



17 Electromagnetic induction

Content

- 17.1 Magnetic flux
- 17.2 Laws of electromagnetic induction

Learning Outcomes

Candidates should be able to:

- (a) define magnetic flux as the product of an area and the component of the magnetic flux density perpendicular to that area
- (b) recall and solve problems using $\phi = BA$
- (c) define magnetic flux linkage
- (d) infer from appropriate experiments on electromagnetic induction:
 - (i) that a changing magnetic flux can induce an e.m.f.
 - (ii) that the direction of the induced e.m.f. opposes the change producing it
 - (iii) the factors affecting the magnitude of the induced e.m.f.
- (e) recall and solve problems using Faraday's law of electromagnetic induction and Lenz's law
- (f) explain simple applications of electromagnetic induction.

9749 (2021)

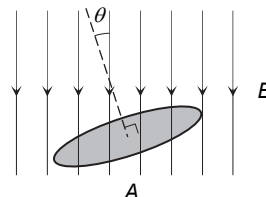
17.1 Magnetic flux

Define

Magnetic flux

Magnetic flux (Φ) passing through a plane surface, is a measure of quantity of *magnetism* and is defined as the product of the *magnetic field density* (B) and the area element (A_{\perp}) perpendicular to the field.

- SI unit of *magnetic flux* is the *weber* [**Wb**] or [**kg m² s⁻² A⁻¹**] or [**V s**] or [**T m²**], and the unit of *magnetic flux density* (B) is the *weber per square metre* [**Wb m⁻²**] or [**T**].



- Mathematically, it can be expressed as:

$$\Phi = BA_{\perp} \equiv BA \cos \theta$$

$$\Rightarrow \Phi = BA \text{ if } \theta = 0^{\circ} \quad \bullet$$

where Φ = magnetic flux [Wb]
 B = magnetic flux density [T]
 A_{\perp} = element plane area normal to B -field [m²]
 A = plane area in B -field [m²]
 θ = angle between a normal to plane surface & B -field
[$^{\circ}$ or rad]

[Examined in 2016p1.33]

- If a *normal* to the surface is perpendicular to the B -field, i.e., $\theta = 90^{\circ}$, the magnetic flux passing through the surface will be zero.
- From \bullet , [1 Wb] \equiv [1 T] \times [1 m²] \Rightarrow [**Wb**] \equiv [**T m²**]
Conversely, [**T**] \equiv [**Wb m⁻²**].

Weber

The **weber** is defined, in terms of *Faraday's law*, as a change in *magnetic flux* of one weber per second through a loop to the *electric field* around the loop which will induce an *electromotive force* of one volt.

[Examined in 2016p1.32]

Example

- \bullet A single turn coil of cross sectional area 5.0 cm² is orientated with its normal at an angle of 30 $^{\circ}$ to magnetic field lines of flux density 20×10^{-2} T.

$$\Rightarrow \text{Magnetic flux through coil, } \Phi = BA \cos 30^{\circ} \\ = (20 \times 10^{-2}) \times (5.0 \times 10^{-4}) \cos 30^{\circ} = 8.7 \times 10^{-5} \text{ Wb (2sf) (ans)}$$





Magnetic flux linkage

Magnetic flux linkage passing through a coil of N turns, is defined as the product of the *magnetic flux* (Φ) and the number of turns (N).

☞ SI unit of *magnetic flux linkage* is the **weber–turns [Wb–turns]**.

☞ Mathematically, it can be expressed as:

$$\text{flux linkage} = N\Phi = BA_{\perp}N \equiv BAN\cos\theta$$

where Φ = magnetic flux [Wb]

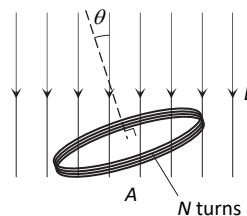
N = number of turns

B = magnetic flux density [T]

A_{\perp} = element plane area normal to B -field [m^2]

A = plane area in B -field [m^2]

θ = angle between a normal to plane surface & B -field [$^{\circ}$ or rad]



[Examined in 2016p1.33, 2013p1.30]

Infer

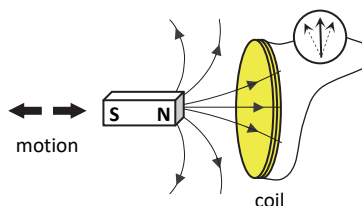
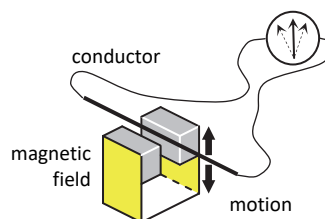
Electromagnetic induction

Electromagnetic induction is the process in which an *e.m.f.* is induced in a closed circuit due to changes in the *magnetic field* around the circuit.

☞ Whenever a conductor cuts a magnetic field or when the magnetic field through a coil changes, an *e.m.f.* would be induced.

☞ Two important electrical devices basically use the phenomenon of *electromagnetic induction*:

- A **generator** that converts mechanical energy into electrical energy, and
- A **transformer** that is used in electrical power transmission.

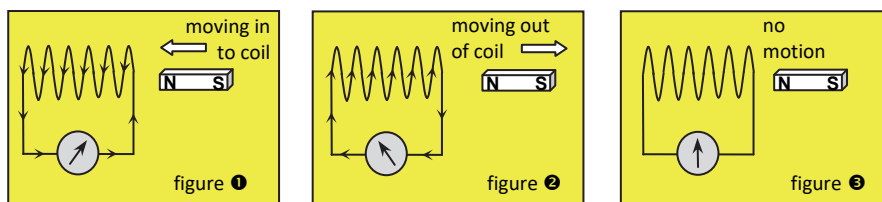


☞ The merger of electricity and magnetism from distinct phenomena into electromagnetism is tied to three closely related events. The first was **Hans Christian Ørsted**'s accidental discovery of the influence of an electric current on a magnetic needle – namely, that magnetic fields are produced by electric currents. Ørsted's 1820 report of his observation spurred an intense effort by scientists to prove that magnetic fields can induce currents. The second event was **Faraday**'s experimental proof that a changing magnetic field can induce a current in a circuit. The third was **Maxwell**'s prediction that a changing electric field has an associated magnetic field. The technological revolution attributed to the development of electric power and radio communications can be traced to these three landmarks.

Faraday's Experiment

Apparatus: Solenoid connected to a galvanometer, bar magnet.

① A changing magnetic flux can induce an e.m.f. in a circuit (first observation)

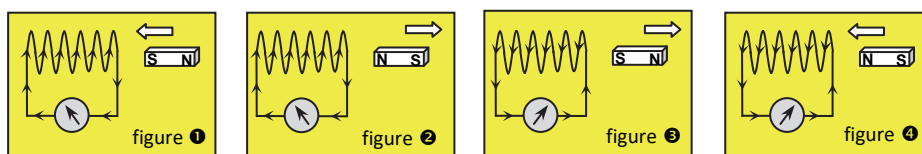


- Galvanometer pointer deflected when the bar magnet is moving in or out of the coil. (figure ① and ②)
- Pointer is at centre-zero when the magnet is stationary. (figure ③)

Conclusion

Electromotive force (e.m.f.) is induced whenever the magnetic lines of force passing through the coil change. This results in current flow, hence, the deflection of the galvanometer. (*Faraday's law*)

② The direction of the induced e.m.f. opposes the change producing it (second observation)



- Pointer deflects to say, left (current flows clockwise) when S pole of the bar magnet is moving into the coil or N pole is moving out of the coil. (figure ① and ②)
- Pointer deflects to say, right (oppositely directed, current flows anti-clockwise) when bar magnet S pole is moving out of the coil or N pole is moving into the coil. (figure ③ and ④)

Conclusion

Direction of the induced e.m.f. opposes the change producing it. (*Lenz's law*)

- In figure ①, the induced *e.m.f.* created a S pole on the right hand side of the solenoid, which opposes the S pole of the bar magnet that is moving into the coil. In other words, like poles repel, *i.e.*, the coil current flows such that it tries to prevent the magnet from coming closer.

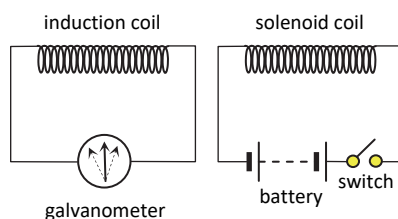


Current flow is clockwise as shown in figure ❶, when looking from right end of the coil (recall electrical method of magnetisation).

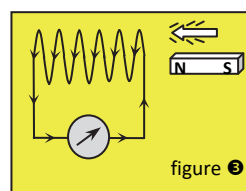
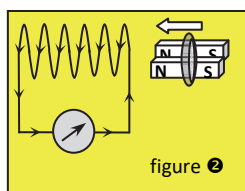
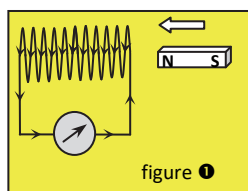
- Similarly in figure ❷, the induced *e.m.f.* created a N pole on the right hand side of the solenoid, which attracts the S pole of the bar magnet that is moving out of the coil. In other words, unlike poles attract, i.e., the coil current flows such that it tries to prevent the magnet from leaving.

Current flow is anti-clockwise as shown in figure ❸, when looking from right end of the coil.

- Current flow is reversed that as shown in the four diagrams if the bar magnet is inserted or removed from the left hand side of the solenoid.
- Replacing the bar magnet with a switch-operated circuit (as shown), the effect remains the same as the above, i.e., switching on the battery-operated circuit is similar to plunging the bar magnet towards the induction circuit. Conversely, by switching off the battery-operated circuit is equivalent to moving the bar magnet away.



❸ The factors affecting the magnitude of the induced e.m.f. (third observation)



- Large deflection in the galvanometer pointer is observed when:
 - ❶ the number of turns in the solenoid is increased (figure ❶)
 - ❷ the magnetic field is strengthened (figure ❷)
 - ❸ the magnet is moved at a relatively faster speed (figure ❸)

Conclusion

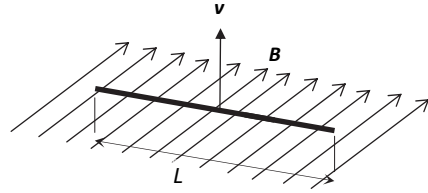
Larger deflection in the galvanometer pointer indicates that a larger current is flowing in the circuit. Hence, magnitude of *e.m.f.* depends on number of turns on the coil, strength of the magnet, and rate of change of magnetic field lines.

Mathematical formula

- The magnitude of the e.m.f. induced in a conductor moving at right angles to a uniform magnetic field, is:

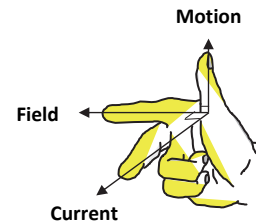
$$\xi = B_{\perp} \ell v$$

where ξ = induced e.m.f. [V]
 B_{\perp} = perpendicular flux density of magnetic field [T]
 ℓ = length of conductor [m]
 v = velocity of the conductor [m s^{-1}]



- The direction of induced e.m.f. (hence induced current) is given by **Fleming's Right hand rule**.
- To be most effective in the *electromagnetic induction*, the direction of *motion* should be at right angle to the *field* direction. If the *motion* and *field* directions are parallel to each other, no e.m.f. (current) would be induced.

[Examined in 2017p1.24]



Worked Example

Example 1

The current in coil A is switched on. The deflection of the galvanometer is only observed at that instant when the circuit is on or off; the induced e.m.f is zero when a steady current is passing through the coil. Why?

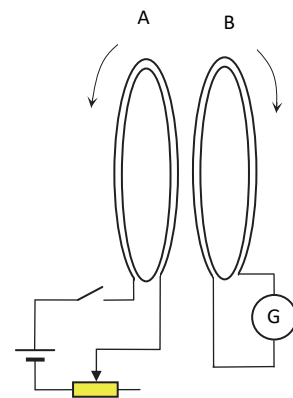
Solution

At the instant when the circuit is on, the current in A grows to its steady value. This rate of growth of current causes an increasing magnetic field to be set up in coil A.

The magnetic field in A is linked to B due to its close proximity, hence coil B experiences a change in magnetic flux resulting in an induced e.m.f. in it.

When the circuit is opened, the sudden cut off of the current also causes a decrease in the magnetic flux and thus an induced e.m.f in coil B. The deflection would be in one direction when the circuit is made and in the opposite direction when it is broken.

When a steady current is passing through the coil, there is no change in magnetic flux and thus no e.m.f is induced. **(ans)**



[Examined in 2012p2.5]





17.2 Laws of electromagnetic induction

State

Faraday's (Neumann's) law of electromagnetic induction

Faraday's law of electromagnetic induction states that the magnitude of the induced e.m.f. is proportional to the rate of change of magnetic flux linkage or rate at which magnetic flux is cut by the conductor.

[Examined in 2013p3.4(a)]

Lenz's law

Lenz's law states that the induced current produced in the conductor always flows in a direction such that it opposes the change that is producing it.

- Another way of looking at *Lenz's law* is based on the **principle of conservation of energy**. If we move a magnet towards a loop, the field due to the induced current in the loop exerts a force that opposes the motion of the magnet. The loop sets up a magnetic field similar to that of a magnet with its north pole pointing towards the north pole of the magnet, and the two north poles repel each other. Therefore, we must exert a greater force in order to continue pushing the magnet towards the loop.
- Suppose instead that the current was produced in the opposite direction. Then the south pole of the induced magnetic field would be in the direction of the north pole of the magnet, and the magnet would be accelerated by the field. As the magnet accelerates, the current in the loop would increase, causing an increasing force on the magnet and an increasing acceleration. Both the kinetic energy of the magnet and the rate of energy dissipation in the loop would increase. This means that for a very small push we would get a large energy dissipation which clearly violates the *law of conservation of energy*. Therefore, the e.m.f. opposes the change that induces it, *i.e.* the change in magnetic flux.

Neumann's equation

- Mathematically, the **Neumann's law** can be expressed as:

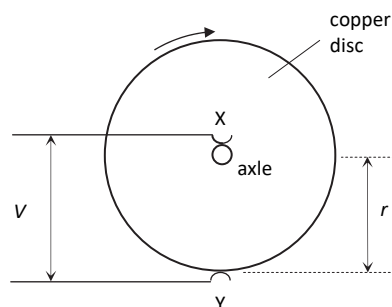
$$\xi = - \frac{d(N\Phi)}{dt}$$

where ξ = induced e.m.f. [V]
 N = number of turns
 Φ = magnetic flux [Wb]

Some applications

① Homopolar or disc generator

- ✎ A copper disc is placed perpendicular in a uniform magnetic field (into the page) and is made to rotate as shown. Contacts X and Y are then connected to a galvanometer to detect any current flow. As the disc rotates, the free electrons on the disc are forced to move in a magnetic field and they will feel a force and this will induce a current in the disc.



- ✎ Applying *Fleming's right-hand rule*, the induced current flows from X (axle) to Y (rim) and deduce that Y will be at a higher electrical potential than X. The induced e.m.f. (ξ) is:

$$\xi = -\frac{d(N\Phi)}{dt} = \left| \frac{\Delta(N\Phi)}{\Delta t} \right| = \left| \frac{[(1)BA] - 0}{T} \right| = \left| \frac{BA}{T} \right| = BAf$$

- where ξ = induced e.m.f. [V]
 A = area of copper disk in field [m^2]
 B = magnetic flux density [T]
 f = frequency of rotation [Hz]

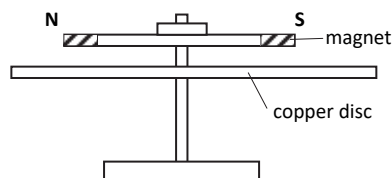
[Examined in 2019p1.26]

- ✎ The induced e.m.f. is dependent on the speed of rotation, the faster the disc turns, the higher the induced e.m.f. and hence, the current. One application could be to measure the speed of the vehicle by connecting one of its wheels to one of these disc generators. The galvanometer is then calibrated to read the speed of the vehicle:

$$\omega = 2\pi \left(\frac{\xi}{BA} \right) \text{ - where } \omega \text{ is the angular speed [rad s}^{-1}\text{].}$$

② Arago's rotation

- ✎ A magnet free to rotate about an axis is mounted on top of a copper disc that is then set rotating.

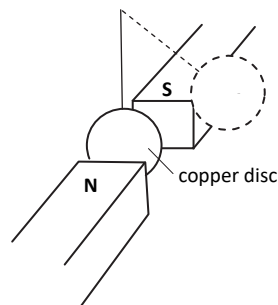


- ✎ The rotating disc cuts the magnetic field of the magnet and an e.m.f. is induced in the copper disc. Since each free electron has different relative proximity to the magnetic field, different e.m.f. are induced in the disc. This gives rise to potential differences, leading to eddy currents being produced in the disc.
- ✎ By *Lenz's Law*, the eddy currents tend to minimise relative motion between the magnet and the disc. Thus, the magnet will tend to follow the motion of the disc.



3 Damped oscillations of a copper disc

- When a solid copper disc swings in a perpendicular magnetic field, the free electrons in the copper disc will feel a force and hence, induce an e.m.f. Since each free electron has different relative proximity to the magnetic field, different e.m.f. are induced in the disc. This gives rise to potential differences, leading to eddy currents being produced in the disc.



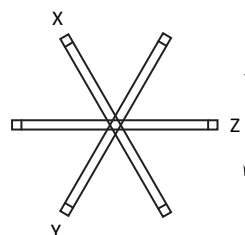
- By *Lenz's Law*, these eddy currents set up a magnetic field to oppose the field of the magnet, leading to retardation of the disc's motion.

- Eddy currents can therefore be minimised if the copper disc is sliced as shown.

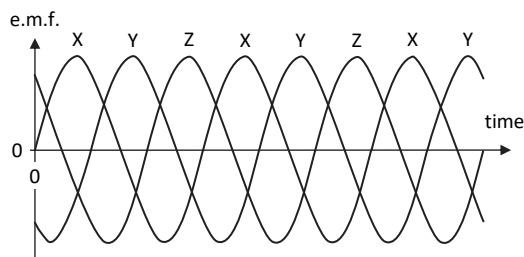


Example

- In a generator in a commercial power station, rectangular coils rotate in a strong magnetic field. There are three coils, all on the same axle, with angles of 120° between them, as shown in the end view. Deduce their e.m.f. outputs on the same axes varying with time.



\therefore Since the coils are placed 120° apart, their e.m.f. will also be similarly arranged:



[Teachers' Comments: This question was not well-answered. There were many random choices for the answer. Candidates are advised to understand the concept fundamentally.]

[Examined in 2012p1.35]



Worked Examples

Example 1

A 20-turn circular coil of diameter 4.0 cm is at right angles to a magnetic flux density of 50 mT. The flux density is then reduced steadily to zero in 10 s. What is the magnitude of the e.m.f induced in the coil?

Solution

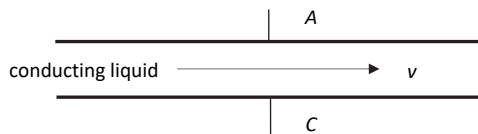
Magnitude of induced e.m.f in the coil, according to Faradays law, is

$$E = \frac{d\phi}{dt} = \frac{NBA \cos \theta}{10} = \frac{20 \times (50 \times 10^{-3}) \times (\pi \times 0.02^2) \times (\cos 0^\circ)}{10}$$
$$= 1.3 \times 10^{-4} \text{ V (2sf) (ans)}$$



Example 2

A meter consists of a measuring instrument connected to two electrodes A and C on diametrical ends of a pipe which carries a conducting liquid. If a magnetic field $B = 0.010 \text{ T}$ is directed into the plane of the paper at the conducting liquid in the region of the electrodes, determine the volume rate of flow of the liquid (in $\text{m}^3 \text{s}^{-1}$) if the diameter of the pipe is 50 mm and the e.m.f generated between A and C is 0.20 mV.



Solution

Generation of e.m.f between A and C establishes an electric field which produces an electric force opposing the magnetic force,

$$v = \frac{E}{B} = \frac{0.20 \times 10^{-3}}{0.010} = 0.020 \text{ ms}^{-1}$$

$$\text{Volume flow rate} = Av = \frac{\pi}{4} (50 \times 10^{-3})^2 \times 0.020 = 3.9 \times 10^{-5} \text{ m}^3 \text{ s}^{-1} \text{ (ans)}$$



Example 3

[Examined in 2018p1.26]

To send an electric pulse to the brain of a patient, a small circular coil is implanted within the hypothalamus of the brain. Outside the patient's skull is a bigger coil connected to a battery. The coils are in the same plane with the smaller coil located at the center of the larger coil.

- (a) From the data given below, estimate the maximum instantaneous potential difference induced in the smaller coil when the outer circuit is open.

Small coil: 200 turns ; area = 0.5 cm^2

Large coil: 750 turns ; radius = 10 cm, resistance = 5Ω

Battery: 50 V; internal resistance = 5Ω



The mean time for the current in the large coil to fall to zero is 10^{-4} s.
(Answer can be given in terms of π)

- (b) In the above arrangement, the induced e.m.f. is larger when the current is switched off than when the current is switched on. Suggest a reason for this.

Solution

(a) Current in outer coil, $I = \frac{E}{R+r} = \frac{50}{5+5} = 5.0$ A

Magnetic flux density at the center of the large coil carrying a current I is $B =$

$$\frac{\mu_0 NI}{2r} = \frac{(4\pi \times 10^{-7})(750)(5.0)}{0.2} = 7.5\pi \times 10^{-3} \text{ T}$$

Hence flux linkage through the small coil

$$\Phi = N'BA = 200 \times 7.5\pi \times 10^{-3} \times 0.5 \times 10^{-4} = 7.5\pi \times 10^{-5} \text{ Wb}$$

Using Faraday's law of electromagnetic induction,

Induced e.m.f. = - rate of change of magnetic flux

$$= \frac{0 - 7.5\pi \times 10^{-5}}{10^{-4}} = -0.75\pi \text{ V (ans)}$$

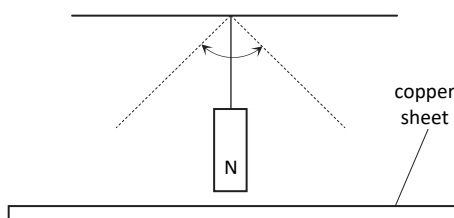
- (b) When the current in the outer coil is switched on, it takes some time for the current to reach its steady value. The change in magnetic flux through the inner coil is slow and a small e.m.f. is induced. When the current is switched off, the circuit is broken and the current in the outer coil drops immediately to zero. The rate of change in the magnetic flux through the inner coil is much greater and a larger e.m.f. is induced. **(ans)**



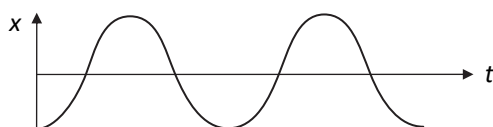
Worked Problems

Example 1

A magnet is attached to a string to make a simple pendulum. A copper sheet is placed underneath the magnet as illustrated.



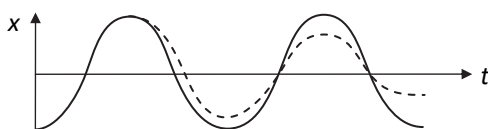
The magnet is set to oscillate. The variation of time t of the displacement x of the magnet is predicted to be as shown.



- (a) However when the experiment was carried out damped oscillations were observed.
- Sketch the new variation with time t of the displacement x of the mass on the graph above.
 - State Faraday's law of electromagnetic induction and explain why the oscillations of the mass are damped.
- (b) Suggest how critical damping could be demonstrated using the apparatus shown above.

Solution

- (a)
- New variation with time is shown as dotted line.



The period increases and the amplitude decreases with damped oscillations.
(ans)

- Faraday's law of electromagnetic induction* states that the magnitude of the e.m.f induced in a circuit is proportional to the rate of change of the flux linkage of the magnetic flux that cuts across the circuit.

The magnet produces a magnetic field around the copper plate. As the magnet moves, the plate cuts the magnetic flux around it. According to Faraday's law, this changing flux will give rise to induced e.m.f in the plate. The different e.m.f induced in the plate results in potential differences and hence induced current, known as eddy currents, in the plate. According to Lenz's law, the induced current will flow in a direction so as to oppose the



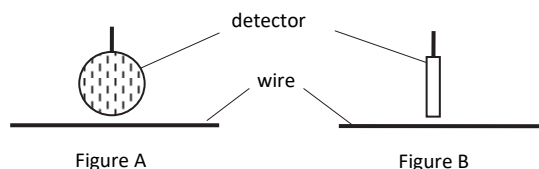
change that is producing it, i.e., oppose the movement of the plate and the mass. The opposing effects damped the oscillations. **(ans)**

- (b) By applying a stronger current in the electromagnet, a stronger current will be induced in the plate and so a greater damping effect will happen. The current may be increased to a magnitude such that the copper sheet will not oscillate but will return to its rest position quickly when displaced, and so demonstrate critical damping. **(ans)**



Example 2

In overhead cables, a small detector, attached to a cathode ray oscilloscope, is placed near the cable to monitor the alternating current passing through the cable.



- (a) By reference to the laws of electromagnetic induction, explain why
- the detector should be placed in the position shown in figure A rather than that in figure B.
 - the current must be alternating.
- (b) Transformers are used in overhead cables to change the voltage of the electricity supplied to households.
- State Lenz's law.
 - Use the laws of electromagnetic induction to suggest why the input voltage and the output e.m.f have the same frequency.
 - Explain how currents arise in the core of a transformer.
 - Explain how laminating the core reduces energy losses due to the currents.

Solution

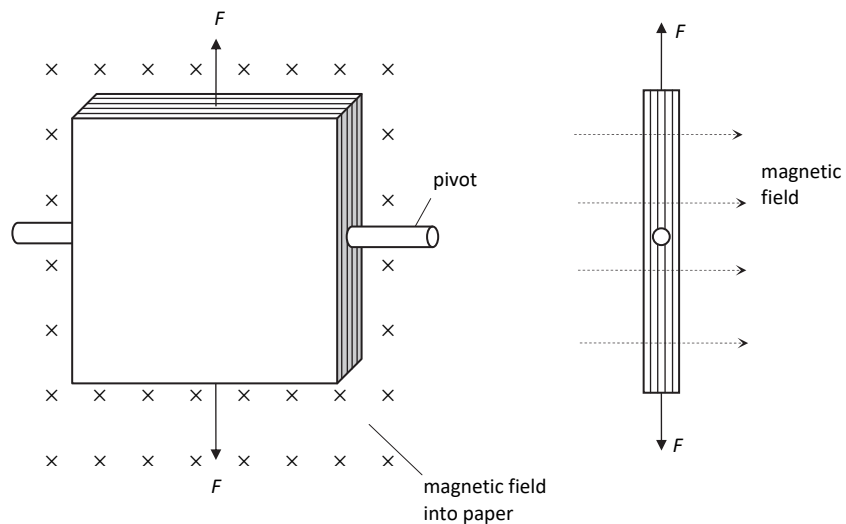
- (a) (i) The e.m.f induced in the detector is dependent on the area of the detector normal to the magnetic flux associated with the wire. The area normal to the flux is maximum in figure A and minimum in figure B. **(ans)**
- (ii) The e.m.f induced in the detector is dependent on the rate of change of the magnetic flux. The flux from a direct current is fixed and there would be no induced e.m.f. The flux from an alternating current will also alternate and hence induce an e.m.f in the detector. **(ans)**
- (b) (i) **Lenz's law** states that an induced current will flow in a direction that produces effects to oppose the change that induced it. **(ans)**

- (ii) The frequency of change of flux linkage is the same as that of the alternating current in the primary coil, which will be the same as that of the input voltage. According to Lenz's law, the output current will be in a direction that produces effects to oppose the change in flux linkage and so will have the same frequency of change as the flux linkage. Therefore, the output e.m.f will have the same frequency as the input voltage. **(ans)**
- (iii) The alternating flux in the core, due to the alternating current in the coils, induce e.m.f which circulate the currents, known as eddy currents, in the core. **(ans)**
- (iv) Laminating the core reduces the energy losses by reducing the eddy currents considerably. With laminated cores, the induced e.m.f are distributed over several sheets and the cross-section area across the path of the eddy currents are smaller, i.e., the resistance per path is higher. The eddy currents, which is $\frac{V}{R}$, are considerably reduced. The energy losses, which are proportional to the square of the current, are therefore reduced. **(ans)**



Example 3

The figure below shows the front view of a pivoted square coil. The plane of the coil is at right angles to a uniform magnetic field directed into the paper. Included is a side view of the same coil.



- (a) The coil conducts a current, causing electromagnetic forces to act on the coil. The directions of the forces F on the upper and lower sides are shown in both figures. State the direction of
- the current in the coil
 - the electromagnetic forces acting on the other sides of the coil.
- (b) Suggest why the forces mentioned in (a)(ii) are not considered when calculating the torque produced by the coil.



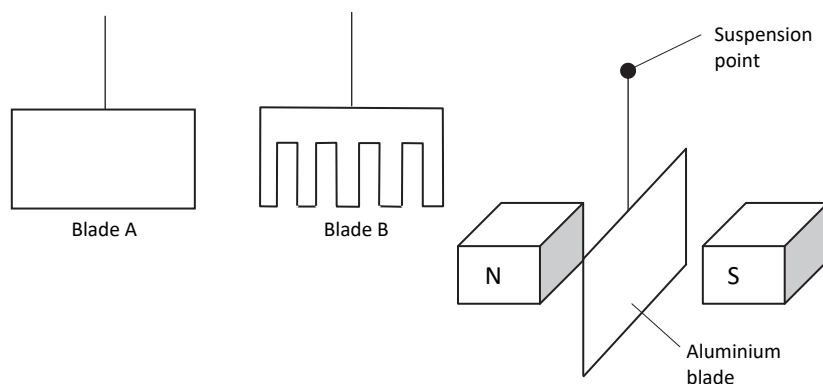
Solution

- (a) (i) Current flows anti-clockwise. (Taking the top of the coil and using Fleming's right hand rule, force acts upwards while magnetic field is into the plane of the paper, indicating current to be flowing towards the left and thus anti-clockwise.) **(ans)**
- (ii) Left-side of coil: force to the right (Using Fleming's left hand rule, current is moving downwards while the magnetic field is inwards into the plane of the paper. Force is thus acting towards the right.)
- Right-side of coil: force to the left (Using Fleming's left hand rule, current is moving upwards while the magnetic field is inwards into the plane of the paper. Force is thus acting towards the left.) **(ans)**
- (b) The forces are along the axis of the pivot. Since torque = Fx and $x = 0$, they are not considered. **(ans)**



Example 4

The diagram shows two blades of aluminium. Blade A is complete. Blade B has been cut to form a comb. Each blade is suspended in turn between the poles of a strong permanent magnet. Electromagnetic induction produces current loops in blade A as it swings between the poles.



- (a) Which electrical property of the blade is increased by cutting away the aluminium?
- (b) The oscillations of blade A are rapidly damped. Explain why.
- (c) Suggest why the oscillations of blade B are only very lightly damped when it replaces blade A as the blade swinging between the poles.

Solution

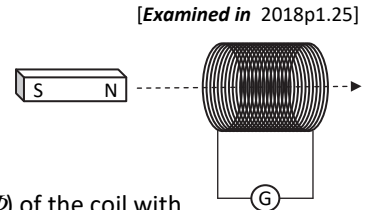
- (a) Resistance is increased when the aluminium is cut. **(ans)**
- (b) As the blade swings through the magnets, an e.m.f. is induced as there is a change in magnetic flux. A large current is induced as resistance is low. The large current causes thermal energy within the blade. Kinetic energy is changed to thermal energy causing the damping. **(ans)**

- (c) When blade B is used, resistance is large and current induced will be small. Less thermal energy is produced and less kinetic energy is converted. Therefore blade B is only slightly damped. **(ans)**



Example 5

A short bar magnet passes at a steady speed through a long solenoid. A galvanometer is connected across the solenoid.

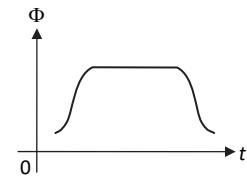


Deduce the graphs to represent:

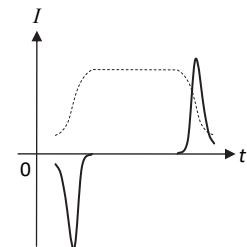
- (a) the variation of the magnetic flux linkage (Φ) of the coil with time (t), and
 (b) the variation of the current (I) of the galvanometer with time (t)?

Solution

- (a) Deduce that if coil area (A) and number of turns (N) are fixed, then magnetic flux linkage ($\Phi = BAN$) will have the same shape as magnetic flux (B). When the North pole approaches the coil, there would be increasing magnetic flux. Once the magnet is fully inside the coil, the magnetic flux will be maximum and not changing. Only when the magnet once again moves out of the coil will there be decreasing magnetic flux. The graph is deduced as shown. **(ans)**



- (b) Deduce that if the electric circuit of the galvanometer has constant resistance (R), then the current across the galvanometer ($I = \left(\frac{1}{R}\right)V$) will have the same shape as its p.d. (V) or emf (E). When the magnetic flux linkage (Φ) is increasing, there would be induced negative emf ($E = -\frac{d\Phi}{dt}$).



When the magnetic flux linkage is not changing, there would be no induced emf. Conversely, when the magnetic flux linkage (Φ) is decreasing, there would be induced positive emf. The induced emf is maximum if its rate of change of magnetic flux linkage is maximum. The graph is deduced as shown. **(ans)**





Example 6

A large aluminum plate is suspended by a light helical spring. It is set to freely oscillate by a small displacement downwards. A small bar magnet is then brought near to the centre of the oscillating plate. The oscillations of plate were found to be lightly damped.

Explain?

Solution

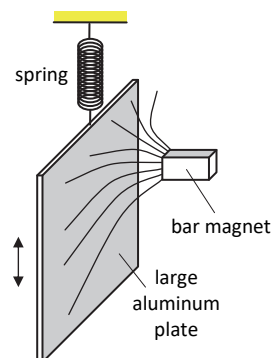
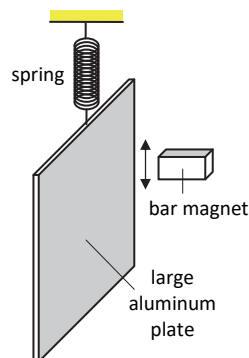
When the bar magnet is brought near to the oscillating plate. A magnetic field (B) is set up by the bar magnet linking the plate.

The magnetic field linkage ($\Phi = BAN$) is maximum for regions nearest to the bar magnet.

Deduce that at any moment, the speed of the plate (v) is constant throughout its plate, hence, the rate of change of flux linkage $\left(-\frac{d\Phi}{dt} = \mathcal{E}\right)$ will be different

for different regions in the plate. These different regions will induce different e.m.f.

Uneven e.m.f. will cause eddy currents to flow. When eddy current flows, energy is dissipated. The source of this energy must come from somewhere, *i.e.*, the potential energy residing in the oscillations, represented by the amplitude of oscillations. Hence, the oscillating plate will lose energy and amplitude be reduced and oscillations damped. **(ans)**



8

Notes: