TOPIC 1 Force on a Current-Carrying Conductor in a Uniform Magnetic Field

SQ 10.1.1 Why is electromagnetism important for modern technology?

Answer

Electromagnetism is crucial for modern technology, including phones, computers and medical devices. Understanding it helps us appreciate how it influences our world and drives innovation.

SQ 10.1.2 What is observed when a current-carrying conductor is placed in a magnetic field?

Observation

It has been observed experimentally that a current-carrying conductor placed in a magnetic field experiences a force.

SQ 10.1.3 Why does a current-carrying conductor experience a force in a magnetic field?

Reason

The force arises due to the interaction between the conductor's own magnetic field and the external magnetic field, just as two magnets exert forces on each other through their magnetic fields.

SQ 10.1.4 In which direction does a current-carrying conductor move in a magnetic field?

Answer

The two fields reinforce each other on one side of the conductor and oppose each other on the other side. Consequently, the conductor moves towards the side where the field is weaker.

SQ 10.1.5 State Fleming's left-hand rule.

Statement

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

SQ 10.1.6 State the right hand rule for finding the direction of the force.

Statement

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

SQ 10.1.7 On what does the magnitude of the force on a conductor depend?

Answer

The magnitude of the force is directly proportional to the current I in the conductor, the length L of the conductor, and the strength B of the external magnetic field.

SQ 10.1.8 Write the formula for the force on a conductor placed perpendicular to a magnetic field.

Formula

$F = BIL$

SQ 10.1.9 Define magnetic induction B.

Definition

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.

Formula

$B = \frac{F}{IL}$

SQ 10.1.10 Write the SI unit of magnetic induction.

SI Unit

The SI unit of B is the tesla (T), where
$1\,\mathrm{T} = 1\,\mathrm{N\,A^{-1}m^{-1}}$.

SQ 10.1.11 Is magnetic induction a vector quantity?

Answer

Yes. Magnetic induction is a vector quantity, and its direction is the same as that of the magnetic field.

SQ 10.1.12 Write the force on a conductor placed at an angle θ with the field.

Formula

$F = BIL\sin\theta$
In vector form,
$\mathbf{F} = I(\mathbf{L} \times \mathbf{B})$.

SQ 10.1.13 When is the force on a current-carrying conductor maximum and when is it zero?

Maximum

The force is maximum, equal to BIL, when the conductor is perpendicular to the field, that is
$\theta = 90^\circ$

Zero

It is zero when the conductor is along the field, that is
$\theta = 0^\circ$

SQ 10.1.14 A 20.0 cm wire carrying 10.0 A is at 40° to a 0.30 T field. Find the force on it.

Solution

Using
$F = BIL\sin\theta$

Calculation

$F = 0.30 \times 10.0 \times 0.20 \times \sin 40^\circ$

Result

$F = 0.39\,\mathrm{N}$

TOPIC 2 Magnetic Flux and Flux Density

SQ 10.2.1 Define magnetic flux.

Definition

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

SQ 10.2.2 **Write the magnetic flux through an area perpendicular to the field.**

Formula

$\phi_m = BA$

SQ 10.2.3 **Write the general expression for magnetic flux.**

Formula

$\phi_m = BA\cos\theta = \mathbf{B}\cdot\mathbf{A}$

Here θ is the angle between the directions of $\mathbf{B}$ and $\mathbf{A}$.

SQ 10.2.4 **Why is magnetic flux a scalar quantity?**

Reason

Since

$\phi_m = \mathbf{B}\cdot\mathbf{A}$

is a dot product of two vectors, it is a scalar quantity.

SQ 10.2.5 **When is the magnetic flux through an area maximum?**

Answer

When the field is directed along the normal to the area,

$\theta = 0^\circ$

and

$\cos 0^\circ = 1$

so the flux is maximum and equal to BA.

SQ 10.2.6 **When is the magnetic flux through an area zero?**

Answer

When the field is parallel to the plane of the area, the angle between the field and the normal is 90°, so the flux through the area is zero.

SQ 10.2.7 **How is the flux through a curved surface calculated?**

Method

The curved surface is divided into a number of small surface elements, each assumed plane. The flux through the whole curved surface is the sum of the contributions from all the elements.

SQ 10.2.8 **Write the unit of magnetic flux.**

SI Unit

The unit of magnetic flux is $\mathrm{N\,m\,A^{-1}}$, which is called the weber (Wb).

SQ 10.2.9 **Why is magnetic induction also called magnetic flux density?**

Reason

The magnetic induction B is the flux per unit area of a surface perpendicular to B, hence it is also called magnetic flux density. Its unit is $\mathrm{Wb\,m^{-2}}$.

SQ 10.2.10 **Distinguish between magnetic flux and flux density.**

Magnetic Flux	Magnetic Flux Density
It is the number of magnetic lines passing through an area.	It is the flux per unit area perpendicular to the field.
Its unit is the weber.	Its unit is $\mathrm{Wb\,m^{-2}}$ or tesla.
It is a scalar quantity.	It is a vector quantity.

SQ 10.2.11 **A 25 cm × 20 cm loop is in a 1.2 T field at 60° to the area vector. Find the flux.**

Solution

Using

$\phi_m = BA\cos\theta$

with

$A = 5\times10^{-2}\,\mathrm{m^2}$

Calculation

$\phi_m = 1.2\times5\times10^{-2}\times0.5$

Result

$\phi_m = 3\times10^{-2}\,\mathrm{Wb}$

SQ 10.2.12 **For the same loop at 45° to the area vector, find the magnetic flux.**

Solution

$\phi_m = 1.2\times5\times10^{-2}\times0.707$

Result

$\phi_m = 4.2\times10^{-2}\,\mathrm{Wb}$

SQ 10.2.13 **For the same loop at 30° to the area vector, find the magnetic flux.**

Solution

$\phi_m = 1.2\times5\times10^{-2}\times0.866$

Result

$\phi_m = 5.2\times10^{-2}\,\mathrm{Wb}$

TOPIC 3 Magnetic Flux Linkage

SQ 10.3.1 **Define 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.

Formula

$\phi = N\phi_m$

SQ 10.3.2 **What does magnetic flux linkage measure?**

Answer

It essentially measures how much magnetic flux is linked with the coil due to its multiple turns.

SQ 10.3.3 **Where does magnetic flux linkage play a crucial role?**

Answer

Magnetic flux linkage plays a crucial role in the design and operation of transformers, electric motors, generators and inductors.

SQ 10.3.4 **In which law is the concept of flux linkage particularly important?**

Answer

The concept is particularly important in Faraday's law of electromagnetic induction.

TOPIC 4 Motion of a Charged Particle in a Magnetic Field

SQ 10.4.1 **Does an individual charge moving across a magnetic field experience a force?**

Answer
Yes. Experiments show that a charged particle does experience a force when it moves across a magnetic field.

SQ 10.4.2 **Write the force on a single charged particle moving in a magnetic field.**

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

SQ 10.4.3 **Write the magnitude of the force on a moving charged particle.**

Formula
$F = qvB \sin\theta$
Here θ is the angle between $\mathbf{B}$ and $\mathbf{v}$.

SQ 10.4.4 **When is the magnetic force on a moving charge maximum and when is it zero?**

Maximum
The force is maximum when $\mathbf{B}$ is perpendicular to $\mathbf{v}$, that is $\theta = 90^\circ$

Zero
The force is zero when $\mathbf{B}$ is in the direction of $\mathbf{v}$, that is $\theta = 0^\circ$

SQ 10.4.5 **How is the direction of the force on a moving charge found?**

Answer
The direction of the force can be known by applying Fleming's left hand rule, or the right hand rule for vector product.

SQ 10.4.6 **In which direction is a positively charged particle deflected in a magnetic field?**

Answer
A positively charged particle entering the field experiences a force in the upward direction, due to which it is deflected along a curved path in that direction.

SQ 10.4.7 **In which direction is a negatively charged particle deflected in a magnetic field?**

Answer
The negatively charged particle is deflected downward, by the force acting on it in the downward direction.

SQ 10.4.8 **Why does a charged particle move in a circle in a magnetic field?**

Reason
The magnetic force acts perpendicular to the velocity, so it provides the centripetal force required to keep the particle in a circle.

Formula
$$qvB = \frac{mv^2}{r}$$

SQ 10.4.9 **Write the radius of the circular path of a charged particle in a magnetic field.**

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

SQ 10.4.10 **An electron enters a 2.5 Wb m^{-2} field at 10^7 m s^{-1} perpendicularly. Find the radius of its path.**

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

Calculation
$$r = \frac{9.11 \times 10^{-31} \times 10^7}{1.6 \times 10^{-19} \times 2.5}$$

Result
$r = 2.3 \times 10^{-5}\,\mathrm{m}$

TOPIC 5 Velocity Selector

SQ 10.5.1 **What is a velocity selector?**

Definition
A velocity selector is a device used to determine the velocity of a charged particle. Electric and magnetic forces are applied so that they balance each other only for one value of velocity.

SQ 10.5.2 **Describe the construction of a velocity selector.**

Construction
A velocity selector consists of a cylindrical tube located within a magnetic field B. Inside the tube is a parallel plate capacitor that creates a uniform electric field E, oriented perpendicular to the magnetic field.

SQ 10.5.3 **Explain the working of a velocity selector.**

Working
When a positively charged particle enters the tube, the magnetic force acts upward while the electric force acts downward.

Result
If the field strengths are adjusted appropriately these forces cancel out, so with no net force the particle moves in a straight line at constant velocity and exits the tube.

SQ 10.5.4 **Which law explains the constant velocity of the selected particle?**

Answer
With no net force acting on the particle, its velocity remains constant in accordance with Newton's first law.

SQ 10.5.5 **Derive the expression for the velocity selected.**

Derivation
For no deflection, the magnetic force equals the electric force, so
$Bqv = qE$.

Result
$$v = \frac{E}{B}$$

SQ 10.5.6 **What happens to particles whose velocity differs from the selected value?**

Answer
The particles with velocities different from v will be deflected and will not exit at the right end of the tube.

SQ 10.5.7 **Alpha particles enter a selector with E = 300 V m^{-1} and B = 0.20 T. Which speed passes undeviated?**

Solution

Using

$$v = \frac{E}{B}$$

Calculation

$$v = \frac{300}{0.20}$$

Result

$$v = 1500\,\mathrm{m\,s^{-1}}$$

SQ 10.5.8 **A particle passes a selector with E = 4.8 × 10^5 N C^{-1} and B = 0.2 T, then circles with r = 3.0 cm. Find q/m.**

Derivation

The selected velocity is

$$v = \frac{E}{B}$$

and in the circular path

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

so

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

Result

$$\frac{q}{m} = \frac{E}{B^2 r} = 4.0 \times 10^7\,\mathrm{C\,kg^{-1}}$$

TOPIC 6 Induced EMF and Faraday's Law

SQ 10.6.1 **What is motional emf?**

Definition

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

SQ 10.6.2 **What is observed when a conductor moves across a magnetic field?**

Observation

An electromotive force is induced between its ends. If the ends are connected by a wire to form a closed circuit, a current will flow through it.

SQ 10.6.3 **Describe the experiment demonstrating motional emf.**

Setup

A conducting rod of length L is placed on two parallel metal rails with a galvanometer connected between the ends of the rails, forming a complete loop in a uniform magnetic field directed into the page.

Observation

When the rod is stationary the galvanometer shows no current, but when the rod is pulled with constant velocity a current flows.

SQ 10.6.4 **Why do charges accumulate at one end of a moving conductor?**

Reason

A charge q within the rod moves with velocity v in the field and experiences a force

$$F = qvB$$

directed along the rod. As a result the charges migrate to the top end, leaving a deficiency at the bottom end.

SQ 10.6.5 **How does the moving conductor reach equilibrium?**

Answer

The redistribution of charge creates an electrostatic field directed opposite to the magnetic force. The system quickly reaches an equilibrium state where the two forces are balanced, so

$$qE = qvB$$

SQ 10.6.6 **Derive the expression for motional emf.**

Derivation

At equilibrium

$$E = vB$$

and the electric intensity is the negative of the potential gradient, so

$$\Delta V = -LE$$

Result

$$\varepsilon = -vBL$$

SQ 10.6.7 **Write the motional emf when the angle between v and B is θ.**

Formula

$$\varepsilon = -vBL\sin\theta$$

SQ 10.6.8 **Why does the induced current continue to flow in the moving rod?**

Reason

As the current flows, the charge at the top decreases which reduces the electric field intensity, while the magnetic force remains unchanged. This imbalance favours the magnetic force, which carries the charges back to the top end.

SQ 10.6.9 **Express the motional emf in terms of change of magnetic flux.**

Derivation

As the rod moves through Δx, the increase in area is

$$\Delta A = \Delta x\, L$$

and the increase in flux is

$$\Delta\phi_m = B\,\Delta A$$

Result

$$\varepsilon = -\frac{\Delta\phi_m}{\Delta t}$$

SQ 10.6.10 **State Faraday's law of electromagnetic induction.**

Statement

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.

Formula

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

SQ 10.6.11 **What does the minus sign in Faraday's law indicate?**

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

SQ 10.6.12 **A rod of length 25 cm moves at 0.5 m s⁻¹ perpendicular to a 0.25 T field. Find the emf.**

Solution
Using
$\varepsilon = vBL$

Calculation
$\varepsilon = 0.5 \times 0.25 \times 0.25$

Result
$\varepsilon = 3.13 \times 10^{-2}\,\mathrm{V}$

SQ 10.6.13 **A loop in a 0.6 T field shrinks at 0.8 m² s⁻¹. Find the induced emf.**

Solution
Using
$\varepsilon = NB\dfrac{\Delta A}{\Delta t}$

Calculation
$\varepsilon = 1 \times 0.6 \times 0.8$

Result
$\varepsilon = 0.48\,\mathrm{V}$

TOPIC 7 Lenz's Law and Direction of Induced EMF

SQ 10.7.1 **Who discovered the principle behind the direction of induced emf?**

Answer
The principle was based on the discovery made by the Russian physicist Heinrich Lenz in 1834.

SQ 10.7.2 **State Lenz's law.**

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

SQ 10.7.3 **Does Lenz's law apply to induced emf or induced current?**

Answer
Lenz's law specifically applies to induced currents and not directly to induced emf.

SQ 10.7.4 **How is Lenz's law applied to a loop that is not closed?**

Answer
If the loop is not closed, we can imagine it as if it were closed to determine the direction of the induced current, and from this we can infer the direction of the induced emf.

SQ 10.7.5 **Apply Lenz's law to a bar magnet pushed into a coil.**

Explanation
A current-carrying coil generates a magnetic field similar to that of a bar magnet, with one face acting as the north pole and the other as the south pole.

Result
To oppose the motion of the bar magnet, the face of the coil towards the magnet must become a north pole, so that the two north poles repel each other.

SQ 10.7.6 **Why does Lenz's law forbid a current in the opposite direction?**

Reason
If the induced current were in the opposite direction, the magnetic force would be in the direction of v and would accelerate the rod, inducing a stronger current and an even greater force.

Result
The process would become self-perpetuating, giving ever-increasing kinetic energy from nowhere, which is against the law of conservation of energy.

SQ 10.7.7 **Of which conservation law is Lenz's law a consequence?**

Answer
Lenz's law is a consequence of the law of conservation of energy.

TOPIC 8 Factors Affecting EMF

SQ 10.8.1 **How does the rate of change of magnetic flux affect the induced emf?**

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

SQ 10.8.2 **How does the number of turns of the coil affect the induced emf?**

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

SQ 10.8.3 **How does relative speed affect the induced emf?**

Answer
The speed of the coil or conductor through the magnetic field affects the magnitude of the induced emf. A faster speed increases the rate of change of magnetic flux, which increases the induced emf.

TOPIC 9 Ferrofluids

SQ 10.9.1 **What is a ferrofluid?**

Definition
Ferrofluid is a unique material that exhibits both liquid and magnetic properties. Essentially it is a colloidal suspension of magnetic particles in a carrier fluid such as oil or water.

SQ 10.9.2 **Of what are the magnetic particles of a ferrofluid made?**

Answer
Typically the magnetic particles are iron oxide, ground to the nano-scale and approximately 10 nanometres in size.

SQ 10.9.3 What is the purpose of the surfactant coating in a ferrofluid?

Answer

A surfactant is a substance that reduces surface tension. This coating prevents the particles from clumping together, ensuring they remain evenly dispersed in the fluid.

SQ 10.9.4 What prevents the particles of a ferrofluid from settling down?

Answer

The viscosity of the fluid, the nanometre size of the particles, and their constant movement prevent the particles from settling down.

SQ 10.9.5 How does a ferrofluid behave with and without a magnet?

Without Magnet

A ferrofluid acts like a liquid.

With Magnet

The particles are temporarily magnetized and the fluid becomes a magnet, forming structures that make it act more like a solid. When the magnet is removed the particles are demagnetized and it acts like a liquid again.

SQ 10.9.6 Why are spikes formed in a ferrofluid?

Reason

The phenomenon is due to the competition between magnetic forces, surface tension and gravity. Chain-like structures align along the field lines and increase the viscosity, and spikes are formed where the magnetic forces overcome the other forces.

SQ 10.9.7 Give the applications of ferrofluids in electronics.

Applications

In electronics, ferrofluids are used in rotary seals for computer hard drives and other rotating shaft motors.
In loudspeakers, ferrofluids cool the voice coil and dampen vibrations to improve sound quality.

SQ 10.9.8 Give the medical applications of ferrofluids.

Applications

Ferrofluids can be directed to specific areas in the body using external magnets, allowing targeted drug delivery to a tumor or other site, which reduces side effects.
They can also be used as contrast agents in magnetic resonance imaging.

TOPIC 10 A Seismometer

SQ 10.10.1 What is a seismometer?

Definition

A seismometer is an instrument that responds to any movement of the rocks under the ground, or to vibration caused by earthquakes, volcano eruption and explosion.

SQ 10.10.2 Describe the construction of a seismometer.

Construction

Typically a seismometer includes a weight suspended by a spring. The weight is often attached to a magnet which moves inside a coil of wire.

SQ 10.10.3 Why is there relative motion between the weight and the frame?

Reason

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, which is attached to the ground.

SQ 10.10.4 On which law does a seismometer work?

Answer

It works according to Faraday's law of electromagnetic induction, that is the changing magnetic flux through the coil induces an emf, which gives rise to an induced electric current.

SQ 10.10.5 To what is the induced current in a seismometer proportional?

Answer

The induced current is proportional to the velocity of the ground motion. The electrical signals generated are then amplified and recorded.

SQ 10.10.6 What data does a seismometer provide?

Answer

It provides data on the amplitude, frequency and duration of the earthquake waves.

SQ 10.10.7 How are earthquakes categorized by depth?

Categories

Most earthquakes are caused by plate tectonics and occur at a depth of 60 km; these are categorized as shallow.
Intermediate earthquakes can be as deep as 300 km, while deep earthquakes can reach depths past 300 km.