

Chapter # 10

Electromagnetism

STUDENT'S LEARNING OUTCOMES (SLO's)

After studying this unit, the students will be able to:

- State that a force might act on a current-carrying conductor placed in a magnetic field
- Use the equation $F = BIL \sin \theta$ [with directions as interpreted by Fleming's left-hand rule to solve problems]
- Define magnetic flux [as the product of the magnetic flux density and the cross-sectional area perpendicular to the direction of the magnetic flux density]
- Use $\phi = BA$ to solve problems
- Use the concept of magnetic flux linkage
- Define magnetic flux density [as the force acting per unit current per unit length on a wire placed right angles to the magnetic field]
- Use $F = BqV \sin \theta$ to solve problems
- Describe the motion of a charged particle moving in a uniform magnetic field perpendicular to the direction of motion of the particle
- Explain how electric and magnetic fields can be used in velocity selection
- Explain experiments that demonstrate Faraday's and Lenz's laws [(a) that a changing magnetic flux can induce an emf in a circuit, (b) that the induced emf is in such a direction as to oppose the change producing it, (c) the factors affecting the magnitude of the induced emf.]
- Use Faraday's and Lenz's laws of electromagnetic induction to solve problems
- Describe how ferrofluids work [they make use of temporary soft magnetic materials suspended in liquids to develop fluids that react to the poles of a magnet and have many applications in fields such as electronics]
- Explain how seismometers make use of electromagnetic induction to the earthquake detection [specifically in terms of: (i) any movement or vibration of the rock on which the seismometer rests (buried in a protective case) results in relative motion between the magnet and the coil (Suspended by a spring from the frame.) (ii) The emf induced in the coil is directly proportional to the displacement associated]

10.1 FORCE ON A CURRENT-CARRYING CONDUCTOR IN A UNIFORM MAGNETIC FIELD



1. Find an expression for the force exerted on a current-carrying conductor placed in a uniform magnetic field.

Ans. Force on a Current-Carrying Conductor in a Uniform Magnetic Field

A current-carrying conductor placed in a magnetic field experiences a force. Consider a straight conductor carrying a steady current is placed perpendicular to uniform magnetic field. Assume the direction of the current is out of the paper shown by $\odot$; Fig. 1. The direction of magnetic field produced by the current is also shown.

A current-carrying conductor experiences a force due to the interaction between its own magnetic field and the external magnetic field. To determine the direction of this force, consider the interaction between the two fields.

The magnetic field produced by the current and the external uniform magnetic field reinforce each other on the left side of the conductor and oppose each other on the right side. Consequently, the conductor moves towards the side where the field is weaker. That is, the force on the conductor is directed to the right as viewed from the front. Thus, the force F is perpendicular to both the conductor and the magnetic field.

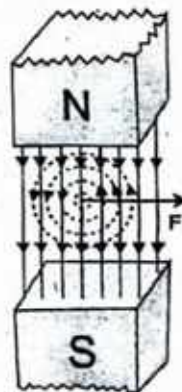


Fig. 1

Direction of Force Experienced by a Current-Carrying Conductor

Fleming's left-hand rule is used to predict the direction of the force experienced by a current-carrying conductor in a magnetic field.

For your information

Magnetism started with lodestone, a natural mineral discovered in ancient Türkiye. Lodestone, or magnetite (Fe_3O_4), can attract metals like iron and steel and aligns with the Earth's magnetic poles, leading to the invention of the compass.

Fleming's Left-Hand Rule

Position your left hand such that the first finger points in the direction of magnetic field, the second finger points in the direction of current, the thumb will then point in the direction of force.

Right-Hand Rule

However, direction of force can also be found by using right hand rule that can be stated as:

Curl fingers of your right hand from current to magnetic field through smaller angle, the stretched thumb will indicate the direction of force.

Determination of Magnitude of force on a Current-Carrying conductor

Let us determine the magnitude of the force on a current-carrying conductor placed inside a magnetic field. Since the magnitude of the force acting on the conductor is directly proportional to the current I in the conductor, the length L of the conductor, and the strength of the external magnetic field B . The strength of the magnetic field is also known as the magnetic induction B , which has the same direction as the field. Thus, the force F on a conductor is given by

$$F \propto BIL \quad ; \quad F = kBIL$$

In SI units, the value of $k = 1$, therefore,

$$F = BIL \quad \dots\dots (i)$$

From Eq. (i), we can see that $B = \frac{F}{IL}$, so we can define magnetic field strength B as:

The magnetic strength is numerically equal to the force exerted on a conductor of length one metre carrying one ampere current, placed perpendicular to the magnetic field.

Unit: Equation $B = \frac{F}{IL}$ also gives the unit of magnetic field strength. The SI unit of magnetic field strength is tesla (T).

$$1 \text{ T} = 1 \text{ N A}^{-1} \text{ m}^{-1}$$

Magnetic induction is a vector quantity. Its direction is the same as that of magnetic field.

We can also consider a vector L which has a magnitude equal to the length of the conductor and its direction is along the flow of current.

Now consider a conductor L placed at an angle ' θ ' w.r.t the magnetic field, then we will use the component of L perpendicular to B i.e., $(L \sin \theta)$, Fig. 3.

Now Eq. (i) will become:

$$F = BIL \sin \theta \quad \dots\dots (ii)$$

In vector form, Eq. (ii) can be written as:

$$F = I \mathbf{L} \times \mathbf{B}$$

Equation (ii) shows that the force will be maximum (BIL) when the conductor is perpendicular to the field, i.e., $\theta = 90^\circ$, and it will be zero when the conductor is along the field i.e., $\theta = 0$.

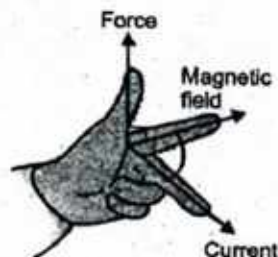


Fig. 2: Fleming's left-hand rule

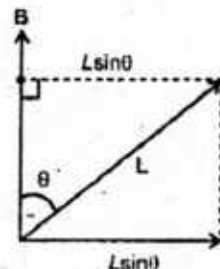


Fig. 3

Example 10.1: A 20.0 cm wire carrying a current of 10.0 A is placed in a uniform magnetic field of 0.30 T. If the wire makes an angle of 40° with the direction of magnetic field, find the magnitude of the force acting on the wire.

Solution:

Given that:

Length of the wire	$= L = 20.0 \text{ cm} = 0.20 \text{ m}$
Current	$= I = 10.0 \text{ A}$
Strength of magnetic field	$= B = 0.30 \text{ T}$
Angle	$= \theta = 40^\circ$

To Find:

Force $F = ?$

Calculations: Using the formula:

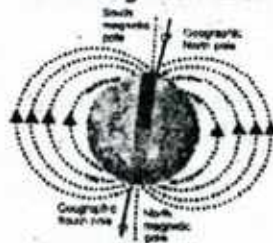
Substituting the values

$$F = BIL \sin \theta$$

$$F = 10.0 \text{ A} \times 0.30 \text{ T} \times 0.20 \text{ m} \times \sin 40^\circ$$

$$F = 0.39 \text{ N} \text{ Ans.}$$

Interesting Information



The Earth's magnetic field is approximately that of a dipole, like that of the fictitious bar magnet, where the south magnetic pole is towards the geographic north pole and the north magnetic pole is towards the geographic south pole.



2. Explain magnetic flux and flux density. How are they related?

Ans. Magnetic Flux

Definition

Magnetic flux is a measure of the total magnetic field through a given area.

Thus,

The magnetic flux through a patch of area A is the number of magnetic lines passing through this area.

If B represents the number of lines passing through unit area placed perpendicular to the field, then the total flux through area A perpendicular to the field will be:

$$\phi_B = \frac{\phi_B}{A}$$

The surface A may not be perpendicular to the field, that is the normal to the surface makes an angle θ with B ; Fig. 4. Then, we will have to use component of B ($B \cos \theta$) along the vector area A ; Fig. 5. Therefore, the flux passing through the surface will be

$$\phi_B = BA \cos \theta \quad \dots\dots (i)$$

As B and A both are vectors, so we can write

$$\phi_B = B \cdot A \quad \dots\dots (ii)$$

Equation (ii) shows that ϕ_B is a scalar quantity. Therefore, we can define magnetic flux as:

The magnetic flux ϕ_B , through a plane element of area A in a uniform magnetic field B is given by dot product of B and A .

Note: A is a vector whose magnitude is the area of the element and whose direction is along the normal to the surface of the element and θ is the angle between the directions of the vectors B and A ; Fig. 5.

In Fig. 6(a), the field is directed along the normal to the area, so θ is zero ($\cos 0^\circ = 1$) and the flux is maximum, equal to BA . When the field is parallel to the plane of the area; Fig. 6(b), the angle between the field and normal to area is 90° i.e., $\theta = 90^\circ$ ($\cos 90^\circ = 0$), so the flux through the area in this orientation is zero.

In case of a curved surface placed in a uniform magnetic field, the curved surface is divided into a number of small surface elements, each element being assumed plane and the flux through the whole curved surface is calculated by the sum of the contributions from all the elements of the surface using Eq. (i).

Magnet Flux Density

Definition

Magnet flux density is the amount of magnetic flux passing through a unit area perpendicular to the direction of the magnetic field.

From the definition of tesla, the unit of magnetic flux is $N \cdot m \cdot A^{-1}$ which is called weber (Wb). According to Eq. (i), the magnetic induction B is the flux per unit area of a surface perpendicular to B , hence, it is also called as magnetic flux density. Its unit is $Wb \cdot m^{-2}$. Therefore, magnetic induction, i.e. the magnetic field strength is measured in terms of $Wb \cdot m^{-2}$ or $N \cdot A^{-1} \cdot m^{-1}$ (tesla).

Relation between Magnetic Flux and Magnetic Flux Density

Magnetic flux is the product of magnetic flux density and the area through which it acts.

$$\phi_B = B \cdot A \cos \theta$$

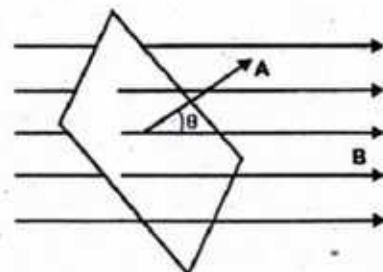


Fig. 4

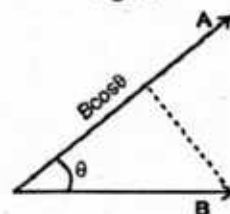


Fig. 5

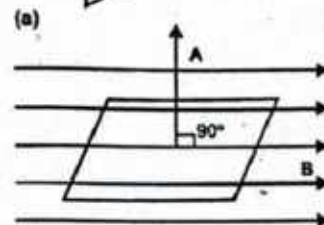
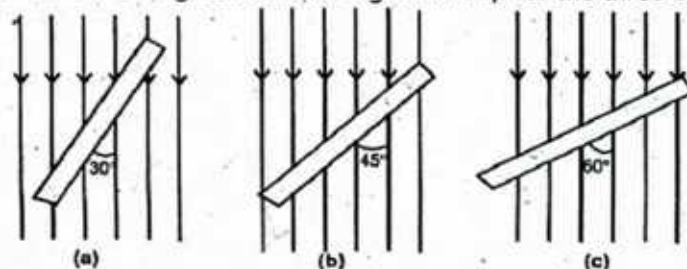


Fig. 6

So, magnetic flux depends on the magnetic flux density, the size of the area, and the orientation of the magnetic field relative to the surface.

Example 10.2: A rectangular loop of wire is placed in a uniform magnetic field of magnitude 1.2 T. If the loop is 25 cm long and 20 cm wide, determine the magnetic flux through the loop for the three orientations as shown in Figure.



Solution:

Given that:

$$B = 1.2 \text{ T}, A = 20 \text{ cm} \times 25 \text{ cm}$$

To Find:

$$\phi_B = ?$$

Calculations: For orientation (a), angle between B and area vector A is, $\theta = 60^\circ$

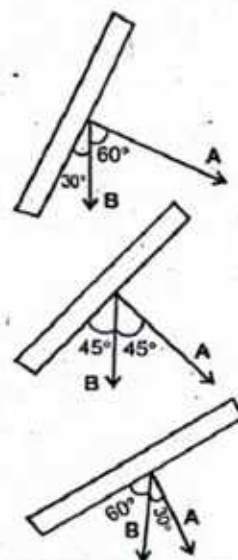
$$\begin{aligned} \text{Using } \phi_B &= BA \cos \theta \\ &= 1.2 \text{ T} \times 20 \text{ cm} \times 25 \text{ cm} \times \cos 60^\circ \\ &= 1.2 \text{ T} \times 5 \times 10^{-2} \text{ m}^2 \times 0.5 \\ &= 3 \times 10^{-2} \text{ Wb} \end{aligned}$$

For orientation (b), angle $\theta = 45^\circ$

$$\begin{aligned} \phi_B &= 1.2 \text{ T} \times 5 \times 10^{-2} \text{ m}^2 \times 0.707 \\ &= 4.2 \times 10^{-2} \text{ Wb} \end{aligned}$$

For orientation (c), angle $\theta = 30^\circ$

$$\begin{aligned} \phi_B &= 1.2 \text{ T} \times 5 \times 10^{-2} \text{ m}^2 \times 0.866 \\ \phi_B &= 5.2 \times 10^{-2} \text{ Wb} \text{ Ans.} \end{aligned}$$



10.3 MAGNETIC FLUX LINKAGE



3. What is magnetic flux linkage? Describe its use.

Ans. Magnetic Flux Linkage

Definition

Magnetic flux linkage is the product of the magnetic flux through a coil and the number of turns in the coil.

Use of Magnetic Flux Linkage

Magnetic flux linkage is a key concept in electromagnetism, particularly in the study of inductance and electromagnetic induction. It essentially measures how much magnetic flux is linked with the coil due to its multiple turns, and is an important factor in understanding how coils and inductors operate in electrical circuits.

$$\text{Magnetic flux linkage} = \phi = N \phi_B$$

where ϕ_B is the magnetic flux through a single loop of area A and N is the total number of turns of the coil. Magnetic flux linkage plays a crucial role in the design and operation of transformers, electric motors, generators, and inductors.

It allows for the calculation of induced emf and is a fundamental to understand and designing electromagnetic system.

For Your Information



A magnetic strip on the ATM card contains millions of tiny magnetic domains held together by a resin binder. The machine reads the information encoded on the magnetic strip and it makes your access to your account.



4. Determine the force acting on a charged particle moving through a uniform magnetic field.

Ans. Motion of a Charged Particle in a Uniform Magnetic Field:

A current-carrying conductor placed perpendicularly in a uniform magnetic field experiences a force F . We can calculate this force by examining the behaviour of a current-carrying conductor in a magnetic field.

Consider a conductor of length L through which N charged particles, each with charge q , are passing in time t . The motion of these charged particles produces a current I in the conductor, which is given by

$$I = \frac{Q}{t} = \frac{Nq}{t}$$

where Q is the total charge flowing in time t . If $\mathbf{v}$ is the velocity of charged particles, then the velocity of the particles along the conductor is

$$\mathbf{v} = v \hat{\mathbf{L}}$$

where $\hat{\mathbf{L}}$ is the unit vector in the direction of the current. The sign of the force depends on whether the charge q is positive or negative. However, the unit vector $\hat{\mathbf{L}}$ is directed along the direction of the current, which is the direction of motion of positive charges.

Since the particles take time t to move across the conductor of length L , therefore,

$$t = \frac{L}{v}$$

Then
$$I = \frac{Nq}{t} = \frac{Nqv}{L} \quad \dots (i)$$

If this conductor is placed in a uniform magnetic field $\mathbf{B}$, it will experience a force $\mathbf{F}$ equal to:

$$\mathbf{F} = I \mathbf{L} \times \mathbf{B} \quad \dots (ii)$$

As
$$\mathbf{L} = L \hat{\mathbf{L}}$$

Substituting the values of I and L in Eq. (ii)

$$\mathbf{F} = \frac{Nqv}{L} (L \hat{\mathbf{L}} \times \mathbf{B})$$

or
$$\mathbf{F} = Nqv \hat{\mathbf{L}} \times \mathbf{B} \quad \dots (iii)$$

As velocity $\mathbf{v}$ is directed along the conductor $\mathbf{L}$, so we can write

$$v \hat{\mathbf{L}} = v \hat{\mathbf{v}} = \mathbf{v} \quad (\text{as } \hat{\mathbf{L}} = \hat{\mathbf{v}})$$

$\therefore \mathbf{F} = Nq (\mathbf{v} \times \mathbf{B}) \quad \dots (iv)$

Thus, force on a single particle will be:

$$\mathbf{F} = q (\mathbf{v} \times \mathbf{B}) \quad \dots (v)$$

If θ is the angle between $\mathbf{B}$ and $\mathbf{v}$, then magnitude of force F is given by

$$F = qvB \sin \theta \quad \dots (vi)$$

Therefore, the force is maximum when $\mathbf{B}$ is perpendicular to $\mathbf{v}$, i.e., $\theta = 90^\circ$, and force is zero when $\mathbf{B}$ is in the direction of $\mathbf{v}$, i.e., $\theta = 0$. The direction of force can be known by applying Fleming's left hand rule or right hand rule for vector product.

- The positively charged particle enters into the magnetic field along the dotted line on plane of paper. It experiences a force in the upward direction due to which it is deflected along a curved path; Fig. 7 (a).
- The negatively charged particle is deflected downward by the force acting on it downwards; Fig. 7 (b).

Point to Ponder!

Why does a picture become distorted when a magnetic bar is brought near to the screen of TV, computer monitor or oscilloscope?

Ans. A picture becomes distorted when a magnetic bar is brought near the screen of a CRT (Cathode Ray Tube) TV, computer monitor, or oscilloscope because of how these devices work:

How CRT Screens Work?

CRT screen creates images by firing a stream of electrons from an electron gun at the back of the tube toward the front of the screen, which is coated with phosphorescent material. Magnetic fields inside the CRT (called deflection coils) guide and steer the electron beam to the correct spot on the screen.

What Happens with a Magnetic Bar?

When you bring a magnetic bar close to the screen:

- The external magnetic field interferes with the internal magnetic field used to steer the electron beam.
- This causes the screen beam to deviate from its intended path, hitting the wrong phosphor spots on the screen.
- As a result, the image becomes distorted, wavy, or shows wrong colour (due to misalignment of the red, green, and blue beams in colour CRTs).

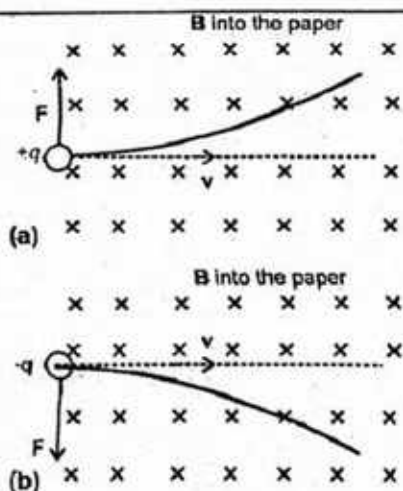


Fig. 7

Example 10.3: An electron enters into a uniform magnetic field perpendicularly with a speed of 10^4 m s^{-1} . What path the electron will move along inside the field?

Solution:

Given that;

$$B = 2.5 \text{ Wb m}^{-2}, m = 9.11 \times 10^{-31} \text{ kg}, e = 1.6 \times 10^{-19} \text{ C}$$

To Find:

$$r = ?$$

Calculations: The Force F acting on the electron will be:

$$F = qvB \sin \theta$$

As the velocity v is perpendicular to B , i.e., $\theta = 90^\circ$, the charge $q = e$, so

$$F = evB \times 1 = evB$$

Since F acts perpendicular to v , so this force provides centripetal force to the electron to keep it in a circle of radius r . Then

$$evB = \frac{mv^2}{r}$$

$$r = \frac{mv}{eB}$$

Putting the values in above equation, we have

$$r = \frac{9.11 \times 10^{-31} \text{ kg} \times 10^4 \text{ m s}^{-1}}{1.6 \times 10^{-19} \text{ C} \times 2.5 \text{ Wb m}^{-2}}$$

$$r = 2.3 \times 10^{-8} \text{ m} \text{ Ans.}$$

The path of electron will be a circle of radius $2.3 \times 10^{-8} \text{ m}$.



- Two parallel straight wires carrying current in same direction will:
 - Repel each other
 - Attract each other ✓
 - No effect
 - May repel or attract
- A current flowing towards the reader be denoted by
 - Cross
 - A bracket
 - A dot ✓
 - Positive sign
- The SI unit of magnetic induction Tesla is equal to:
 - $\text{NA}^{-1} \text{m}^{-1}$ ✓
 - NA m^{-1}
 - $\text{NA}^{-1} \text{m}$
 - $\text{NA}^{-2} \text{m}^{-1}$
- If fingers of right hand show the direction of magnetic field and palm shows the direction of force, then thumb points for:
 - Torque
 - Voltage
 - current ✓
 - inducted
- Electric current produces magnetic field was suggested by
 - Faraday
 - Oersted ✓
 - Henry
 - Lenz
- Tesla is a unit of:
 - Flux density ✓
 - Magnetic flux
 - Self inductance
 - Mutual inductance
- The correct relation is:
 - $1 \text{ T} = 10^4 \text{ G}$ ✓
 - $1 \text{ T} = 10^{-4} \text{ G}$
 - $1 \text{ T} = 10^{-2} \text{ G}$
 - $1 \text{ T} = 10^2 \text{ G}$
- Two parallel straight wires carrying current in opposite direction:
 - Repel each other ✓
 - Attract each other
- Have no effect upon each other
- they cancel out their individual magnetic effect
- A current-carrying conductor experiences maximum magnetic force in a uniform magnetic field when it is placed:
 - Perpendicular to field ✓
 - Parallel to field
 - At angle of 60° to the field
 - At angle 180° to the field
- A 5m wire carrying a current of 2A is at right angles to the uniform magnetic field of 0.5 weber m^{-2} . The force on the wire is:
 - 2 N
 - 4 N
 - 5 N ✓
 - 1.5 N
- A current-carrying conductor is placed in uniform magnetic field parallel to it. The magnetic force experienced by the conductor is:
 - $F = ILB$
 - $F = ILB \sin \theta$
 - $F = ILB \cos \theta$
 - F is zero ✓
- The force on current carrying conductor placed in magnetic field is expressed by
 - $\vec{F} = I \vec{L} \times \vec{B}$
 - $\vec{F} = I \vec{L} \cdot \vec{B}$ ✓
 - $\vec{F} = I^2 \vec{L} \cdot \vec{B}$
 - $\vec{F} = I \vec{B} \cdot \vec{L}$
- The SI unit of magnetic induction (flux density) is:
 - weber
 - henry
 - tesla ✓
 - gauss

14. Force on current-carrying conductor per unit length is given by
(A) $ILB \sin \theta$ (B) ILB
(C) IB (D) $IB \sin \theta$ ✓
15. One tesla (T) is equal to:
(A) 1 NA^{-1} (B) 1 Nm^{-1}
(C) $1 \text{ NA}^{-1} \text{ m}$ (D) $1 \text{ NA}^{-1} \text{ m}^{-1}$ ✓
16. A power line 10m height carries a current 200A. The magnetic field of the wire at the ground is:
(A) $4 \times 10^{-6} \text{ T}$ ✓ (B) $4 \times 10^6 \text{ T}$
(C) $4 \times 10^{-4} \text{ T}$ (D) $4 \times 10^{-3} \text{ T}$
17. Two long parallel wires carrying current in the same direction:
(A) Attract ✓ (B) Repel
(C) Turn (D) No effect
18. Fleming left hand rule is used to determine the direction of:
(A) Magnetic field (B) Induced current
(C) Force on a current-carrying conductor ✓
(D) Electric field
19. In Fleming left hand rule, the middle finger represents:
(A) Force (B) Magnetic field
(C) Direction of current ✓ (D) Induced voltage
20. Fleming left hand rule is mainly used in:
(A) Electric motors ✓ (B) Electric generators
(C) Transformers (D) Inductors
21. The SI units of magnetic flux and magnetic flux density, respectively are:
(A) weber (Wb), gauss (G) (B) weber (Wb), tesla (T) ✓
(C) newton (N), henry (H) (D) gauss (G), ampere (A)
22. If the angle between the magnetic field and the area vector is 90° , the magnetic flux is:
(A) Maximum (B) Minimum
(C) Infinite (D) Zero ✓
23. Magnetic flux increases when:
(A) Magnetic field decreases
(B) Area perpendicular to the field decreases
(C) Angle between field and area increases
(D) Field strength or effective area increases ✓
24. If the number of turns in a coil is doubled, the magnetic flux linkage:
(A) Remains the same (B) Is halved
(C) Doubles ✓ (D) Becomes zero
25. What physical phenomenon results from a change in magnetic flux linkage?
(A) Electric resistance
(B) Electromagnetic induction ✓
(C) Capacitance (D) Magnetic force
26. Magnetic field of 0.5 T is parallel to vector area of 1 m^2 of a coil, flux through the coil is:
(A) Zero ✓ (B) 5 weber,
(C) 0.2 weber (D) 0.5 weber
27. If the coil is wound on iron core, the flux through it:
(A) Decreases (B) Becomes zero
(C) Remains constant (D) Increases ✓
28. The unit of magnetic flux is:
(A) tesla (B) weber ✓
(C) weber m^{-2} (D) tesla m^2
29. The SI unit of magnetic flux is given by
(A) Nm A^{-1} ✓ (B) $\text{NA}^{-1} \text{ m}^{-1}$
(C) $\text{Nm}^2 \text{ A}^{-1}$ (D) $\text{Nm}^{-1} \text{ A}$
30. Magnetic field $\vec{B} = (40\hat{i} + 18\hat{k}) \text{ Web}^{-2}$ passes through $(5\hat{k})$ area. Net flux through the area is:
(A) 20 Wb (B) $90 \times 10^{-4} \text{ WB}$
(C) 90 Wb ✓ (D) zero
31. The magnetic flux ϕ_B is equal to:
(A) $\vec{B} \cdot \vec{A}$ ✓ (B) $\vec{B} \times \vec{A}$
(C) $\frac{B}{A}$ (D) $BA \sin \theta$
32. Magnetic lines of force are:
(A) Imaginary ✓ (B) Real
(C) Perpendicular of force (D) In phase with elect lines
33. Magnetic flux is minimum, when angle between vector area and B is:
(A) 0° (B) 45°
(C) 90° ✓ (D) 180°
34. The SI unit of magnetic flux density is:
(A) Wbm (B) Wbm^{-1}
(C) Wbm^{-2} ✓ (D) Wbm^{-3}

10.5 VELOCITY SELECTOR



5. What is velocity selector? Explain its working and find an expression for its magnitude.

Ans. Velocity Selector

A velocity selector is a device used to determine the velocity of a charged particle.

In this device, electric and magnetic forces are applied to the moving particle in such a way that they balance each other only for one value of velocity, allowing the particle to continue moving with a constant velocity.

Consider a particle with a positive charge $+q$ that enters a uniform magnetic field B at a right-angles to it, with a velocity v . The magnetic force acts on the particle in the upward direction; Fig. 8. To balance this magnetic force, an electric force must act downward on the particle.

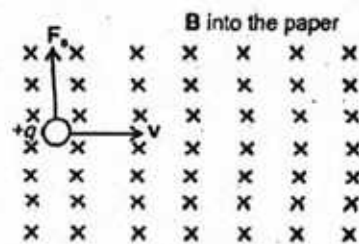


Fig. 8

Construction and Working

A velocity selector consists of a cylindrical tube located $+q$ within a magnetic field $\mathbf{B}$. Inside the tube is a parallel plate capacitor that creates a uniform electric field $\mathbf{E}$. The electric field $\mathbf{E}$ is oriented perpendicular to the magnetic field $\mathbf{B}$; Fig. 9.

When the charged particle enters the left end of the tube, the magnetic force acts upward, while the electric force acts downward in the direction of the electric field $\mathbf{E}$ on the positively charged particle. If the strengths of

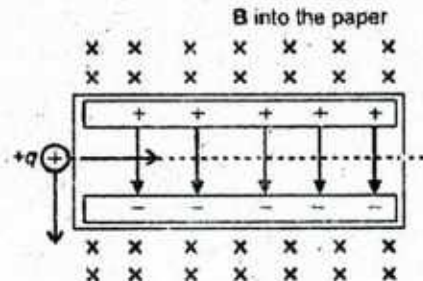


Fig. 9

the electric and magnetic fields are adjusted appropriately, these forces will cancel each other out. With no net force acting on the particle, its velocity $\mathbf{v}$ remains constant in accordance with Newton's first law. As a result, the particle moves in a straight line at a constant velocity and exits the right end of the tube.

The particles with velocities different from $\mathbf{v}$ will be deflected and will not exit at the right end of the tube.

The magnitude of the velocity selected can be determined as below.

As the velocity $\mathbf{v}$ is perpendicular to both $\mathbf{B}$ and $\mathbf{E}$, therefore,

$$\text{Magnetic force (upward)} = Bqv$$

$$\text{Electric force (downward)} = qE$$

$$\text{For no deflection of particle, } Bqv = qE$$

$$\text{or } v = \frac{E}{B} \quad \dots\dots (i)$$

Example 10.4: Alpha particles ranging in speed from 1000 m s^{-1} to 2000 m s^{-1} enter into a velocity selector where the electric intensity is 300 V m^{-1} and the magnetic induction 0.20 T . Which particle will move undeviated through the field?

Solution:

Given that:

$$E = 300 \text{ V m}^{-1} = 300 \text{ N C}^{-1}, \quad B = 0.20 \text{ T}$$

To Find:

$$v = ?$$

Calculations: Only those particles will be able to pass through the plate for which the electric force qE acting on the particles balances the magnetic force Bqv on the particles as shown in the Fig. 10.12.

$$\text{Therefore } qE = Bqv$$

Thus, the selected speed is:

$$v = \frac{E}{B} = \frac{300 \text{ N C}^{-1}}{0.20 \text{ N A}^{-1} \text{ m}^{-1}} = 1500 \text{ m s}^{-1} \quad \text{Ans.}$$

The alpha particles having a speed of 1500 m s^{-1} will move undeviated through the field.

Example 10.5: A charged particle moves through a velocity selector at a constant velocity in a straight line. The electric field of the velocity selector is $4.8 \times 10^3 \text{ N C}^{-1}$, while the magnetic field is 0.2 T . When the electric field is turned OFF, the charged particle travels on a circular path of radius 3.0 cm . Find the charge to mass ratio of the particle.

Solution:

Given that:

$$E = 4.8 \times 10^3 \text{ N C}^{-1}, \quad B = 0.2 \text{ T}, \quad r = 3.0 \text{ cm}$$

To Find:

$$\frac{q}{m} = ?$$

Point to Ponder!

A force is exerted on a moving charged particle in a magnetic field. In what direction it should move that the force is not exerted on it?

Ans. For a charged particle to experience no force in a magnetic field, it must move parallel to the magnetic field lines.

The force on a charged particle moving with certain velocity in a magnetic field is given by

$$\mathbf{F} = q(\vec{v} \times \vec{B})$$

This force is the cross product of the velocity and the magnetic field vectors. For the cross product to be zero, the velocity $\vec{v}$ must be either zero or parallel to the magnetic field, the angle between $\vec{v}$ and $\vec{B}$ is zero, and thus the cross product is zero. It means that no force is exerted on the particle.

So, the particle should move along the direction of the magnetic field to avoid the force.

Calculations: Since the particle is moving in a direction perpendicular to both **E** and **B**, so the magnitude of velocity **v** will be given by

$$qE = Bqv \quad \text{or} \quad v = \frac{E}{B}$$

When the electric field is turned off, the particle will move along a circular path of radius *r*. Then the magnetic force provides necessary centripetal force. Then

$$Bqv = \frac{mv^2}{r}$$

So, charge to mass ratio becomes:

$$\frac{q}{m} = \frac{v}{Br}$$

Putting the value of $v = \frac{E}{B}$, we have

$$\frac{q}{m} = \frac{E}{B^2 r}$$

Putting the values of *E*, *B* and *r*, we have

$$\frac{q}{m} = \frac{4.8 \times 10^3 \text{ N C}^{-1}}{(0.20 \text{ T})^2 (3 \times 10^{-2} \text{ m})}$$

$$\frac{q}{m} = \frac{4.8 \times 10^3 \text{ N C}^{-1}}{1.2 \times 10^{-3} \text{ m}} = 4 \times 10^6 \text{ C kg}^{-1} \text{ Ans.}$$



- | | |
|---|---|
| <p>1. A velocity selector is a device that uses:
 (A) Only electric field
 (B) Only magnetic field
 (C) Both electric and magnetic fields ✓
 (D) Gravitational and magnetic fields</p> <p>2. In a velocity selector, the electric and magnetic fields are oriented:
 (A) Parallel to each other
 (B) In the same direction
 (C) Perpendicular to each other ✓
 (D) Randomly</p> <p>3. A charged particle passes through a velocity selector undeflected when:
 (A) $qE = qvB$ ✓ (B) $E = B$
 (C) $E = qv$ (D) $v = qEB$</p> <p>4. If a charged particle moves through a velocity selector and gets deflected, it means:
 (A) The particle is neutral
 (B) The particle is moving at $v = \frac{E}{B}$
 (C) The particle is not moving at the selected velocity ✓
 (D) The fields are not perpendicular</p> | <p>5. The velocity selector is most commonly used in:
 (A) Electric circuits
 (B) Particle accelerator and mass spectrometer ✓
 (C) Capacitors (D) Electromagnets</p> <p>6. In a velocity selector, what happens to the particles moving slower than the selected velocity?
 (A) They pass straight through
 (B) They are deflected upward
 (C) They are deflected downward ✓
 (D) They stop moving</p> <p>7. In a velocity selector, for a charged particle to pass through undeflected, the electric and magnetic forces must be:
 (A) In the same direction (B) Zero
 (C) Both attractive (D) Balance and opposite ✓</p> <p>8. Which charged particles are selected by the velocity selector?
 (A) Only fast-moving ones
 (B) Only negatively charged ones
 (C) Only those with a specific velocity ✓
 (D) All charged particles</p> |
|---|---|

10.6 INDUCED EMF AND FARADAY'S LAW



6. What is induced emf and motional emf? Find an expression for motional emf.

Ans. Induced emf

Definition

Induced emf (electromotive force) is the voltage generated in a conductor when it experiences a change in magnetic field.

When a conductor moves across a magnetic field, an electromotive force (emf) is induced between its ends. The induced emf in the moving conductor is similar to that of a battery. That is, if the ends of the conductor are connected by a wire to form a closed circuit, a current will flow through it.

Motional emf

Definition

The emf induced by the motion of a conductor across a magnetic field is called motional emf.

Expression for Motional emf

Consider an experiment; Fig. 10. A conducting rod of length L is placed on two parallel metal rails separated by a distance L . A galvanometer is connected between the ends c and d of the rails. This forms a complete conducting loop $abcd$. A uniform magnetic field $\mathbf{B}$ is applied directed into the page. Initially, when the rod is stationary, galvanometer indicates no current in the loop. If the rod is pulled to the right with constant velocity $\mathbf{v}$, the galvanometer indicates a current flowing through the loop. Obviously, the current is induced due to the motion of the conducting rod across the magnetic field. The moving rod is acting as a source of emf $\varepsilon = V_b - V_a = \Delta V$.

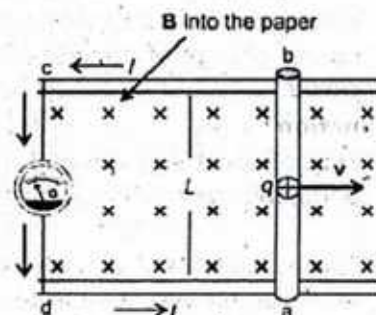


Fig. 10

When the rod moves, a charge q within the rod also moves with the same velocity $\mathbf{v}$ in the magnetic field $\mathbf{B}$ and experiences a force given by

$$\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$$

The magnitude of the force is:

$$F = qvB \sin \theta$$

Since, angle θ between $\mathbf{v}$ and $\mathbf{B}$ is 90° , so

$$F = qvB \quad \dots\dots (i)$$

Applying right hand rule, we see that the force $\mathbf{F}$ acting on the charge q is directed from point a to point b along the rod. As a result, charges migrate to the top end of the conductor. As more charges move, a concentration of charge builds up at the top end b , while there is a deficiency of charges at the bottom end a . This redistribution of charge creates an electrostatic field $\mathbf{E}$ directed from

b to a . The electrostatic force on the charge is $\mathbf{F}_e = q\mathbf{E}$ directed from b to a . The system quickly reaches an equilibrium state where these two forces on the charge are balanced. If E is the electric field intensity in this state, then

$$qE = qvB$$

or $E = vB \quad \dots\dots (ii)$

The motional emf (ε) will be equal to the potential difference $\Delta V = V_b - V_a$ between the two ends of the moving conductor in this equilibrium state. The gradient of potential is given by $\Delta V/L$. As the electric intensity is given by the negative of the gradient, therefore,

$$E = -\frac{\Delta V}{L} \quad \dots\dots (iii)$$

or $\Delta V = -LE = -(LvB)$

The motional emf is:

$$\varepsilon = \Delta V = -LvB \quad \dots\dots (iv)$$

This is the magnitude of motional emf. However, if the angle between $\mathbf{v}$ and $\mathbf{B}$ is θ , then

$$\varepsilon = -vBL \sin \theta \quad \dots\dots (v)$$

Do you know!



Wireless charging works under the principle of electromagnetic induction.

Point to Ponder!



This heater operates on the principle of electromagnetic induction. The water in the metal pan is boiling whereas that in the glass pan is not. Even the glass top of the heater is cool to touch. The coil just beneath the top carries AC that produces changing magnetic flux. Flux linking with pans induces emf in them. Current is generated in the metal pan that heats up the water, but no current flows through the glass pan, why?

Ans. The key reason that the glass pan does not heat is that it is non-conductive, so it cannot support the induced currents needed to generate heat. Induction heating only works with electrically conductive materials, preferably those that are also ferromagnetic (like iron or some stainless steels), which enhances the heating effect.



7. State and explain Faraday's law of electromagnetic induction.

Ans. Faraday's Law

Statement

The induced electromagnetic force (emf) in a closed circuit is directly proportional to the rate of change of magnetic flux through the circuit.

Explanation

The motional emf induced in a rod moving perpendicular to a magnetic field is:

$$\epsilon = -vBL$$

The motional emf as well as other induced emfs can be described in terms of magnetic flux.

Consider the experiment; Fig. 11 again. Let

the conducting rod be moving from position 1 to position 2 in a small interval of time Δt .

The distance travelled by the rod in time Δt is:

$$x_2 - x_1 = \Delta x$$

Since the rod is moving with constant velocity v , therefore,

$$v = \frac{\Delta x}{\Delta t}$$

Putting this value of v in equation; $\epsilon = \Delta v = -LvB$

$$\epsilon = -vBL = -\frac{\Delta x}{\Delta t} BL \quad \dots (i)$$

As the rod moves through the distance Δx , therefore, the increase in the area of loop is given by $\Delta A = \Delta x L$. This increases the flux through the loop by $\Delta \phi_B = (\Delta A)B$. Putting $(\Delta x L)B = \Delta \phi_B$ in Eq. (i)

$$\epsilon = -\frac{\Delta \phi_B}{\Delta t} \quad \dots (ii)$$

Equation (ii) shows that if the magnetic flux is changing through the single loop of a conducting coil, then the negative of the rate of change of magnetic flux is equal to the emf induced in the loop.

If there is a coil of N loops instead of a single loop, then the induced emf will become N times.

i.e.,
$$\epsilon = -N \frac{\Delta \phi_B}{\Delta t}$$

For Your Information



Faraday's homopolar generator with which he was able to produce a continuous induced current.

This is known as Faraday's law of electromagnetic induction which states that:

The average emf induced in a conducting coil of N loops is

equal to the negative of the rate at which the magnetic flux through the coil is changing with time.

The minus sign indicates that the direction of the induced emf is such that it opposes the change in flux.

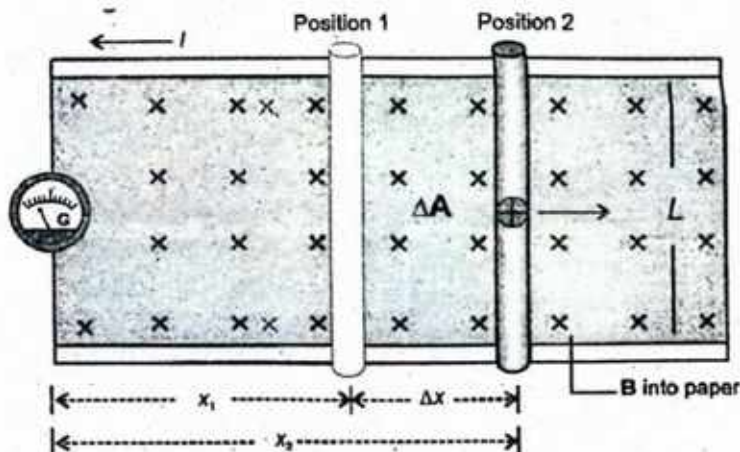
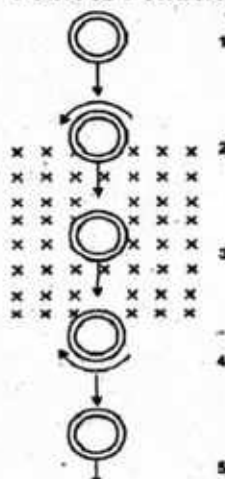


Fig. 11

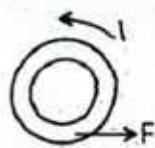
Point to Ponder!



A copper ring passes through a rectangular region where a constant magnetic field is directed into the page. What do you guess about the current in the ring at the positions 2, 3 and 4?

Ans. Yes, a constant current in a coil can set up a potential differences across the coil, even when resistance is neglected. For the ring:

Stage 2: When the ring enters the magnetic field, the magnetic flux changes (increases) through the ring. By Right Hand Rule, the force on the charge is shown in the figure and current will be anticlockwise.



Stage 3: No flux changes, therefore, no current.

Stage 4: Flux changes (decreases), therefore, current will be clockwise.



8. State and explain Lenz's law.

Ans. Lenz's Law

From Faraday's law

$$\varepsilon = -N \frac{\Delta\phi}{\Delta t}$$

The minus sign in the expression relates to the direction of the induced emf. To determine the direction, we use a principle based on the discovery physicist Lenz. He found that the polarity of an induced emf always produces an induced current that opposes the change in the magnetic field that causes the emf. This principle is known as Lenz's Law, which states that:

The direction of the induced current is always such that it opposes the change that causes the current.

Direction of Induced EMF

Let us apply Lenz's law to a coil in which a current is induced by the movement of a bar magnet. A current-carrying coil generates a magnetic field similar to that of a bar magnet, with one face of the coil acting as the north pole and the other as the south pole. To oppose the motion of the bar magnet, the face of the coil towards the magnet must become a north pole; Fig. 12. This arrangement causes the two north poles to repel each other. According to the right-hand rule, the induced current in the coil must flow anticlockwise when viewed from the side of the bar magnet.

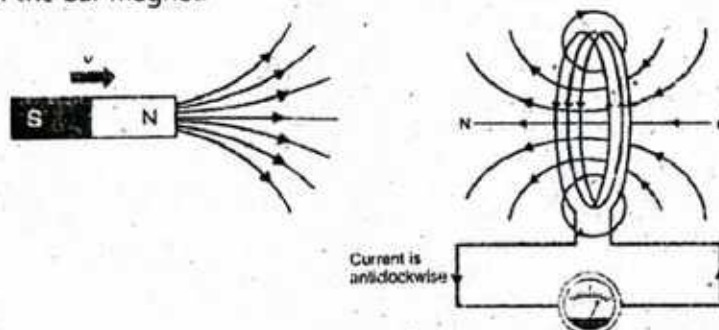


Fig. 12

According to Lenz's law, the "push" of the magnet is the "change" that produces the induced current, and the current acts to oppose the push. On the other hand, if we pull the magnet away from the coil, the induced current will oppose the "pull" by creating a south pole on the face of coil towards the bar magnet.

Lenz's Law and Law of Conservation of Energy

Lenz's law is also a manifestation of the law of conservation of energy and can be conveniently applied to circuits involving induced currents. To understand this, see the experiment, Fig. 16. When the rod moves to the right, an emf is induced in it, causing an induced current to flow through the loop in anticlockwise direction. Because the current-carrying rod is moving within the magnetic field, it experiences a magnetic force F_m with the magnitude of $F_m = ILB \sin 90^\circ$.

According to the right-hand rule, the direction of the magnetic force F_m is opposite to that of the velocity v , so it tends to stop the rod; Fig. 13(a). To keep the rod moving with a constant velocity, an external force equal in magnitude to F_m but opposite in direction must be applied. This external force provides the energy necessary for the induced current to flow. Thus, electromagnetic induction adheres to the law of conservation of energy.

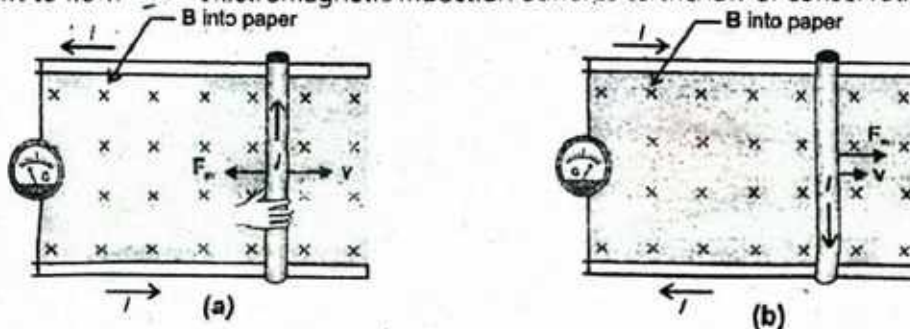


Fig. 13

The Lenz's law forbids the induced current directed clockwise in this case, because the force F_m would be, then, in the direction of v that would accelerate the rod towards right; Fig. 13(b). This in turn would induce a stronger current, the magnetic field due to it also increases and the magnetic force increases further. Thus, the motion of the wire is accelerated more and more. Starting with a minute quantity of energy, we obtain an ever-increasing kinetic energy of motion apparently from nowhere. Consequently, the process becomes self-perpetuating which is against the law of conservation of energy.

Example 10.6: A metal rod of length 25 cm is moving at a speed of 0.5 m s^{-1} in a direction perpendicular to a 0.25 T magnetic field. Find the emf produced in the rod.

Solution:

Given that;

$$\begin{aligned}\text{Speed of rod} &= v = 0.5 \text{ m s}^{-1} \\ \text{Length of rod} &= L = 25 \text{ cm} = 0.25 \text{ m} \\ \text{Magnetic flux density} &= B = 0.25 \text{ T} = 0.25 \text{ N A}^{-1} \text{ m}^{-1}\end{aligned}$$

To Find:

$$\text{Induced emf} = \epsilon = ?$$

Calculations: Using the relation,

$$\epsilon = vBL$$

Putting the values

$$\epsilon = 0.5 \text{ m s}^{-1} \times 0.25 \text{ N A}^{-1} \text{ m}^{-1} \times 0.25 \text{ m}$$

$$\epsilon = 3.13 \times 10^{-2} \text{ J C}^{-1} = 3.13 \times 10^{-2} \text{ V} \text{ Ans.}$$

Example 10.7: A loop of wire is placed in a uniform magnetic field that is perpendicular to the plane of the loop. The strength of the magnetic field is 0.6 T . The area of the loop begins to shrink at a constant rate of $\frac{\Delta A}{\Delta t} = 0.8 \text{ m}^2 \text{ s}^{-1}$.

What is the magnitude of emf induced in the loop while it is shrinking?

Solution:

Given that;

$$\text{Rate of change of area} = \frac{\Delta A}{\Delta t} = 0.8 \text{ m}^2 \text{ s}^{-1}$$

$$\text{Magnetic flux density} = B = 0.6 \text{ T} = 0.6 \text{ N A}^{-1} \text{ m}^{-1}$$

$$\text{Number of turns} = N = 1$$

To Find:

$$\text{Induced emf} = \epsilon = ?$$

Calculations:

$$\text{Rate of change of flux} = \frac{\Delta \Phi}{\Delta t} = B \frac{\Delta A}{\Delta t} \cos 0^\circ = B \frac{\Delta A}{\Delta t}$$

Applying Faraday's law, magnitude of induced emf is:

$$\epsilon = N \frac{\Delta \Phi}{\Delta t} = NB \frac{\Delta A}{\Delta t}$$

Putting the values

$$\epsilon = 1 \times 0.6 \text{ N A}^{-1} \text{ m}^{-1} \times 0.8 \text{ m}^2 \text{ s}^{-1}$$

$$\epsilon = 0.48 \text{ J C}^{-1} = 0.48 \text{ V}$$

Point to ponder!

By neglecting the resistance, can a constant current in a coil set up a potential difference across the coil?

Ans. If the resistance is neglected and the current is constant, there is no potential difference across the coil. The coil behaves like a short circuit.

10.8 FACTORS AFFECTING EMF



9. Describe the factors which affect the induced emf.

Ans. 1. Rate of Change of Magnetic Flux

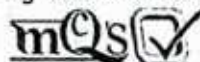
Faraday's law suggests that faster changes in magnetic flux result in greater induced emf.

2. Number of Turns of the Coil

According to Faraday's law, induced emf is also proportional to the number of turns of the coil. More turns result in a greater induced emf.

3. Relative Speed

The speed of the coil (or conductor) through a magnetic field also affects the magnitude of the induced emf. Faster speed increases the rate of change of magnetic flux that results into an increase in the induced emf.



1. If we make the magnetic field stronger, the value of induced current.
(A) Decreased (B) Increased ✓
(C) Vanished (D) Kept constant
2. The induced current in a loop can be increased by:
(A) Using strong magnetic field
(B) Moving the loop faster
(C) Replacing loop by a coil
(D) All of these ✓
3. Lenz's law is in accordance with law of conservation of:
(A) Mass (B) momentum
(C) Charge (D) Energy ✓
4. The Lenz's law refers to:
(A) Induced current ✓ (B) Induced potential
(C) Motional emf (D) All of these
5. The direction of induced current is always so as to oppose the change which causes the current is:
(A) Faraday's law (B) Lenz's law ✓
(C) Ohm's law (D) Kirchhoff's law
6. If velocity of a conductor moving through a magnetic field 'B' is made zero, then motional emf is:
(A) $-vBL$ (B) $\frac{v}{BL}$
(C) $\frac{BL}{v}$ (D) zero ✓
7. The rod of unit length is moving at 30° through a magnetic field of 1 T. If velocity of rod is 1 m/s, then induced emf in the rod will be given by:
(A) 1 V (B) 0.25 V
(C) 0.5 V ✓ (D) 0.6 V
8. The motional emf is given by:
(A) qvB (B) iBL
(C) eBL (D) vBL ✓
9. The motional emf depends upon the:
(A) Length of conductor (B) Speed of conductor
(C) Strength of magnet (D) All of these ✓
10. Lenz's law is related to the:
(A) Conservation of momentum
(B) Conservation of mass
(C) Conservation of charge
(D) Conservation of energy ✓
11. Lenz's law helps to determine the:
(A) Magnitude of induced current
(B) Direction of induced current ✓
(C) Resistance in the circuit (D) Power consumed
12. Lenz's law ensures that:
(A) The induced emf is zero
(B) The induced emf supports the change in magnetic field
(C) The total energy is conserved ✓
(D) There is no magnetic force
13. Faraday's law is the fundamental principle behind:
(A) Electric motors
(B) Batteries
(C) Transformers and generators ✓
(D) Thermocouples
14. The magnitude of induced emf is given by
(A) $\text{emf} = IR$ (B) $\text{emf} = -N \frac{d\phi}{dt}$ ✓
(C) $\text{emf} = N \frac{d\phi}{dt}$ (D) $\text{emf} = B \cdot A$
15. According to Faraday's law, emf can be induced by
(A) Changing area of the coil
(B) Changing magnetic field strength
(C) Rotating the coil in magnetic field
(D) All of these ✓
16. Induced emf can be increased by
(A) Increasing resistance of the coil
(B) Decreasing resistance of the coil
(C) Increasing number of turns of coil ✓
(D) Decreasing rate of magnetic flux
17. If a conductor of length 1 m is moved with velocity v across a magnetic field B at an angle 30° with B , then the Motional emf will be:
(A) vBL (B) $\frac{1}{2} vBL$
(C) $\frac{1}{2} vB$ ✓ (D) $0.866 vB$
18. Emf is induced due to change in:
(A) Electric flux (B) Magnetic flux ✓
(C) Electric potential (D) Electric current
19. Electric current producing magnetic field was discovered by:
(A) Faraday (B) Maxwell
(C) Oersted ✓ (D) Lenz
20. The current flowing through a coil due to induced emf in it depends upon:
(A) Shape of the coil (B) Resistance of the coil ✓
(C) Area of the coil (D) Magnetic flux
21. The induced emf primarily produced at the cost of:
(A) Internal energy (B) Chemical energy
(C) Electrical energy (D) Mechanical energy ✓
22. Maximum motional emf in a conductor is given by vBL . At which angle the conductor moves in magnetic field such that emf in it becomes half then its maximum value is:
(A) 0° (B) 30° ✓
(C) 45° (D) 60°



10. Explain how do ferrofluids work?

Ans. Ferrofluids

Ferrofluids are liquids that become strongly magnetized in the presence of a magnetic field. They are made by suspending very small magnetic particles; usually nano-particles of iron oxide (like magnetite) in a carrier fluids such as oil or water. To prevent the particles from clumping together, they are coated with a surfactant (a substance that reduces surface tension).

Key Characteristics of Ferrofluids

1. Magnetic Response

They flow like a liquid but can be manipulated using a magnetic field.

2. Stability

The particles remain suspended without settling, due to their small size and the surfactant.

3. Spiking Effect

When exposed to a magnetic field, the surface of the ferrofluid forms spikes along the field lines, a visually striking demonstration of magnetic force.

Working

When there is no magnet around, a ferrofluid acts like a liquid, but when there is a magnet nearby, the particles are temporarily magnetized and the fluid becomes a magnet. They form structures within the fluid causing the ferrofluid to act more like a solid. When the magnet is removed, the particles are demagnetized and the ferrofluid acts like a liquid again.

This phenomenon is due to the competition between magnetic forces, surface tension and gravity. In the presence of strong magnetic field, the formation of chain-like structures is a result of magnetic forces pulling the fluid upwards while gravity and surface tension work to pull it back down. These chains align along the magnetic field lines and increase the viscosity, making it behave like a solid bulging in certain directions. These are commonly

known as spikes. However, the spikes are formed where the magnetic forces overcome the other forces: Fig 14). The following experiment will exhibit this phenomenon.

Experiment

You need some laser printer toner, some cooking oil, a test tube, a glass bottle, a small stick and a magnet.

Procedure

Pour some toner in the test tube. Remember that laser printer toner contains 40 % iron oxide in nanometre particle size. Add some cooking oil in it and mix it well with the stick to form ferrofluid. Put this fluid in the bottle. The fluid will act like a liquid on shaking the bottle. Now bring the magnet near to fluid outside of the bottle.

You will observe that the fluid jumps towards the magnet, because it has itself become a magnet. If we hold the magnet on the side of the bottle, you will see a structure with spikes formed by the fluid; Fig. 15.

For Your Information

The first ferrofluid developed by NASA in 1960, was ground from natural magnetite. Ferrofluid was invented to move liquids through space.



Fig. 14

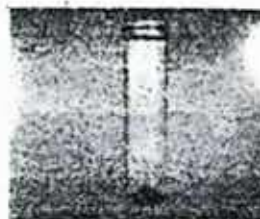


Fig. 15

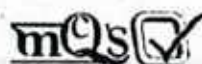


11. Briefly describe some applications of ferrofluids.

Ans. Applications of Ferrofluids

There are many applications of ferrofluids in the fields of **electronics, medicine, engineering, and active research** in Physics and **Material science**.

1. In **electronics**, ferrofluids are used in rotary seals for computer hard drives and other rotating shaft motors. In loudspeakers, ferrofluids are used to cool the voice coil which can heat up during operation. The magnetic field holds the fluid in place around the coil, allowing it to absorb and dissipate heat more effectively. Ferrofluids are also used in speakers to dampen vibrations and improve sound quality.
2. In **medical** applications, ferrofluids can be directed to specific areas in the body using external magnets, allowing for targeted drug delivery. The magnetic particles can carry drugs directly to a tumor or other targeted site, reducing side effects and improving treatment efficiency. Ferrofluids can also be used as contrast agents in magnetic resonance imaging (MRI).
3. Ferrofluids are used in art and education for demonstration of magnetism. Other applications of ferrofluids include damping or precisely controlling the flow of liquids by manipulating the magnetic field.



- | | |
|--|---|
| <ol style="list-style-type: none"> 1. A ferrofluid is a:
 (A) Gas with magnetic properties
 (B) Liquid that becomes magnetized in the presence of a magnetic field ✓
 (C) Solid magnetic material dissolved in water
 (D) Non-magnetic fluid used for insulation 2. Ferrofluids are typically composed of:
 (A) Mercury mixed with graphite
 (B) Iron filings in water
 (C) Melted magnets
 (D) Suspended nano-magnetic particles in a carrier fluid ✓ 3. Which property allows ferrofluids to respond to magnetic fields?
 (A) Thermal conductivity (B) Paramagnetism
 (C) Ferromagnetism ✓ (D) Superconductivity 4. Which of the following is a common application of ferrofluids?
 (A) Sealing hard drives ✓ (B) Cooling computer chips
 (C) Magnetic resonance imaging (MRI)
 (D) Fuel additives in diesel engines 5. The carrier liquid in a ferrofluid can be:
 (A) Only water (B) Only oil
 (C) Water, oil, or organic solvents ✓ | <ol style="list-style-type: none"> (D) Only mercury 6. In the absence of magnetic field, a ferrofluid behaves like a:
 (A) Solid (B) Plasma
 (C) Gas (D) Regular liquid ✓ 7. Which force balances the magnetic attraction to prevent ferrofluid particles from settling?
 (A) Buoyant force (B) Brownian motion ✓
 (C) Electrostatic repulsion (D) Gravitational pull 8. What keeps the magnetic particles in a ferrofluid from clumping together?
 (A) Gravity (B) Friction
 (C) Surface tension
 (D) Surfactants or dispersing agents ✓ 9. When exposed to a magnetic field, a ferrofluid:
 (A) Forms spike-like patterns ✓ (B) Boils
 (C) Becomes transparent (D) Solidifies permanently 10. In a loudspeaker, ferrofluids are used to:
 (A) Absorb sound
 (B) Cool the voice coil and dampen vibrations ✓
 (C) Increase magnetic field strength
 (D) Create colourful patterns |
|--|---|

10.10 A SEISMOMETER



12. What is a seismometer? Describe its construction and working.

Ans. Seismometer

A seismometer is an instrument that responds to any movement of the rocks under the ground or vibration caused by earthquakes, volcano eruption and explosion. A seismometer detects earthquakes by using electromagnetic induction to convert ground motion into electrical signals.

Construction and Working

Typically, a seismometer includes a weight suspended by a spring. When an earthquake occurs, the ground moves but the weight tends to stay stationary due to inertia. This results in relative motion between the weight and the frame of the seismometer which is attached to the ground. The weight is often attached to a magnet which moves inside a coil of wire; Fig. 16. This setup works according to Faraday's law of electromagnetic induction,

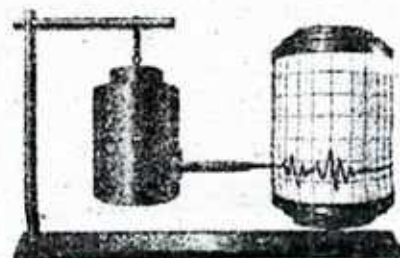


Fig. 16

For Your Information

Most earthquakes are caused by plate

that is, the changing magnetic flux through the coil induces an emf in the coil. This gives rise to an induced electric current.

The induced current is proportional to the velocity of the ground motion. The electrical signals generated are then amplified and recorded. Thus, data is provided on the amplitude, frequency and the duration of the earthquake waves.

The data is analyzed to determine various characteristics of the earthquake, such as its location, magnitude and depth.

Usually, a seismometer is buried under the ground at a depth of 50-1000 metres. It is placed in a protective case called a vault. This is a cylindrical steel tank that is approximately 1 metre wide and 2 metres deep with a concrete pad at the bottom; Fig. 17.

tectonics (displacement) and occur at a depth of 60 km. These earthquakes are categorized as shallow. Intermediate and deep intermediate can be as deep as 280 km beneath the crust, while deep earthquakes can reach depths past 280 km.

For Your Information

There are two main types of seismic waves that generate earthquakes i.e., P-waves are primary waves which are longitudinal and S-waves are secondary waves which are transverse in nature.

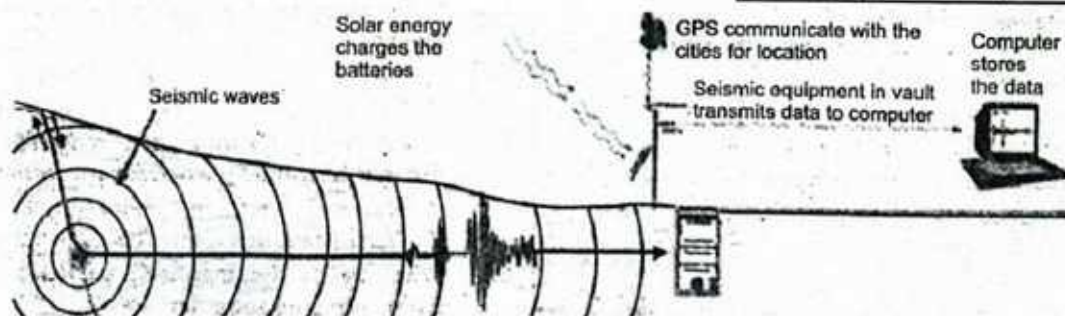


Fig. 17



- What does a seismometer measure?
 - Rainfall
 - Earthquakes ✓
 - Wind speed
 - Temperature
- The working principle of a seismometer is based on:
 - Magnetic fields
 - Electrical resistance
 - Inertia of a suspended mass ✓
 - Buoyancy
- What type of energy does a seismometer detect?
 - Electrical energy
 - Sound energy
 - Thermal energy
 - Seismic energy ✓
- Why are seismometers often placed underground?
 - To increase their sensitivity to heat
 - To protect them from rain
 - To reduce surface noise and vibration interference ✓
 - To keep them cool
- Which type of seismic wave reaches a seismometer first during an earthquake?
 - Surface waves
 - S-waves (secondary waves)
 - L-waves (long waves)
 - P-waves (primary waves) ✓
- A digital seismometer records seismic activity by converting motion into:
 - Sound waves
 - Electrical signals ✓
 - Chemical changes
 - Light pulses
- What aspect of an earthquake can seismometers help to determine?
 - Colour of soil
 - Rainfall levels
 - Time of day only
 - Depth and magnitude ✓
- Seismometers can detect seismic activity from how far away?
 - Only within 100 km
 - Only with 10 km
 - Only on the same continent
 - From anywhere on the Earth ✓

ADDITIONAL SHORT ANSWER QUESTIONS



Q.1 Distinguish between magnetic flux and magnetic flux density.

Ans.

(i) Magnetic Flux

The number of magnetic lines of force passing through certain element of area is known as magnetic flux. Mathematically,

It is defined as the scalar (dot) product of magnetic field and vector area.

Formula:

$$\phi_B = \vec{B} \cdot \vec{A} = BA \cos \theta$$

Units: Its SI units is weber (Wb) which can be expressed as NmA^{-1} .

(ii) Magnetic flux Density (Magnetic Induction)

The magnetic flux per unit area of a surface perpendicular to magnetic field is known as magnetic flux density.

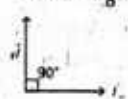
Formula:

$$B = \frac{\phi_B}{A}$$

Units: Its SI unit is tesla.

Q.2 Electric force does work, while no work is done by the magnetic force. Why?

Ans.

Electric Force	Magnetic Force
Let a charged particle q be placed in an electric field $\vec{E}$. It will be accelerated under the action of electric force $\vec{F}_e$ in the direction of force. $\vec{F}_e = q\vec{E}$ So $W = \vec{F}_e \cdot \vec{d}$ $= F_e d \cos \theta$ $(\because \vec{F}_e \uparrow \vec{d}, \text{ so } \theta = 0^\circ)$ $= F_e d \cos 0^\circ$ $W = F_e d \quad (\because \cos 0^\circ = 1)$ So, work is done by the electric force because it is an accelerating force.	Let a charged particle q be placed in a magnetic field $\vec{B}$. Then it will be deflected into the circular path under the action of magnetic force $\vec{F}_B = q(\vec{v} \times \vec{B})$ So $W = \vec{F}_B \cdot \vec{d}$ $W = F_B d \cos \theta$  $(\because \therefore \theta = 90^\circ)$ $= F_B d \cos 90^\circ$ $= F_B d (0) \quad (\because \cos 90^\circ = 0)$ $W = 0$ So, no work is done by the magnetic force because it is only a deflecting force.

Q.3 A sensitive galvanometer cannot be stable. Explain?

Ans. A sensitive galvanometer cannot be stable.

Reason:

When the current passing through the galvanometer is discontinued, the coil will not come to rest due to its inertia. It keeps on oscillating about its mean position before coming to rest. In the same way if the current is established suddenly in a galvanometer, the coil will shot beyond its final equilibrium position and will oscillate several times before coming to rest at its equilibrium.

Q.4 Is it possible to obtain an isolated north pole? Give reasons.

Ans. No, it is not possible to make a magnet having north or south pole. The existence of the pole is due to the currents, within an atom due to its spin and orbital motion. This is just like a current in a loop of wire, making one side north and other side south pole.

Reason: When the current passing through the galvanometer is discontinued, the coil will not come to rest due to its inertia. It keeps on oscillating about its mean position before coming to rest. In the same way if the current is established suddenly in a galvanometer, the coil will shot beyond its final equilibrium position and will oscillate several times before coming to rest at its equilibrium.

Q.5 Prove that; $\text{NA}^{-1} \text{m}^{-1} = \text{Wbm}^{-2}$. As we know that, $F = ILB \sin \theta$. Its units are given as $B = \frac{N}{\text{Am}}$

Ans. $\boxed{B = \text{NA}^{-1} \text{m}^{-1}} = \text{Tesla} \quad \dots (i)$

Also $\phi_B = BA$

$$\vec{B} = \frac{\phi_B}{A}$$

$$\vec{B} = \frac{\text{weber}}{\text{m}^2}$$

$$\boxed{\vec{B} = \text{Wbm}^{-2}} = \text{Tesla} \quad \dots (ii)$$

Comparing Eqs. (i) and (ii)

$$\text{NA}^{-1}\text{m}^{-1} = \text{Wbm}^{-2}$$

Q.6 Why ohmmeter gives full deflection in zero resistance?

Ans. Because before using the ohmmeter, zero ohm on the scale is marked by short circuiting terminal and value of r_s is so adjusted that galvanometer give full scale deflection.

Q.7 A plane conducting loop is located in a uniform magnetic field that is directed along x-axis. For what orientation of the loop is the flux a maximum? For what orientation is the flux a minimum?

Ans. (i) Maximum Flux

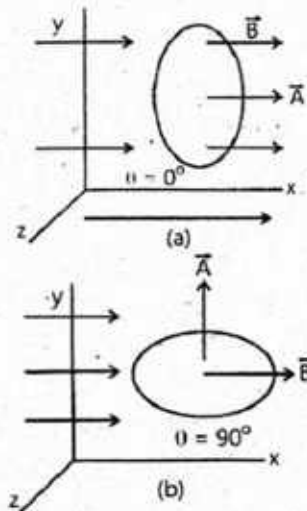
Flux passing through the loop will be maximum when the plane of the loop is held perpendicular to the direction of magnetic induction.

$$\begin{aligned} \text{i.e.,} \quad \phi &= \vec{B} \cdot \vec{A} \\ \phi &= BA \cos 0^\circ \\ \boxed{\phi &= BA} \quad (\text{Maximum}) \end{aligned}$$

(ii) Minimum Flux

Flux passing through the loop will be minimum when the plane of the loop is held parallel to the direction of magnetic induction.

$$\begin{aligned} \text{i.e.,} \quad \phi &= \vec{B} \cdot \vec{A} = BA \cos \theta \\ &= BA \cos 90^\circ \\ &= BA (0) \\ \boxed{\phi &= 0} \quad (\text{Minimum}) \end{aligned}$$



Q.8 What happens when a current-carrying conductor is placed in a magnetic field?

Ans. It experiences a force due to the interaction between the magnetic field and the moving charge in the conductor.

Q.9 On What factor does the magnetic force depend?

Ans. As the magnetic force on a conductor placed in a magnetic field is:

$$\vec{F} = I (\vec{L} \times \vec{B})$$

$$\text{or} \quad F = ILB \sin \theta$$

Therefore, the magnetic force F depends on current I , magnetic field B , length of conductor L , and the angle θ between L and B .

Q.10 In which applications, the magnetic force on a current-carrying conductor is used?

Ans. Electric motors, loud speakers, and galvanometer reply on this principle.

Q.11 What happens when a charged particle enters a magnetic field?

Ans. It experiences a force perpendicular to both its velocity and the magnetic field, causing it to move in a curved path.

Q.12 What is the formula for a magnetic force on a moving charge? When is this force maximum and zero?

$$\text{Ans. As } \vec{F} = q(\vec{v} \times \vec{B}) \quad \text{or} \quad F = qvB \sin \theta$$

This force is maximum, when angle between v and B is 90° , and is zero when angle is 0° or 180° .

Q.13 What is the radius of the circular path?

Ans. $r = \frac{mv}{qB}$, where m is mass, v is velocity, q is charges and B is magnetic field strength.

Q.14 At a given instant, a proton moves in the positive x-direction in a region where there is magnetic field in the negative z-direction. What is the direction of the magnetic force? Will the proton continue to move in the positive x-direction? Explain.

Ans. (a) Magnetic force is directed along positive y-direction.

Reason:

As magnetic force acting on proton is given by

$$\vec{F} = q(\vec{v} \times \vec{B})$$

By right hand rule, $\vec{F}$ is directly perpendicular to the plane containing $\vec{v}$ and $\vec{B}$ i.e., along positive y-direction.

(b) No, it will move along a circle.

Reason:

As the proton experiences a force that acts at right angle to its velocity, so it will change only direction of velocity. Thus under the action of this force proton moves in a circle.

Q.15 Two charged particles are projected into a region where there is a magnetic field perpendicular to their velocities. If the charges are deflected in opposite direction, what you can say about them?

Ans.

$$\vec{F} = q(\vec{v} \times \vec{B})$$

They must have opposite nature i.e. one is positive charge and other one is negative charge.

Force on a Proton:

$$q = +e$$

So

$$\vec{F} = +e(\vec{v} \times \vec{B})$$

For a +ve charge such as proton the direction of force is given by the right-hand rule. The +ve charge carrier or a proton will be deflected upward because force $\vec{F}$ is in upward direction.

Force on an Electron:

$$q = -e$$

So

$$\vec{F} = -e(\vec{v} \times \vec{B})$$

The direction of force will be opposite to that of +ve charge. The electrons would be deflected downwards as they enter in the magnetic field.

Q.16 Suppose that a charge q is moving in a uniform magnetic field with a velocity v . Why is there no work done by the magnetic force that acts on the charge q ?

Ans. The magnetic force acting on charge particle is given by

$$\vec{F} = q(\vec{v} \times \vec{B})$$

Due to magnetic force the charge particle will moves in a circular path. In the circular path, the magnetic force $\vec{F}$ will be perpendicular to velocity $\vec{v}$. As the displacement $\vec{d}$ is parallel to the velocity $\vec{v}$, so the angle between the displacement $\vec{d}$ and the magnetic force $\vec{F}$ is 90° .

$$W = \vec{F} \cdot \vec{d}$$

$$\left(\because \begin{array}{c} \vec{d} \\ \uparrow \\ \text{ } \\ \downarrow \\ \vec{F} \end{array} \right)$$

$$W = Fd \cos \theta$$

$$\left(\because \theta = 90^\circ \right)$$

$$W = Fd \cos 90^\circ$$

$$\left(\because \cos 90^\circ = 0 \right)$$

$$\boxed{W = 0}$$

So, there is no work done by the magnetic force. This means that the magnetic force is only a deflecting force.

Q.17 If a charged particles moves in a straight line through some region of space, can you say that the magnetic field in the region is zero?

Ans. No, it may or may not be zero.

Reason: The magnetic force acting on a charged particle is given by

$$\vec{F} = q(\vec{v} \times \vec{B})$$

or $\vec{F} = qvB \sin \theta \hat{n}$

Now, $\vec{F} = 0$, if:

(i) $\vec{B} = 0$

(ii) $\theta = 0^\circ$ (i.e., the charged particle moves parallel to magnetic field)

(iii) $\theta = 180^\circ$ (i.e., the charged particle moves opposite to magnetic field)

(iv) $\vec{v}$ is perpendicular to both $\vec{E}$ and $\vec{B}$ ($\vec{E}$ & $\vec{B}$ are also perpendicular) such that $F_E = F_B$ so that net force acting on charge particle will become zero. (velocity selector method).

Q.18 What is velocity selector?

Ans. It is a device that allows charged particles of a specific velocity to pass through undeflected.

Q.19 What is the condition for a particle to pass through a velocity selector undeflected?

Ans. The electric force must equal the magnetic force.

i.e., $qE = -qvB$, therefore, $v = \frac{qE}{qB} = \frac{E}{B}$

Q.20 Where is a velocity Selector used?

Ans. In mass spectrometers and other particle physics experiments.

Q.21 Why does the picture on a TV screen become disturbed when a magnetic is brought near the screen?

Ans. The picture on a TV screen becomes distorted when a magnet is brought near the screen because of change in path of electrons.

Reason: Picture on TV Screen is formed by beam of electrons emitted from the electron gun. When a magnet is brought near a TV screen, a magnetic force, i.e., $\vec{F} = -e(\vec{v} \times \vec{B})$ acts on the electrons moving towards the TV-screen and the path of electrons will change due to the magnetic force. Therefore, picture on the TV-screen becomes distorted.

Q.22 Is it possible to orient a current loop in a uniform magnetic field such that the loop will not tend to rotate? Explain.

Ans. Yes, it is possible to orient a current loop in a uniform magnetic field such that the loop will not tend to rotate if plane of loop is placed perpendicular to the magnetic field.

Reason: The torque on a current carrying coil is given by

$$\tau = NIBA \cos \alpha$$

For a loop: $N = 1$

So $\tau = IBA \cos \alpha$

Where α is the angle between magnetic field and the plane of loop.

When the plane of loop is placed perpendicular to the magnetic field ($\alpha = 90^\circ$), then

$$\tau = IBA \cos 90^\circ$$

$$\tau = IBA (0)$$

$$\tau = 0$$

Thus, the loop will not tend to rotate.

Q.23 How can a current loop be used to determine the presence of a magnetic field in a given region of space?

Ans. The torque acting on a current carrying loop in magnetic field is given by:

$$\tau = IBA \cos \alpha$$

If a current loop experiences a torque on placing with different orientations (directions) in a given region of space, then a magnetic field is present in that region. (other than $\alpha = 90^\circ$)

Q.24 How can you use a magnetic field to separate isotopes of a chemical element?

Ans. When the isotopes of an element (in ionic form) are projected from the same spot in a perpendicular magnetic field. Magnetic force provides the necessary centripetal force to these isotopes to move them into circular paths.

$$evB = \frac{mv^2}{r}$$

$$eB = \frac{mv}{r}$$

$$r = \frac{mv}{eB}$$

$$\boxed{r \propto m} \quad (\text{If } v \text{ and } B \text{ are constant.})$$

This shows the radius of the circular path of charged particle in a magnetic field depends on its mass. As isotopes of an element have different masses. So, they will move in orbits of different radii according to their masses and can be separated from each other.

Q.25 What should be the orientation of a current-carrying coil in a magnetic field so the torque acting upon the coil is (a) maximum (b) minimum?

Ans. (a) When the plane of current carrying coil is held parallel to the field, torque will be maximum.

Explanation:

As $\tau = NIAB \cos \alpha$

Then $\tau = NIAB \cos 0^\circ$ (since $\alpha = 0^\circ$)

$$\boxed{\tau = NIAB} \quad (\text{maximum})$$

(b) When the plane of current carrying coil is held perpendicular to the magnetic field, torque will be minimum.

Explanation:

As $\tau = NIAB \cos \alpha$

Then $\tau = NIAB \cos 90^\circ$ (since $\alpha = 90^\circ$)

$$\boxed{\tau = 0} \quad (\text{minimum})$$

Q.26 A loop of wire is suspended between the poles of a magnet with its plane parallel to the pole faces. What happens if a direct current is put through the coil? What happens if an alternating current is used instead?

Ans. In both cases (A.C and D.C) the plane of the loop will not rotate.

Reason:

Since in both cases the plane of the loop and magnetic field are perpendicular. So the torque will be zero. i.e.,

$$\tau = NIAB \cos \alpha$$

or $\tau = IAB \cos 90^\circ$ (Since $\alpha = 90^\circ$, for one loop $N = 1$)

$$\boxed{\tau = 0}$$

Q.27 Why the resistance of an ammeter should be very low?

Ans. The resistance of an ammeter should be very low so it does not affect the circuit current.

Explanation:

An ammeter is always connected in series with a circuit whose current is to be measured. If the resistance of ammeter is large, it will increase the resistance of the circuit, hence current is decreased. A good ammeter should not change the circuit current, so it must have very small resistance as compared to the resistance of circuit itself.

Q.28 Why the voltmeter should have a very high resistance?

Ans. The voltmeter should have a very high resistance so it does not become a load and draw circuit current.

Explanation:

A voltmeter is connected in parallel with the circuit across which the potential difference is to be measured. If the voltmeter has a small resistance, it will draw some current from the circuit and will alter the circuit current. So, the potential difference measured by the voltmeter is also altered. For no change in the potential difference of the circuit voltmeter should draw either no current or very small current. This is only possible when the resistance of the voltmeter is very high as compared to the circuit resistance.

Q.29 What is induced emf?

Ans. It is the electromotive force generated in a conductor when there is a change in magnetic flux linked with it

Q.30 What causes an emf to be induced in a coil?

Ans. A change in magnetic flux through the coil, either by changing the magnetic field, the area, or the orientation.

Q.31 What factors affect the magnitude of induced emf?

Ans. Rate of change of magnetic flux, strength of the magnetic field, number of turns, and area of the loop.

Q.32 Give an example of electromagnetic induction.

Ans. Moving a magnet in and out of a coil generates an emf in the coil.

Q.33 How does Lenz's law obey the law of conservation of energy?

Ans. By opposing the change, it prevents free energy creation and ensures that work must be done to induce current.

Q.34 Give an example of Lenz's law in everyday life.

Ans. In electric brakes of trains, changing magnetic fields, induce currents that opposes motion, slowing the train.

Q.35 Can Lenz's law be applied to all cases of electromagnetic induction?

Ans. Yes, it is a universal rule for determining the direction of induced emf and current

Q.36 What is a ferrofluid?

Ans. It is a liquid that becomes strongly magnetized in the presence of a magnetic field.

Q.37 What are ferrofluids made of?

Ans. They are made of tiny magnetic nanoparticles (like iron oxide) suspended in a carrier fluid (such as oil or water).

Q.38 What keeps the particles in a ferrofluid suspended?

Ans. A surfactant coats the particles, preventing them from clumping together due to magnetic attraction.

Q.39 How do ferrofluids respond to magnetic fields?

Ans. They form spikes or patterns along the magnetic field lines due to magnetic forces acting on the fluid.

Q.40 What is one common use of ferrofluids?

Ans. In electric devices, such as sealing hard drives or in speakers to dampen vibrations

Q.41 What is a seismometer?

Ans. It is an instrument used to detect and measure seismic waves caused by earthquakes or other ground vibrations.

Q.42 What does a seismometer measure?

Ans. It measurement motion of the ground, including amplitude and frequency of seismic waves.

Q.43 How does a basic seismometer work?

Ans. It typically has a suspended mass that stays still as the ground moves; the relative motion between the mass and the Earth is recorded.

Q.44 What type of waves does a seismometer detect?

Ans. It detects both primary (P) waves and secondary (S) waves from seismic activity.

Q.45 Where are seismometers usually placed?

Ans. In seismic stations, often underground or on bedrock to minimize surface noise.

Q.46 Can seismometers help to predict earthquakes?

Ans. They cannot predict earthquakes, but they help to monitor seismic activity and assess risk.

Q.47 Can a seismometer detect small tremors?

Ans. Yes, modern digital seismometers are very sensitive and can detect even very weak ground motions.

SOLVED EXERCISE

MULTIPLE CHOICE QUESTIONS

Tick (✓) the correct answer.

10.1 A current is flowing towards north along a power line. The direction of the magnetic field over the wire is directed towards:

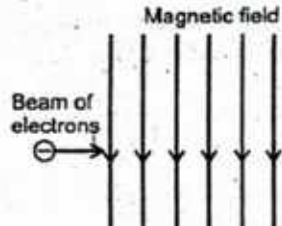
- (a) north (b) south (c) east ✓ (d) west

10.2 The radius of curvature of the path of a charged particle in a uniform magnetic field is directly proportional to:

- (a) the particle's charge (b) the particle's momentum ✓
(c) the particle's energy (d) the flux density of the field

10.3 The diagram shows a beam of electrons entering a magnetic field. What is the effect of magnetic field on the electrons?

- (a) They are deflected into the plane of the diagram
- (b) They are deflected out of the plane of the diagram ✓
- (c) They are deflected towards the bottom of the diagram
- (d) They are deflected towards the top of the diagram



10.4 The force exerted on a wire of 1 metre length carrying 1 ampere current placed at right angle to the magnetic field is called:

- (a) magnetic field intensity
- (b) magnetic flux
- (c) magnetic induction ✓
- (d) none of these

10.5 The unit of flux density is:

- (a) $\text{NA}^{-1} \text{m}^{-1}$ ✓
- (b) NAm^{-1}
- (c) NmA^{-2}
- (d) NmA

10.6 A moving charged particle is surrounded by:

- (a) electric field only
- (b) magnetic field only
- (c) both electric and magnetic field ✓
- (d) no field

10.7 Magnetic force on the charge q moving parallel to magnetic field with velocity v is:

- (a) $qvB \sin \theta$
- (b) qvB
- (c) zero ✓
- (d) ILB

10.8 The unit $\text{NA}^{-1} \text{m}^{-1}$ is called:

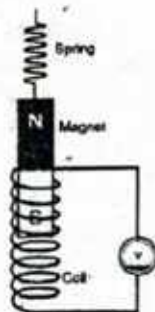
- (a) weber
- (b) tesla ✓
- (c) coulomb
- (d) none of these

10.9 Electrons while moving perpendicularly through a uniform magnetic field are:

- (a) deflected towards north pole
- (b) deflected towards south pole
- (c) deflected along circular path ✓
- (d) not deflected at all

10.10 A magnet is suspended from a spring. The magnet oscillates and moves in and out of the coil connected to a galvanometer. When the magnet oscillates, the galvanometer shows:

- (a) deflection to the left and to the right with constant amplitude
- (b) deflected on one side
- (c) no deflection
- (d) deflection to the left and right, but the amplitude steadily decreases ✓



SHORT ANSWER QUESTIONS

10.1 It is said that Lenz's law specifically applies to induced currents and not directly to induce emf. Explain briefly.

Ans. Lenz's law is typically stated in terms of induced current, rather than directly in terms of induced emf. That is why, emf is cause and current is the effect. Lenz's law is fundamentally about the effect (the induced current and how it opposes the change in magnetic flux.)

The emf itself does not oppose anything physically, it just provides the potential to drive current.

Only when a closed circuit exists, a current produces a magnetic field that opposes the change, as per Lenz's law. In short, Lenz's law applies more directly to the induced current that generates the opposing magnetic field. The emf is just the precursor to that current and does not by itself cause an opposing magnetic effect unless current flows.

10.2 A square loop of wire is moving through a uniform magnetic field. The normal to the loop is oriented parallel to the magnetic field. Is an emf induced in the loop? Give a reason for your answer.

Ans. No, an emf is not induced in the loop.

According to Faraday's law of electromagnetic induction, an emf is induced in a loop when there is a change in the magnetic flux through the loop. The magnetic flux is given by:

$$\phi_B = BA \cos \theta$$

In this case, the normal to the loop is parallel to the magnetic field, meaning $\theta = 0^\circ$ or 180° , so $\cos \theta = 1$, and the flux is simply:

$$\phi_B = BA$$

Since the loop is moving but not rotating or changing its area, the flux through the loop remains constant over time. Faraday's Law states that the induced emf is:

$$\epsilon = \frac{\Delta\phi_B}{\Delta t}$$

Since ϕ_B is constant (i.e., $\frac{\Delta\phi_B}{\Delta t} = 0$), no emf is induced in the loop.

However, if the loop were rotating or its area were changing, then an emf could be induced.

10.3 Does the induced emf always act to decrease the magnetic flux through a circuit?

Ans. Yes, according to Lenz's law, the induced emf in a circuit always acts in a direction that opposes the change in magnetic flux that caused it. This is a direct consequence of Faraday's law of induction, which states that:

$$\epsilon = -\frac{\Delta\phi_B}{\Delta t}$$

where ϵ is the induced emf, and ϕ_B is the magnetic flux through the circuit. The negative sign represents Lenz's law.

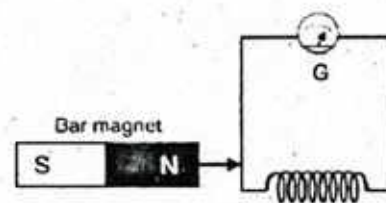
However, it is important to clarify what is meant by "decreasing the magnetic flux." The induced emf does not necessarily reduce the total magnetic flux through the circuit; rather, it opposes the change in flux.

If the flux is increasing, the induced emf generates a current that creates a magnetic field opposing the increase. If the flux is decreasing, the induced emf generates a current that creates a magnetic field attempting to maintain the flux.

Thus, the induced emf resists the change in flux, whether that means trying to reduce an increase or trying to sustain a decrease.

10.4 When a magnet is pushed into the solenoid, as shown in the figure, the galvanometer indicates a small current. Why is the current produced? What will be the magnetic pole produced at the left end of the solenoid?

Ans. When a magnet is pushed into a solenoid, the magnetic flux through the solenoid changes. According to Faraday's law, an emf is produced across the solenoid. It gives rise to a current flowing through it and the solenoid becomes an electromagnet. According to Lenz's law, the direction of current should be such that it should oppose its cause, i.e., motion of the magnet. Therefore, the left end of the solenoid should become an opposite pole of that of magnet, i.e., south (S) as per figure.



10.5 A bar magnet falls through a fixed metal ring (Fig.). Will the magnet fall with an acceleration of a freely falling body? Give reason.

Ans. The metal ring is just like a loop of coil. A bar magnet falling through it induces an emf in it that gives rise to a current. According to Lenz's law, the direction of current is such that the upper face of the ring becomes a magnetic pole opposite to that of lower pole of the bar magnet. As a result, the ring pushes the magnet upward and does not allow it to fall with an acceleration of a freely falling body.



10.6 Which of the two charged particles of the same mass will be deflected most in the magnetic field (a) fast moving (b) slow moving?

Ans. The deflection of a charged particle in a magnetic field is determined by the Lorentz force, given by

$$F = qvB \sin \theta$$

In a uniform magnetic field, the particle moves in a circular or helical path with a radius of curvature given by

$$r = \frac{mv}{qB}$$

Comparing Fast versus Slow Moving Particles

A faster-moving particle (v is large) will have a larger radius of curvature, meaning less deflection.

A slower-moving particle (v is small) will have a smaller radius, meaning more deflection.

The slow-moving particle (b) will be deflected the most in the magnetic field.

10.7 An electron and a proton are projected into a magnetic field at right angles to it with a certain velocity. Which of the particles will suffer greater deflection? Why?

Ans. The electron will suffer greater deflection than the proton. This is because the radius of the circular path of a charged particle moving perpendicular to a magnetic field is given by

$$r = \frac{mv}{qB}$$

Since the charge of an electron (e) and a proton (e) are the same in magnitude, the primary factor affecting deflection is mass. The mass of a proton is approximately 1836 times greater than the mass of an electron ($m_p \approx 1836 m_e$).

Since the radius r is directly proportional to mass, the proton, being much heavier, will have a much larger radius and therefore a smaller deflection. The electron, with its much smaller mass, will have a significantly smaller radius and thus experience much greater deflection in the magnetic field.

10.8 Can a single moving proton produce magnetic field?

Ans. Yes, a single moving proton can produce a magnetic field. According to classical electromagnetism, a moving charged particle generates a magnetic field around its path. This is described by the Biot-Savart law and Ampère's law.

For a single moving proton:

- The proton has a positive charge ($q = +1.6 \times 10^{-19} \text{ C}$).
- When it moves with velocity v , it creates a magnetic field in a circular pattern around its trajectory.
- The magnitude of the magnetic field at a distance B from the proton (assuming it moves in a straight line with constant velocity) can be given by:

$$B = \frac{\mu_0 q v \sin \theta}{4\pi r^2}$$

Thus, even a single proton moving through space generates a magnetic field. However, in quantum mechanics, the proton also has an intrinsic magnetic moment due to its spin, which contributes to its magnetic properties even when it is not moving.

10.9 A magnetic field is necessary if there is to be a magnetic flux passing through a coil of wire. Yet, just because there is a magnetic field does not mean that a magnetic flux will pass through a coil. Account for this situation.

Ans. A magnetic flux passes through a coil when there is a component of the magnetic field that penetrates the area enclosed by the coil. However, the presence of a magnetic field alone does not necessarily mean that magnetic flux will pass through the coil. This can be explained using the equation for magnetic flux:

$$\phi_B = BA \cos \theta$$

Cases where no magnetic flux passes through the coil

1. Magnetic Field is Parallel to the Plane of the Coil

If the magnetic field lies entirely in the plane of the coil, then the angle $\theta = 90^\circ$, and $\cos 90^\circ = 0$. This results in zero magnetic flux ($\phi_B = 0$) despite the presence of a magnetic field.

2. Magnetic Field is Absent or Too Weak

If there is no magnetic field ($B = 0$), then the flux is also zero.

3. Coil is Small or Has No Defined Area

If the coil is reduced to a point (i.e., its enclosed area A approaches zero), the flux will be negligible or zero.

Conclusion: A magnetic field is necessary for magnetic flux, but the field must have a component perpendicular to the plane of the coil. If the field is aligned parallel to the plane, the flux is zero, even though the field exists.

CONSTRUCTED RESPONSE QUESTIONS

10.1 A charge is lying stationary between the opposite poles of two magnets. Is a magnetic force exerted on it? Why?

Ans. No, a magnetic force is not exerted on a stationary charge, even if it is placed between the opposite poles of two magnets. That is why, the magnetic force on a charge is given by the Lorentz force law:

$$\vec{F} = q (\vec{v} \times \vec{B})$$

Since the charge is stationary, its velocity $v = 0$, so

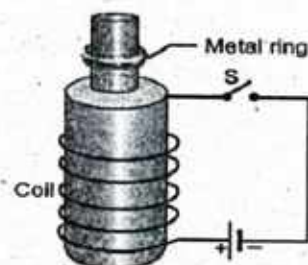
$$\vec{F} = q (0 \times \vec{B}) = 0$$

Thus, no magnetic force acts on a stationary charge; only moving charges experience magnetic forces.

10.2 When the switch in the circuit is closed a current is established in the coil and the metal ring jump upward why? Describe what would happen to the ring if the battery polarity were reversed?

Ans. (a) Reason: When the switch is closed, then current through coil increases from zero to a maximum steady value. So, the magnetic flux through ring is increased which produces an emf in the ring. (By Faraday's law). This induced emf acts to decrease the magnetic flux through ring (By Lenz's law). That is why ring jumps upward.

(b) Reason: When the polarity of battery is reversed again, the magnetic flux through ring is increased, which produces an emf in the ring. By Lenz's law, the ring again jumps upward to decrease the magnetic flux through it.

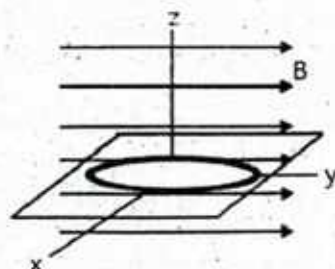


10.3 The figure shows a coil of wire in the xy plane with a magnetic field directed along the y-axis. Around which of the three coordinate axes should the coil be rotated in order to generate an emf and a current in the coil?

Ans. To generate an emf in the coil, it must be rotated along x-axis.

Reason: If the coil is rotated about y-axis or z-axis, then no change of magnetic flux takes place and hence, no emf and no current is induced in the coil.

If the coil is rotated about x-axis the change of magnetic flux takes place which induces the emf and current in the coil.



10.4 Is it possible to change both the area of the loop and the magnetic field passing through the loop and still not have an induced emf in the loop? Give reason.

Ans. Yes, it is possible to change both the area of the loop and the magnetic field passing through the loop and still not have an induced electromotive force (emf) in the loop.

According to Faraday's law, the induced emf in a loop is given by

$$\varepsilon = \frac{\Delta \phi_B}{\Delta t}$$

where ϕ_B is the magnetic flux through the loop, defined as:

$$\phi_B = BA \cos \theta$$

For no induced emf, the rate of change of magnetic flux must be zero:

$$\frac{\Delta \phi_B}{\Delta t} = 0$$

This can happen if the changes in B and A are such that their effects cancel each other out. For example, if the magnetic field increases while the area of the loop decreases at a precisely balanced rate, the total flux $Fd = 0$ can remain constant, leading to no induced emf.

Mathematically, if $\frac{\Delta BA}{\Delta t} = 0$, then no emf is induced. This means that if B increases while A decreases proportionally (or vice versa), the total magnetic flux remains unchanged, and no current is induced in the loop.

10.5 Does the application of uniform magnetic field to a moving charged particle result in a change in kinetic energy of the particle? Explain.

Ans. No, the application of a uniform magnetic field to a moving charged particle does not result in a change in its kinetic energy. This is because the magnetic force always acts perpendicular to the velocity of the particle.

Explanation:

1. Magnetic Force Direction:

The force on a charged particle due to a magnetic field is given by the Lorentz force equation:

$$\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$$

Since the cross-product of velocity ($\mathbf{v}$) and magnetic field ($\mathbf{B}$) is always perpendicular to $\mathbf{v}$, the magnetic force does no work on the particle.

2. No Work Done:

The work done by a force is given by:

$$W = Fd$$

But since $\mathbf{F}$ is perpendicular to the displacement $\mathbf{d}$, the product $Fd = 0$, meaning no work is done.

3. Constant Kinetic Energy:

The kinetic energy of a particle is given by:

$$K.E = \frac{1}{2} mv^2$$

Since work is the only way to change kinetic energy (by the work-energy theorem), and no work is done by the magnetic force, the kinetic energy remains constant.

Motion of the Particle:

- (i) Instead of changing the speed, the magnetic force changes the direction of the velocity.
 - (ii) This results in circular or helical motion, depending on the initial velocity relative to the field.
- Thus, a uniform magnetic field alters the direction of motion but does not change the kinetic energy of the charged particle.

10.6 A uniform electric field and a magnetic field act in the same direction. A proton is projected, into the space, with a uniform velocity in opposite direction. What will happen to the proton?

Ans. Let us analyze the motion of the proton step by step.

Given conditions:

- (i) A uniform electric field (E) and magnetic field (B) are both acting in the same direction (say, along the x-axis).
- (ii) A proton is projected with a uniform velocity in the opposite direction (along the x-axis).

Forces acting on the proton:

1. Electric Force:

The electric field applies a force on the proton given by

$$F_e = qE$$

Since the proton has a positive charge, the force due to the electric field will be in the direction of the field (along x-axis).

2. Magnetic Force:

The magnetic force on a moving charge is given by:

$$F_B = q (\mathbf{v} \times \mathbf{B})$$

Here, the velocity of the proton is along $-x$, and the magnetic field B is along $+x$.

Since velocity and magnetic field are parallel (or anti-parallel), the cross-product $\mathbf{v} \times \mathbf{B}$ becomes zero.

Therefore, the magnetic force does not act on the proton.

Motion of the Proton

The only force acting on the proton is the electric force, which accelerates the proton in the $+x$ -direction (opposite to its initial velocity).

Initially, the proton moves in the $-x$ -direction, but due to the electric field, it slows down.

Eventually, the proton stops momentarily and then starts moving in the $+x$ -direction, accelerating due to the electric force.

Conclusion: The proton will decelerate, stop, and then accelerate in the direction of the electric field ($+x$ -direction). The magnetic field does not affect the motion in this case because the velocity and magnetic field are parallel/anti-parallel, making the magnetic force zero.

10.7 A conductor moves in a magnetic field when a current is passed through the conductor. Would you expect the reverse effect to occur? That is, would a current be produced if a conductor is moved across the magnetic field?

Ans. Yes, the reverse effect does occur. When a conductor moves through a magnetic field, a current is induced in the conductor due to electromagnetic induction, as described by Faraday's law and Lenz's law.

Explanation: Faraday's Law states that a change in magnetic flux through a conductor induces an electromotive force (emf), which can drive a current if a closed circuit is present.

Lenz's law determines the direction of the induced current, stating that the induced current will oppose the change that caused it.

Application to the Scenario:

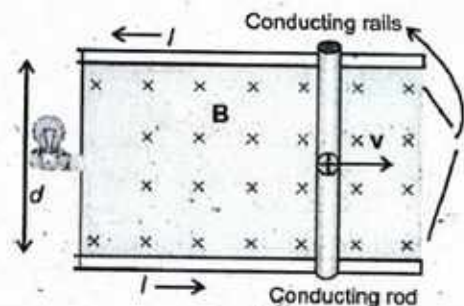
If a conductor moves perpendicular to a magnetic field, the free electrons inside the conductor experience a force due to the Lorentz force ($\mathbf{F} = q\mathbf{v} \times \mathbf{B}$).

This force causes charge separation within the conductor, generating a potential difference (voltage).

If the circuit is closed, the potential difference drives a current.

This is the principle behind electric generators, where mechanical motion (e.g., moving a coil in a magnetic field) is converted into electrical energy.

- 10.8** Consider a conducting rod of length L moving with velocity v to the right as shown in the figure. Left ends of the conducting rails are connected to a bulb. Due to motion of the rod through the magnetic field, an emf is produced across the ends of the rod. This emf gives rise to a current I . As a result, the bulb lights up. Explain where does the electrical energy consumed by the bulb come from?



- Ans.** The emf is produced across the rod due to its motion with velocity v through a magnetic field acting perpendicularly to its velocity.

To do this, some force must be applied to the rod to keep it moving. Energy is provided to apply this force. This energy is consumed by the bulb as an electrical energy.

- 10.9** What will you do if you want to save a sensitive instrument from stray magnetic fields?

- Ans.** To protect a sensitive instrument from stray magnetic fields, I would use magnetic shielding. This can be done in several ways:

1. Using High-Permeability Materials:

- (i) Enclose the instrument in a shield made of materials like mu-metal or permalloy, which have high magnetic permeability and can effectively redirect and absorb magnetic fields.
- (ii) Multiple layers of shielding can improve effectiveness.

2. Using a Faraday Cage (for Electromagnetic Fields):

If the instrument is also sensitive to electromagnetic interference, a conductive enclosure (Faraday cage) can help block unwanted fields.

3. Active Cancellation:

Use Helmholtz coils or electromagnetic field compensation systems that generate opposing fields to cancel out stray magnetic fields.

4. Positioning and Distance:

- (i) Place the instrument far from magnetic sources (e.g., electric motors, transformers).
- (ii) Align the instrument to minimize exposure to strong magnetic gradients.

Would you like recommendations for a specific type of instrument or environment?

COMPREHENSIVE QUESTIONS

- 10.1** Distinguish between magnetic flux and flux density. How are they related?

Ans. See Q. 2.

- 10.2** Find an expression for the force exerted on a current-carrying conductor placed in a uniform magnetic field.

Ans. See Q. 7.

- 10.3** State and explain Faraday's law and Lenz's law. Also describe factors affecting the induced emf.

Ans. See Q. 7, Q. 8 and Q. 9.

- 10.4** Determine the force acting on a charged particle moving through a uniform magnetic field.

Ans. See Q. 4.

- 10.5** What is a velocity selector? Explain its working.

Ans. See Q. 5.

- 10.6** Explain how ferrofluids work?

Ans. See Q. 10.

NUMERICAL PROBLEMS

- 10.1** A positively charged particle is projected perpendicularly into a magnetic field at a speed of 1500 m s^{-1} . It experiences a force of magnitude F . At what angle θ with the field, the

particle should be projected at a speed of 2000 m s^{-1} , so that it experiences the same magnitude of force?

Solution:

Given data:

$$\text{Initial speed} = v_1 = 1500 \text{ ms}^{-1}$$

$$\text{Initial angle} = \theta_1 = 90^\circ; \sin \theta_1 = 0.1$$

$$\text{Force } F = qvB = q \times 1500 \times B \quad \dots\dots (i)$$

For second case:

$$\text{Speed} = v_2 = 2000 \text{ ms}^{-1}$$

To Find:

$$\text{Angle} = \theta_2 = ?$$

Calculations: Force remains the same, so

$$F = q \times 2000 \text{ ms}^{-1} \times B \times \sin \theta_2 \quad \dots\dots (ii)$$

Now equating Eqs. (i) and (ii) for F:

$$q \times 1500 \text{ ms}^{-1} \times B = q \times 2000 \text{ ms}^{-1} \times B \times \sin \theta_2$$

$$1500 = 2000 \times \sin \theta_2$$

$$\sin \theta_2 = \frac{15}{20}$$

$$\theta_2 = \sin^{-1} \left(\frac{3}{4} \right)$$

$$\theta_2 = \sin^{-1} (0.75)$$

$$\theta_2 = 49^\circ \text{ Ans.}$$

The particle should be projected at an angle of 49° with the magnetic field.

10.2 Electrons are accelerated from rest through a potential difference of 15 kV in an oscilloscope. The electrons then pass through a 0.35 T magnetic field that deflects them to the desired position on the screen. Find the magnitude of the maximum force that an electron can experience.

Solution:**Given data:**

$$\text{Potential difference} = V = 15 \text{ kV} = 15,000 \text{ V}$$

$$\text{Magnetic field strength} = B = 0.35 \text{ T}$$

$$\text{Charge on an electron} = e = 1.6 \times 10^{-19} \text{ C}$$

To Find:

$$\text{Maximum force} = F = ?$$

Calculations: To find the maximum force, an electron can experience in a magnetic field, we use the formula:

$$F = qv \quad \dots\dots (i)$$

First, we find the velocity of the electron.

The K.E. gained by the electron is equal to the electrical P.E.

$$\frac{1}{2} mv^2 = qV$$

$$\text{or } v^2 = \frac{2qV}{m}$$

$$\text{or } v = \sqrt{\frac{2qV}{m}}, \text{ where } m = 9.1 \times 10^{-31} \text{ kg}$$

Putting the values

$$v = \sqrt{\frac{2 \times (1.6 \times 10^{-19} \text{ C}) \times 15,000}{9.1 \times 10^{-31} \text{ kg}}}$$

$$v = \sqrt{\frac{4.8 \times 10^{-15}}{9.11 \times 10^{-31}}} = \sqrt{5.27 \times 10^{15}}$$

$$= 7.26 \times 10^7 \text{ ms}^{-1}$$

For the calculations of magnetic force, put the value of v in Eq. (i)

$$F = 0.35 \text{ T} \times (1.6 \times 10^{-19}) \times (7.26 \times 10^7 \text{ ms}^{-1})$$

$$= 0.35 \times 1.1616 \times 10^{-11}$$

$$= 4.07 \times 10^{-12} \text{ N}$$

$$F = 4.1 \times 10^{-12} \text{ N Ans.}$$

10.3 A square coil of side 15 cm each consists of 60 turns. Initially, it is located in a uniform magnetic field of magnitude 0.8 T such that plane of the coil is perpendicular to the field. The coil is then turned through an angle of $\theta = 30^\circ$ in a time of 2 s. Determine the average induced emf.

Solution:**Given data:**

$$\text{Number of turns} = N = 60$$

$$\text{Time interval} = \Delta t = 2 \text{ s}$$

$$\text{Magnetic field} = B = 0.8 \text{ T}$$

Angle = The angle between the field and normal to the coil changes from

$$\theta_1 = 0^\circ \text{ to } \theta_2 = 30^\circ$$

$$\text{Area of square coil} = A (0.15 \text{ m})^2 = 0.0225 \text{ m}^2$$

To Find:

$$\text{Average induced emf} = ?$$

Calculations:

The magnetic flux through the coil is:

$$\phi = BA \cos \theta$$

$$\text{So Initial flux } \phi_1 = BA \cos 0^\circ = 0.8 \text{ T} \times 0.0225 \text{ m}^2 \times 1$$

$$= 0.018 \text{ Wb}$$

$$\text{Final flux } \phi_2 = BA \cos 30^\circ$$

$$= 0.8 \text{ T} \times 0.0225 \text{ m}^2 \times 0.866$$

$$= 0.0156 \text{ Wb}$$

$$\text{Change in flux} = \Delta \phi = \phi_1 - \phi_2$$

$$= 0.018 \text{ Wb} - 0.0156 \text{ Wb}$$

$$\Delta \phi = 0.0024 \text{ Wb}$$

Using the average emf formula:

$$\text{Average emf} = \frac{|\Delta \phi|}{\Delta t} \times N$$

Putting the values

$$\text{Average emf} = \frac{0.0024 \text{ Wb}}{2 \text{ s}} \times 60$$

Average emf = 0.07 V Ans.

10.4 A metallic rod is moving through a uniform magnetic field of 0.2 T. The emf induced across its ends is found to be 0.8 V. It is required to induce an emf of 2.4 V across its ends. How much field strength is needed for this?

Solution:

Given data:

Magnetic field strength = $B_1 = 0.2 \text{ T}$

Emf induced = $\text{emf}_1 = 0.8 \text{ V}$

$\text{emf}_2 = 2.4 \text{ V}$

To Find:

Magnetic field strength = $B_2 = ?$

Calculations: We can use the formula for the motional emf induced in a moving rod in a magnetic field.

$$\text{emf} = B.l.v$$

Assuming that the length of the rod and its velocity remain unchanged, we can write:

$$\frac{\text{emf}_2}{\text{emf}_1} = \frac{B_2}{B_1}$$

Putting the values

$$\frac{2.4 \text{ V}}{0.8 \text{ V}} = \frac{B_2}{0.2 \text{ T}}$$

$$\text{or } B_2 = \frac{2.4}{0.8} \times 0.2$$

$$B_2 = 0.6 \text{ T Ans.}$$

Thus, the required magnetic field strength is 0.6 T.

10.5 A copper ring has a radius of 4.0 cm and resistance of 1.0 mΩ. A magnetic field is applied over the ring, perpendicular to its plane. If the magnetic field increases from 0.2 T to 0.4 T in a time interval of $5 \times 10^{-3} \text{ s}$, what is current in the ring during the interval?

Solution:

Given Data:

Radius of copper ring = $r = 4 \text{ cm} = 4 \times 10^{-2} \text{ m}$

Resistance of copper ring = $R = 1 \text{ m}\Omega = 1 \times 10^{-3} \Omega$

Initial magnetic field = $B_1 = 0.2 \text{ T}$

Final magnetic field = $B_2 = 0.4 \text{ T}$

Change in magnetic field = $\Delta B = B_2 - B_1$
 $= 0.4 - 0.2 = 0.2 \text{ T}$

Time interval = $\Delta t = 5 \times 10^{-3} \text{ s}$

Number of turn = $N = 1$

To Find:

Current in the ring = $I = ?$

Calculations: Using, $\epsilon = N \frac{\Delta \phi}{\Delta t}$

$$\text{or } \epsilon = N \frac{\Delta BA}{\Delta t} \quad (\because \Delta \phi = \Delta BA)$$

$$\text{or } \epsilon = N \frac{\Delta B \pi r^2}{\Delta t} \quad (\because A = \pi r^2)$$

Putting the values

$$\epsilon = (1) \frac{(0.2)(3.14)(4 \times 10^{-2})^2}{5 \times 10^{-3}}$$

$$\text{or } \epsilon = \frac{10.048 \times 10^{-4}}{5 \times 10^{-3}}$$

$$\epsilon = 0.201 \text{ V}$$

$$\text{As } I = \frac{\epsilon}{R}$$

$$I = \frac{0.201 \text{ V}}{1 \times 10^{-3} \Omega}$$

$$I = 201 \text{ A Ans.}$$

10.6 A coil of 10 turns and 35 cm^2 area is perpendicular magnetic field of 0.5 T. the coil is pulled out of the field in 1.0 s. Find the induced emf in the coil as it is pulled out of the field.

Solution:

Given Data:

Number of turns = $N = 10$

Area = $A = 35 \text{ cm}^2 = 35 \times 10^{-4} \text{ m}^2$

Change in magnetic field = $\Delta B = 0.5 - 0 = 0.5 \text{ T}$

Time interval = $\Delta t = 1 \text{ s}$

To Find:

Induced emf = $\epsilon = ?$

Calculations: Using, $\epsilon = N \frac{\Delta \phi}{\Delta t}$

$$\text{or } \epsilon = N \frac{\Delta BA}{\Delta t} \quad (\because \Delta \phi = \Delta BA)$$

Putting the values

$$\epsilon = 10 \left(\frac{0.5 \times 35 \times 10^{-4}}{1} \right)$$

$$\epsilon = 175 \times 10^{-4} \text{ V}$$

$$\epsilon = 1.75 \times 10^{-2} \text{ V}$$

10.7 A proton is accelerated by a potential difference of 6×10^5 volts. It then enters perpendicularly in a uniform magnetic field $B = 1.0 \text{ Weber m}^{-2}$. Find the radius of curvature of the path of the proton. $m = 1.67 \times 10^{-27} \text{ kg}$, $e = 1.6 \times 10^{-19} \text{ C}$.

Solution:

Given data:

Potential difference = $V = 6 \times 10^5 \text{ V}$

Magnetic field = $B = 1.0 \text{ Weber m}^{-2}$

Charge on an electron = $q = e = 1.6 \times 10^{-19} \text{ C}$

Mass of proton = $m = 1.67 \times 10^{-27} \text{ kg}$

To Find:

Radius of curvature = $r = ?$

Calculations: To find the radius of curvature of the path of the proton, we can use the following equations:

Step 1: Energy of the proton:

When a proton is accelerated by a potential difference V , the energy it gain is equal to the work done on it, which is:

$$\text{K.E.} = q \cdot V$$

Putting the values

$$\text{K.E.} = 1.6 \times 10^{-19} \text{ C} \times 6 \times 10^5 \text{ V}$$

$$\text{K.E.} = 9.6 \times 10^{-14} \text{ J}$$

Step 2: Velocity of the proton:

The K.E. of the proton is given by

$$\text{K.E.} = \frac{1}{2} m v^2$$

or

$$v^2 = \frac{2 \text{ K.E.}}{m}$$

or

$$v = \sqrt{\frac{2 \text{ K.E.}}{m}}$$

Putting the values

$$v = \sqrt{\frac{2 (9.6 \times 10^{-14}) \text{ J}}{1.67 \times 10^{-27} \text{ kg}}} = \sqrt{1.15 \times 10^{14}}$$

$$v = 1.07 \times 10^7 \text{ ms}^{-1}$$

Step 3: Radius of Curvature

The radius of curvature ' r ' of a charged particle in a magnetic field is given by

$$r = \frac{mv}{qB}$$

Substituting the values

$$r = \frac{(1.67 \times 10^{-27} \text{ kg}) (1.07 \times 10^7 \text{ ms}^{-1})}{(1.6 \times 10^{-19} \text{ C}) (1.0)}$$

$$= \frac{1.79 \times 10^{-20}}{1.6 \times 10^{-19}} = 0.112 \text{ m}$$

$$\boxed{r = 11.2 \text{ cm}}$$

10.8 A proton enters a uniform magnetic field $B = 0.3 \text{ weber m}^{-2}$ in a direction making an angle 45° with the magnetic field. What will be the radius of the circular path if the velocity of proton is 10^4 m s^{-1} .

Solution:

Given data:

Magnetic field = $B = 0.300 \text{ Weber m}^{-2}$

Angle = $\theta = 45^\circ$

Velocity of proton = $v = 10^4 \text{ ms}^{-1}$

Mass of proton = $m = 1.67 \times 10^{-27} \text{ kg}$

To Find:

Radius of circular path = $r = ?$

Calculations: To calculate the radius of the circular path of the proton in the magnetic field, we use the Formula:

$$r = \frac{mv}{qB \sin \theta}$$

Step 1: The force causing circular motion is due to the perpendicular component of the velocity.

Putting the values

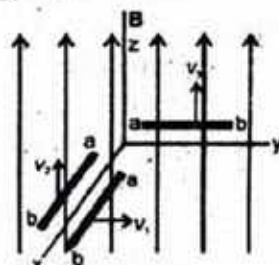
$$r = \frac{(1.67 \times 10^{-27} \text{ kg}) (10^4 \text{ ms}^{-1})}{(1.6 \times 10^{-19} \text{ C}) (0.300 \text{ Weber m}^{-2}) (\sin 45^\circ)}$$

$$= \frac{(1.67 \times 10^{-27}) (10^4)}{(1.6 \times 10^{-19}) (0.300) \left(\frac{1}{\sqrt{2}}\right)}$$

$$= \frac{(1.67 \times 10^{-27}) (10^4)}{(1.6 \times 10^{-19}) (0.300) (0.707)}$$

$$r = 2.46 \times 10^{-4} \text{ m} \quad \text{Ans.}$$

10.9 Three identical conducting rods L_1 , L_2 and L_3 are moving in different planes with the same speeds $v_1 = v_2 = v_3 = 2.5 \text{ m s}^{-1}$ as shown in the figure.



The length of each rod is 60 cm. A constant magnetic field of magnitude $B = 0.5 \text{ T}$ is directed along z -axis. Find the magnitude of emf induced in each rod and indicate which end of the rod is positive.

Solution:

Given data:

Speed of three conducting rods = $v_1 = v_2 = v_3 = 2.5 \text{ ms}^{-1}$

Length of each conducting rod = $L_1 = L_2 = L_3 = 60 \text{ cm} = 0.6 \text{ m}$

Magnetic field strength = $B = 0.5 \text{ T}$

To Find:

Magnitude of induced emf = ?

Calculations: To calculate induced emf in each rod, we use the Formula:

$$\epsilon = BLv \sin \theta$$

Since the rods are moving in different planes, we analyze them individually.

(i) Rod L_1 is moving in the xy -plane along the x -axis. In this case; $\theta = 90^\circ$ (as $v \perp B$). Thus,

$$\epsilon_{L_1} = BL \sin \theta$$

Putting the values

$$\epsilon_{L_1} = 0.5 \text{ T} \times 0.6 \text{ m} \times 2.5 \text{ ms}^{-1} \times 1 \quad (\because \sin 90^\circ = 1)$$

$$\epsilon_{L_1} = 0.75 \text{ V}$$

By right hand rule, current flows from 'a' to 'b'.

Therefore, end 'a' is positive.

- (ii) **For L_2 rod:** $\vec{v}_2$ is parallel to z-axis, $\theta = 0^\circ$ between $\vec{v}$ and $\vec{B}$.

$$\begin{aligned} \text{emf} &= v_2 B L_2 \sin \theta = v_2 B L_2 \sin (0^\circ) \\ &= v_2 B L_2 (0) \quad (\because \sin 0^\circ = 0) \\ \text{emf} &= 0 \end{aligned}$$

- (iii) **For L_3 rod:** $\vec{v}_3$ is parallel to z-axis, $\theta = 0^\circ$ between $\vec{v}_3$ and $\vec{B}$.

$$\begin{aligned} \text{emf} &= v_3 B L_3 \sin \theta = v_3 B L_3 \sin (0^\circ) \\ \text{emf} &= 0 \end{aligned}$$

10.10 An emf of 0.5 V is induced across the ends of a metal rod moving through a magnetic field of 0.4 T. If an emf of 1.5 V has to be induced, what field strength would be needed for that? Assume that all other factors remain the same.

Solution:

Given data:

$$\text{Emf} = \varepsilon_1 = 0.5 \text{ V}$$

$$\text{Magnetic field strength} = B_1 = 0.4 \text{ T}$$

To Find:

$$\text{Field strength} = B_2 = ? \text{ , if } \varepsilon_2 = 1.5 \text{ V}$$

Calculations: To induce emf (ε) in a metal rod moving through a magnetic field is given by the formula,

$$\varepsilon = BVL$$

Since all the other factors remain the same (V and L are constant), the emf is directly proportional to the magnetic field strength:

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{B_1}{B_2}$$

$$\text{or } B_2 = B_1 \times \frac{\varepsilon_2}{\varepsilon_1}$$

Putting the values

$$B_2 = 0.4 \text{ T} \times \frac{1.5 \text{ V}}{0.5 \text{ V}}$$

$$\boxed{B_2 = 1.2 \text{ T}}$$

10.11 A charged particle moves through a velocity selector at a constant velocity of $4.96 \times 10^4 \text{ m s}^{-1}$ in a direction perpendicular to both E and B . If the magnetic field strength is 0.114 T, what should be the magnitude of electric field intensity so that the particle moves undeflected?

Solution:

Given data:

$$\text{Velocity} = V = 4.96 \times 10^4 \text{ ms}^{-1}$$

$$\text{Magnetic field strength} = B = 0.114 \text{ T}$$

To Find:

Magnitude of electric field intensity = $E = ?$

Calculations: To ensure that a charged particle moves undeflected through a velocity selector, the electric force and magnetic force acting on the particle must balance each other. Thus,

$$F_E = F_B$$

$$\text{or } qE = qVB$$

$$\text{or } E = VB$$

Putting the values

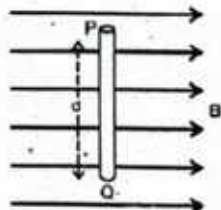
$$E = 4.96 \times 10^4 \text{ ms}^{-1} \times 0.114 \text{ T}$$

$$E = 5.65 \times 10^3 \text{ NC}^{-1} \text{ Ans.}$$

10.12 A current-carrying

conductor PQ of length 2 m is placed perpendicularly to a magnetic field of flux density 0.5 T as shown in the figure. The resulting force on the conductor is

1 N acting into the plane of the paper. What is the magnitude and direction of the current?



Solution:

Given data:

$$\text{Length of the conductor} = L = 2 \text{ m}$$

$$\text{Magnetic flux density} = B = 0.5 \text{ T}$$

$$\text{Force} = F = 1 \text{ N}$$

To Find:

- (i) Magnitude of current = $I = ?$
(ii) Direction of current = $I = ?$

Calculations:

- (i) The force on a current-carrying conductor is given by the Formula:

$$F = BIL \sin \theta$$

Since the conductor is perpendicular to the magnetic field, so $\theta = 90^\circ$.

$$F = BIL \sin 90^\circ$$

$$F = BIL (1)$$

$$F = BIL$$

$$(\because \sin 90^\circ = 1)$$

$$\text{or } I = \frac{F}{BL}$$

Putting the values

$$I = \frac{1 \text{ N}}{0.5 \text{ T} \times 2 \text{ m}}$$

$$I = 1 \text{ A} \text{ Ans.}$$

- (ii) The direction of the force is into the plane of the paper. Using the right hand rule, align your fingers with the magnetic field (B), point your thumb in the direction of the current (I), and the resultant force will be in the direction of your palm faces. Since the force is into the plane of the paper, the current I must flow from Q to P.