that electricity and magnetism were somehow connected to each other. You will learn it now.

6.3 ELECTRIC ORIGIN OF MAGNETISM : BIOT-SAVART'S LAW

Oersted's discovery generated great excitement and scientists were engaged in a variety of experiments to arrive at a law to establish a relation between electricity and magnetism. The basic law was proposed by Biot and Savart which gives the magnetic field produced by a current flowing in a short length segment of a wire.

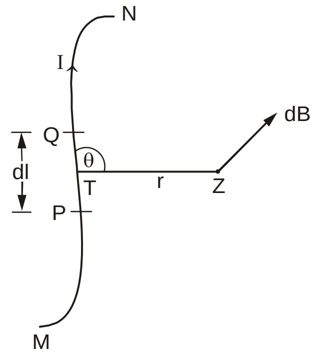


Figure 6.3 : Magnetic Field *dB* due to Current Element *I dl*

Let us consider a conductor wire *MN* in which a steady current *I* is flowing as shown in Figure 6.3. Let *Z* is the point at a distance *r* from the centre (*T*) of the small length element *PQ* (*dl*). It was observed that the magnetic field at point *Z* due to the current element *I dl* is :

(a) directly proportional to the magnitude of the current,

$$dB \propto I \qquad \text{. . . (6.1)}$$

(b) directly proportional to the magnitude of length element,

$$dB \propto dl \qquad \text{. . . (6.2)}$$

(c) directly proportional to the sine of the angle θ between the direction of the flow of current in the wire and the line joining the current element to the observation point *Z*,

$$dB \propto \sin\theta \qquad \text{. . . (6.3)}$$

(d) inversely proportional to the square of the distance *r* between the point *Z* and the current element *I dl*,

$$dB \propto \frac{1}{r^2} \qquad \text{. . . (6.4)}$$

Combining Eqs. (6.1), (6.2), (6.3) and (6.4), we get :

$$dB = \frac{K\,I\,dl\,\sin\theta}{r^2} \qquad \text{. . . (6.5)}$$

where *K* is the proportionality constant. In SI unit, the value of *K* in free space or vacuum is given as :

$$K = \frac{\mu_0}{4\pi}$$

$$= 10^{-7}\ \mathrm{T\,A^{-1}\,m} = 10^{-7}\ \mathrm{Wb\ A^{-1}\,m^{-1}}$$

where μ_0 is called **absolute permeability** or permeability of vacuum or free space. Therefore, we can write Eq. (6.5) as :

$$dB = \frac{\mu_0}{4\pi}\,\frac{I\,dl\,\sin\theta}{r^2} \qquad \text{. . . (6.6)}$$

Eq. (6.6) is known as the **Biot-Savart's law** and gives the magnitude of the magnetic field produced due to a short current element. You may ask : **What is the direction of the magnetic field**? In fact, a more appropriate way of writing the Biot-Savart's law is by using vector notations because, the answer to this question is implicit in the vector form of the law. In vector notation, Biot-Savart's law is given as :

$$d\boldsymbol{B} = \frac{\mu_0}{4\pi} \frac{I\, d\boldsymbol{l} \times \hat{\boldsymbol{r}}}{r^2} \qquad \text{. . . (6.7)}$$

where $\hat{\boldsymbol{r}}$ is the unit vector along the line joining the current element to the point *Z*. The direction of the magnetic field is given by the vector cross-product, $I\, d\boldsymbol{l} \times \hat{\boldsymbol{r}}$. You may recall that the direction of a vector (such as the magnetic field, $d\boldsymbol{B}$) represented by a cross product is given by the **right-hand rule**. According to this rule, if you curl the fingers of the right hand in the sense that will rotate the vector $d\boldsymbol{l}$ (first vector) into $\hat{\boldsymbol{r}}$ (second vector), the extended thumb gives the direction of the magnetic field $d\boldsymbol{B}$. Thus, the magnetic field is directed along a line perpendicular to the plane containing the current element $I\, d\, l$ and the distance *r*.

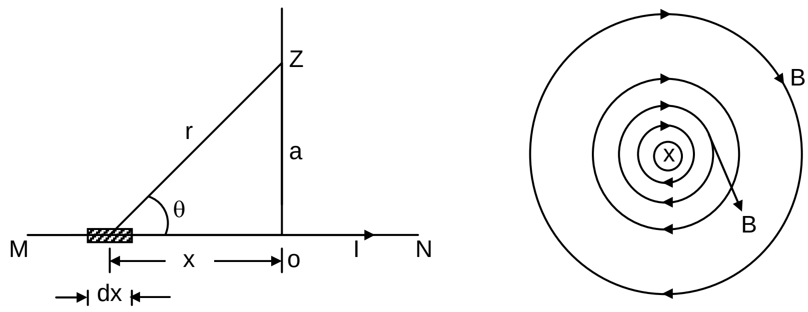
If you look at Eq. (6.6) carefully, you will note that the Biot-Savart's law for magnetic field is very similar to the Coulomb's law for the electric field! Both the fields exhibit inverse square $\left(\frac{1}{r^2}\right)$ dependence on the distance of the point of observation from the sources of the respective fields. The source of magnetic field is the current element $I\, dl$ and the source of the electric field is the point charge *q*. However, there is an important difference between the two fields. While the direction of the electrical field is radial (along the line joining the point charge with the point at which field is measured), the direction of the magnetic field is perpendicular to the distance *r* between the source of the field and the point of observation.

Now, let us apply the Biot-Savart's law to obtain an expression for the magnetic field at a point due to a current carrying wire.

6.3.1 Magnetic Field due to Current in a Straight Long Wire

Let current *I* is flowing in a long, straight wire *MN* (Figure (6.4)). Let the point *Z* at which magnetic field is to be calculated is at a perpendicular distance *a* from the wire. Let us first consider a small portion of length *dx* of the wire such that $ZP = r$ and the angle between *r* and *dx* is θ. Then, according to the Biot-Savart's law, the magnitude of the magnetic field at *Z* due to current element *Idx* is :

$$dB = \frac{\mu_0}{4\pi} \frac{I\; dx \sin\theta}{r^2} \qquad \text{. . . (6.6)}$$



(a) (b)

Figure 6.4 : (a) Magnetic Field due to a Long Straight Current Carrying Wire; and (b) Magnetic Field due to Current into the Page

Now, to obtain the magnetic field due to the entire length of the wire *MN*, note that the wire can be considered as a series of length elements, each of length *dx*. The direction of the magnetic fields due to all such length elements would be along the same line. You should convince yourself about this by using the right hand rule. Further, the magnitude of total field at point *Z* can be obtained by taking the sum of contributions by each current element. That is, we can find the desired result by integrating *dB* over the entire length of the wire :

$$B = \int dB = \frac{\mu_0}{4\pi} \int \frac{I \; dx \sin\theta}{r^2} \qquad \text{. . . (6.8)}$$

Since the wire *MN* is very long, the limits of integration of *dB* can be taken as $x = -\infty$ to $x = +\infty$. Note that these limiting values of *x* refers to an infinitely long wire, which is an idealization.

Further, from the geometry of Figure 6.4, we have

$$\sin\theta = \frac{a}{r} \text{ and } r^2 = a^2 + x^2 ,$$

Substituting for $\sin\theta$ and *r*, in Eq. (6.8) we get :

$$B = \frac{\mu_0}{4\pi} \int_{-\infty}^{+\infty} \frac{I\,a\,dx}{r^3}$$

$$= \frac{\mu_0}{4\pi} \int_{-\infty}^{+\infty} \frac{I\,a\,dx}{(a^2 + x^2)^{3/2}} \qquad \text{. . . (6.9)}$$

We write the final result (without solving the integral) for the magnitude of the magnetic field (Eq. (6.9)) as :

$$B = \frac{\mu_0 I}{2\pi a} \qquad \text{. . . (6.10)}$$

Eq. (6.10) gives the magnitude of the magnetic field at a point due to current in a long, straight wire. The direction of the field can be ascertained by using the right hand rule mentioned earlier. Figure 6.4(b) shows the magnetic field due to a wire carrying current into the page (direction of the current into the page is shown by $\otimes$.

The concept that magnetic fields are produced by charges in motion (that is, current) is rather difficult to visualise. This difficulty is overcome if we consider the magnetic field produced by a current carrying loop. The profile of the magnetic field of a current loop is very similar to that of a bar magnet and hence easier to visualise. You will learn it now. But, first you should solve the following SAQ.

SAQ 1

Determine the magnitude of the magnetic field at a point 20 cm away from a straight wire which carries a current of 5 A.

6.3.2 Magnetic Field due to a Current Loop

The magnetic field due to a circular loop (ring shaped current carrying wire) can be determined using the Biot-Savart's law. For simplicity of derivation, we determine the magnetic field at a point on the axis of the loop. Let *P* is the point on the axis of the loop at a distance *x* from its centre *O* (Figure 6.5).

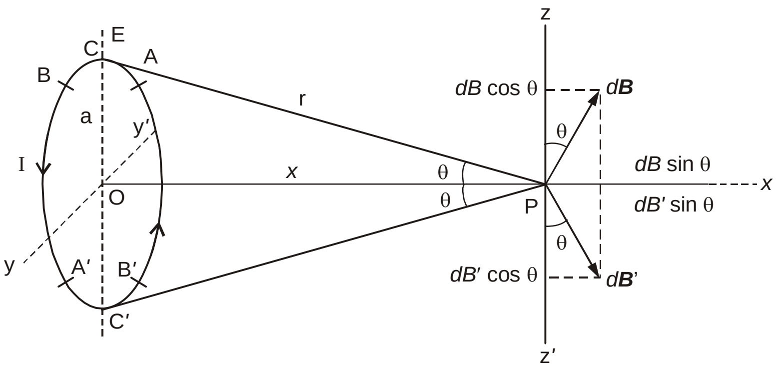


Figure 6.5 : Magnetic Field at a Point *P* on the Axis of the Current Loop

First, we consider a small length element *AB* of the loop and find the magnetic field due to it. Let *r* is the distance of the point *P* from the middle point *C* of the current element *AB* (that is, *Idl*). Then, according to the Biot-Savart's law (Eq. (6.6)), the magnitude of the magnetic field at *P* due to *AB* is :

$$dB = \frac{\mu_o}{4\pi} \frac{I\ dl}{r^2} \qquad \ldots (6.11)$$

because the angle between *I dl* and *r* is 90°.

Let us consider another current element *A′B′* opposite to the current element *AB* on the circular loop. Let the magnetic field due to this current element be $d\mathbf{B}'$. The symmetry of the figure (refer to Figure 6.5) suggests that the magnitudes of $d\mathbf{B}$ and $d\mathbf{B}'$ would be the same. That is, $dB = dB'$. However, the directions of $d\mathbf{B}$ and $d\mathbf{B}'$ is not the same. $d\mathbf{B}$ and $d\mathbf{B}'$ being vectors, they can be resolved into components as shown in the figure. The perpendicular components (components along *zz′*) of the two fields cancel each other being equal in magnitude and opposite in direction. Thus, the resultant field at *P* due to these current elements will be along the *x*-axis, *PX*. The same argument holds true for such other pairs of current elements over the entire circumference of the loop. Therefore, the magnetic field at a point on the axis of the loop points along the axis and its magnitude is obtained by integrating the *x*-component of *dB* over the circular loop :

$$B = \int dB_x$$

$$= \int dB \sin\theta$$

$$= \frac{\mu_0}{4\pi} \int \frac{I\,dl\,\sin\theta}{r^2} \qquad \ldots (6.12)$$

using Eq. (6.11). From Figure 6.5, we have :

$$r^2 = (a^2 + x^2)$$

and $$\sin\theta = \frac{a}{r}$$

$$= \frac{a}{(a^2 + x^2)^{1/2}}$$

Thus, we can write Eq. (6.12) as :

$$B = \frac{\mu_0}{4\pi} \cdot \frac{I\,a}{(a^2 + x^2)^{3/2}} \int dl$$

Since the integral of length element *dl* over the loop is equal to its circumference, we have :

$$\int dl = 2\pi a$$

Thus, we can write :

$$B = \frac{\mu_0}{4\pi} \cdot \frac{2\pi\, I\, a^2}{(a^2 + x^2)^{3/2}} \qquad \ldots (6.13)$$

If the point *P* is taken at the centre of the loop, we have $x = 0$, and Eq. (6.13) reduces to :

$$B = \frac{\mu_0}{4\pi} \cdot \frac{2\pi\, I}{a}$$

$$= \frac{\mu_0 I}{2a} \qquad \ldots (6.14)$$

(a) **(b)**

Figure 6.6 : Magnetic Field Lines due to (a) a Current Loop; and (b) a Small Bar Magnet

Now, in order to visualise the similarity between the magnetic fields produced by electric current and a permanent magnet, refer to Figure 6.6. It shows that the magnetic field lines due to current loop and a small bar magnet are very similar to each other.

Till now, you studied the magnetic field and also learnt the electric origin of magnetism in terms of magnetic field produced by electric current. So, you now know that stationary charge or a charge distribution gives rise to electric field and moving charges (electric current) produce magnetic fields. Looking at the similarities between the electric and magnetic fields, a logical question which may be asked at this point is : **Does magnetic field exert force of charged particles?** Let us learn about this aspect of magnetic field. But, before that, how about solving an SAQ?

SAQ 2

5A current is flowing in a circular loop of diameter 0.5 m. Calculate the magnetic field due to this coil at a distance of 0.15 m along the axis of the loop from its centre. What will be the magnetic field if the point is taken at the centre of the coil?

6.4 EFFECTS OF MAGNETIC FIELD ON ELECTRIC CURRENT

You know from Unit 5 that a charge q placed in an electric field E experiences electric force F given as $F = q\,E$. However, if you bring a magnet near a **stationary** charged particle, nothing happens : *a stationary charge does not experience force due to magnetic field*. This is a crucial difference between the electric field and the magnetic field.

However, when a charged particle is **moving** in a magnetic field, it experiences a force. For example, when a magnet is brought near a cathode-ray tube, the beam of electrons is deflected. You may ask : **What is the magnitude of the force due to magnetic field**? To find the answer, consider a charge q moving with velocity v along OP and a magnetic field B, directed along OQ, is acting on it (Figure 6.7). The magnitude of the force experienced by charge q is given as :

$$F = qvB \sin\theta \qquad \text{. . . (6.15)}$$

where θ is the angle between the direction of motion of charge q (OP) and the direction of the magnetic field (OQ). Note that OP and OQ are in the same plane. You may ask : **What is the direction of the force**? To answer this question, we may write Eq. (6.15) in vector form as :

$$\boldsymbol{F} = q\boldsymbol{v} \times \boldsymbol{B}$$

Note that the above expression is a vector cross-product. You know that, direction of a vector represented by a cross-product of two vectors $\boldsymbol{A}$ and $\boldsymbol{B}$ is along a line perpendicular to the plane containing $\boldsymbol{A}$ and $\boldsymbol{B}$. Thus, the direction of the magnetic force ($\boldsymbol{F}$) is along a line (OX) perpendicular to the plane containing $\boldsymbol{v}$ and $\boldsymbol{B}$ with a right hand sense. Further, due to the magnetic field, the direction of the force on a negative charge is opposite to the direction of the force on a positive charge. This follows from the fact that the direction of $-q\,\boldsymbol{v} \times \boldsymbol{B}$ is opposite to the direction of
$q\,\boldsymbol{v} \times \boldsymbol{B}$.

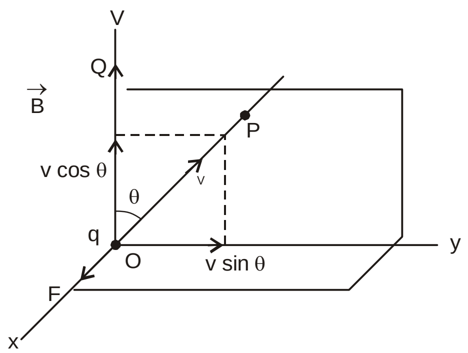


Figure 6.7 : Force Exerted by Magnetic Field (*B*) on a Charge *q* Moving with Velocity *v*

Note from Eq. (6.15) that the magnitude of the force will be maximum when $\theta = \frac{\pi}{2}$ (because $\sin\frac{\pi}{2} = 1$, maximum value of the sine function). This implies that, the moving charge experiences maximum force if its direction of motion is perpendicular to the direction of the magnetic field. On the other hand, when the charge is moving along or opposite to the direction of magnetic field (that is, θ = 0, or π), it does not experience any force. This direction is known as *zero-force direction*.

Thus, you can conclude that a particle placed in a magnetic field will experience a force :

- if it carries electric charge, and
- if it is moving.

An important aspect of magnetic field is that the force exerted by it on a moving charge does not change the magnitude of its velocity; only the direction of motion of the charge is changed (deflection). **This implies that the kinetic energy of the charged particle remains the same while it moves in a magnetic field**.

Since the moving charges constitute electric current, we should expect that a current carrying wire in a magnetic field will also experience a force and get deflected. This is indeed the case. The deflecting force depends on the length of the wire, the value of current and the magnetic field. To obtain the relation between these parameters, let us consider a wire of length l in which current I is flowing (Figure 6.8). Let the wire be placed in a uniform magnetic field B.

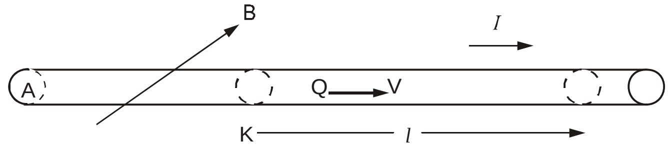


Figure 6.8 : Force on a Current Carrying Wire in a Magnetic Field

If the charges constituting the current are moving with a velocity v in the wire, they will travel the total length l of the wire in time $t = \frac{l}{v}$. Thus, we can write the total charge moving through the conductor as :

$$q = I\,t$$

$$= I\left(\frac{l}{v}\right)$$

Substituting the above value of q in Eq. (6.15), we get :

$$F = I\left(\frac{l}{v}\right) \times v\ B \sin\theta$$

$$= I\,l\,B \sin\theta \qquad \ldots (6.16)$$

where θ is the angle between the direction of current flow in the wire and the direction of the magnetic field. The direction of the force experienced by a current carrying wire in a magnetic field is determined by **Fleming's left hand rule**. *According to this rule, if we stretch the thumb, middle finger and first finger of the left hand mutually perpendicular to each other, and the first finger points along the direction of the magnetic field, the central finger points along the direction of the current then the thumb points along the direction of the force on the current carrying wire.*

The effect of magnetic field on a current carrying wire can be generalised for the situation when the wire is in the shape of a loop. Such a current carrying loop experiences torque due to the magnetic field and this phenomenon has been put to use in developing a variety of instruments and appliances. It is, therefore, important to learn about the torque on a current carrying loop placed in a magnetic field.

6.4.1 Torque on a Current Loop

Refer to Figure 6.9 which depicts a current carrying rectangular loop (or coil) *ABCD* suspended in a uniform magnetic field *B*. Suppose *I* is the current flowing in the coil. The direction of the magnetic field *B* is along the plane of the paper from left to right. Let *l* be the length (*AB* or *CD*) and *b* be the breadth (*AD* or *BC*) of the coil. Let normal to the plane of the coil makes an angle θ with the direction of the magnetic field.

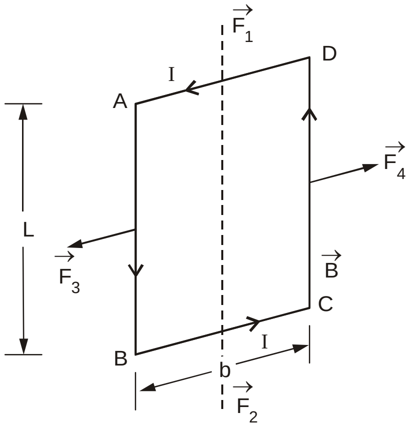


Figure 6.9 : Current Carrying Loop in a Uniform Magnetic Field

Now, the question is : **What is the force experienced by the coil *ABCD* due to the magnetic field**? To find an answer, you must remember that the direction of the force due to magnetic field depends on the directions of the current in the wire and the magnetic field. With this thing in mind, let us consider different length segments of the loop.

The directions of current in the sides *AD* and *BC* of the coil is such that the forces F_1 and F_2 acting on them respectively are equal in magnitude but opposite in direction (see Figure 6.13). You should convince yourself about this statement by using the Fleming's left hand rule stated above. Further, these forces have the same line of action. Therefore, their resultant effect on the coil is zero.

The forces F_3 and F_4 acting on sides *AB* and *CD* respectively are equal in magnitude but they do not act along the same line (that is, they have different lines of action). These forces produce a torque on the loop and tries to turn it. The magnitude of torque, τ, is given by :

τ = Force (F_3 or F_4) × Perpendicular distance between the lines of action of these forces.

$$= B\,I\,l \times (b \sin\theta)$$

Since the surface area of the coil, $A = l \times b$, we can write :

$$\tau = B\,I\,A \sin\theta \qquad \text{. . . (6.17)}$$

If instead of a single loop, we have a coil having *N* turns (loops), Eq. (6.17) reduces to :

$$\tau = N\,B\,I\,A \sin\theta \qquad \text{. . . (6.18)}$$

In case the plane of the loop is perpendicular to the magnetic field, net torque on it is zero (as evident from the above expression). The above expression also holds for planar current loop of any shape.

Therefore, the net results of keeping a current loop in a magnetic field is that the loop tends to rotate. This effect has been used to develop electrical instruments such as galvanometer, ammeter and voltmeter. You will learn about them now.

6.4.2 Galvanometer, Ammeter and Voltmeter

Galvanometer

Galvanometer is an instrument which is used for detection and measurement of small current or small potential difference in an electrical circuit. It is also called **moving coil galvanometer** because its main component is a coil which moves (rotates) when current flows through it. The working of this instrument is based on the principle that when a current carrying coil is placed in a magnetic field, it experiences a torque.

A schematic diagram of the galvanometer is shown in Figure 6.10. It consists of a coil *OPQR* wound on a soft iron core and placed between the poles of a permanent magnet *NS*. The coil is suspended from the torsion head with a suspension wire and the other end of the coil is attached to a spring. A concave mirror *M* is attached to the suspension wire. A pointer is attached to the coil which moves on a galvanometer scale for measuring current. **The deflection of the pointer on the scale is proportional to the current in the coil**. The zero of the galvanometer is usually in the middle of the scale. Thus, we can measure current flow in either direction. The whole arrangement is enclosed in a non-magnetic case to avoid disturbance due to air. The leveling screws are used to level the galvanometer so that the coil can rotate freely without touching the poles of the magnet or iron core. T_1 and T_2 are the binding screws used to connect the galvanometer in the electrical circuit.

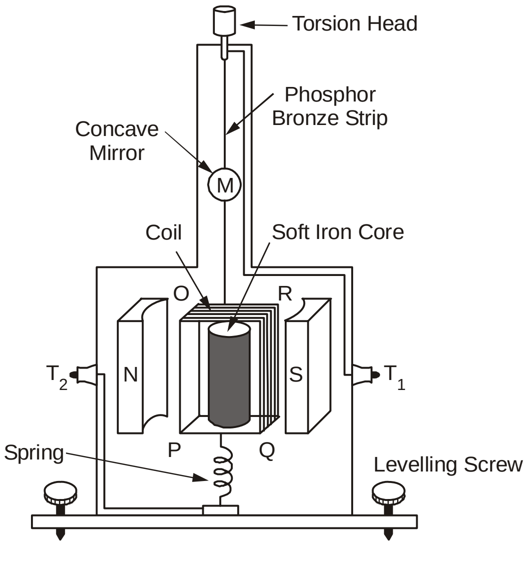


Figure 6.10 : Schematic Diagram of a Galvanometer

When current is not flowing through the galvanometer, the plane of the coil is parallel to the magnetic field. As the galvanometer is connected in a circuit and current flows through it, the coil rotates due to the torque acting on it as discussed above. Rotation of the coil is opposed by the restoring torque developed in the spring. The coil rotates and attains an equilibrium position when the deflecting torque is balanced by the restoring torque developed in the spring.

Let K be the restoring torque per unit twist and α is the angle of twist (that is, the coil comes to rest after rotating through an angle α). Thus, for the equilibrium position, we can write from Eq. (6.18) :

$$N\,B\,I\,A \sin\theta = K\,\alpha \qquad \text{. . . (6.19)}$$

The left hand side of Eq. (6.19) represents the deflecting torque and the right-hand side represents the restoring torque. The poles of the magnet are made concave to produce radial magnetic field. For radial magnetic field, $\theta = 90$, and we can write Eq. (6.19) as :

$$N\,B\,I\,A = K\,\alpha$$

or,
$$I = \left(\frac{K}{N\,B\,A}\right)\alpha$$

The term $\left(\frac{K}{N\,B\,A}\right)$ is called the **galvanometer constant**, G. Thus, we can write :

$$I = G\,\alpha \qquad \text{. . . (6.20)}$$

Eq. (6.20) shows that the current flowing through galvanometer is proportional to the deflection of its coil. Such a galvanometer will have a linear scale.

The galvanometer constant, G, plays an important role in determining the sensitivity of a galvanometer. If a galvanometer gives a large deflection even when a small current passes through it or a small voltage applied across the coil of the galvanometer produces a large deflection of the pointer (that is, the coil) of the galvanometer, it is said to be **sensitive**. Sensitivity of the galvanometer is of two types : current sensitivity and voltage sensitivity.

Current Sensitivity is defined as the deflection produced in the galvanometer on passing unit current through its coil. That is,

$$\text{Current sensitivity } = \frac{\alpha}{I}$$

$$= \frac{N\,B\,A}{K}$$

where α is the deflection corresponding to a current I through the coil.

Voltage Sensitivity is defined as the deflection produced in the galvanometer when a unit voltage (V) is applied across its coil. That is,

$$\text{Voltage sensitivity} = \frac{\alpha}{V}$$

Using the relation $V = I\,R$, where R is the resistance of the coil, we get :

$$\text{Voltage sensitivity } = \frac{\alpha}{I\,R} = \frac{N\,B\,A}{K\,R}$$

Thus, on the basis of the expressions for current and voltage sensitivities, you may conclude that a galvanometer will be highly sensitive if the values of N, B and A are large and that of K and R are small.

To obtain a large value of B, a strong horse-shoe magnet is used. To decrease the value of the restoring torque, K, the suspension wire is made of phosphor bronze or quartz. The value of N and A cannot be increased beyond a certain limit because increase in the size and in number of turns in the coil will lead to increase in electrical resistance of the galvanometer.

Ammeter

An ammeter is an instrument used to measure current in electrical circuits. Ammeter is essentially a galvanometer in which a known low resistance called shunt (S) is connected in parallel to the galvanometer as shown in Figure 6.11. You may ask : **Why do we do so**?

Suppose S is a shunt, G is the galvanometer and G_R is the resistance of the coil of the galvanometer. Since the value of G_R is low, large current passing through the galvanometer may damage its coil. This means that **we cannot measure large currents using a galvanometer**. This limitation is overcome by joining a low resistance (shunts) in parallel to the galvanometer. By doing so, the galvanometer is protected from strong currents so that its coil does not get damaged.

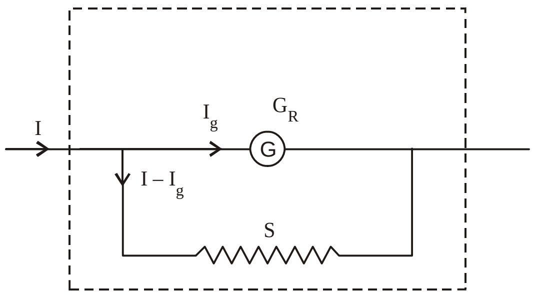


Figure 6.11 : An Ammeter

Let I is the total current in the circuit, I_g be the value of current through the galvanometer for which it gives full scale deflection. $(I - I_g)$ is the current through the shunt resistance. Since the galvanometer and S are in parallel, the potential difference across them will be equal. That is,

$$(I - I_g) \times S = I_g G_R$$

$$S = \frac{I_g}{(I - I_g)} G_R \qquad \text{. . . (6.21)}$$

And, the total resistance of the ammeter is given by :

$$\frac{1}{R_T} = \frac{1}{G_R} + \frac{1}{S}$$

$$\frac{1}{R_T} = \frac{S + G_R}{S G_R}$$

$$\boxed{R_T = \frac{S G_R}{S + G_R}} \qquad \text{. . . (6.22)}$$

The resistance of the ammeter is very low as compared to that of the galvanometer. Therefore, the ammeter is placed in series in a circuit and the resistance of the circuit practically remains unchanged. That is, connecting an ammeter in a circuit does not affect the current in the circuit.

To measure potential difference between two points in a circuit, we use a voltmeter. We now discuss the construction and working of a voltmeter.

Voltmeter

Voltmeter is essentially a galvanometer to which a known high resistance (R) is connected in series (Figure 6.12).

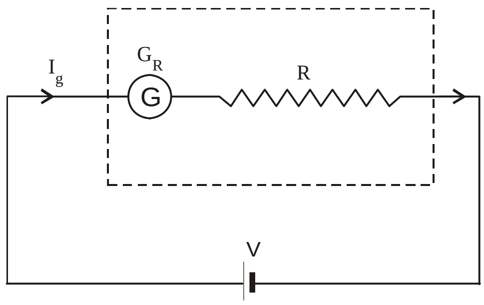


Figure 6.12 : A Voltmeter

The modification in the galvanometer is done so that it can measure potential difference without causing any change in the value of current flowing through a circuit. The value of R is so adjusted that when a battery of V volt is connected to the galvanometer, it gives fullscale deflection. As galvanometer G and, high resistance R are connected in series, the total resistance of voltmeter is equal to $G_R + R$. Thus, using Ohm's law, we can write :

$$I_g = \frac{V}{G_R + R}$$

or, $$I_g \; (G_R + R) = V$$

or, $$R = \frac{V}{I_g} - G_R \qquad \text{. . . (6.23)}$$

Voltmeter is a high resistance instrument. Therefore, it is connected in parallel to the points between which voltage is to be measured.

By now, you are familiar with the magnetic field due to electric current and the effect of magnetic field on current carrying conductors. Let us now discuss the nature of motion of isolated charged particles under the influence of magnetic field.

6.5 MOTION OF A CHARGED PARTICLE IN MAGNETIC FIELD

You may recall from Unit 5 that the magnitude of force experienced by a charged particle q in an electric field E is given by :

$$F = qE \qquad \text{. . . (6.24)}$$

And the magnitude of force on the charged particle q moving with velocity v in a magnetic field B is given by (Eq. 6.15) :

$$F = q\,v\,B \sin\theta \qquad \text{. . . (6.15)}$$

Thus, if a charged particle moves in a region where electric and magnetic fields exist, it will experience a force which can be written by combining Eqs. (6.24) and (6.15) :

$$F = qE + qvB \sin\theta \qquad \text{. . . (6.25)}$$

Eq. (6.25) is called the **Lorentz force**. Also, the second term on the right hand side of Eq. (6.25) is called **magnetic Lorentz force**.

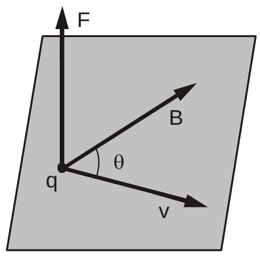


Figure 6.13 : Force on a Charge Moving in Magnetic Field

You may recall that the force experienced by the charge acts in a direction perpendicular to both – its velocity *v* and the magnetic field *B* (Figure 6.13). The question is : **How do we describe the motion of a charged particle in magnetic field when *v* is perpendicular to *B*?**

When the velocity of the charged particle is perpendicular to the direction of *B*, it moves along a **circular path**. The trajectory of charge is circular because *v* and the force (and hence acceleration) due to magnetic field are perpendicular to each other. Let *m* be the mass of the charged particle and *r* is the radius of its circular path. The centripetal acceleration $\left(= \frac{v^2}{r} \right)$ of the charged particle is due to the magnetic Lorentz force and we can write (Eq. (6.25)) :

$$q\ v\ B \sin\ \theta = \frac{mv^2}{r} \qquad \text{. . . (6.26)}$$

where $\frac{mv^2}{r}$ is the centripetal force. Since *v* is perpendicular to *B*, $\theta = 90^\circ$ and Eq. (6.26) reduces to :

$$q\ v\ B = \frac{mv^2}{r}$$

or,

$$r = \frac{mv}{qB} \qquad \text{. . . (6.27)}$$

Eq. (6.27) gives the radius of the circular path of the charged particle. Since the motion of the charged particle is circular, we can write the expression for the time period of this motion as :

$$T = \frac{2\pi\ r}{v}$$

$$= \frac{2\pi\ m}{Bq} \qquad \text{. . . (6.28)}$$

using Eq. (6.27). Further, expression for angular frequency is given by :

$$\omega = \frac{2\pi}{T}$$

$$= \frac{Bq}{m} \qquad \text{. . . (6.29)}$$

using Eq. (6.28). **Note from Eqs. (6.28) and (6.29) that the time period (*T*) and angular frequency (ω) of a charged particle moving in a uniform magnetic field do not depend on (i) the magnitude of its velocity, and (ii) the radius of circular path**. This characteristic of the motion of charged particle in magnetic field is made use of to accelerate positive ions and such an accelerator is called **cyclotron**. Let us discuss its construction and working now.

6.5.1 Cyclotron

It is a device used to accelerate positive ions such as proton and α-particles.

Refer to Figure 6.14 which shows a schematic diagram of a cyclotron. It consists of two dees D_1 and D_2 which are hollow semicircular metal chambers of *D* shape connected to a source of high frequency electric field. They are placed horizontally with a small gap separating them. In this gap, the positive ions are produced by the ionization of the gas. The dees are enclosed in a metal box containing a gas at a low pressure (~ 10^{-3} mm of Hg). The whole apparatus is placed between the two poles of a strong electromagnet. The magnetic field is perpendicular to the plane of the dees.

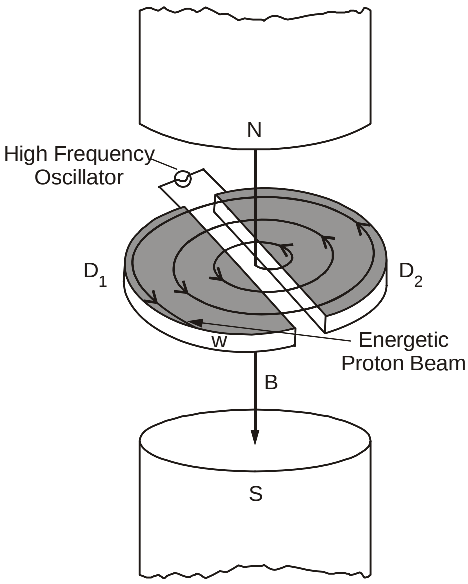


Figure 6.14 : Schematic Diagram of a Cyclotron

Suppose, initially the dee D_1 is at positive potential and dee D_2 is at negative potential. When the positive ion is produced at the centre of the gap, it moves along a direction from D_1 to D_2. Since the magnetic field is perpendicular to the motion of the positive ion, the ion experiences a force which deflects it in a circular path. The radius, *r*, of a semicircular path is given by Eq. (6.27).

When the positive ion reaches the gap between the two dees after traversing the semicircular path, the polarity of the dees reverses due to alternating electric field, that is, D_1 becomes negative and D_2 becomes positive. As a result, the positive ion is accelerated because it is attracted by the dee D_1. Again, when it reaches the gap, the polarity of dees reverses and the ion is further accelerated and gains energy. This process is repeated till the ion acquires desired acceleration or kinetic energy. In this manner, the positive ion is accelerated by the combined effect of electric and magnetic fields.

The expression for time period *T* for the circular path of the ion is given by Eq. (6.28) and using this equation, we can write the time (*t*) spent inside a dee to cover semicircular path as :

$$t = \frac{T}{2} = \frac{\pi m}{Bq} \qquad \text{. . . (6.30)}$$

Thus, we can write the cyclotron frequency which is also known as **magnetic resonance frequency** as :

$$f = \frac{1}{T}$$

$$= \frac{Bq}{2\pi m} \qquad \text{. . . (6.31)}$$

using Eq. (6.30). Further, from Eq. (6.27) we write the maximum velocity v_{max} of the ion as :

$$v_{max} = \frac{qBr}{m} \qquad \text{. . . (6.32)}$$

So, the maximum kinetic energy of the ion is expressed as :

$$E_{max} = \frac{1}{2} m v_{max}^2$$

$$= \frac{1}{2} \frac{B^2 q^2 r^2}{m} \qquad \text{. . . (6.33)}$$

Eq. (6.33) shows that larger is the radius of the circular path of the ion, higher is its kinetic energy.

SAQ 3

The radius of a cyclotron's dees is 50 cm and the value of cyclotron frequency is 15 MHz. Calculate the magnetic field required for accelerating protons. Also, calculate the kinetic energy of the proton beam produced by the cyclotron. Take the value of *e* to be 1.6×10^{-19} C and mass of the electron, *m* to be 1.67×10^{-27} kg.

6.6 MAGNETIC MATERIALS

The present day understanding of the magnetic properties of materials is based on the atomic currents. The basic argument in favour of this understanding is rather simple. It says that the negatively charged electrons circulating around the nucleus in the atoms of a material constitute electric current. This microscopic current is known as atomic current. Now, you may recall from Section 6.3 that a current flowing in a loop and a (small) bar magnet produce similar magnetic fields. Thus, atomic currents are responsible for magnetism of materials. Further, the atomic current in materials depends on their electronic structure. This is one of the major reasons why different materials show different magnetic properties. Before we discuss the characteristic features of different types of magnetic materials, it is important to define some terms such as magnetic intensity, magnetic flux and magnetic susceptibility which are used in describing the magnetic properties of materials.

Physical Parameters of Magnetic Materials

Magnetic Intensity

It is defined as the ratio of magnetic field in vacuum (B_0) to the absolute permeability (μ_0). It is also known as magnetic field strength (H). Mathematically, it is expressed as :

$$H = \frac{B_0}{\mu_0} \qquad \ldots (6.34)$$

where $\mu_0 = 4\pi \times 10^{-7}$ T (tesla) mA^{-1}. Therefore, the unit of magnetic intensity is Am^{-1} or $\text{Nm}^{-2}\,\text{T}^{-1}$ or N Wb^{-1}.

Intensity of Magnetization

It is defined as the magnetic dipole moment (M) developed per unit volume when a magnetic specimen is subjected to a magnetic field. Mathematically, it can be written as :

$$I = \frac{M}{V} \qquad \ldots (6.35)$$

where V is the volume of the specimen which acquires magnetic dipole moment M due to the magnetising field. The unit of magnetic dipole moment is Am^2. Therefore, the unit of intensity of magnetisation is Am^{-1}.

Magnetic Flux

It is defined as the number of magnetic field lines passing normally through the surface. It is expressed as :

$$\Phi = BS \cos\theta \qquad \ldots (6.36)$$

where θ is the angle between the direction of the magnetic field and normal to the surface S and S is the surface area held in B. The SI unit of magnetic flux is Weber (Wb).

Magnetic Induction

It is defined as the magnetic field lines inside the material crossing per unit area normally through the magnetic substance. It is also known as *magnetic flux density*. Mathematically, it can be written as :

$$B = B_o + \mu_o I \qquad \ldots (6.37)$$

where B_o is the uniform magnetic field in vacuum and $\mu_o I$ is the magnetic field produced due to magnetisation of the substance. Thus, using Eq. (6.34), Eq. (6.37) we can write :

$$B = \mu_o (H + I) \qquad \ldots (6.38)$$

The SI unit of magnetic induction is Wb m^{-2}.

Magnetic Susceptibility

It is defined as the ratio of the intensity of magnetisation to the magnetic intensity. Mathematically, it is written as :

$$\chi_m = \frac{I}{H} \qquad \ldots (6.39)$$

Magnetic susceptibility is a member because both I and H have the same unit.

Magnetic Permeability

It is defined as the ratio of the magnetic induction to the magnetic intensity. Mathematically, it is written as :

$$\mu = \frac{B}{H} \qquad \text{. . . (6.40)}$$

The SI unit of magnetic permeability is T m A^{-1}.

The relation between magnetic susceptibility and relative permeability can be obtained by dividing Eq. (6.38) by *H*.

$$\frac{B}{H} = \mu_o \left(1 + \frac{I}{H}\right) \qquad \text{. . . (6.41)}$$

Substitute Eqs. (6.40) and (6.39) in Eq. (6.41), we get :

$$\mu = \mu_o \ (1 + \chi_m)$$

or
$$\frac{\mu}{\mu_o} = 1 + \chi_m$$

If we define $\frac{\mu}{\mu_o} = \mu_r$ *as the relative permeability of the magnetic substance,* we get :

$$\mu_r = 1 + \chi_m \qquad \text{. . . (6.42)}$$

With the help of the physical parameters defined above, it is easier to describe different types of magnetic materials. Now in this section, we will study these.

Types of Magnetic Materials

Magnetic materials are classified into three categories : diamagnetic substances, paramagnetic substances, and ferromagnetic substances. Each of these categories are characterised by different values or range of values of various parameters discussed above. The classification helps in proper selection of materials for different applications involving magnetism.

Diamagnetic Substance

When a diamagnetic substance is placed in a uniform magnetic field, it is weakly magnetised along a direction opposite to that of the field. But, when it is placed in a non-uniform magnetic field, the diamagnetic substance tends to move from stronger to the weaker region of the magnetic field. Diamagnetic effects are too feeble to be detected, unless the applied magnetic field is strong. Silver, gold, copper, water, glass etc. are examples of diamagnetic substances. The other important properties of diamagnetic substances are :

- A diamagnetic substance is weakly repelled by a magnet.
- The behaviour of a diamagnetic substance is independent of temperature.
- The intensity of magnetisation, for a diamagnetic substance, has a small negative value.
- The magnetic susceptibility of a diamagnetic substance has a small negative value (~ 10^{-6} to 10^{-3}).

- The relative permeability of a diamagnetic substance is slightly less than one.
- When a diamagnetic substance is placed in a magnetising field, the magnetic flux density in its interior is lesser than that in vacuum.

Paramagnetic Substance

If a paramagnetic substance is placed in a magnetic field, the strength of magnetic field in the interior of the substance is slightly greater than the external magnetic field. But in a non-uniform field, unlike diamagnets, it moves from weaker to the stronger region of the field. The paramagnetic effects are perceptible only with a strong magnetic field. *When a paramagnetic substance is placed in a magnetic field, it is weakly magnetised along the direction of the field*. Aluminium, copper, sodium, chromium, antimony etc. are examples of paramagnetic substances. The other important properties of paramagnetic substances are :

- A paramagnetic substance is weakly attracted by a magnet.
- The intensity of magnetisation has a small positive value for paramagnetic substance.
- When a paramagnetic material is placed in a magnetic field, the magnetic field lines become slightly more dense in its interior.
- The magnetic susceptibility of a paramagnetic substance has a small positive value.
- The relative permeability of a paramagnetic substance is slightly greater than one.
- The behaviour of a paramagnetic material is temperature dependent.

Ferromagnetic Substance

When a ferromagnetic substance is placed in a magnetic field, the field in the interior of the substance increases significantly. And, when it is placed in a non-uniform magnetic field, the ferromagnetic substance moves **quickly** from weaker to the stronger region of the magnetic field. Therefore, *ferromagnetic substance in a magnetic field is strongly magnetised along the direction of the field*. Iron, nickel, cobalt, etc. are examples of ferromagnetic substances. The other important properties of ferromagnetic substances are :

- They are strongly attracted by a magnet.
- A rod of ferromagnetic substance placed in a magnetic field aligns itself quickly in the direction of magnetic field.
- For a ferromagnetic substance, the intensity of magnetisation and the magnetic susceptibility has a large positive value.

- The relative permeability of the ferromagnetic substance is extremely large as compared to diamagnetic and paramagnetic substances.
- When a ferromagnetic substance is placed in a magnetising field, the magnetic flux density in its interior is much larger than that in vacuum.
- The ferromagnetic behaviour is temperature dependent.
- The ferromagnetic substances do not obey Curie's law.

6.7 SUMMARY

- Before Oersted's discovery that electric current flowing in a wire deflected the compass needle just as a permanent magnet did, magnetism and electricity were considered two separate and unrelated phenomenon.
- Magnetic effects can be described in terms of magnetic field *B*. The unit of magnetic field is Tesla.
- According to the Biot-Savart's law, the magnetic field *dB* at a distance *r* from the current element due to current element *I d l* is given by :

$$dB = \frac{\mu_0}{4\pi} \frac{I\ dl \sin\theta}{r^2}$$

  where θ is the angle between directions of *I d l* and *r*.
- The magnetic field due to current in a straight infinitely long wire is given by :

$$B = \frac{\mu_0}{2\pi} \frac{I}{a}$$

  where *a* is the perpendicular distance of the point from the wire at which magnetic field is to be determined.
- The magnetic field at a point on the axis of a current carrying loop of radius *a* is given by :

$$B = \frac{\mu_0}{4\pi} \frac{2\pi\ I\ a^2}{(a^2 + x^2)^{3/2}}$$

- The magnetic field at the centre of a solenoid having *n* turns per unit length is given by :

$$B = \frac{\mu_0\ n\ I}{2a}$$

- The total Lorentz force on a charged particle *q* in a uniform electric and magnetic field is given by :

$$F = q\,[E + v\ B \sin\theta]$$

  where θ is the angle between the directions of the motion of the charged particle and the magnetic field.
- Moving coil galvanometer is an instrument used for the detection and measurement of small currents and small voltages in an electrical circuit.

- A galvanometer can be converted into an ammeter by connecting a shunt (low resistance) in parallel with it and into a voltmeter by connecting a high resistance in series with the galvanometer.
- Cyclotron is a device used to accelerate positive ions such as protons and α-particles. The expressions for the cyclotron frequency and the maximum kinetic energy of the charged particle are given by :

$$f = \frac{1}{T} = \frac{Bq}{2\pi m}$$

and $$E_{\max} = \frac{1}{2}\frac{B^2 q^2 r^2}{m}$$

- In a magnetic field, the diamagnetic substances are weakly magnetised along a direction opposite to that of the magnetising field.
- Paramagnetic substances in a magnetic field are weakly magnetised along the direction of the magnetising field.
- Ferromagnetic substances in a magnetic field are strongly magnetised along the direction of magnetic field.

6.8 ANSWERS TO SAQs

SAQ 1

As per the problem, $I = 5$ A and $a = 20\text{ cm} = 0.2\text{ m}$.

Using Eq. (6.11),

$$B = \frac{\mu_0}{2\pi}\frac{I}{a}$$

$$= \frac{(10^{-7}\text{ Wb A}^{-1}\text{ m}^{-1}) \times (5\text{ A}) \times 2}{0.2\text{ m}}$$

$$= 5 \times 10^{-6}\text{ T}$$

SAQ 2

As per the problem, $I = 5\text{A}$; $a = \frac{0.50\text{ m}}{2} = 0.25\text{ m}$; $x = 0.15\text{m}$; and

$\frac{\mu_0}{4\pi} = 10^{-7}\text{ T m A}^{-1}$.

From Eq. (6.13), the magnitude of magnetic field at a point distance 0.15 m from the centre of the loop is,

$$B = \frac{\mu_0}{4\pi} \cdot \frac{2\pi I a^2}{(a^2 + x^2)^{3/2}}$$

$$= \frac{(10^{-7}\text{ T m A}^{-1}) \times 2 \times 3.14 \times (5\text{A}) \times (0.25\text{m})^2}{\{(0.25\text{m})^2 + (0.15\text{m})^2\}^{3/2}}$$

$$= 7.92 \times 10^{-6}\text{ T}.$$

When the point of measurement of the field is the centre of the coil, we have been Eq. (6.14) :

$$B = \frac{\mu_0 I}{2a}$$

$$= \frac{\mu_0}{4\pi} \cdot \frac{2\pi I}{a}$$

$$= \frac{(10^{-7}\,\mathrm{T\,m\,A^{-1}}) \times 2 \times 3.14 \times (5\mathrm{A})}{(0.25\,\mathrm{m})}$$

$$= 1.25 \times 10^{-5}\,\mathrm{T}$$

SAQ 3

As per the problem, $f = 15$ MHz $= 15 \times 10^6$ Hz; $r = 50$ cm $= 0.5$ m; $m = 1.67 \times 10^{-27}$ kg; and $e = 1.6 \times 10^{-19}$ C.

Using Eq. (6.33), we can write :

$$B = \frac{2\pi\, m\, f}{e}$$

$$= \frac{2 \times 3.14 \times (1.67 \times 10^{-27}\,\mathrm{kg}) \times (15 \times 10^{6}\,\mathrm{Hz})}{1.6 \times 10^{-19}\,\mathrm{C}}$$

$$= 0.98\ \mathrm{T}$$

For the maximum kinetic energy of the proton, we have from Eq. (6.35) :

$$E_{\mathrm{max}} = \frac{B^2 e^2 r^2}{2m}$$

$$= \frac{(0.98\,\mathrm{T})^2 \times (1.6 \times 10^{-19}\,\mathrm{C})^2 \times (0.5\,\mathrm{m})^2}{2 \times (1.67 \times 10^{-27}\,\mathrm{kg})}$$

$$= 1.84 \times 10^{-12}\,\mathrm{J}\,.$$

FURTHER READING

A Text Book of Physics, (Class XI and XII) National Council for Educational Research and Training (NCERT), New Delhi.

David Halliday and Robert Resinik, *Physics*, John Wiley and Sons.

Alan Van Heuvelen, *Physics : A General Introduction*, Little, Brown and Company.

F. Bueche, *Principles of Physics*, McGraw Hill Book Company.

Richard Wolfson and Jay M., Pasachoff, *Physics*, Volume 1 and 2, Little Brown and Company.

PHYSICS

The natural phenomena such as sunrise and sunset, periodic changes in climate, the colours of rainbow, the lightening and thunder during rainy season have always fascinated human mind. The quest for understanding the nature gave birth to natural sciences and physics is of central importance in natural sciences. In modern times, in designing buildings, bridges, machines, electric power plants, electronic and telecommunication circuits, we require the knowledge of physics. So, physics is fundamental and the knowledge of its basic concepts is necessary for a proper understanding of the subject matter of any branch of engineering and technology. This is the motivation for the present course on physics.

This course deals with the basic concepts of physics. For convenience, the subject matter of the course has been arranged into units : Properties of Matter; Thermal Energy; Sound; Light; Electricity and its Effects; and Magnetism. Each unit is further divided into different sections and sub-sections.

In Unit 1, titled *Properties of Matter*, the topics such as surface tension, viscosity, hydrostatic pressure and elasticity have been discussed. The reason of studying these properties is their wide ranging applications in engineering industry and even in our day-to-day lives.

In Unit 2, titled *Thermal Energy*, you will study the thermal behaviour of matter. You will learn the precise meanings and subtle differences among the terms heat, temperature and thermal energy. You will also learn various processes through which heat energy is transported from one point to another. The basics of kinetic theory of gases have also been discussed in this unit.

Unit 3, titled *Sound*, describes the sound waves which is an example of transport of energy by waves. You will learn about different types of waves and their common characteristics. The perceptual characteristics of sound and their relations with physical parameters have also been discussed. After studying these characteristics of sound, you will be able to understand what distinguishes a pleasant sound from an unpleasant sound.

In Unit 4 on *Light*, you will study the laws of reflection and the laws of refraction. On the basis of these laws, the phenomenon of image formation by plane mirror, curved mirrors and lenses can be understood. The phenomenon of total internal reflection and its application in explaining phenomena like mirage, looming, and optical fibres has also been discussed. In addition, you will study the principles of operation of optical instruments like telescopes and microscopes.

The laws governing the behaviour of electric charge and the concept of electric field have been discussed in Unit 5, titled *Electricity and its Effects*. You will learn Kirchhoff's rules which govern the distribution of currents in a complex electrical circuits. You will also study the construction and working of different types of cells.

In the last unit, titled *Magnetism*, you will learn the electric origin of magnetic field in the form of Biot-Savart's law. You will discover that current carrying loop is equivalent to a tiny bar magnet. A detailed account of some electric instruments like galvanometer, ammeter and voltmeter have also been given. The behaviour of a charged particle subjected to electric and magnetic fields simultaneously has also been discussed at length. Lastly, you will learn the broad classification of magnetic materials and their properties.

It has been attempted to make this study material self-sufficient. Efforts have also been made to keep the language simple and lucid. We have used bold type face letters to represent vector quantities. However, this representation for vectors have been used as and when the vector nature of a quantity plays an important role for explaining a phenomenon. As you will find from the contents, the main focus of this course is to emphasise on the basic principles of physics and to highlight their usefulness in everyday lives. You will find many examples which are incorporated to sustain your interest.

Further, each unit contains self assessment questions (SAQs) related to the concepts covered in these units. The purpose of SAQs is to provide you an opportunity to check your understanding of the concepts. Each unit is provided with a summary at its end for a quick overview of the contents of the unit. This is followed by the Answer to SAQs.

We hope that you enjoy studying this course.

We wish you success.