



Dr. Bbosa Science

This document is sponsored by
The Science Foundation College Kiwanga- Namanve
Uganda East Africa
Senior one to senior six
+256 778 633 682, 753 802709
Based on, best for sciences



1. (a) Explain the sources of energy loss in a transformer when in use. (03 marks)
- Heating in the coil causes loss of energy due to the electrical resistance of the wires
 - Heating in the core causes loss of energy due to eddy currents.
 - Heating in the core due to loss due to magnetic reversals
 - Energy loss due to magnetic flux leakage
- (b) A machine rated 200W is operated at 230V. The resistance of the transmission line from the power station to the machine is 3Ω.
- (i) Calculate the power lost in the cables if the transmission is done at 230V. (03marks)
- Current in the transmission wire, $I = \frac{P}{V} = \frac{200}{230} = 0.8696A$
- Power loss, $P = I^2R$
- $$= (0.866)^2 \times 3$$
- $$= 2.11W$$
- (ii) Explain how this power can be transmitted to the machine with minimum loss using the same cable. (03marks)

At the power station the voltage is stepped up thereby reducing current. Power loss, $P = I^2R$ is thus minimized. At the machine, the voltage is stepped down to the required value to enable the operation of the machine

- (c) A rectangular coil of N turns, each of area A is rotated at constant angular velocity, ω , with its plane perpendicular to a Uniform magnetic flux B. derive an expression for e.m.f in the coil. (04marks)
- Magnetic flux linking N turns of the coil, $\phi = BAN\cos\theta$ but $\theta = 0$
- $$\Rightarrow \phi = BAN$$

The induced emf $E = \frac{-d\phi}{dt} = \frac{-d}{dt}(BAN)$

Since BAN is constant , $E = 0$

Or

$$\phi = BAN\cos\omega t$$

$$E = \frac{-d\phi}{dt} = -(BAN) \frac{d}{dt} \cos \omega t$$

$$= \omega BAN \sin \omega t$$

But $t = 0$

Hence, $E = 0$

- (d)(i) What is meant by the statement that two coils have a mutual inductance of 1 henry? (01mark)

Two circuits have a mutual inductance of 1 henry if the induced emf in the secondary coil is 1V when the current in the primary coil changes at a rate of 1A per second.

- (ii) The Mutual inductance of two coils is 30 henrys. A current of 11.5A in the primary coil is reduced at a steady rate to zero in a period of 0.002s. Calculate the e.m.f induced in the secondary coil. (03marks)

$$E = -M \frac{dI}{dt} = -30 \frac{(0-11.5)}{0.002} = 22,500V$$

- (e)(i) Explain what is meant by back e.m.f in a motor. (02 marks)

When the armature of the motor rotates in the magnetic field, emf is induced in the coil. This emf opposes the supply (applied) Voltage. This emf is called back emf.

- (ii) State one advantage of back e.m.f in a motor (01mark)

- it reduces current which would have damaged the coil
- work done against back emf is converted into mechanical work. It increases efficiency of the motor

2. (a) Define

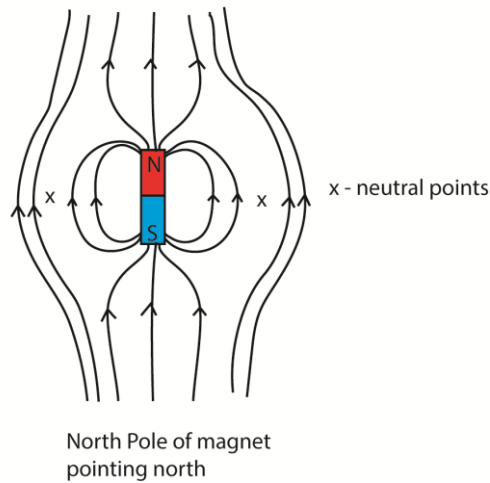
- (i) Magnetic field (01mark)

It is a region in space where magnetic force is experienced.

- (ii) Magnetic saturation (01mark)

Magnetic saturation occurs when a given material has attained its maximum magnetic strength such that further magnetization does not increase its magnetic strength.

- (b)(i) Draw the magnetic field pattern for a bar magnet placed with its north pole facing the earth's north pole. (01mark)



- (ii) Describe an experiment to determine the angle of dip at a given place using an earth inductor. (04marks)
- The inductor is placed with the plane of its coil horizontal. The coil is turned through 180° about the vertical diameter. The first deflection θ is noted. The coil is now placed with plane of the coil vertical such that its plane is perpendicular to N-S direction. The coil rotated through 180° . The first deflection θ_1 is noted. The angle of dip, ϕ now calculated from $\phi = \tan^{-1} \left(\frac{\theta}{\theta_1} \right)$
- (c)(i) Define an Ampere. (01mark)
- The ampere is a steady current which when flowing in each of two infinitely long straight wire parallel conductors of negligible cross section area and 1 meter apart in a vacuum produces between the wires a force of 2.0×10^{-7} N per meter of the length.
- (ii) A rectangular frame XWVY is pivoted about a horizontal axis XY such that the length PQ is equal to the length YW. The end VW lies half-way inside the solenoid of n turns per meter. The solenoid is arranged so that its magnetic field of flux density B is perpendicular to VW and the metal frame is connected in series with the solenoid as shown in figure 1.

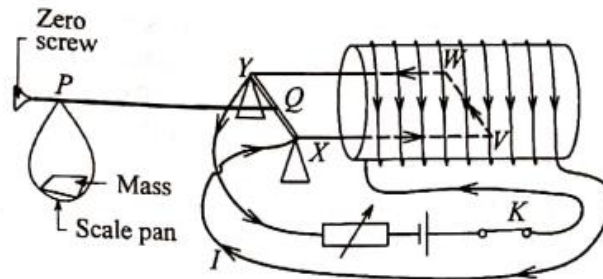


Fig. 1

When switch K is closed, the frame balances when the mass on the pan is m . Show that the current I , flowing is given by

$$I = \sqrt{\frac{mg}{\mu_0 n l}} \text{ where } l \text{ is length of the side VW (03mark)}$$

When Switch K is closed, current flows and wire WV experiences a force, $F = BIl$ downwards. Weight $F' = mg$ is placed in the scale.

At balance $F \times PQ = F' \times YW$

Since $PQ = YW$

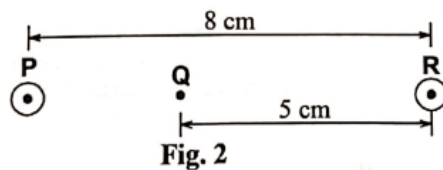
$$ng = BIl$$

$$= (\mu_0 n I) l$$

$$\Rightarrow I = \sqrt{\frac{mg}{\mu_0 n l}}$$

..

- (d) Figure 2 shows two wires P and R carrying currents of 9A and 5A out of paper



Find the

- (i) Magnetic flux density at point. (04marks)

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

$$B_Q = B_P - B_R = \frac{4\pi \times 10^{-7}}{2\pi} \left(\frac{9}{0.03} - \frac{5}{0.05} \right) = 4.0 \times 10^{-5} T$$

- (ii) Force per meter acting on the wire P. (03marks)

$$\frac{F}{L} = \frac{\mu_0 I_P I_R}{2\pi a} = \frac{4\pi \times 10^{-7} \times 9 \times 5}{2\pi \times 0.08} = 11.25 \times 10^{-3} Nm^{-1}$$

- (e) State four factors which determine the current sensitivity of a moving coil galvanometer. (02mark)

B- magnetic flux density

A- Area of the coil

N- Number of turns

K- strength of the hairspring

3. (a) What is meant by the following;

- (i) Root mean square value of an alternating current, (01mark)

It is the value of steady/direct current that dissipates heat in a given resistor at the same rate as alternating current.

- (ii) reactance (01mark)

Reactance is non-resistive opposition to the flow of a.c in a circuit containing either an inductor or a capacitor.

- (iii) Impedance (01 mark)

Impedance is the total opposition to the flow of an alternating current in an a.c circuit containing resistive and reactive components.

- (b) Show that the average value of power dissipated in a capacitor in completely cycle is zero. (03marks)

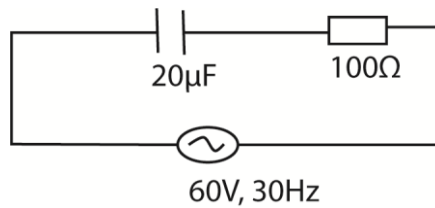
Consider a capacitor connected to an a.c source of $V = V_0 \sin \omega t$ and $I = I_0 \cos \omega t$

$$\begin{aligned}
 P &= IV \\
 &= I_0 \cos \omega t \times V_0 \sin \omega t \\
 &= I_0 V_0 \sin \omega t \cos \omega t \\
 &= \frac{1}{2} I_0 V_0 \sin 2\omega t
 \end{aligned}$$

$$\langle P \rangle = \frac{1}{2} I_0 V_0 \langle \sin 2\omega t \rangle, \quad \langle \sin 2\omega t \rangle = 0$$

$$\text{Hence } \langle P \rangle = 0$$

- (c) A capacitor of $20 \mu\text{F}$ is connected in series with a resistor of 100Ω across an a.c source of frequency 30 Hz and peak voltage 60 V . Determine the root mean square of the current that flows. (05marks)



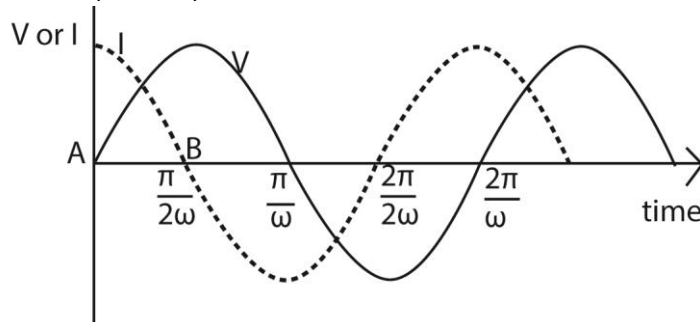
$$\text{For a capacitor, } X_C = \frac{1}{\omega C} = \frac{1}{2\pi \times 30 \times 20 \times 10^{-6}} = 265.4 \Omega$$

$$Z = \sqrt{X_C^2 + R^2} = \sqrt{265.4^2 + 100^2} = 283.6 \Omega$$

$$V = IZ \Rightarrow I_0 = \frac{V_0}{Z} = \frac{60}{283.6} = 0.212 \text{ A}$$

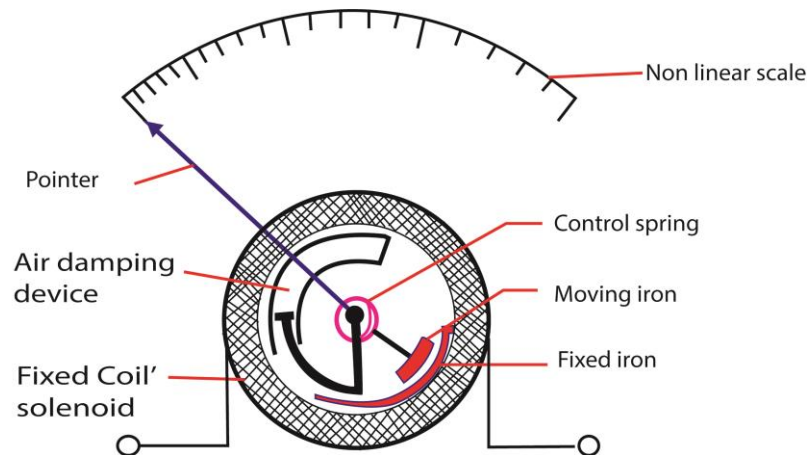
$$I_{rms} = \frac{I_0}{\sqrt{2}} = \frac{0.212}{\sqrt{2}} = 0.15 \text{ A}$$

- (d) (i) On the same axes, draw graphs of voltage $V = V_0 \sin \omega t$ and the resulting current against time for a circuit in which the a.c supply is connected across a capacitor. (02mark)



- (ii) Explain the values of I when $V = V_0$ and when $V = 0$. (02marks)
 When $V = V_0$, $I = 0$ the capacitor is fully charged, and opposition to the flow of charge is maximum
 When $V = 0$, I is maximum because the opposition to the flow of charge is minimum or zero

- (e) Describe the mode of operation of a repulsive type ammeter. (05marks)



When a current is passed through the coil, the iron rods magnetize in the same poles adjacent to each other in whatever the direction of current. Hence they repel and the pointer move in the same direction until it is stopped by the restoring spring.

Since the magnetic force is proportional to the square of the average current, hence, the deflection is proportional to the square of average current

- 1.
2. (a)(i) Write down an expression for the force on a charge, q coulombs moving with velocity, u , at an angle, α , to a uniform magnetic field of flux density B . (01mark)

$$F = Bq u \sin \alpha$$

- (ii) Use the expression in (a)(i), to deduce the force on a conductor carrying a current in magnetic field. (03marks)

Using $F = Bq u \sin \alpha$

$$q = It$$

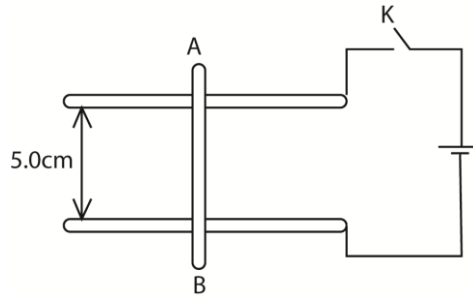
$$\Rightarrow F = BIt u \sin \alpha$$

Where t is the time and I the current flowing

Since $tu = L$, the length of a conductor

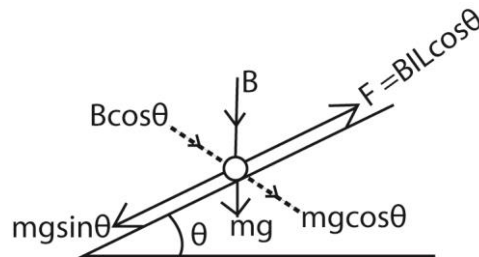
Then, $F = BIL \sin \alpha$

- (b) Figure below shows an aluminium bar AB resting on two horizontal aluminium rails connected to a battery through switch K . a magnetic field of flux density 0.10T acts perpendicularly into paper.



- (i) Explain what happens to AB when switch K is closed (03marks)
 Current flows in the bar in the direction BA. From the Fleming's left hand rule, the bar BA will experience a magnetic force and it will move towards the right.
- (ii) Calculate the angle to horizontal to which the rail must be tilted to keep AB stationary if its mass is 5.0g, current in it is 4.0A and the direction of the field remains unchanged. (04marks)

Let the angle be θ



At equilibrium, $F = mg \sin \theta$

$$BIL \cos \theta = mg \sin \theta$$

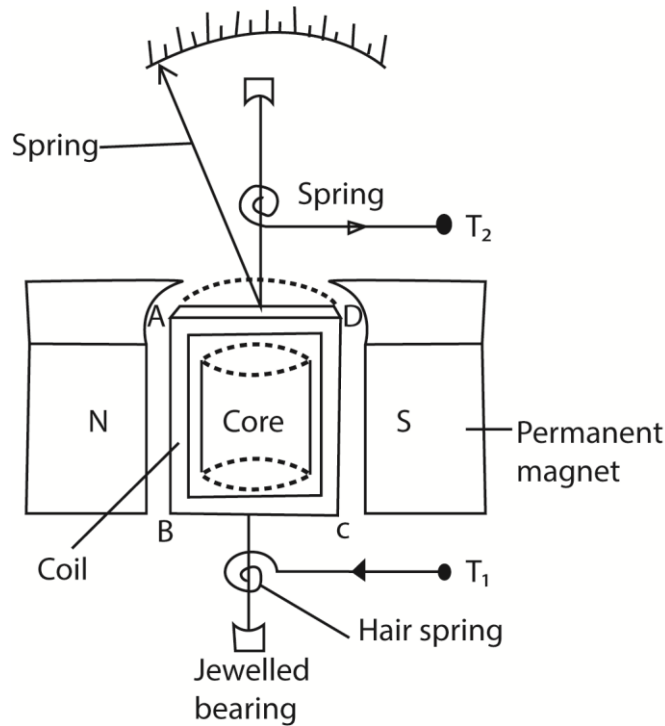
$$0.10 \times 4 \times 5 \times 10^{-2} \cos \theta = 5 \times 10^{-3} \times 9.81 \sin \theta$$

$$\frac{\sin \theta}{\cos \theta} = \frac{5 \times 10^{-3} \times 9.81}{0.1 \times 4 \times 10^{-2}}$$

$$\tan \theta = 0.40775$$

$$\theta = 22.18^\circ$$

- (c)(i) With the aid of a labelled diagram, describe the structure and mode of operation of a moving coil galvanometer. (06marks)



Structure

- It consists of a rectangular coil of fine insulated copper wire wound on an aluminium frame to provide electromagnetic damping.
- The coil together with the frame of aluminium are mounted over a soft iron cylindrical core and freely pivoted on jewelled bearing to minimize friction at contact.
- The suspension torsion wire suspending the coil is attached to a pair of control hair springs T_1 and T_2 for feeding current in and out of the coil and control rotation of the coil.
- The coil is then suspended between concave pieces of a strong magnet to provide magnetic field.

Mode of action

- Current I to be measured is passed into the coil via hair spring T_1 .
- The current then causes the coil to experience a deflection torque, $\tau = NABl$ due to a couple force causing rotation in a radial magnetic field.
- The coil turns with the pointer through angle θ until stopped by restoring torque, $\tau = k\theta$ provided by a pair of hair springs T_1 and T_2 .

- At equilibrium, $NABl = k\theta$

$$\therefore \text{current } I = \left(\frac{k}{NAB} \right) \theta$$

- $I \propto \theta$, hence the instrument has a linear scale

Where B = magnetic field strength between the poles of the magnets

A = area of the plane of the coil

N = number of turns of the coil

k = torsion constant of suspension wire

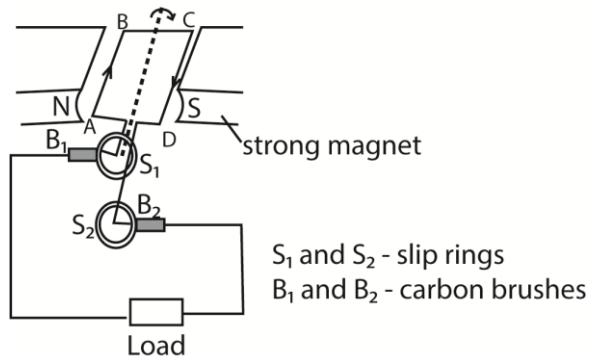
(iii) Discuss the factors which affect the current sensitivity of a moving coil galvanometer (03marks)

- Strength of magnet, current sensitivity is proportional to the strength of the magnets
- Number of turns, current sensitivity is proportional to the number of turns
- Nature of suspension torsion wire, current sensitivity is inversely proportional to the torsion constant of the suspension torsion wire.
- Area A of the plane of the coil; current sensitivity is proportional to the area of the plane of the coil
- Size of copper wire making the coil; current sensitivity is proportional to the size of copper wires making the coil since the bigger the wires the lower the resistance.

3. (a) State the laws of electromagnetic induction. (02marks)

- **Faraday's law** states that the magnitude of the e.m.f induced in a circuit is directly proportional to the rate of change of magnetic flux linked with the circuit.
- **Lenz's Laws** states that induced current flows always in such a direction as to oppose the change which is giving rise to it.

(b)(i) With the aid of a diagram, describe how a simple a.c. generator works (04marks)



How it works

- The coil is rotated in a magnetic field, the magnetic field linked with it changes and hence e.m.f is led away by means of slip rings which press slightly against the carbon brushes.
- Applying Fleming's right hand rule, the induced current enters the coil AB and leave the coil via CD.
- Starting with the coil in the vertical position, the magnetic flux linking it is maximum and hence no induced e.m.f.
- The induced e.m.f increases with the position of the coil in the magnetic field until it becomes maximum with the coil in horizontal position and then decrease to zero as the coil rotates to the vertical position
- The force acting on the sides of the coil change as the coil passes over the position and hence the current flowing in the coil reverses. Hence an alternating e.m.f or current flows through the load.

(ii) What are the main energy losses in a practical a.c. generator and how are they minimized? (02marks)

- Eddy current loss are minimized by laminating the armature
- I^2R losses are minimized by use of low resistance winding wires
- loss due to friction minimized by lubricating the rubbing parts
- energy loss due magnetic reversal is minimized by use of pure soft iron

(c) A circular coil having 20 turns each of radius 8.0cm is rotated about its vertical diameter with angular speed of 50 radians per second in a uniform horizontal magnetic field of magnitude 30mT.

(i) Calculate the r.m.s value of the e.m.f. induced in the coil (03marks)

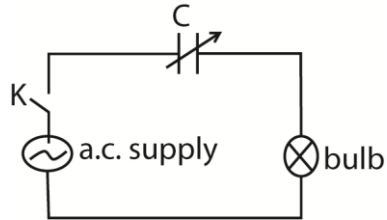
$$E = NAB\omega = 20 \times [3.14 \times (8 \times 10^{-2})^2] \times (30 \times 10^{-3}) \times 50 = 0.603V$$

$$E_{r.m.s} = \frac{E_0}{\sqrt{2}} = \frac{0.603}{\sqrt{2}} = 0.426V$$

(ii) If the coil forms a closed loop of resistance 10Ω, how much power is dissipated as heat in it? (02marks)

$$P = \frac{V_{r.m.s}^2}{\sqrt{2}} = \frac{(0.426)^2}{\sqrt{2}} = 0.018W$$

(d) The figure below shows a capacitor and a bulb connected to a.c supply



Explain

- (i) Why the bulb lights when switch K, is closed (01marks)
The capacitor is continuously charging and discharging. This cause continuous charge (current) flow in the bulb
- (ii) What would happen if the capacitance were reduced? (02marks)
When the capacitance is reduced the reactance increases and therefore the charging and discharging current is decrease. The bulb dims or goes off.

(e) Explain the following observation:

- (i) A spark is seen at the switch when the circuit of a current carrying coil is broken (02marks)

When the switch is broken, the magnetic flux linking the coil collapses. A large e.m.f is induced between the contacts creating a high electric field intensity which ionizes the air there. The ions meet and neutralize violently producing sparks.

- (ii) A magnetized iron bar dropped vertically through a hollow region of a thick cylindrical shell made of copper experiences a retarding force. (02marks)

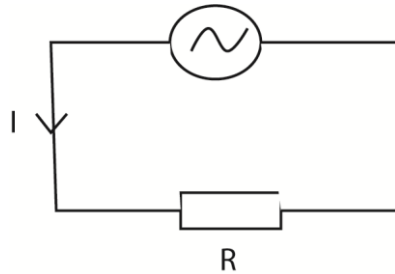
Magnetic flux linking the shell changes inducing eddy currents that oppose motion of the bar magnet thus causing retardation.

4. (a) Define the following

- (i) Peak value(01mark)
Peak value of alternating current is the maximum value attained by such a current in a cycle.
- (ii) Root mean square (r.m.s) value of alternating current.(01mark)
Root mean square (r.m.s) value of an alternating current, is the value of steady/direct current that would dissipate heat in a given resistor at the same rate as alternating current.

(b) Derive an equation relating peak value and r.m.s value of alternating current (03marks)

Consider an alternating current $I = I_0 \sin \omega t$ through a resistor, R.



The average rate at which heat is dissipated = $I^2 R$

$$P = I_0^2 R \sin^2 \omega t$$

$$= I_0^2 R \times \frac{1}{2}$$

$$= \frac{I_0^2 R}{2}$$

Let I_d be the steady value of direct current that dissipates heat at the same rate as a.c. in a given resistance

$$\text{Power} = I_d^2 R$$

From definition of $I_{r.m.s}$

$$I_d^2 R = \frac{I_0^2 R}{2}$$

$$I_d = \frac{I_0}{2}$$

But $I_d = I_{r.m.s}$

$$\text{Thus } I_{r.m.s} = \frac{I_0}{2}$$

- (c) An electric current flow through a coil of 4Ω immersed in 200kg of water placed in a container. If the temperature of the water rises by 1K per minute, calculate the peak value of current supplied. (03marks)

$$R = 4\Omega, m = 200\text{g}, \Delta\theta = 1\text{K}, t = 60\text{s}$$

$$\frac{m}{t} \times c \times \Delta\theta = I_{r.m.s}^2 R$$

$$\frac{0.200}{60} \times 4200 \times 1 = 4I_{r.m.s}^2$$

$$I_{r.m.s}^2 = 1.871\text{A}$$

$$\text{Peak value, } I_0 = \sqrt{2} \times I_{r.m.s} = \sqrt{2} \times 1.871 = 2.646\text{A}$$

- (d) What is meant by resonance in a circuit? (01mark)

Resonance is the condition that exists in a circuit when the inductive reactance and the capacitive reactance are of equal magnitude, causing electrical energy to oscillate between the magnetic field of the inductor and the electric field of the capacitor.

(e) A lamp of resistance 10Ω , a capacitor of capacitance $0.4\mu\text{F}$ and an inductor of inductance 0.4H are connected in series to an alternating voltage source of 0.01V (r.m.s). The frequency, f , is varied from low to high value while maintaining the amplitude of the applied voltage constant.

- (i) Explain how the brightness of the lamp rises. (03marks)

Initially the brightness of the bulb increases as current through the circuit increases with increasing frequency. At resonant frequency, the current through the circuit becomes maximum and the brightness of the bulb becomes maximum. However, the brightness of the bulb dims until it dies off at frequencies greater than the resonant frequency since the current flowing reduces in it.

- (ii) Calculate the resonance frequency. (03marks)

At resonant frequency, $X_C = X_L$

$$2\pi f_0 L = \frac{1}{2\pi f_0 C}$$

$$4\pi^2 LC f_0^2 = 1$$

$$f_0 = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{0.4 \times 0.4 \times 10^{-6}}} = 397.9\text{Hz}$$

(iii) Find the voltage across the capacitor. (03marks)

Impedance, $Z = R = 10\Omega$

$V = IZ$

$0.01 = I \times 10$

$I = 1 \times 10^{-3} \text{A}$

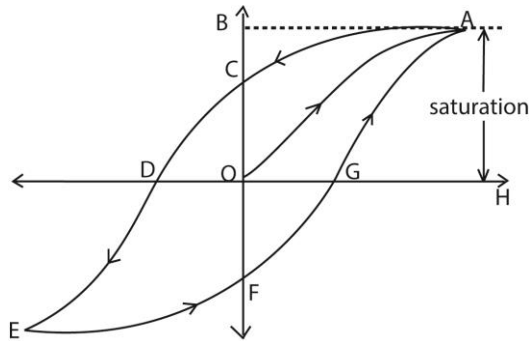
Using $V_c = IX_c = \frac{1}{2\pi fC} = \frac{1 \times 10^{-3} \times 10^6}{2\pi \times 397.9 \times 0.4} = 1V$

(f) Explain why in an R-C circuit, power is only absorbed by resistive part of the circuit. (02marks)

In one quarter cycle as the capacitor charges, power is transferred from the source to the capacitor. In the next quarter cycle as the capacitor discharges, power is returned to the source.

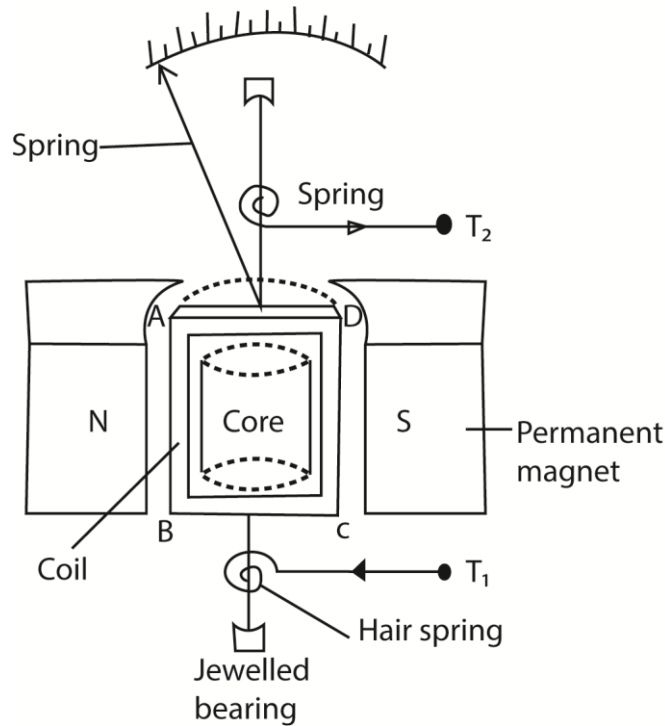
5. (a) With the aid of a sketch graph, explain the hysteresis curve for ferromagnetic material (07mark)

Solution



- When a magnetic field is applied to a ferromagnetic material, the magnetic domains tend to align with the applied field. The magnetic flux density increases along OA until saturation. When the magnetizing field is reduced to zero, there is residue magnetization at C. This is due to failure of the dipoles to respond instantly. Energy is lost.
- To bring the dipoles to their original orientation, a magnetic field OD is applied in opposite direction. As the magnetic field is increased in this reversed direction, saturation is attained at E
- When reversed magnetic field is reduced to zero, state F is attained. Reversal of dipoles requires an increase of magnetic field in opposite direction to state EF. The cycle is then repeated on further increase of magnetic field
- The curve of B verses H is called a hysteresis curve

(b)(i) Describe with the aid of a labeled diagram, the structure and mode of action of a moving coil galvanometer (06marks)



Structure

- It consists of a rectangular coil of fine insulated copper wire wound on an aluminium frame to provide electromagnetic damping.
- The coil together with the frame of aluminium are mounted over a soft iron cylindrical core and freely pivoted on jewelled bearing to minimize friction at contact.
- The suspension torsion wire suspending the coil is attached to a pair of control hair springs T_1 and T_2 for feeding current in and out of the coil and control rotation of the coil.
- The coil is then suspended between concave pieces of a strong magnet to provide magnetic field.

Mode of action

- Current I to be measured is passed into the coil via hair spring T_1 .
- The current then causes the coil to experience a deflection torque, $\tau = NABl$ due to a couple force causing rotation in a radial magnetic field.
- The coil turns with the pointer through angle θ until stopped by restoring torque, $\tau = k\theta$ provided by a pair of hair springs T_1 and T_2 .

- At equilibrium, $NABl = k\theta$

$$\therefore \text{current } I = \left(\frac{k}{NAB} \right) \theta$$

- $I \propto \theta$, hence the instrument has a linear scale

Where B = magnetic field strength between the poles of the magnets

A = area of the plane of the coil

N = number of turns of the coil

k = torsion constant of suspension wire

- (iii) Explain why eddy currents are useful in a moving coil galvanometer. (02marks)

Eddy current are induced in the core when the coil moves in magnetic field. The eddy current damp the oscillations of the coil. This makes the pointer to settle at a point quickly. It is desirable for quick and accurate reading of the value.

- (c) A conducting disc of radius 0.05m with its plane perpendicular to uniform magnetic field of flux density 0.25T, rotates at 15 revolution per second about an axis through its center and perpendicular to its plane.

Calculate

- (i) Magnetic flux threading the disc at any time (03marks)

$$\begin{aligned} \text{Magnetic flux, } \phi &= BA \text{ but } A = \pi r^2 \\ - \phi &= B\pi r^2 \\ &= 0.25 \times 3.14 \times (0.05)^2 = 1.96 \times 10^{-3} \text{Wb} \end{aligned}$$

- (ii) E.m.f generated between the center of the disc and any point on its rim.

$$\varepsilon = B\pi r^2 f = 0.25 \times 3.14 \times (0.05)^2 \times 15 = 2.9 \times 10^{-2} \text{V}$$

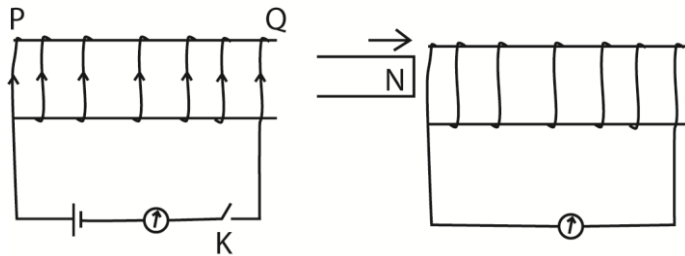
$$\text{or } \varepsilon = \phi f = 1.96 \times 10^{-3} \times 15 = 2.9 \times 10^{-2} \text{V}$$

6. (a) state **Faraday's law** of electromagnetic induction (01 mark)

The magnitude of e.m.f induced in the circuit is directly proportional to the rate of change of magnetic flux linked with the circuit

- (b) With the aid of a diagram describe an experiment to illustrate **Lenz's law** of electromagnetic induction. (05marks)

Solution



- The galvanometer is first connected in series with the battery and the coil PQ. The switch K is closed. The direction of deflection of the galvanometer for which current flows in an anticlockwise direction at the end P of the coil is noted.
- The battery is then disconnected and the circuit containing the coil and the switch is made complete.
- A strong permanent magnet is brought towards the coil with a North Pole facing end P of the coil.
- The galvanometer deflects in such a direction indicating that the side of the coil facing the magnet is North Pole.

- When the magnet is moved away from the coil, the galvanometer deflects in the opposite direction implying that the pole of the coil near the magnet is a south pole.
- In the first case, the pole due to the increased current was repelling the approaching magnet while in the second case, the pole was attracting the receding magnet. The induced current therefore is in such a direction as to oppose the change causing it, which is Lenz's law

(c) Define **magnetic moment** of a coil. (01mark)

Magnetic moment is torque experienced by the coil per tesla of magnetic field acting along the plane of the coil.

Or

Magnetic moment of a coil is a couple exerted on a coil when it is placed with its plane parallel to a magnetic field of 1T

(d) A small circular coil of 20 turns of wire lies in a uniform magnetic field of flux density 5.0×10^{-2} T. The normal to the coil makes an angle of 30° with the direction of the magnetic field. If the radius of the coil is 4cm and the coil carries a current of 2.0A, find the

(i) magnetic moment of the coil (02marks)

$$M = NIA = 20\pi \times (4 \times 10^{-2})^2 \times 2 = 0.2\text{Am}^2$$

(ii) torque on the coil

$$T = MB\sin\theta = 0.2 \times 5 \times 10^{-2}\sin 30^\circ = 5.0 \times 10^{-3}\text{Nm}$$

(e) (i) State and define the unit of magnetic flux density.

One tesla (1 T) is defined as the field intensity generating one newton (N) of force per ampere (A) of current per meter of conductor:

(ii) Show that when the magnetic flux linking a coil changes, the total charge which passes through is depends only on the resistance of the coil and total flux linking it (05marks).

Consider a coil of N turns each linked by magnetic flux of ϕ_1 .

Suppose the magnetic flux changes to ϕ_2 .

When the magnetic flux ϕ changes, an e.m.f ϵ is induced in the coil.

$$\epsilon = \frac{-Nd\phi}{dt}$$

$$I = \frac{\epsilon}{R}; R = \text{the resistance of the coil}$$

$$\epsilon = IR$$

$$\text{Hence } IR = \frac{-Nd\phi}{dt}$$

$$\text{But } I = \frac{dQ}{dt}; \text{ where } Q \text{ is the induced charge}$$

$$\Rightarrow \frac{dQ}{dt} = \frac{-N}{R} \cdot \frac{d\phi}{dt}$$

$$dQ = \frac{-N}{R} d\phi$$

The amount of the charge which passes through the coil when the magnetic flux changes from ϕ_1 to ϕ_2 is

$$Q = \frac{-N}{R} \int_{\phi_1}^{\phi_2} d\phi = \frac{-N}{R} (\phi_2 - \phi_1)$$

(iii) State any two factors which determine the efficiency of a transformer. (01mark)

- Resistance of wire used to make the primary and secondary coils/resistance of windings
- Coupling between the primary and secondary coil
- The design of the core/eddy current in the core

7. (a)(i) What is meant by **capacitive reactance**? (01mark)

Capacitive reactance is non-resistive opposition flow of a.c. through a capacitor.

(ii) Peak value of an alternating voltage. (01mark)

Peak value of an alternating voltage is the maximum value of the alternating voltage

(iii) Show that the r.m.s value of an alternating voltage is $V_{r.m.s} = \frac{V_0}{\sqrt{2}}$, where V_0 is the peak voltage (03marks)

Instantaneous power $= \frac{V^2}{R}$, where $V = V_0 \sin \omega t$

$$P_{inst} = \frac{V_0^2 \sin^2 \omega t}{R}$$

Average power, $P = \frac{V_0^2 \sin^2 \omega t}{R}$

$$\text{But } \sin^2 \omega t = \frac{1}{2}$$

For steady voltage, $P = \frac{V_{r.m.s}^2}{2R}$

$$\Rightarrow \frac{V^2}{R} = \frac{V_{r.m.s}^2}{2R}$$

$$\text{Hence } V_{r.m.s} = \frac{V_0}{\sqrt{2}}$$

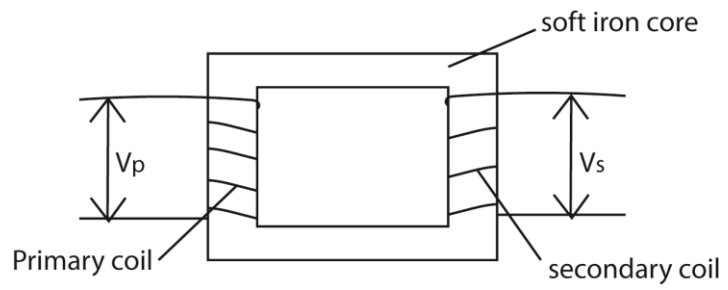
(b) Distinguish between mutual and self-induction. (02marks)

Mutual induction is a production of e.m.f in a conductor caused by change in magnetic field linking it due to change in current due to nearby circuit

while

Self-induction is the production of an e.m.f in a conductor caused by change in magnetic flux linking it due to the change in the current in the same conductor.

(c)(i) Describe with the aid of a diagram, the structure and working of a.c. transformer (02marks)



$V_p =$ primary voltage, $V_s =$ secondary voltage

- Transformer consists of two coil of insulated wire, the primary and secondary wound on laminated soft iron core.
- When alternating voltage, V_p is connected to primary coil, it drives alternating current in the primary coil.
- The alternating current produces a varying magnetic flux ϕ_p that link the primary coils inducing a back e.m.f E_B in the primary.
- The varying magnetic flux, ϕ_s links the secondary coil by mutual induction/inducing alternating voltage, V_s in the secondary

$$V_p = N_p \frac{d\phi_p}{dt} \dots\dots\dots(i)$$

$$V_s = N_s \frac{d\phi_p}{dt} \dots\dots\dots(ii)$$

Eqn. (i) \div Eqn (i)

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

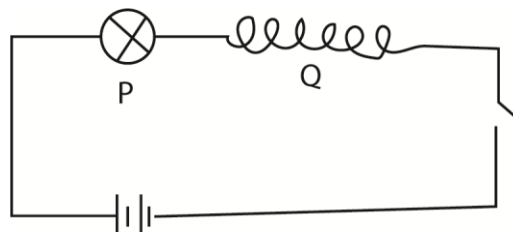
When $N_s > N_p$ the transformer is a step up

$N_s < N_p$ the transformer is a step down

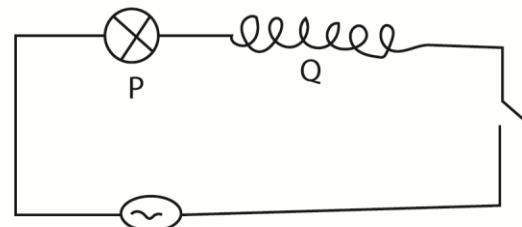
(ii) Explain the steps taken to minimize power losses in electric power transformation. (03marks)

- Voltage generated is stepped up using a transformer so as to transmit high voltage and low current.
- Low resistance cables are used

(d) In figure below, P is a 6V lamp and Q is a coil of negligible resistance



(a)



(b)

(i) Explain which of the lamps in the figure above will be brighter when K is closed (02marks)

The bulb in (a) will be brighter.

When the switch is closed in (a), current flows and back e.m.f is induced. This limits brightness of the bulb. When the current reaches the steady value, the back e.m.f is zero, the bulb lit brightest

In coil (b) the continuous change in direction and quantity of current induces continuous change in magnetic flux and thus back e.m.f and the bulb is dim.

- (ii) Explain what happens when a soft iron core is introduced in the coil in each of the circuit (03marks)

When soft iron core is introduced, magnetic flux is enhanced in (a), the back e.m.f increases and the current decreases. The brightness of the bulb reduces. The back e.m.f reduces to zero when the current increases to the maximum (and the change in charge reduces to zero) leading to increase in brightness of the bulb.

In (b) the back e.m.f increases and the current reduces. The brightness of the bulb thus reduces.

8. (a) Define magnetic flux density. (01mark)

Magnetic flux density is the force acting on conductor of length 1m and carrying of 1A placed perpendicular to magnetic field.

- (b) Write the expression for the

- (i) Magnetic flux density B at a distance r from long straight wire carrying current I . (01mark)

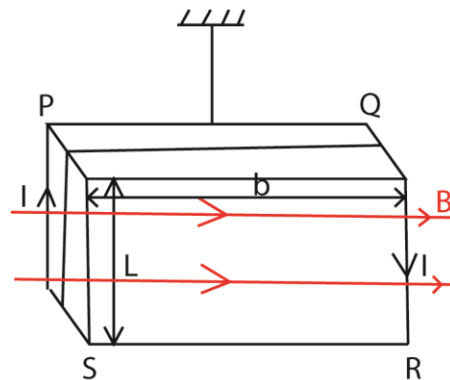
$$B = \frac{\mu_0 I}{2\pi r}$$

- (ii) Force F on a straight wire of length L carrying current I perpendicular to a uniform magnetic field of flux density B .

$$F = BIL$$

- (c) A moving-coil galvanometer consists of a rectangular coil of N -turns each of area A suspended in a radial magnetic field of flux density B .

- (i) Derive an expression for the torque on the coil when a current I passes through it (04marks)



There is no force on the sides PQ and SR since they are parallel to the field

Applying Fleming's left hand rule, the force initially on PS, $F = \mu BIL$ (into the plane)

The force initially on QR, $F = \mu BIL$ (out of the plane)
 These force constitute a couple whose moment is given by
 Torque, $\tau = F \times b$
 $= \mu BIL \times b$
 But $L \times B = A$
 \therefore torque, $\tau = \mu BIA$

(ii) If the coil is suspended by a torsion wire for which the couple per unit twist is C , show that the instrument will have a linear scale.(03mark)

Torque on the coil, $\tau = \mu BIA$
 Torque due to torsion wire, $\tau = C\theta$
 At balance, $C\theta = \mu BIA$

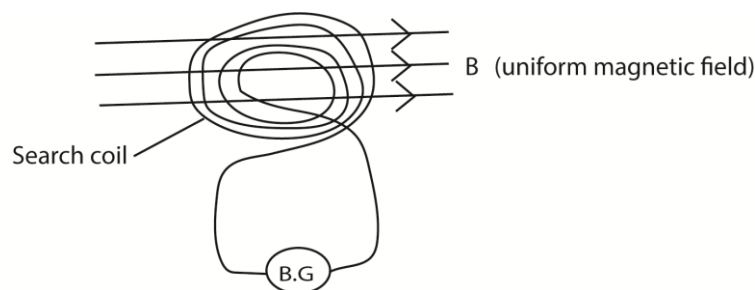
$$\Rightarrow \theta = \frac{\mu BIA}{C}$$

Since, μ , B , C and A are constant
 $\theta \propto I$, the scale is linear

(iii) How can current sensitivity of the instrument be measured? (02marks)

The instrument is connected in series with an ammeter to a voltage source. The current measured, and the deflection, θ , of the instrument is recorded.
 Current sensitivity is given by, $S_i = \frac{\theta}{I}$

(d) Describe an experiment to determine the magnetic flux density of a uniform magnetic field using a search coil and ballistic galvanometer



A search coil of cross section area A and number of turns, N , is connected in series with ballistic galvanometer. The search coil is then placed in uniform magnetic field such that the plane of the coil is perpendicular to the magnetic field. The coil is then pulled completely out of the field. The first deflection of the ballistic galvanometer noted θ_1 .

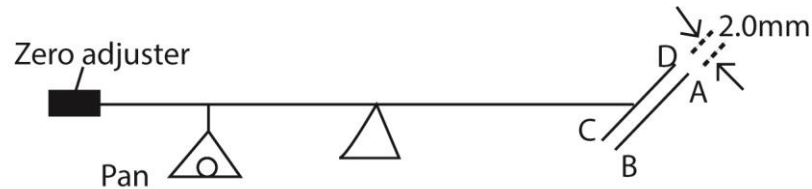
A capacitor of known capacitance C is then charged to a p.d. V and then charged through the ballistic galvanometer, θ_2 is noted

The magnetic flux density of uniform magnetic field is obtained from

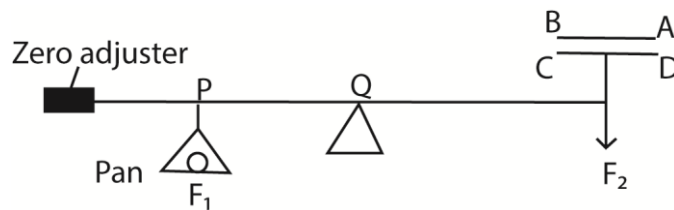
$$B = \frac{CVR}{AN} \times \frac{\theta_1}{\theta_2}$$

Where R is the resistance of the whole circuit.

(e) Figure 2 shows an ampere balance, wires AB and CD each of length 100cm, lie in the same vertical plane and separated by 2.0mm.



When a current I is passed in opposite direction through the wires, a mass of 0.3g is placed in the pan to obtain balance. Find the value of the current I



Assumption made

- PQ = QR and AB is fixed
- AB is above CD

In equilibrium

$$F_1 \times PQ = F_2 \times QR$$

$$F_1 = F_2$$

$$mg = \frac{\mu_0 I^2 L}{2\pi a}$$

$$I = \sqrt{\frac{2\pi m g a}{4\pi \times 10^{-7} \times L}}$$

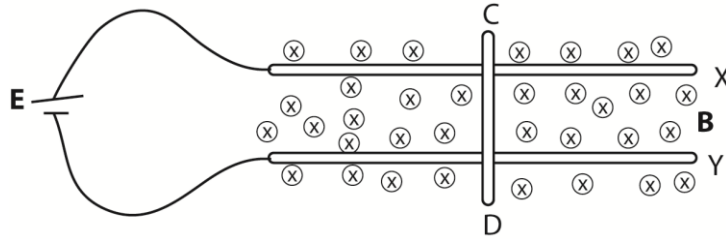
$$= \sqrt{\frac{0.3 \times 10^{-3} \times 9.81 \times 2 \times 10^{-3}}{2 \times 1 \times 10^{-7}}} = 5.4 \text{ A}$$

Alternatively if CD is above AB force at P is downward and force R is upwards. Hence equilibrium will not be attained.

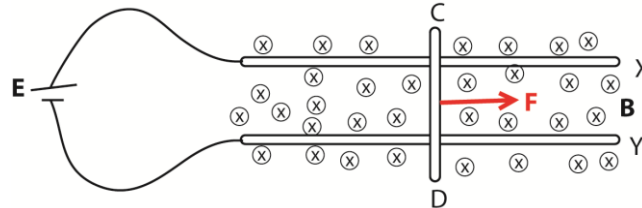
Or

Both forces produce a turning effect in the same direction. Equilibrium will not be attained.

9. In the figure below X and Y are smooth conducting rails connected to a source of e.m.f, E. CD is a metal rod of length L m placed horizontally on X and Y perpendicular to magnetic field of flux density B



(i) Copy the diagram and indicate the direction of Force acting on the rod. (01mark)



(ii) Using the principle of conservation of energy, show that $F = BIL$, where I is the current supplied by the source. (04marks)

Induced e.m.f, $\epsilon = BLV$ where V is the velocity of the rod.

Let I be the current induced, electrical power generated = EI

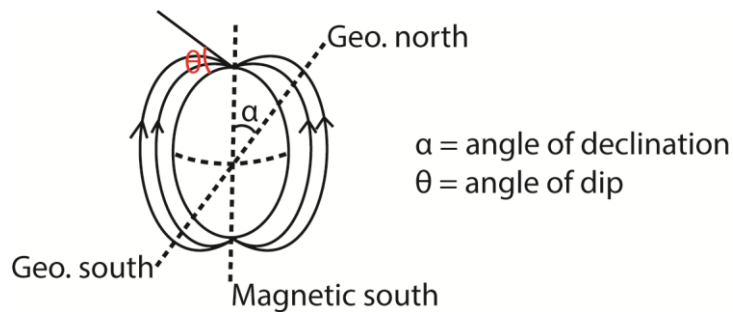
Mechanical power spent = FV

\therefore From the principle of conservation of energy, $FV = EI$

$$= BIVL$$

$$\text{Force, } F = BIL$$

(b) (i) Describe the feature of earth's magnetic field (05marks)

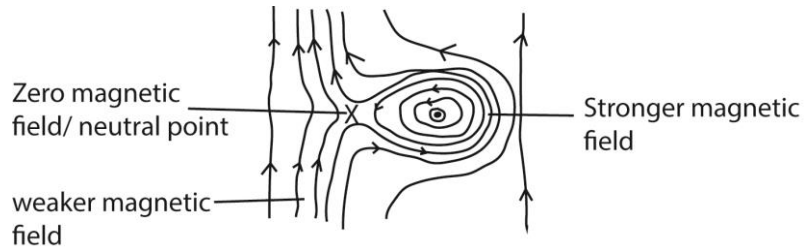


Geographical meridian is the vertical plane containing the geographical axis

Magnetic meridian is the vertical plane containing magnetic axis.

Angle of dip varies from 0° at the magnetic equator to 90° at the poles.

(ii) Sketch the resultant magnetic flux around a wire carrying current vertically upwards in in earth's magnetic field. (02marks)



- (c) A circular coil of 50 turns and radius 0.5m is placed with its plane perpendicular to earth's magnetic meridian. It is connected to a ballistic galvanometer of sensitivity $5.7 \times 10^3 \text{ radC}^{-1}$ and circuit resistance of 100Ω . When the coil is rotated through 180° about a horizontal axis, the galvanometer deflects through 0.8 rads.

Calculate

- (i) Horizontal component of earth's magnetic flux density. (04marks)

$$Q = \frac{2BAN}{R} = \frac{\theta}{\alpha}$$

$$B = \frac{R\theta}{2\alpha nA} = \frac{100 \times 0.8}{2 \times 5.7 \times 10^3 \times 50 \times \pi \times (0.5)^2} = 1.79 \times 10^{-4} \text{ T}$$

- (ii) p.d across a solenoid of 2000 turns per meter and resistance 5Ω that produces the same magnetic flux density as calculated in (c)(i). (04marks)

$$B = \mu_0 n I \text{ But } I = \frac{V}{R}$$

$$B = \mu_0 n \times \frac{V}{R}$$

$$V = \frac{BR}{\mu_0 n} = \frac{1.77 \times 10^{-4} \times 5}{4\pi \times 10^{-7} \times 2000} = 0.36 \text{ V}$$

10. (a) Define root mean square value of an alternating current. (01mark)

Root mean square value of an a.c. is the value of steady current which dissipates heat at the same rate in a given resistor as alternating current.

- (b)(i) Write down an expression for the e.m.f generated by a dynamo and use it to identify the factors which determine the maximum e.m.f. (04marks)

$$\text{Induced e.m.f, } E = 2\pi f \mu AB \sin 2\pi ft$$

$$\text{Maximum e.m.f, } E_0 = 2\pi f \mu AB$$

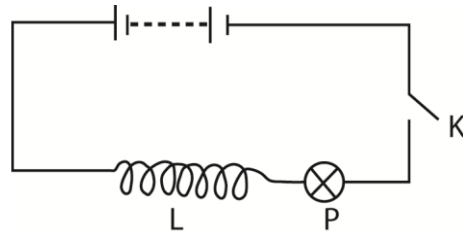
Maximum e.m.f thus increases with increase in

- Frequency or angular velocity
- Number of turns of the coil
- Magnetic flux density

- (ii) Explain the structural modification needed to convert an a.c. generator into a d.c. generator.

The slip rings are replaced by commutators and the brushes are arranged so that the changeover of contacts occur over each half a cycle

- (c) An iron-cored coil having a low resistance and high inductance is connected in series with a filament lamp, P. the coil and lamp are connected across a d.c. supply as shown in the figure below



Explain what is observed when switch K is closed and then opened. (04marks)

When K is closed bulb P lights dimly and increases to full brightness. This is because when K is closed and current begins to flow, back e.m.f is induced in the coil which opposes the flow of current in the circuit. Gradually the back e.m.f reduces to zero because current reaches maximum (and the change in induced magnetic field reduce to zero) and brightness increases.

When K is closed, bulb goes off since current is cut off.

- (d) An alternating voltage $V = V_0 \cos \omega t$ is connected across an inductor of inductance L.

- (i) Derive the expression for the reactance of the inductor, X_L . (04marks)

$$V = V_0 \cos \omega t$$

$$\text{Induced e.m.f } E = -L \frac{dI}{dt}$$

Since the inductor is a coil of zero resistance (for finite current) $V = -E$

$$V_0 \cos \omega t = L \frac{dI}{dt}$$

$$dI = \frac{V_0}{L} \cos \omega t \cdot dt$$

$$\int dt = \frac{V_0}{L} \int \cos \omega t \cdot dt$$

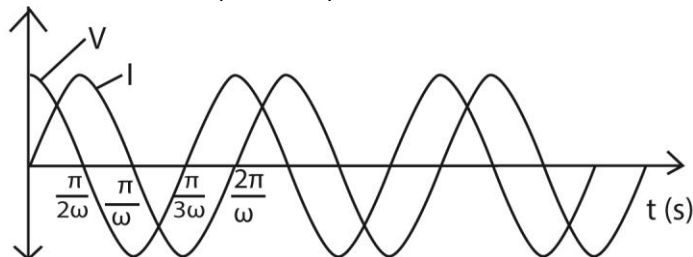
$$I = \frac{V_0}{L} \sin \omega t$$

$$\text{But } I_0 = \frac{V_0}{\omega L}$$

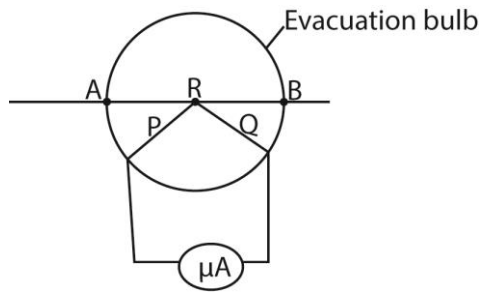
$$I = I_0 \sin \omega t$$

$$X_L = \frac{V_0}{I_0} = \frac{V_0}{V_0 / \omega L} = \omega L$$

- (ii) Sketch using the same axes the variation of applied voltage and current through the inductor with time. (02marks)



- (e) Describe how a thermocouple ammeter is used to measure an alternating current. (03marks)



P and Q are dissimilar wires

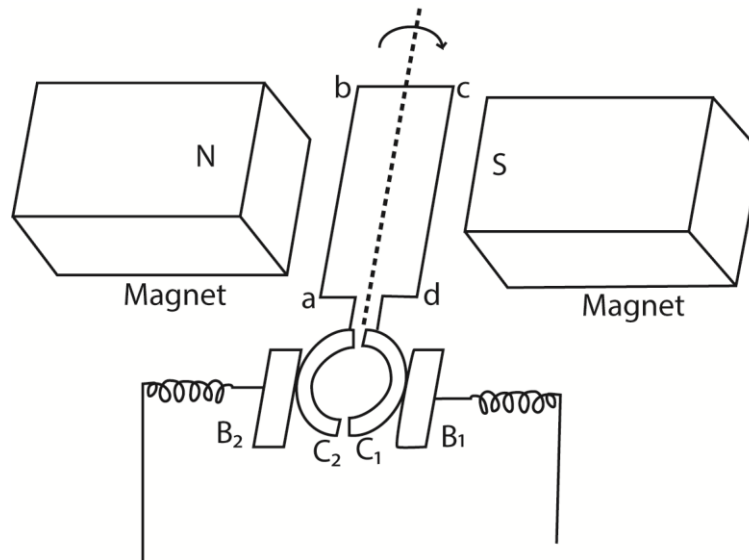
Current to be measured is passed through the wire AB and heats the junction R of the thermocouple.

The thermoelectric effect generated at R causes a direct current to flow through the micrometer calibrated to measure the r.m.s value of current.

11. (a) (i) what is the difference between a motor and a dynamo? (01mark)

A dynamo converts mechanical energy to electrical energy while a motor converts electrical energy into mechanical energy.

(ii) Describe with the aid of a labelled diagram the structure and mode of operation of a d.c generator. (06marks)



B_1 and B_2 are carbon brushes, C_1 and C_2 are split ring commutators and abcd is a rectangular coil

When the coil rotates at uniform velocity in magnetic field, e.m.f is induced in it.

When the coil is in vertical position, the commutators change brushes C_1 to B_2 and C_2 to B_1 .

E.m.f reverses direction but the current does not change direction. Hence current flows in the same direction in a resistor.

- (iii) Describe briefly the factors that determine the peak value of the induced e.m.f. (03 marks)

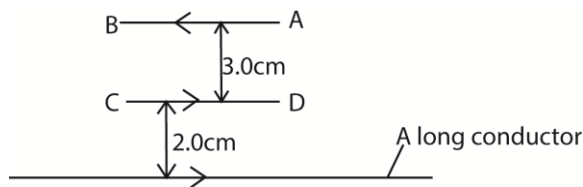
The peak value of induced e.m.f increases with increase in

- The number of turns in the coil
- The area of the coil
- The strength of the magnetic field
- The frequency of rotation of the coil

- (iv) How can a d.c. generator be converted into an a.c. generator. (01mark)

To convert a d.c. generator to an a.c. generator, the ends of the rectangular coil are connected to a pair of slip rings instead of the commutators.

- (b) Figure below shows two wires AB and CD of length 5.0cm each carrying a current of 10.0A in the direction shown. A long conductor carrying a current of 15A is placed parallel to the wire CD 2.0cm below it.



- (i) Calculate the net force on the long wire (06marks)

$$F_1 = \frac{\mu_0 I_1 I_2}{2\pi r_1} \times CD$$

$$= \frac{4\pi \times 10^{-7} \times 10 \times 15 \times 10^{-2}}{2\pi \times 2 \times 10^{-2}} = 7.5 \times 10^{-5} \text{N}$$

$$F_2 = \frac{\mu_0 I_1 I_2}{2\pi r_0} \times AB$$

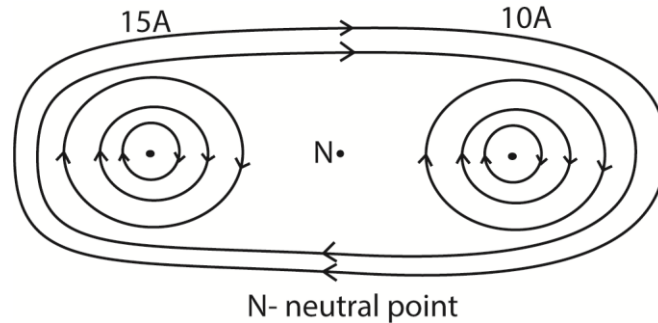
$$= \frac{4\pi \times 10^{-7} \times 10 \times 15 \times 10^{-2}}{2\pi \times (2+3) \times 10^{-2}} = 3 \times 10^{-5} \text{N}$$

$$\text{Net force} = F_1 - F_2$$

$$= 7.5 \times 10^{-5} \text{N} - 3 \times 10^{-5} \text{N}$$

$$= 4.5 \times 10^{-5} \text{N toward CD.}$$

- (ii) Sketch the magnetic field pattern between the long wire and wire CD after removing wire AB. Use the field pattern to define a neutral point (03marks)



N- neutral point
 A neutral point is a point where two magnetic fields are equal and opposite and the resultant is zero.

12. (a) What is meant by the following as applied to the earth's magnetic field?

(i) Magnetic meridian (01mark)

Magnetic meridian is a vertical plane in which a freely suspended magnet sets itself.

(ii) Magnetic variance (01mark)

Magnetic variation is the angle between the magnetic and geographical meridians.

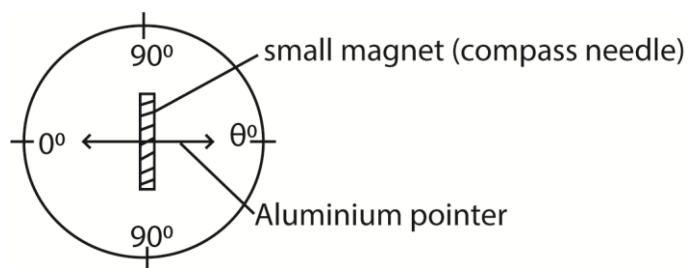
Or,

angle between the earth's magnetic axis and geographical axis.

(b) Describe the structure and mode of action of the deflected magnetometer (06marks)

It is used to compare magnetic moments of magnets

It consists of a small compass needle (small magnet) which is pivoted on a vertical axis and carries a light aluminium pointer. The pointer can rotate over a circular scale (0-90°)



The deflection magnetometer is used to compare two magnetic field flux densities, one being the horizontal component of the earth's flux density B_H .

The two fields i.e. B_H and any other field to be compared are arranged at right angles to each other. The compass needle then sets itself at angle θ , to its initial direction when it was in the field B_H alone.

The needle now points in the direction of the resultant field of B_H and B_C .

The angles of deflection θ_1 and θ_2 of the needle are measured.

The average deflection $\theta = \frac{\theta_1 + \theta_2}{2}$ is determined.

The ratio $\frac{B_C}{B_H} = \tan \theta$

(c) A circular coil of four turns and diameter 11cm has its plane vertical and parallel to the magnetic meridian of the earth. Determine the resultant magnetic flux density at the center of the coil when a current of 0.35A flows in it.

(Take the horizontal component of the earth's magnetic flux density to be 1.6×10^{-5} T)
(04marks)

$$B_C = \frac{\mu_0 NI}{2r} = \frac{4\pi \times 10^{-7} \times 4 \times 0.35}{2 \times 5.5 \times 10^{-2}} = 1.6 \times 10^{-5} \text{T (due to east or west)}$$

Let the resultant field be B_R

$$B_R = \sqrt{(B_C^2 + B_H^2)} = \sqrt{(1.6 \times 10^{-5})^2 + (1.6 \times 10^{-5})^2} = 2.26 \times 10^{-5} \text{T}$$

$$\tan \theta = \frac{B_C}{B_H} = \frac{1.6 \times 10^{-5}}{1.6 \times 10^{-5}} = 1$$

$$\theta = 45^\circ$$

(d) (i) Define **self-induction** and **mutual induction** (02marks)

Self – induction is the generation of e.m.f in a circuit (coil) due to a change in the current in the same circuit; and mutual induction is the generation of e.m.f in a circuit (coil) due to a change in current in adjacent but separate circuit.

(ii) Give the causes of power loss in an a.c. transformer and state how each can be minimized. (04marks)

Cause of power loss	Means of minimizing the loss
Ohmic loss	Use of thick copper wires
Eddy currents	Use of a laminated core
Magnetic flux leakage	Winding secondary coil on primary coil

(iii) Explain why the current in the primary coil of a transformer increases when the secondary is connected to the load.

When load is connected to the secondary winding, a current flows in it. The current flows in such a direction as to reduce the back e.m.f in primary coil, hence the current increase.

13. (a) Define root mean square (rms) value of alternating voltage (01mark)

Root mean square value (r.m.s) of an alternating current is the steady current which would dissipate heat at the same rate in a conductor as the a.c.

(b) A resistor of resistance 100Ω is connected across an alternating voltage, $V = 20\sin 120\pi t$.

(i) Find the frequency of the alternating voltage (01mark)

$$\omega = 2\pi f$$

$$120\pi = 2\pi f$$

$$f = 60\text{Hz}$$

(ii) Calculate the mean power dissipated in the resistor. (03marks)

$$\text{Power, } P = \frac{V_{r.m.s}^2}{R} = \frac{V_0^2}{2R} = \frac{20 \times 20}{2 \times 100} = 2\text{W}$$

(c) (i) Show that when an inductor is connected to an a.c supply voltage of $V = V_0\sin 2\pi ft$, the resulting current lags the voltage by 90° . (04marks)

$$E_B = -L \frac{dI}{dt}$$

But for finite current, $V = -E_B$

$$V = \frac{LdI}{dt}; \text{ but } V = V_0\sin 2\pi ft,$$

$$\frac{dI}{dt} = \frac{-V_0}{L} \sin 2\pi ft$$

$$\int dI = \frac{V_0}{L} \int \sin 2\pi ft dt$$

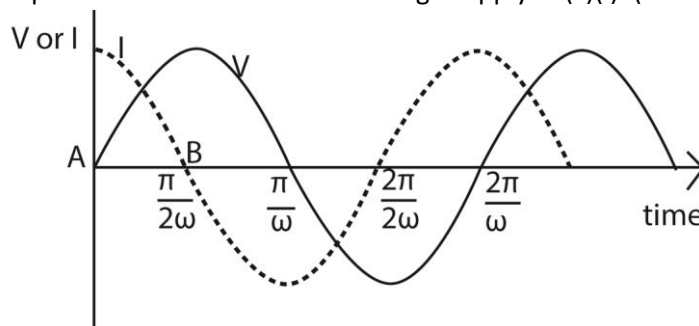
$$I = \frac{-V_0}{2\pi ftL} \cos 2\pi ft$$

$$\text{From trigonometry, } \cos 2\pi ft = \sin(2\pi ft + \frac{\pi}{2})$$

$$\text{Thus, } I = \frac{-V_0}{2\pi ftL} \sin(2\pi ft + \frac{\pi}{2})$$

$$\Rightarrow I \text{ lags } V \text{ by } \frac{\pi}{2} \text{ or } 90^\circ$$

(ii) Sketch on the same axes the variation with time of the voltage and current if a capacitor is connected to the voltage supply in (c)(i). (02marks)



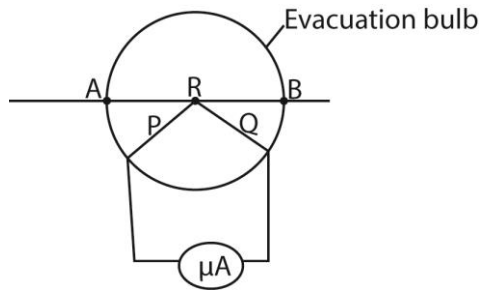
Explanation

The current I through (not across) a capacitor is $C \frac{dV}{dt}$. This is the slope of the voltage.

When a capacitor is connected to an AC voltage (at the zero crossing) the maximum current flow will occur immediately, i.e. $t = 0$, $\frac{dV}{dt}$ will approach infinity instantly and then repeat as a sinusoidal waveform.

There will be a peak current at every zero crossing of the voltage waveform. The current waveform will lead the voltage waveform 90 degrees.

(d) (i) Describe how thermocouple meter works. (04marks)



P and Q are dissimilar wires

Current to be measured is passed through the wire AB and heats the junction R of the thermocouple. The thermoelectric effect generated at R causes a direct current to flow through the micrometer calibrated to measure the r.m.s value of current.

(ii) Explain any precautionary measure taken in the design of thermocouple meter (02mark)

The fine wire is enclosed in an evacuated glass bulb to shield it from draughts. If the wire was in the open, some heat would be lost to the surrounding so that the temperature difference between the hot and cold junctions would not be proportional to the power dissipated in the wire.

(e) A capacitor of capacitance $60\mu\text{F}$ is connected to an a.c. voltage supply of frequency 40Hz . An a.c. ammeter connected in series with the capacitor reads 2.2A . Find the p.d across the capacitor. (03marks).

$$X_c = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 40 \times 60 \times 10^{-6}}$$

$$\text{Voltage, } V_{r.m.s} = I_{r.m.s} \times X_c$$

$$= \frac{2.2 \times 1}{2\pi \times 40 \times 60 \times 10^{-6}}$$

$$= 146V$$

14. (a) What is meant by the following as applied to the earth's magnetic field?

(i) Magnetic meridian (01 mark)

Magnetic meridian is the vertical plane through the magnetic north and south poles of earth's magnet.

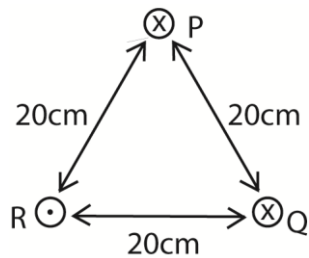
(ii) Angle of dip (01mark)

Angle of dip is the angle between the resultant earth's magnetic field and horizontal.

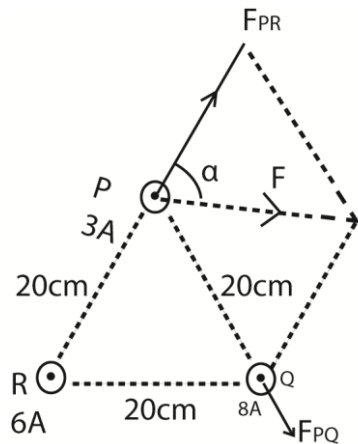
(b) (i) Define the ampere (01mark)

The ampere is steady current flowing in negligible cross-section, one meter apart in vacuum when the force between them is $2 \times 10^{-7} \text{NM}^{-1}$.

(ii) three conductors P, Q and R carrying currents 3A, 6A and 8A respectively are arranged as shown in the figure below



Calculate the force experienced by conductor P. (06marks)



$$\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi r}$$

$$F_{PR} = \frac{4\pi \times 10^{-7} \times 3 \times 8}{2\pi \times 0.2} \times 2.4 \times 10^{-5}$$

$$F_{PQ} = \frac{4\pi \times 10^{-7} \times 6 \times 3}{2\pi \times 0.2} \times 1.8 \times 10^{-5}$$

$$F^2 = F_{PR}^2 + F_{PQ}^2 - 2F_{PR}F_{PQ}\cos\theta$$

$$F^2 = (2.4 \times 10^{-5})^2 + (1.8 \times 10^{-5})^2 - 2 \times (2.4 \times 10^{-5}) \times (1.8 \times 10^{-5}) \cos 60^\circ$$

$$F = 2.16 \times 10^{-5} \text{ N}$$

$$\frac{\sin\alpha}{1.8 \times 10^{-5}} = \frac{\sin 60^\circ}{2.16 \times 10^{-5}}$$

$\alpha = 46.2^\circ$ where α is the angle between F and F_{PR} .

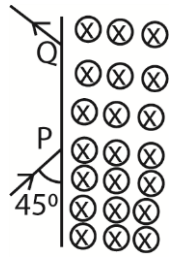
(d) (i) Define magnetic flux and magnetic flux density (02marks)

Magnetic flux is the product of the magnetic flux density and the projection of the area normal to the magnetic field.

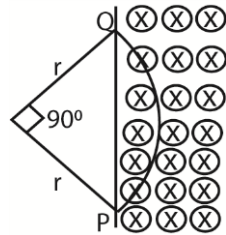
Or

Magnetic flux density is the force acting on a conductor of length 1m carrying current of 1A placed perpendicular to magnetic field.

(ii) A charge particle of mass 1.4×10^{-27} kg and charge 1.6×10^{-19} C enters a region of uniform magnetic field of flux density 0.2T at point P and emerges at a point Q as shown in the figure below



If the speed of the particle is 10^7ms^{-1} , calculate the distance PQ. (04marks)



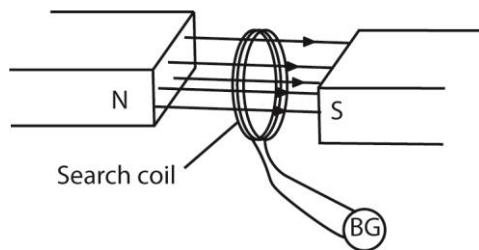
The conductor describes a circle of radius, r .

$$F = BQV = \frac{mV^2}{r}$$

$$r = \frac{mV}{BQ} = \frac{1.4 \times 10^{-27} \times 10^7}{0.2 \times 1.6 \times 10^{-19}} = 0.4375\text{m}$$

$$PQ = \sqrt{r^2 + r^2} = \sqrt{0.4375^2 + 0.4375^2} = 0.62\text{m}$$

(d) Describe an experiment to measure the magnetic flux density between the pole pieces of a strong magnet. (05 marks)



A search coil is connected to a ballistic galvanometer. The coil is then placed with its plane normal to the magnetic field whose magnetic flux density, B is required.

The coil is then pulled completely out of the field and deflection θ_1 of ballistic galvanometer is noted

$$\frac{NAB}{R} = CQ, \text{ where } R = \text{resistance of the coil}$$

A capacitor of known capacitance Q is charged to a p.d. V and is then discharged through the ballistic galvanometer. The deflection θ_2 is noted

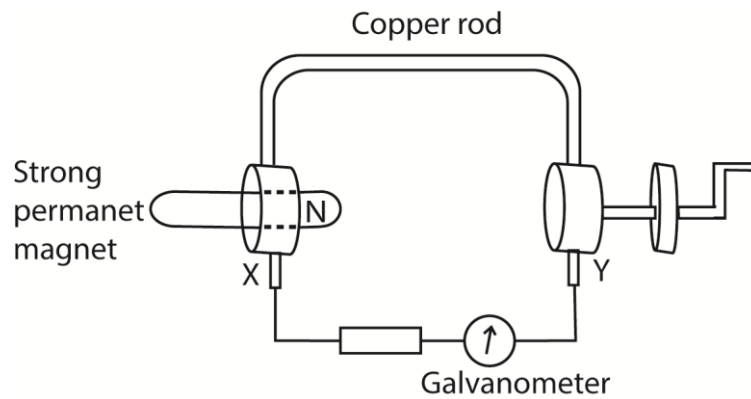
$$CV = C\theta_2$$

The magnetic flux density B is now calculated from $B = \frac{CVR\theta}{NA\theta_1}$ where A is the area of the coil, N is the number of turns in the coil and R is the resistance of the coil circuit.

15. (a) (i) state the laws of electromagnetic induction (02marks)

- **Lenz's law of electromagnetic induction;** the induced e.m.f acts in such a direction as to oppose the change causing it
- Faraday's law of electromagnetic induction; the magnitude of induced e.m.f in a conductor is directly proportional to the rate of change of magnetic flux linking it.

(ii) Describe with aid of a diagram, an experiment to verify Faraday's law of electromagnetic induction (05marks)



X and Y are brush contact.

A copper rod which can rotate round the north pole of permanent magnet is connected as shown above.

The wheel is turned steadily until the deflection of the galvanometer is constant.

The time, t , for N rotations is measured and the number of revolution (n) per second is determined from $n = \frac{N}{t}$. The deflection θ of the galvanometer is also noted.

The experiment is repeated at different speed of rotation of the wheel and values of n and θ tabulated.

A graph of θ against n is plotted.

A straight line graph is obtained implying that $\theta \propto n$

Since $\theta \propto$ e.m.f induced and $n \propto$ speed of rotation of the rod, then the induced e.m.f is proportional to the rate of change of flux linkage.

(b) Explain

- (i) Why when a plate of copper is pushed into a strong magnetic field between the poles of a powerful electromagnet, considerable resistance to the motion is felt, but no such effect is felt with a sheet of glass.

When the copper plate cuts the magnetic field and Eddy currents are induced in it

The magnetic field due to Eddy currents interacts with the applied field opposing the motion.

Glass is an insulator no eddy current is induced in it hence no resistance to its motion.

- (ii) How damping is achieved in moving coil galvanometer (03marks)

The coil is wound on an iron core. When the coil (together with the core) rotates in the magnetic field, Eddy currents are induced in the core. The magnetic field due to the Eddy currents interacts with the applied field causing retardation (opposing the rotation) of the coil. So the coil comes to rest sooner than it would for accurate reading.

- (c) An aero plane of wing span 30m flies horizontally at a speed of 1000kmh^{-1} .

What is the p.d across the tips of its wings, if the horizontal component of the earth's magnetic field is $1.46 \times 10^{-4}\text{T}$? (Angle of dip at the place is 70°) (03marks)

$$E = B_V Lv; \text{ but } B_V = B_H \tan 70^\circ$$

$$E = B_H \tan 70^\circ Lv$$

$$= 1.46 \times 10^{-4} \times \tan 70^\circ \times 30 \times \frac{1000 \times 1000}{1 \times 60 \times 60} = 3.34\text{V}$$

- (d) A coil of 500 turns and area 80cm^2 is rotated at 1200 revolution per minute about an axis perpendicular to its plane and magnetic field of flux density 0.25T.

Calculate the maximum e.m.f induced in the coil (03marks)

$$\text{E.m.f} = BAN\omega$$

$$= BAN.2\pi f$$

$$= 0.25 \times 80 \times 10^{-4} \times 500 \times 2\pi \times \frac{1200}{60}$$

$$= 126\text{V}$$

16. (a) (i) Define root mean square (r.m.s) current of an a.c (01mark)

It is a steady current which converts electrical energy to other forms of energies in a given resistor at the same rate as the alternating current.

(ii) Derive an expression for capacitive reactance (04marks)

$$\text{Applied voltage} = V_0 \sin \omega t$$

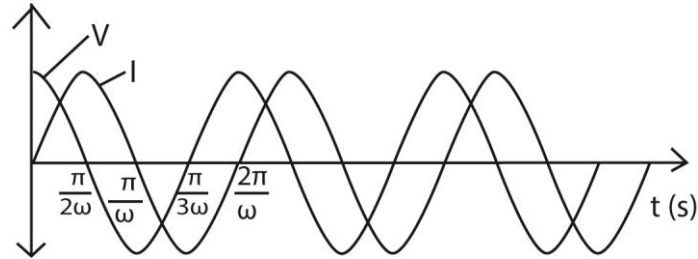
$$Q = CV = C V_0 \sin \omega t$$

$$I = \frac{dQ}{dt} = \frac{d(CV_0 \sin \omega t)}{dt}$$

$$\Rightarrow I_0 = CV_0 \omega$$

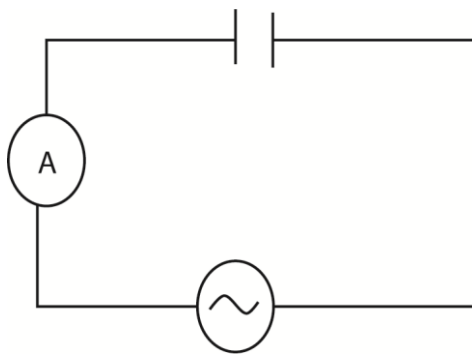
$$X_c = \frac{V_0}{I_0} = \frac{1}{C\omega} \text{ or } \frac{1}{2\pi f c}$$

(iii) Sketch on the same axes, the graphs showing variation of applied p.d and current when an inductor is connected to an a.c. supply. (02marks)



Note that the current starts at zero and rises to its peak *after* the voltage that drives it, i.e., it is voltage that drives current.

(b) (i) A capacitor of capacitance, C, and an ammeter are connected in series across an alternating voltage, V, of frequency f. Explain why current apparently flow through the capacitor. (03marks)



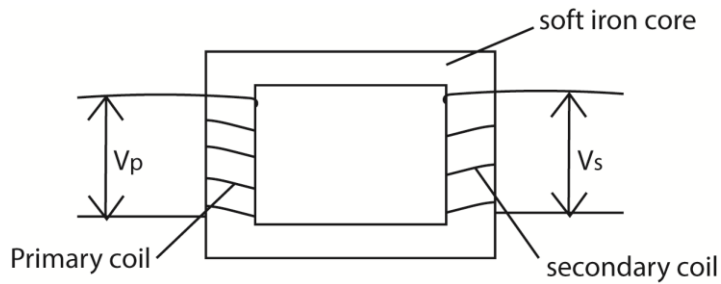
- When the circuit is completed, the ammeter deflects indicating that current is flowing in it.
- When the circuit is closed, the capacitor charges and discharges in opposite direction alternatively. Charge (current) therefore flows in the circuit continuously and the capacitor appears to conduct current.

- In the first quarter, capacitors charges to maximum and in second quarter, it discharges.
- In the third quarter, it charges again but with charge on the plate interchanged.
- In the fourth quarter, it discharges.
- It is repeated at the frequency of the a.c.
- The charging and discharging current flows throughout the circuit though no charge passes across the capacitor.

(ii) A sinusoidal p.d of r.m.s value of 20V and frequency 50Hz is applied across a 100μF capacitor. Calculate the capacitive reactance of the circuit. (02 marks)

$$X_c = \frac{1}{2\pi f c} = \frac{1}{2\pi \times 50 \times 100 \times 10^{-6}} = 31.8\Omega$$

(c) Describe the mode of operation of a transformer. (04marks)



V_p = primary voltage, V_s = secondary voltage

- Transformer consists of two coil of insulated wire, the primary and secondary wound on laminated soft iron core.
- When alternating voltage, V_p is connected to primary coil, it drives alternating current in the primary coil.
- The alternating current produces a varying magnetic flux ϕ_p that link the primary coils inducing a back e.m.f E_B in the primary.
- The varying magnetic flux, ϕ_s links the secondary coil by mutual induction/inducing alternating voltage, V_s in the secondary

$$V_p = N_p \frac{d\phi_p}{dt} \dots\dots\dots(i)$$

$$V_s = N_s \frac{d\phi_p}{dt} \dots\dots\dots(ii)$$

Eqn (i) ÷ Eqn (i)

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

When $N_s > N_p$ the transformer is a step up

$N_s < N_p$ the transformer is a step down

(d) A transformer connected to a.c supply of peak voltage 240V is to supply a peak voltage of 9.0V to a mini-lighting system of resistance 5Ω. Calculate the

(i) r.m.s current supplied to the lighting system (02marks)

$$V_{r.m.s} = \frac{V_0}{\sqrt{2}}$$
$$I_{r.m.s} = \frac{V_{r.m.s}}{R} = \frac{V_0}{\sqrt{2}R}$$
$$= \frac{9.0}{5\sqrt{2}} = 1.27A$$

(ii) average power delivered to the lighting system. (02marks)

$$P = I^2R$$
$$= I_{r.m.s}^2R$$
$$= (1.27)^2 \times 5$$
$$= 8.1W$$

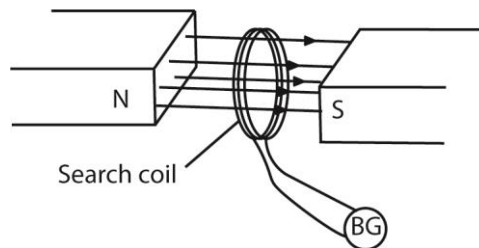
17. (a) State the laws of electromagnetic induction (02marks)

Faraday's law states that the magnitude of the e.m.f induced in a circuit is directly proportional to the rate of change of magnetic flux linked with the circuit.

Lenz's Law states that induced current flows always in such a direction as to oppose the change which is giving rise to it.

(b) Describe a method of measuring the magnetic flux density in the region between the poles of a magnet. (06marks)

Solution



A search coil is connected in series with a ballistic galvanometer, B.G and a resistor.

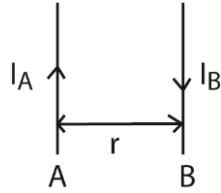
The search coil is placed between the poles pieces of the magnet with its plane normal to the magnetic field.

When the ballistic galvanometer pointer settles, the coil is completely withdrawn from the field and the first deflection θ of the B.G is noted.

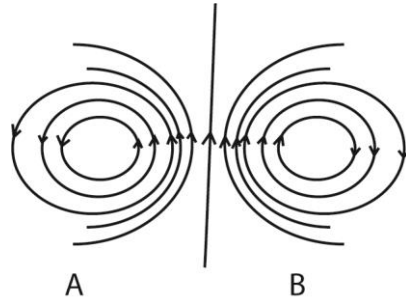
A capacitor of known capacitance C is charged to a p.d V and then discharged through the ballistic galvanometer and the corresponding θ' is noted.

The magnetic flux density B is now calculated from $B = \frac{CVR\theta}{NA\theta'}$ where A is the area of the coil, N is the number of turns in the coil and R is the resistance of the coil circuit.

(c) Two straight parallel wires A and B carrying steady currents I_A and I_B respectively are placed close to each other as shown in figure below



(i) Sketch the resultant magnetic field pattern (02marks)



(ii) Explain what happens when the current I_A and I_B are steady currents. (04marks)

When the two circuit carrying conductors are placed near each other, the conductors repel each other. If the current I_A and I_B are steady, the resultant magnetic field is constant.

$$\text{The force acting per meter length, } \frac{F}{L} = \frac{\mu_0 I_A I_B}{2\pi r}$$

Therefore the force is constant.

(iii) Find the force per unit length of the wires when $I_A = 8.0\text{A}$, $I_B = 11.0\text{A}$ and $r = 3.0\text{cm}$ (04marks)

The magnetic flux density which A produces at B is given by

$$\frac{\mu_0 I_A}{2\pi r} = \frac{4\pi \times 10^{-7} \times 8}{2\pi \times 3 \times 10^{-2}} = 5.30 \times 10^{-5} \text{T}$$

Force exerted by A on B, $F = BI_B L$

$$\frac{F}{L} = BI_B = 5.30 \times 10^{-5} \times 11 = 5.85 \times 10^{-4} \text{Nm}^{-1}.$$

Or

$$\frac{F}{L} = \frac{\mu_0 I_A I_B}{2\pi r} = \frac{4\pi \times 10^{-7} \times 8 \times 11}{2\pi \times 3 \times 10^{-2}} = 5.85 \times 10^{-4} \text{Nm}^{-1}$$

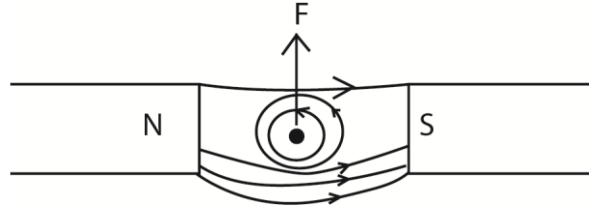
(d) Explain how eddy currents are produced (02marks)

When a conductor cuts through a magnetic field, the magnetic flux linking it changes. This cause small currents to flow in loops in the conductor. These induced currents are called Eddy currents

18. (a) (i) Write an expression for the force exerted on a straight wire of length, L meters carrying a current, I , amperes, placed at right angles to a uniform magnetic field flux density B teslas. (01 marks)

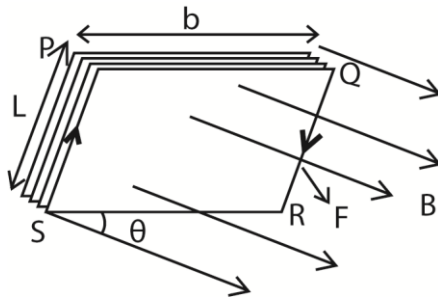
$$F = BIL$$

- (ii) Explain the origin of the force in (a) (i). (04marks)



- The current sets up a magnetic field around the wire.
- When the field due to current interacts with external magnetic field, the resultant magnetic field has greater flux density on one side than the other; in the diagram above, high flux density is created below than above.
- The wire moves from a region of greater to lower flux density; thus it moves up in this case.

- (b) A rectangular coil of N turns each of length, L , and breadth, b , is inclined at an angle θ to a uniform magnetic field of flux density B . Derive an expression for torque of the coil when a current I is passed through it.



- When current flows through the coil, the conductor experiences a magnetic force.
- Force on side $PQ = NBIL \sin \theta$ (downwards) while Force on side $RS = NBIL \sin \theta$ (upwards). The two forces cancel out due to rigidity of the coil.
- Side PS experiences force $NBIL$ perpendicularly into the page while RQ experiences force $NBIL$ perpendicularly out of page. The two forces constitute a couple whose moment of force

$$\begin{aligned} T &= F \times b \cos \theta \\ &= NBILb \cos \theta \end{aligned}$$

- (c) A single rectangular loop of wire with dimensions 35cm by 75cm is arranged such that part of it is inside a region of uniform magnetic field of flux density 0.45T and part of it is outside the field. The total resistance of the loop is 0.23Ω. Calculate the force required to pull the loop from the field at a constant velocity of 3.4ms⁻¹ perpendicular to the field. (05marks)

Solution

Induced e.m.f on the loop on pulling out of the field is given by'

$$E = BLV = 0.45 \times 35 \times 10^{-2} \times 3.4 = 0.5355V$$

$$\text{Current, } I, \text{ that flows in the loop} = \frac{E}{R} = \frac{0.5355}{0.23} = 2.328A$$

Mechanical power experienced = electrical energy developed.

- $FV = IE$
- $F = \frac{IE}{V} = \frac{2.328 \times 0.5355}{3.4} = 0.367N$

Alternatively

From

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

$$I = \frac{E}{R} \dots\dots\dots (ii)$$

$$E = BLV \dots\dots\dots (iii)$$

$$\text{It follows that } F = \frac{B^2 L^2 V}{R} = \frac{0.45^2 \times 0.35^2 \times 0.34}{0.23} = 0.367N$$

(d)(i) Define the term magnetic flux. (01marks)

Magnetic flux is the product of magnetic flux density and projection of the area at right angles to the magnetic field

(ii) An electron revolves in a circular orbit of radius $2.0 \times 10^{-10}m$ at a frequency of 6.8×10^{15} revolution per second. Calculate the magnetic flux density at the center of the orbit (04marks)

The circulation of the electron constitute a current

$$I = \frac{e}{t} = ef$$

$$\text{But } B_0 = \frac{\mu_0 ef}{2R} = \frac{4\pi \times 10^{-7} \times 1.6 \times 10^{-19} \times 6.8 \times 10^{15}}{2 \times 2.0 \times 10^{-10}} = 3.4T$$

19. (a)(i) What is a sinusoidal alternating current? (01mark)

A sinusoidal a.c is a periodic current whose time dependence is given by sine function.

(ii) Define peak value, root mean square (r.m.s) value and frequency of alternating current. (03marks)

Peak value is the maximum value of an alternating current.

Root mean value is the value of direct current which dissipates heat in a given resistor at the same rate as the a.c.

Frequency of alternating current is the number of complete cycles which the current goes through in one second.

(b) A sinusoidal voltage of r.m.s value 13.2V is connected across a 50 μ F capacitor.

(i) Find peak value of the charge on the capacitor (02marks)

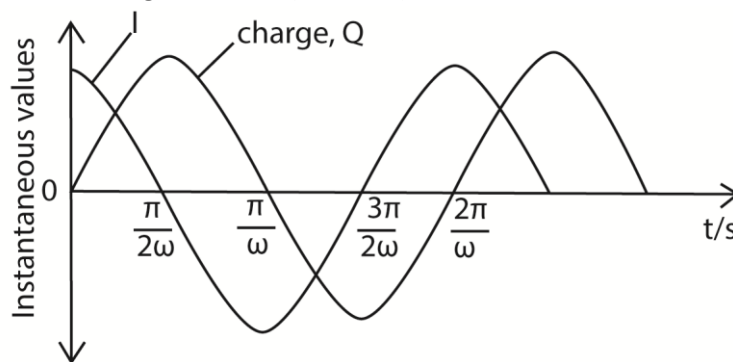
$$Q_0 = CV_0 \text{ but } V_0 = V_{r.m.s} \times \sqrt{2}$$

$$\text{Hence } Q_0 = CV_{r.m.s} \times \sqrt{2}$$

$$= 50 \times 10^{-6} \times 13.2 \times \sqrt{2}$$

$$= 9.333 \times 10^{-4} \text{C}$$

(iii) Sketch using the same axes the graphs of charge Q on the capacitor and current I in the circuit against time. (02marks)



Explanation of the curve

The current I through (not across) a capacitor is $C \frac{dV}{dt}$. This is the slope of the voltage.

When a capacitor is connected to an AC voltage (at the zero crossing) the maximum current flow will occur immediately, i.e. $t = 0, \frac{dV}{dt}$ will approach infinity instantly and then repeat as a sinusoidal waveform.

There will be a peak current at every zero crossing of the voltage waveform. The current waveform will lead the voltage waveform 90 degrees.

(iv) If the frequency of the alternating current is 49.6Hz, calculate the r.m.s value of current through the capacitor. (03marks)

$$\frac{V_{r.m.s}}{I_{r.m.s}} = \frac{1}{2\pi fC} = X_C$$

$$I_{r.m.s} = V_{r.m.s} \times 2\pi fC$$

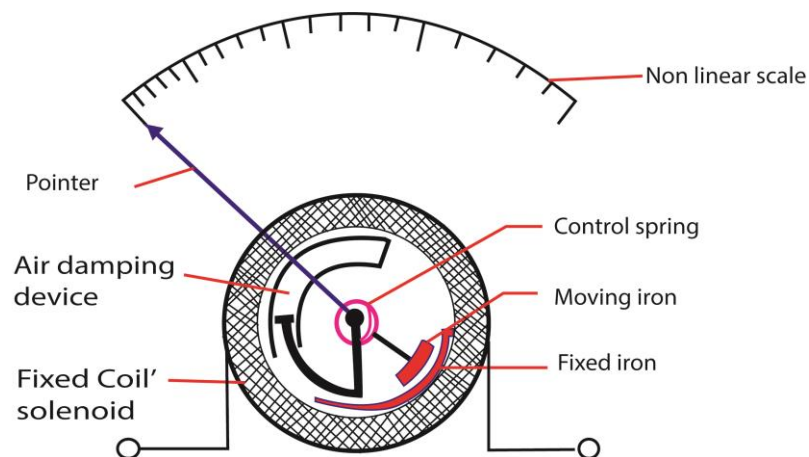
$$= 13.2 \times 2\pi \times 49.6 \times 50 \times 10^{-6} = 0.206A$$

(c) Explain why a capacitor in a circuit blocks the flow of direct current but allows the flow of alternating current. (04marks)

When a capacitor is connected to a d.c. source the capacitor charges and when it is fully charged, current flow stops.

When it is connected to an a.c, it charges when the voltage is increasing and discharges when the voltage is decreasing. Since increase and decrease in voltage is continuous, there is continuous flow of current in the circuit. Hence a capacitor allows flow of a.c.

(d) Describe the structure and mode of operation of the repulsion type moving iron meter. (05marks)



When a current is passed through the coil, the iron rods magnetize in the same poles adjacent to each other in whatever the direction of current. Hence they repel and the pointer move in the same direction until it is stopped by the restoring spring.

Since the magnetic force is proportional to the square of the average current, hence, the deflection is proportional to the square of average current.

Advantage: it measured both direct and alternating current.

Disadvantage: it has nonlinear scale

20. (a) Define the following:

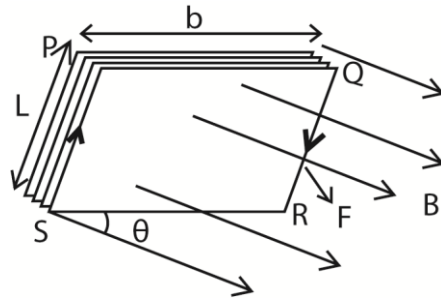
(i) Magnetic flux density (01mark)

Magnetic flux is the product of the magnetic flux density and the projection area normal to the magnetic field.

(ii) Magnetic flux linkage (01mark)

Magnetic flux linkage is the product of the magnetic flux density and the area it links perpendicularly.

(b) (i) A rectangular coil of N turns, length, L and breadth, b , carrying a current, I , is placed with its plane making an angle, θ , to a uniform magnetic field of flux density, B . Derive the expression for torque exerted on the coil. (05marks)



- When current flows through the coil, the conductor experiences a magnetic force.
- Force on side $PQ = NBIsin\theta$ (downwards) while Force on side $RS = NBIsin\theta$ (upwards). The two forces cancel out due to rigidity of the coil.
- Side PS experiences force $NBIL$ perpendicularly into the page while RQ experiences force $NBIL$ perpendicularly out of page. The two forces constitute a couple whose moment of force

$$\tau = F \times b \cos\theta$$

$$= NBILb \cos\theta$$

(ii) A current of 3.25A flows through a long solenoid of 400 turns and length 40.0cm.

Determine the magnitude of force exerted on a particle of charge $15.0\mu\text{C}$ moving at $1.0 \times 10^3 \text{ms}^{-1}$ through the center of the solenoid at an angle of 11.5° relative to the axis of the solenoid. (04marks)

Magnetic flux density, $B = \mu_0 nI$

$$= 4.0\pi \times 10^{-7} \times \frac{400}{40 \times 10^{-2}} \times 3.25 \text{T}$$

$$= 4.084 \times 10^{-3} \text{T}$$

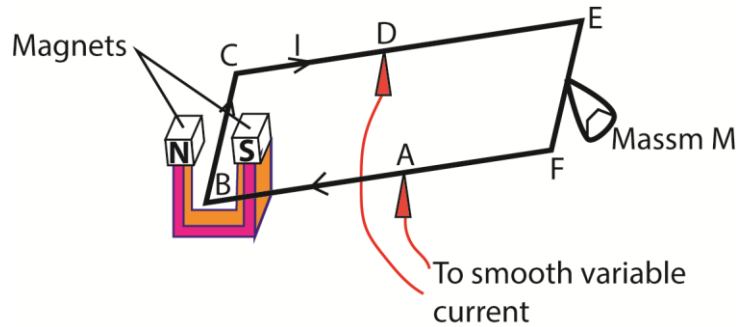
Force, $F = Bqv \sin \theta$

$$= 4.084 \times 10^{-3} \times 15 \times 10^{-6} \times 1.0 \times 10^3 \sin 11.5$$

$$= 1.22 \times 10^{-5} \text{N}$$

(c) Describe with the aid of a diagram, an absolute method of measuring current. (06marks)

Current balance is based on principles of moments



The apparatus setup is as above, $AB = AF$, length $BC = L$ and the current through the wire is I

The magnets provide a uniform magnetic field, B , perpendicular to wire BC .

At equilibrium when the frame $BCEF$ is balanced

The force exerted on the wire = weight of the mass

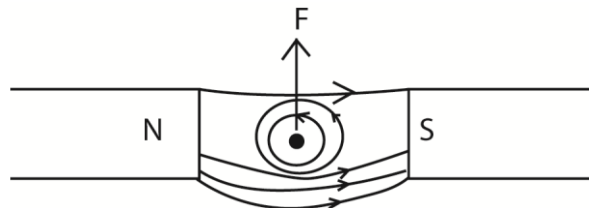
$$BIL = Mg$$

$$\text{Current } I = \frac{Mg}{BL}$$

Sources of error

- Accuracy of length L
- Rigidity of the frame
- To avoid overheating, the current should be switched off as soon as measurements have been taken.
- Shield the set-up from the disturbance of wind.

(d) Explain why a current carrying conductor placed in a magnetic field experiences a force. (03marks)



- The current sets up magnetic field around the wire.
- When the field due to current interacts with external magnetic field, the resultant magnetic field has greater flux density on one side than the other; in the diagram above, high flux density is created below than above.
- The wire moves from a region of greater to lower flux density; thus it move up in this case.

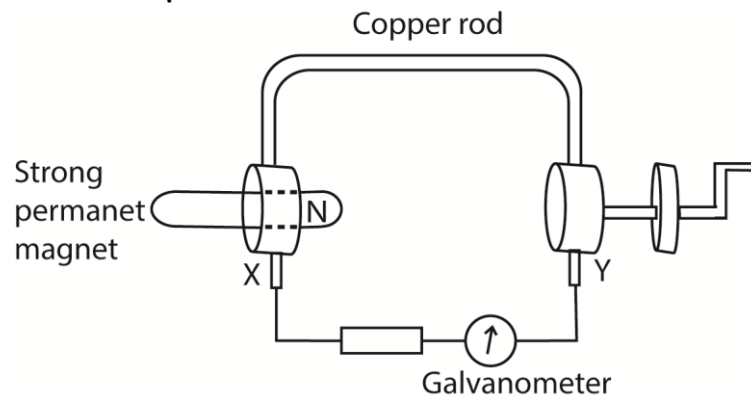
21. (a) (i) State Lenz's law of electromagnetic induction (01mark)

The Induced current flows always in such a direction as to oppose the change which is giving rise to it.

(ii) Describe an experiment to demonstrate Faraday's law of electromagnetic induction. (06marks)

Faraday's law of electromagnetic inductions states that the magnitude of induced e.m.f in a conductor is directly proportional to the rate of change of magnetic flux linking it.

Verification setup



X and Y are brush contact.

A copper rod which can rotate round the north pole of permanent magnet is connected as shown above.

The wheel is turned steadily until the deflection of the galvanometer is constant.

The time, t , for N rotations is measured and the number of revolution (n) per second is determined from $n = \frac{N}{t}$. The deflection θ of the galvanometer is also noted.

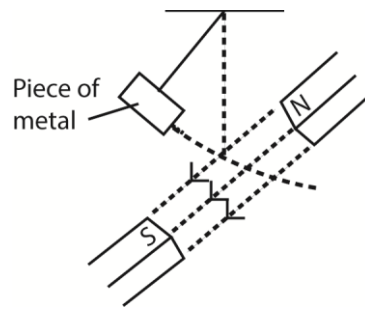
The experiment is repeated at different speed of rotation of the wheel and values of n and θ tabulated.

A graph of θ against n is plotted.

A straight line graph is obtained implying that $\theta \propto n$

Since $\theta \propto$ e.m.f induced and $n \propto$ speed of rotation of the rod, then the induced e.m.f is proportional to the rate of change of flux linkage.

(b) The figure below shows a piece of metal swing in between opposite magnetic poles



Explain what will be observed after some period of time (04marks)

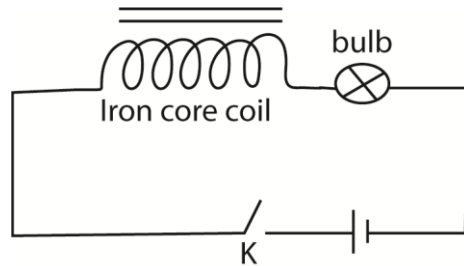
The amplitude of oscillation reduces gradually until oscillation stop because as the metal oscillated, it cuts the magnetic field between the poles. Eddy currents are induced in the metal whose magnetic field oppose the oscillation thus causing the oscillation to slow down.

(c)(i) Define the term self-induction and mutual induction. (02marks)

Self-induction is the process by which e.m.f is induced in a circuit due to changing current in the same circuit.

Mutual induction is the process by which e.m.f is induced in a circuit due change in current in the nearby circuit.

(ii) Describe an experiment which can be used to demonstrate self-induction. (03marks)



An iron cored coil is connected in series with a bulb, cell and switch as shown above. When K is closed, the bulb lights dimly and then its brightness is increased to maximum.

The initial current is small due to large back e.m.f and then increases to the maximum because back e.m.f finally reduce to zero.

(d) A search coil has 40 turns of wire and cross section area of 5cm^2 . The coil is connected to a ballistic galvanometer and then with its plane perpendicular to uniform magnetic field of flux density B.

When the coil is withdrawn from the field, the galvanometer gives a deflection of 240 divisions. When a capacitor of $4\mu\text{F}$ is charged to 20V and then discharged through the

circuit, the galvanometer deflection is 180 divisions. Find the value of B, if the total resistance of the circuit is 20Ω. (04marks).

$$N = 40, A = 5 \times 10^{-4} \text{m}^2, R = 20\Omega, \theta_1 = 240^\circ, C = 4 \times 10^{-6} \text{F}, V = 20\text{V}, \theta_2 = 180^\circ$$

$$\text{From } \frac{NAB}{R} = k\theta_1; k = \frac{NAB}{R\theta_1}$$

$$\text{But } Q = CV = k\theta_2; k = \frac{CV}{\theta_2}$$

$$\therefore \frac{NAB}{R\theta_1} = \frac{CV}{\theta_2}$$

$$B = \frac{CVR\theta_1}{NA\theta_2} = \frac{4 \times 10^{-6} \times 20 \times 20 \times 240}{40 \times 5 \times 10^{-4} \times 180} = 0.107\text{T}$$

22. (a) What is meant by the terms reactance and impedance as applied to alternating currents. (02marks)

Reactance is non resistive opposition to the flow of a.c in a circuit containing either an inductor or a capacitor.

Impedance is the resultant opposition to flow of a.c in circuit containing reactive and resistive components.

- (b)(i) A source of sinusoidal current of amplitude I_0 and frequency, f , is connected across a pure inductor of inductance, L , Derive an expression for the peak voltage across the inductor. (04marks)

$$\begin{aligned} \text{Induced e.m.f in the inductor } E &= -L \frac{dI}{dt} \\ &= -L \frac{d(I_0 \sin \omega t)}{dt} \\ &= \omega L I_0 \cos \omega t \end{aligned}$$

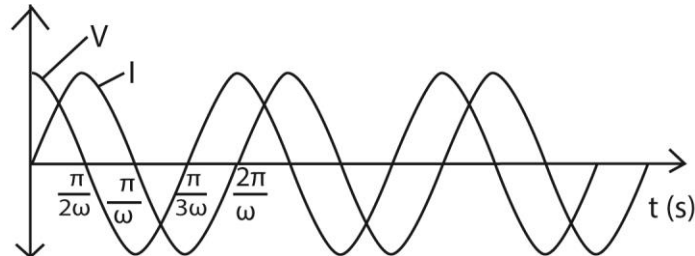
For infinite current flow through a pure inductor

$$V = -E = \omega L I_0 \cos \omega t \text{ where } V_0 = \omega L I_0$$

$$\text{Since } \omega = 2\pi f \text{ then } V_0 = 2\pi f L I_0$$

$$\text{So peak voltage, } V_0 = 2\pi f L I_0$$

- (ii) Sketch using the same time axis, graphs to show variations of the voltage across the inductor and current through it. (02marks)



- (c) An alternating current $I = 5 \sin 200\pi t$, flows through a pure inductor of inductance 2.0H. Calculate the
 (i) reactance of the inductor. (03marks)

$$X_L = 2\pi fL, \text{ From } I = 5 \sin 200\pi t, \Rightarrow f = 100\text{Hz}$$

Hence

$$X_L = 2\pi \times 100 \times 2 = 1256\Omega$$

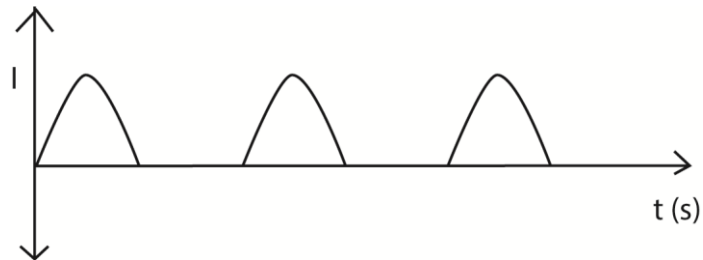
- (ii) root mean square value of the voltage across the inductor. (03marks)

$$V_{r.m.s} = \frac{V_0}{\sqrt{2}}, \text{ but } V_0 = X_L I_0 = 1256 \times 5 = 6280\text{V}$$

$$V_{r.m.s} = \frac{6280}{\sqrt{2}} = 4440\text{V}$$

- (d)(i) Explain how an alternating current can be measured using a rectifier meter (04marks)

When a.c is supplied to a rectifier meter, current flows in only one direction. Current flows in the half cycle for positive bias of the diode and in the next half cycle current flow is zero. The characteristics is shown below



When the frequency is high, the ammeter reads a steady r.m.s value of the current.

- (ii) Explain why a moving coil ammeter is unsuitable for measuring alternating current. (02marks)

When an a.c is passed through a moving coil ammeter, the direction of the couple changes every time the current reverses. With high frequency, the pointer only vibrates about the zero position hence the value of the current cannot be read

23. (a) Define the following:

- (i) Weber (01mark)

The weber is magnetic flux that passes normally through an area of 1m^2 . When the magnetic flux density is 1T.

- (ii) Ampere (01mark)

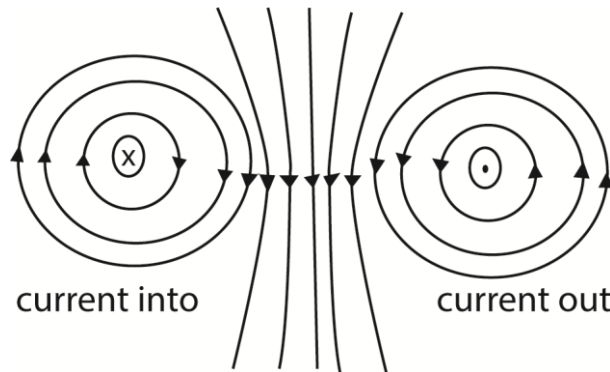
The ampere is a steady current which when flowing in each of two infinitely long straight wire parallel conductors of negligible cross section area and 1 meter apart in a vacuum produces between the wires a force of $2.0 \times 10^{-7} \text{N}$ per meter of the length.

(b) A circular coil of N turns, each of radius R carries a current I .

(i) Write an expression for the magnetic flux density at the center of the coil (01mark)

$$B = \frac{\mu_0 NI}{2R} \text{ where } \mu_0 \text{ is permittivity of free space.}$$

(ii) Sketch the magnetic field pattern associated with the coil. (02marks)



(c) Describe how deflection magnetometer can be used to investigate the variation of magnetic flux density at the center of a circular coil with the current flowing through the coil. (06marks)

The circular coil is set with its plane in the earth's magnetic meridian. A deflection magnetometer is mounted on a vertical axis at the center of the circular coil, with its pointer initially at the zero mark. The coil is then connected through a reversing switch to a battery, rheostat and an ammeter. Adjust the rheostat so that the ammeter a suitable value of I .

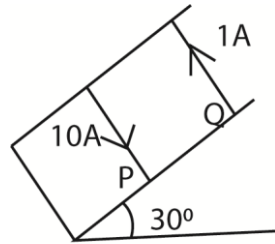
The deflection θ_1 and θ_2 are noted. The procedure is repeated for other suitable values of I and the results tabulated including values of $\theta = \frac{\theta_1 + \theta_2 + \theta_3 + \theta_4}{4}$ and $\tan \theta$.

A graph of $\tan \theta$ against I is plotted and it is linear. This shows that $\tan \theta$ is proportional to I

Since $B = B_H \tan \theta$, where B_H is horizontal component of the earth's magnetic flux density.

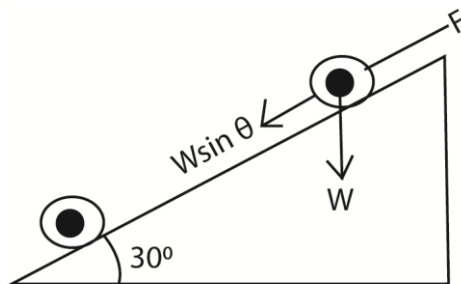
This implies that $B \propto I$

(d) Two parallel wires P and Q, each of length 0.2m carry currents of 10A and 1A respectively



The distance between the wires is 0.04m. If both wires remain stationary and the angle of the plane with the horizontal is 30° . Calculate weight of Q.

Solution



Force F between the two wires is given by

$$F = \frac{\mu_0 I_1 I_2 L}{2\pi a} = \frac{4\pi \times 10^{-7} \times 10 \times 1 \times 0.2}{2\pi \times 0.04} = 1.0 \times 10^{-3} \text{ N}$$

But for equilibrium, the component of the weight along the slope is balanced by the magnetic force on the wire i.e. $F = W \sin \theta$

$$\Rightarrow W = \frac{F}{\sin \theta} = \frac{1.0 \times 10^{-3}}{\sin 30} = 2 \times 10^{-3} \text{ N}$$

(e) (i) State why the damping in the ballistic galvanometer should be as small as possible. (01mark)

When the oscillation in the ballistic galvanometer is damped, the deflection is not proportional to the charge.

(ii) Describe how the damping can be reduced in practice (03marks)

Damping in ballistic galvanometer is reduced in the following ways

- Winding the coil on non-conducting frame
- Using a heavy coil so that it has a large inertia
- Using a fine suspension so as to increase the period of oscillation.

24. (a)(i) Define the terms self-induction and mutual induction. (02marks)

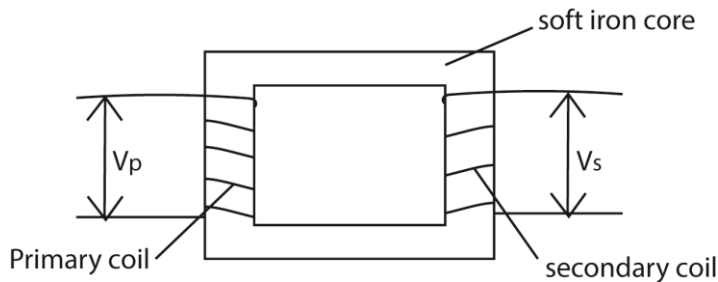
Self-induction is a process of generating e.m.f in a coil due to changing current in the same coil.

Mutual induction is a process of generating e.m.f in a coil due to changing current in neighboring coil.

(ii) State Faraday's law of electromagnetic induction (01mark)

It states that the magnitude of induced e.m.f is directly proportional to the rate of change of magnetic flux linking it.

(b) (i) Describe the structure and action of a.c transformer. (06marks)



$V_p =$ primary voltage, $V_s =$ secondary voltage

- Transformer consists of two coil of insulated wire, the primary and secondary wound on laminated soft iron core.
- When alternating voltage, V_p is connected to primary coil, it drives alternating current in the primary coil.
- The alternating current produces a varying magnetic flux ϕ_p that link the primary coils inducing a back e.m.f E_B in the primary.
- The varying magnetic flux, ϕ_s links the secondary coil by mutual induction/inducing alternating voltage, V_s in the secondary

$$V_p = N_p \frac{d\phi_p}{dt} \dots\dots\dots(i)$$

$$V_s = N_s \frac{d\phi_p}{dt} \dots\dots\dots(ii)$$

Eqn (i) \div Eqn (i)

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

When $N_s > N_p$ the transformer is a step up

$N_s < N_p$ the transformer is a step down

(ii) Explain why the voltage at a generating power station must be stepped up to very high value for long distance transmission (03marks)

Transmission is at high voltage to reduce power loss

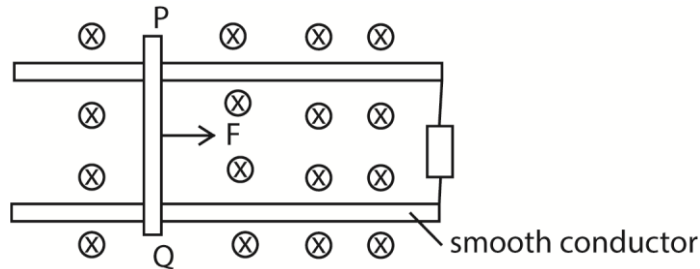
Note that

Power supplied, $P = IV$

$$I = \frac{P}{V}$$

Hence when V is high, I is small. From power loss, $P' = I^2R$, when I is small power loss is reduced.

- (c) In the figure below, a conducting rod PQ of length 20mm rests on a smooth conducting frame to form a complete circuit of resistance 4.0Ω . When a force, F , is applied, the rod moves at a constant velocity of 6.0ms^{-1} perpendicular to a uniform magnetic field of flux density 1.5T .



- (i) Explain why the rod PQ moves with constant velocity. (03 marks)

As PQ moves, it cuts the magnetic field and an e.m.f is induced across it. Since the rod is a closed circuit, induced current flows through it. By Fleming's left hand rule, magnetic force acts on the rod in such a way as to oppose the motion. When magnetic force = applied force, then the resultant force is zero. Therefore PQ moves with constant velocity.

- (ii) Calculate the amplitude of the induced e.m.f (02marks)

$$E = BLV = 1.5 \times 20 \times 10^{-3} \times 6.0 = 0.18\text{V}$$

- (iii) Calculate the magnitude of the force, F . (03marks)

$$F = BIL \text{ and } I = \frac{E}{R} = \frac{0.18}{4} = 0.045\text{A}$$

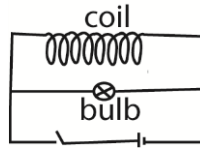
$$F = 1.5 \times 0.045 \times 20 \times 10^{-3} = 1.35 \times 10^{-3}\text{N}$$

25. (a) Define the term peak value and root mean square value of an alternating current. (02 marks)

Peak value is the maximum value of alternating current.

Root mean square value is the value of direct current which dissipates heat in a given resistor at the same rate as the a.c.

(b) A coil of many turns of wire is connected in parallel with an electric bulb to a d.c supply as shown in the figure below.



At the instant switch K is closed, the bulb flashes briefly for a short time and then goes off. Explain the observation.

When switch K is closed, current begins to flow through the coil and the changing magnetic flux due to the change in current induces a back e.m.f in the coil thus most of the current flows through the bulb making it to flash. Latter back e.m.f decay to zero and most of the current then flows through the coil

(c) A sinusoidal alternating voltage of 20V (r.m.s) and frequency 60Hz is applied across a coil of wire of inductance 0.2H and negligible resistance.

(i) Find the reactance of the coil at this frequency. (03marks)

$$\begin{aligned} X_L &= 2\pi fL \\ &= 2\pi \times 60 \times 0.2 \\ &= 75.4\Omega \end{aligned}$$

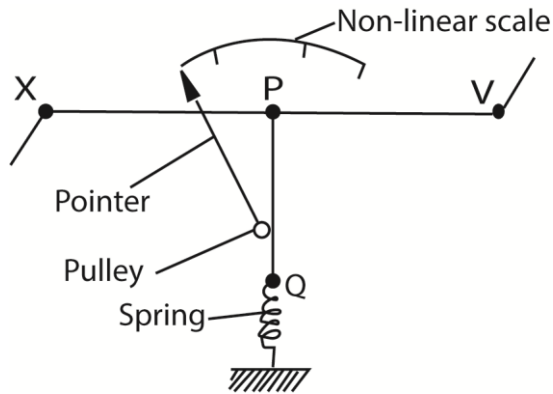
(ii) Calculate the r.m.s value of the current which passes through the coil (02marks)

$$\begin{aligned} X_L &= \frac{V_{r.m.s}}{I_{r.m.s}} \\ \Rightarrow I_{r.m.s} &= \frac{20}{75.4} = 0.265A \end{aligned}$$

(iii) Explain why on average the power delivered to the inductor in one cycle is zero. (03marks)

During the first quarter cycle, when current increases, work is done against the back e.m.f. The energy supplied by the source is stored in the magnetic field of the coil. During the second quarter cycle, as current begins to decay, the magnetic field begins to collapse and energy is returned to the source. The same process is repeated in the next half cycle. Hence the energy supplied in the cycle to the coil is zero.

(d) Describe with aid of a labelled diagram the structure and action of a hot wire ammeter. (06marks)



- The current flows through a fine resistance-wire XY, which it heats.
- The wire warms up to such a temperature that it loses heat-mainly by convection-at a rate equal to the average rate at which heat is developed in the wire.
- The rise in temperature of the wire makes it expand and sag; the sag is taken up by a second fine wire PQ, which is held taut by a spring.
- The wire PQ passes round a pulley attached to the pointer of the instrument, which rotates as the wire XY sags.
- The deflection of the pointer is roughly proportional to the average rate at which heat is developed in the wire XY; it is therefore roughly proportional to the average value of the square of the alternating current, and the scale is a square-law one.

26. (a) Define the following terms as applied to alternating voltage

- (i) Root mean square value (01 marks)

Root mean square value is the value of direct current which dissipates heat in a given resistor at the same rate as the a.c.

- (ii) Peak value

Peak value is the maximum value of alternating Voltage.

(b) (i) An alternating voltage is applied across a capacitor of capacitance, C. show that current in the circuit leads the voltage by $\pi/2$

Instantaneous charge on the capacitor.

$$\text{Let } V = V_0 \sin \omega t = V_0 \sin 2\pi f t$$

$$Q = CV = CV_0 \sin 2\pi f t$$

$$\text{But } I = \frac{dQ}{dt} = \frac{d(CV_0 \sin 2\pi f t)}{dt}$$

$$= 2\pi f CV_0 \cos 2\pi f t.$$

But $\cos 2\pi ft = \sin (2\pi ft + \frac{\pi}{2})$.

This shows that the current varies a quarter-cycle out of step with the voltage-or, as is more often said, $\pi/2$ out of phase.

When the voltage is a maximum, so is the charge on the capacitor. It is therefore not charging and the current is zero.

When the voltage starts to fall, the capacitor starts to discharge; the rate of discharging, or current, reaches its maximum when the capacitor is completely discharged and the voltage across it is zero.

- (ii) Find the expression for capacitive reactance in terms of frequency, f , and capacitance, C .

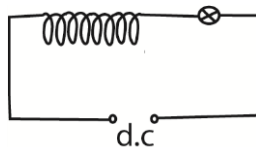
$$I_0 = CV_0\omega$$

$$XC = \frac{V_0}{I_0} = \frac{1}{C\omega} = \frac{1}{2\pi fC}$$

- (iii) A capacitor of $0.1\mu\text{F}$ is in series with an a.c. source of frequency 500Hz . If the r.m.s value of the current flowing is 6mA , calculate the voltage across the capacitor (03marks)

$$\Rightarrow V_{r.m.s} = \frac{I_{r.m.s}}{2\pi fC} = \frac{6 \times 10^{-3}}{2\pi \times 500 \times 0.1 \times 10^{-6}} = 19.1\text{V}$$

- (c) A bulb is connected in series with an inductive coil and a d.c source as shown in the figure below



- (i) What happens to the brightness of the bulb when an iron core is inserted in the coil? (01mark)

Initially the bulb dims and becomes bright.

- (ii) Explain what happens to the brightness of the bulb when the d.c. source is replaced with a.c. and an iron core inserted in the coil. (03marks)

Initially the bulb is dim due to back e.m.f in the coil and then become bright because the back e.m.f decays to zero and current increases to the maximum

- (d) (i) What is hysteresis loss ? (01mark)

Hysteresis loss is the loss in energy due to the change in magnetic domains from one direction to the other as current changes

(ii) How can hysteresis loss be minimized in a.c. transformer? (01mark)

It is minimized by using soft magnetic materials like soft iron and perm alloy in which energy required

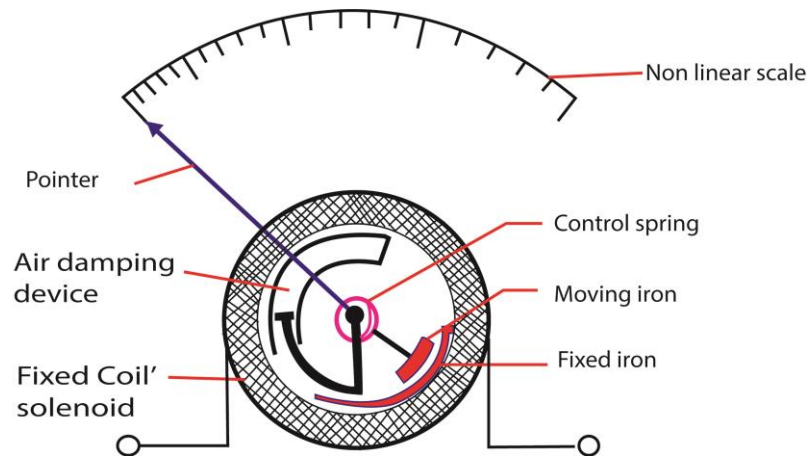
(iii) Explain why the primary current in the a.c. transformer increases when the secondary coil is connected to the load? (04marks)

When a load is connected to the secondary, current flows in the secondary which induces magnetic flux in the core in opposition to magnetic flux due to primary current.

Magnetic flux in the core due to primary current thus reduces.

This leads to a reduction in back e.m.f in the primary and hence the primary current increases.

27. (a)(i) Draw a well labelled diagram to show the structure of repulsion type moving iron ammeter (02marks)



(ii) Explain how the ammeter in (a)(i) above is able to measure alternating current. (05marks)

When a current is passed through the coil, the iron rods magnetize in the same poles adjacent to each other in whatever the direction of current. Hence they repel and the pointer move in the same direction until it is stopped by the restoring spring.

Since the magnetic force is proportional to the square of the average current, hence, the deflection is proportional to the square of average current.

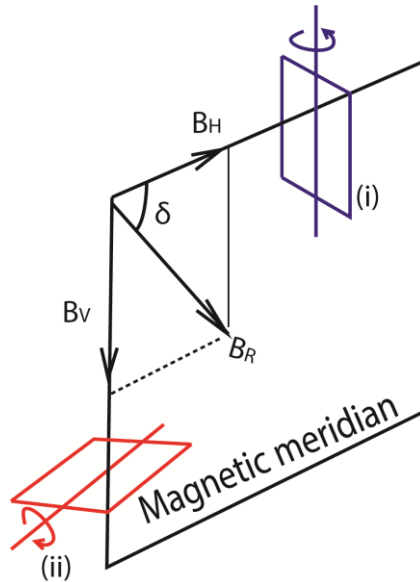
Advantage: it measured both direct and alternating current.

Disadvantage: it has nonlinear scale

(b) (i) Write down an expression for magnetic flux density at the center of a flat circular coil, N, turns each of radius, a, carrying current I. (01mark)

$$B = \frac{\mu_0 NI}{2a} \text{ where } \mu_0 = 4\pi \times 10^{-7} \text{ Hm}^{-1}.$$

(ii) Describe how you would determine the value of the earth's magnetic flux density at a place, using a search coil. (06marks)



- A coil of known number of turns, N (about 100) and area A is connected to a calibrated ballistic galvanometer so that the total resistance in the circuit is R.
- The coil is placed in a vertical plane perpendicular to the magnetic meridian of the earth as shown in (i) in figure above. The coil is then rotated through 180° about the vertical axis. The maximum throw θ_1 is noted.
- The coil is then placed with its plane in horizontal plane perpendicular to the magnetic meridian of the earth as shown in (ii) in figure above. The coil is then rotated through 180° about the horizontal axis. The maximum throw θ_2 is noted.
- Treatment of results

$$B_H = \frac{k\theta_1 R}{2NA} \text{ and } B_V = \frac{k\theta_2 R}{2NA}$$

k is obtained by charging standard capacitor to a known p.d V and then discharging it through the ballistic galvanometer and the deflection α is noted.

$$k = \frac{CV}{\alpha}$$

$$\text{Then } B \text{ is calculated from } b = \sqrt{B_H^2 + B_V^2}$$

(c) A coil of 50 turns and radius 4cm is placed with its plane in the earth's magnetic meridian. A compass needle is placed at the center of the coil. When a current of 0.1A

passes through the coil, the compass needle deflects through 40° . When the current is reversed, the needle deflects through 43° in opposite direction.

(i) Calculate the horizontal component of the earth's flux density. (04marks)

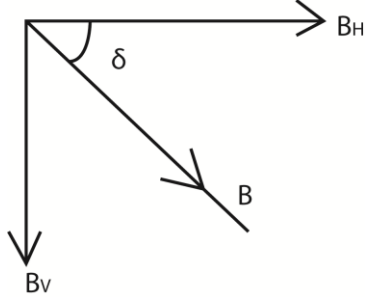
$$\tan \theta = \frac{B_{coil}}{B_H} \text{ and } B_{coil} = \frac{\mu_0 NI}{2R} \text{ where } \theta \text{ is average deflection}$$

$$\text{Hence } \tan \theta = \frac{\mu_0 NI}{2RB_H}$$

$$B_H = \frac{\mu_0 NI}{2R \tan \theta} = \frac{4\pi \times 10^{-7} \times 50 \times 0.1}{2 \times 4 \times 10^{-2} \tan\left(\frac{40+43}{2}\right)} = 8.87 \times 10^{-5} \text{T}$$

(ii) Calculate the magnetic flux density of the earth at that place given that the angle of dip at the place is 15° .

$$\frac{B_H}{B} = \cos \delta \text{ where } \delta \text{ is the angle of dip}$$



$$B = B_H \sec \delta$$

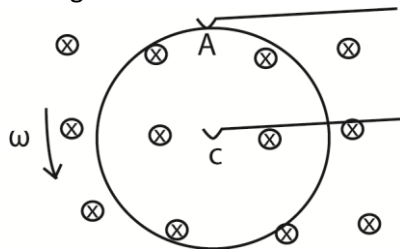
$$= 8.87 \times 10^{-5} \sec 15 = 9.18 \times 10^{-5} \text{T}$$

28. (a) State the laws of electromagnetic induction. (02marks)

Faraday's laws states that the magnitude of the induced e.m.f in a conductor is directly proportional to the rate of change of magnetic flux linking the conductor.

Lenz's law states that the direction of the induced e.m.f is such that the current which it causes to flow opposes the change which is producing it.

(b) (i) A circular metal disc of radius R . rotates in an anticlockwise direction at angular velocity, ω , in a uniform magnetic field of flux density, B , directed in to paper as shown in the figure below



A and C are contact points

Derive an expression for e.m.f induced between A and C.

Let r = radius of the disc

Thus AC cuts the magnetic flux continuously.

The average velocity V of AC = $\frac{0+r\omega}{2} = \frac{r\omega}{2}$

∴ Induced e.m.f in AC = $E = BLV$

$$= \frac{Br.r\omega}{2}$$

$$= \frac{1}{2}Br^2\omega$$

- (ii) A copper disc of radius 10cm is placed in a uniform magnetic field of flux density, 0.02T, with its plane perpendicular to the field. If the disc is rotated parallel to the field about an axis through its center at 3000 revmin⁻¹, calculate the e.m.f that is generated between its rim and the centre. (03marks)

Since $E = \frac{1}{2}Br^2\omega$, $\omega = 2\pi f$

$$= \frac{1}{2}Br^2 \cdot 2\pi f$$

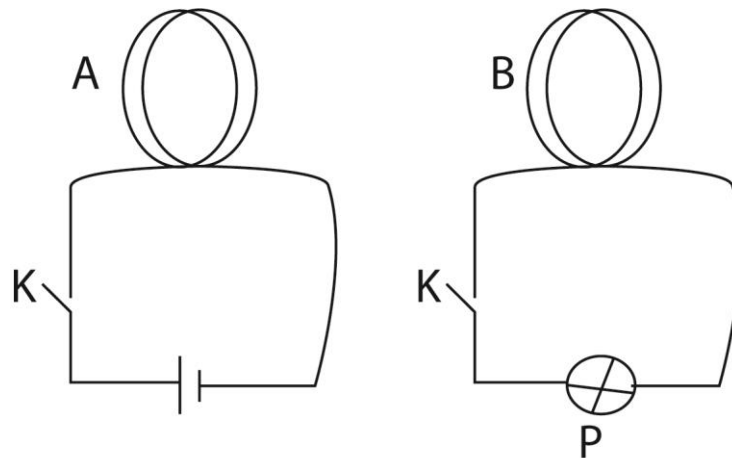
$$= Br^2\pi f$$

If $f = 3000\text{revmin}^{-1}$;

$$= \frac{3000}{60} = 50\text{Hz}$$

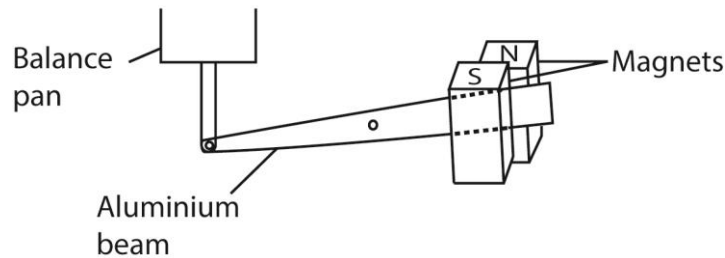
$$\therefore 0.02 \times (0.1)^2 \times 2 \times 3.14 \times 50 = 3,14 \times 10^{-2}\text{V}$$

- (c) Describe an experiment to demonstrate mutual induction (04marks)



Coil A and B are placed close to each other. When K is closed bulb P lights. Hence e.m.f is induced in B. Since the circuit is closed current flows and the bulb lights.

- (d) The diagram in the figure below shows the arrangement by which a laboratory balance is critically damped. The aluminium beam supporting the pan moves in the magnetic field of two powerful magnets.



- (i) Explain how damping is caused. (03marks)

When the beam moves between the magnetic poles, it cuts the magnetic field. Eddy currents are induced in the beam whose magnetic field opposes its movement. Hence damping the motion.

- (ii) What change would occur in the performance of the balance if the magnets were replaced by weaker ones (01mark)

The beam takes longer to settle.

- (e)(i) Define the ampere (01mark)

The ampere is the current which when flowing in each of the two long parallel wires of negligible cross-sectional area and 1m apart in a vacuum produces a force of $2 \times 10^{-7} \text{Nm}^{-1}$ on each other.

- (ii) Two parallel wire, P and Q of equal length 0.1m, each carrying a current of 10A are a distance 0.05m apart with P directly above Q. If P remains stationary, find the weight of P. (03marks)

Force due to magnetic field on P = weight of P, W.

$$W = \frac{\mu_0 I_1 I_2 L}{2\pi a} = \frac{4\pi \times 10^{-7} \times 10 \times 10 \times 0.1}{2\pi \times 0.05} = 4.0 \times 10^{-5} \text{N}$$

29. (a) Define the term **magnetic flux density**. (01mark)

Magnetic flux density is the force acting on a charge of 1C moving with a velocity of 1ms^{-1} at right angle to magnetic field.

- (b) Write expression for the

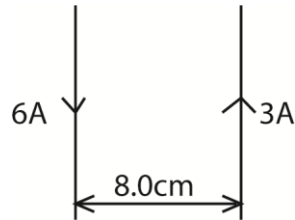
- (i) magnetic flux density at a perpendicular distance, R, from a long straight wire carrying current, I, in air. (01mark)

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

- (ii) Force on a straight conductor of length, L (meters) carrying current, I (ampere) at an angle, θ , to a uniform magnetic field of flux density, B (tesla)

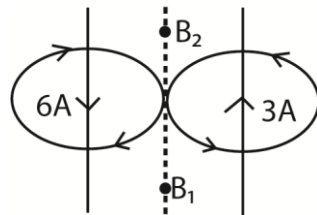
$$F = BIL\sin\theta$$

(c) Two straight long and straight wires of negligible cross-section area carry currents of 6.0A and 3.0A in opposite direction as shown below



If the wire are separated by a distance of 8.0cm, find the;

(i) Magnetic flux density at a point mid-way between the wires (04marks)



Magnetic flux density midway between the wires.

$$\begin{aligned} B &= B_1 + B_2 \\ &= \frac{\mu_0 I_1}{2\pi R} + \frac{\mu_0 I_2}{2\pi R} \\ &= \frac{6 \times 4\pi \times 11110^{-7}}{2\pi \times 0.4} + \frac{6 \times 4\pi \times 11110^{-7}}{2\pi \times 0.4} \\ &= 4.5 \times 10^{-5} \text{T} \end{aligned}$$

(ii) Force per meter between the wire (03marks)

$$\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi a} = \frac{4\pi \times 10^{-7} \times 6 \times 3}{2\pi \times 0.8} = 4.5 \times 10^{-5} \text{Nm}^{-1}$$

(d) Define:

(i) angle of dip (01mark)

Angle of dip is the angle between the earth's resultant magnetic flux density and the horizontal.

(ii) angle of declination (01mark)

Angle of declination is the angle between the earth's magnetic and geographical axes or angle between the earth's meridian and geographical meridian.

(e) A straight conductor of length, L, is perpendicular to magnetic field of flux density B. If the conductor moves with velocity, U, at an angle θ to magnetic field, derive the expression for e.m.f induced. (04marks)

Component of the velocity perpendicular to B is $U\sin\theta$

Area swept by conductor in one second is $L\sin\theta$

Change in magnetic flux linkage in 1s = $BL\sin\theta$

But induced e.m.f = $-\frac{d\theta}{dt}$

$$\therefore |E| = BL\sin\theta$$

- (f) An aircraft of wing 20m is moving horizontally from west to east at a velocity of 250ms^{-1} in a place where the angle of dip is 40° . The e.m.f induced across the tips of the wings is 6mV. Find the magnetic flux density of the earth field. (04marks)

Component of B_E perpendicular to $U = B_E\sin\theta$

\therefore Induced e.m.f of $E = B_E\sin\theta \times LU$

$$B_E = \frac{E}{LU\sin\theta} = \frac{6 \times 10^{-3}}{20 \times 250 \times \sin 40} = 1.867 \times 10^{-6}\text{T}$$

30. (a) State the laws of electromagnetic induction. (02marks)

The magnitude of the induced e.m.f is directly proportional to the rate of change of magnetic flux linking the circuit or conductor.

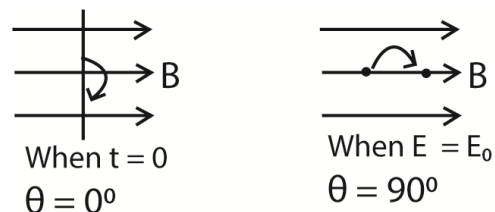
The direction of the induced e.m.f is such that it tends to oppose the change causing it.

- (b) The e.m.f generated in a coil rotating in a uniform magnetic field is given by $E_0\sin\omega t$.

- (i) State the meaning of the symbols used and give their units. (03marks)

- E_0 is the maximum(peak) value of e.m.f in volts
- ω is the steady angular velocity of the coil in radians per second.
- t is time in seconds.

- (ii) Draw diagrams showing the relative positions of the coil and the magnetic field when t is zero and when the e.m.f generated is E_0 . (03marks)



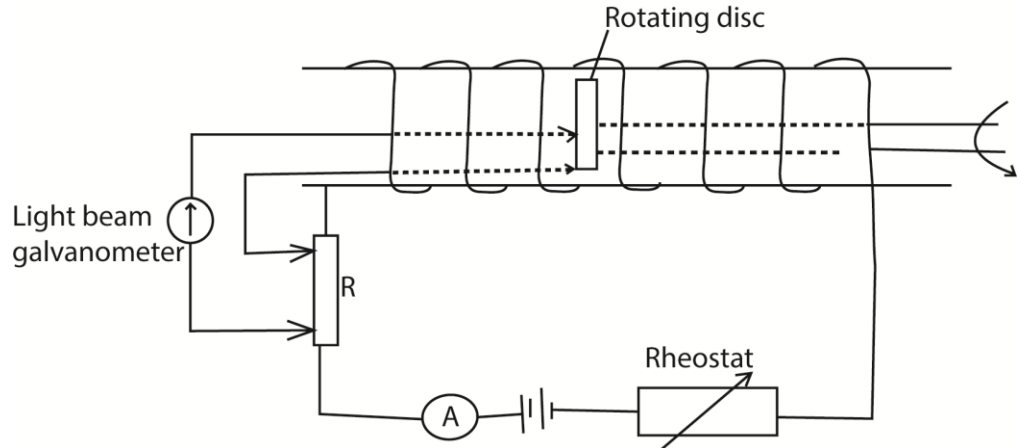
- (c) A rectangular coil of 50turnsis 15.0cm wide and 30.0cm long. If it rotates at a uniform rate of 2000 revolution per minute about an axis parallel to its long side and at right angles to a uniform magnetic field of flux density 0.04T, find the peak value of the e.m.f induced in the coil (03marks)

Induced e.m.f, $E = \omega NAB \sin \omega t$

Where $E_0 = \omega NAB$

$$= \frac{2000}{60} \times 2\pi \times 50 \times 0.15 \times 0.1 \times 0.30 \times 0.04 = 18.84V$$

- (d) A solenoid of n , turns per meter, a resistor, R , an ammeter, A , and a rheostat are connected to the battery as shown in the figure below. A disc of radius, r , is mounted inside the solenoid with its axis coincident with that of the solenoid. The center and rim of the disc are connected across R . The disc is rotated with its plane perpendicular to the axis of the solenoid at a frequency, f .



The rheostat is adjusted until the galvanometer shows no deflection and ammeter reads a current of I amperes.

- (i) Show that the e.m.f induced between the center and rim of the disc is $\pi Br^2 f$, where B is magnetic flux density inside the solenoid. (04marks)

Magnetic flux density with the disc, $\phi = BA$

Now induced e.m.f $E = \frac{-d\phi}{dt} = \frac{dB A}{dt} = B \frac{dA}{dt}$

But $\frac{dA}{dt} = \frac{\pi r^2}{T} = \pi r^2 f$ since $1/T = f$

$\therefore |E| = B \pi r^2 f$

- (ii) Deduce an expression for resistance of R , in terms of n , f , I and r .

$IR = B \pi r^2 f$ but $B = \mu_0 n I$

$IR = \mu_0 n I \pi r^2 f$

$R = \mu_0 n \pi r^2 f$

- (iii) State two limitations of the above set up in measurement of resistance.

Since the e.m.f generated is very small the method is only used to measure very small resistance.

- The earth's magnetic field affects the induced e.m.f.
- The effect of thermal e.m.f generated due to friction at the contact.

- 31.(a) (i) Distinguish between root mean square value and peak value of an alternating current. (02marks)

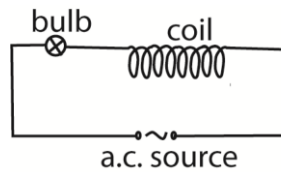
Root mean square value of alternating current is the value of steady or direct current which dissipates heat in a given resistor at the same rate as the alternating current, while **peak value** is the maximum value of current.

- (ii) What is peak value of voltage from a 240 a.c mains? (02marks)

$$V_{r.m.s} = 240$$

$$\begin{aligned} \text{But } V_0 &= \sqrt{2V_{r.m.s}} \\ &= \sqrt{2 \times 240} \\ &= 339.4V \end{aligned}$$

- (b)



An air-cored coil, a bulb and an a.c. source are connected as shown in figure above. When a solid iron core is introduced in the coil, the bulb becomes dimmer and the core hot. Explain the observation. (06marks)

When the iron core is introduced into the coil, the magnetic flux linkage with the coil increases. The rate of change of magnetic flux linkage with the coil increases, and hence an increase in the induced back e.m.f. This leads to a reduction in the current flowing through the bulb that dims.

The changing magnetic flux in the coil induces Eddy currents in the iron core. These currents cause the core to heat up by I^2R mechanism

Secondary, the changing magnetic field continuous reverse magnetization of the core thus reversing the magnetic domains of the core. This leads to heating of the core due to friction between domains or hysteresis.

- (c) (i) What is meant by the term inductive reactance? (01mark)

Inductive reactance is non-resistive opposition to flow of alternating current through the inductor.

- (ii) Derive an expression for reactance of an inductor of inductance L when a sinusoidally varying a.c. of frequency, f, passes through it. (05marks)

Suppose current $I = I_0 \sin 2\pi ft$ flows through an inductor where I_0 is amplitude.

$$\text{Induced back e.m.f } E = -L \frac{dI}{dt}$$

For finite current in a pure inductor applied voltage $V = -E$

$$= -L \frac{d(I_0 \sin 2\pi ft)}{dt}$$

$$= -2\pi f L I_0 \cos 2\pi ft$$

$$\therefore V_0 = 2\pi f L I_0$$

$$\text{Now reactance } X_L = \frac{V_0}{I_0} = \frac{2\pi f L I_0}{I_0} = 2\pi f L$$

- (iii) A sinusoidal alternating voltage of $6.0V_{r.m.s}$ and frequency 1 kHz is applied to a coil of inductance 0.5H. Assuming that the coil has negligible resistance, calculate the root mean square value of current. (03marks)

$$- I_{r.m.s} = \frac{V_{r.m.s}}{X_L} = \frac{V_{r.m.s}}{2\pi f L} = \frac{6.0}{2 \times 3.14 \times 1000 \times 0.5} = 1.9 \times 10^{-3} \text{A}$$

- (d) State one advantage of a.c over d.c.

- a.c can easily and cheaply be changed from one voltage to another.
- a.c can easily be transmitted with little power loss
- a. c. is cheap to generated

32. (a) Define the terms magnetic flux and magnetic flux density. (02marks)

Magnetic flux is the product of magnetic flux density and the projection of area normal to the magnetic field.

Magnetic flux density is the force acting on a 1m long conductor carrying current of 1A in a direction perpendicular to magnetic field.

- (b) A straight wire of length 20cm and resistance 0.25Ω lies at right angles to a magnetic field of flux density 0.4T. The wire moves when a p.d of 2.0V is applied across its ends.

Calculate the;

- (i) initial force on the wire

$$F = BIL = 0.4 \times \frac{2}{0.25} \times \frac{20}{100} = 0.64 \text{N}$$

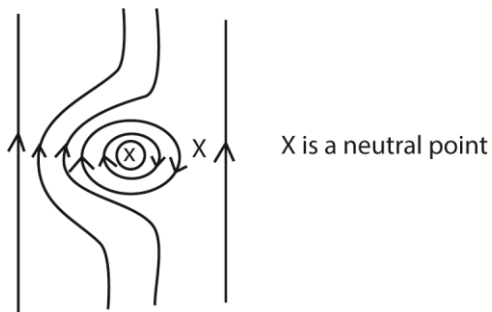
- (ii) force on the wire when it moves at a speed of 15ms^{-1} . (02marks)

$$\begin{aligned}
 \text{Induced e.m.f, } E &= BLV \\
 &= 0.4 \times 0.2 \times 15 = 1.2\text{V} \\
 I &= \frac{V-E}{R} = \frac{2-1.2}{0.25} = 3.2\text{A} \\
 F &= BIL \\
 &= 0.4 \times 3.2 \times 0.2 = 0.256\text{N}
 \end{aligned}$$

(iii) Maximum speed attained by the wire (02marks)

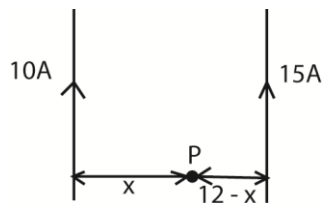
$$\begin{aligned}
 \text{At maximum speed, force, } F &= 0 \\
 \text{Induced e.m.f} &= \text{applied p.d} \\
 \text{But } E &= Blu = V \\
 \text{Speed } u &= \frac{V}{BL} = \frac{2}{0.4 \times 0.2} = 25\text{ms}^{-1}
 \end{aligned}$$

(c) (i) sketch the magnetic field pattern around a vertical straight wire carrying a current in the earth's magnetic field and use it to explain a neutral point in magnetic field. (03marks)



A neutral point is a point where the resultant magnetic flux (density) is zero

(ii) Two long parallel wires placed 12cm apart in air carry currents of 10A and 15A respectively in the same direction. Determine the position where the magnetic flux is zero. (04marks)



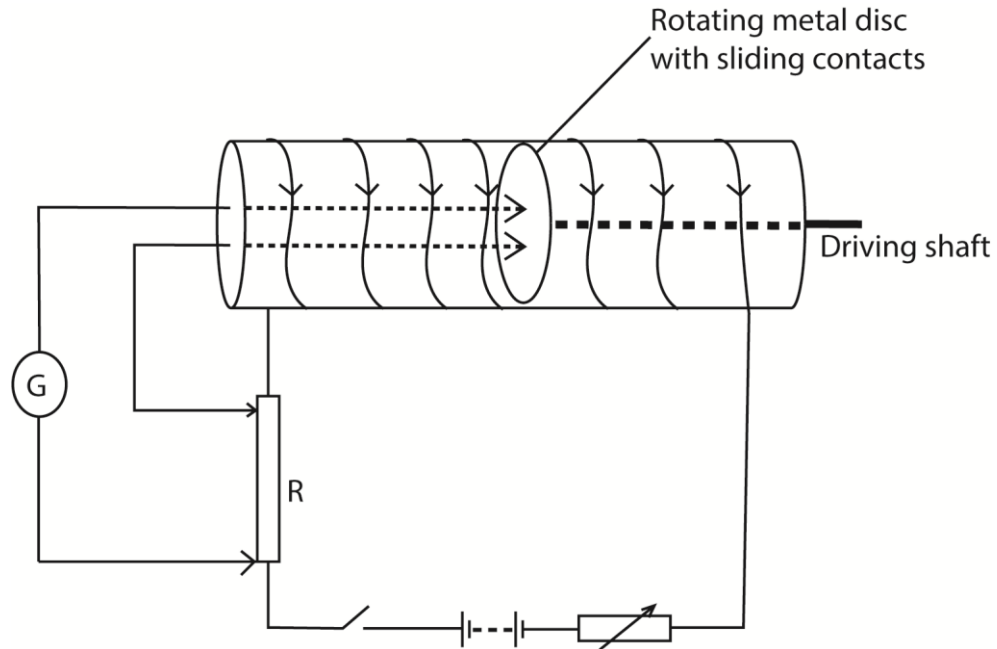
Let P be the point where the resultant magnetic flux is zero

$$\begin{aligned}
 \text{Then, } \frac{\mu_0 I_1}{2\pi x} &= \frac{\mu_0 I_2}{2\pi(12-x)} \\
 \frac{10}{x} &= \frac{15}{12-x}
 \end{aligned}$$

$$x = 4.8\text{cm}$$

P is 4.8cm from 10A current and 7.2 cm from the 15A current carrying conductor.

(d) Describe with the aid of a diagram, an absolute method of determining resistance. (05mark).



The circuit is connected as above. The metal disc of known radius r , is placed at the center of solenoid carrying current with the plane of the disc perpendicular to magnetic field. The disc is rotated using the driving shaft. The speed of rotation of the disc is adjusted until the galvanometer shows no deflection. The number of revolutions for a given interval of time is counted and the frequency, f , determined.

The resistance is then calculated from;

$$R = \mu_0 n \pi r^2 f;$$

Where n is the number of turns per meter of the solenoid

33. (a) Derive an expression for the charge, Q , induced in a coil of N turns when the magnetic flux through it changes. (04marks)

$$\text{Instantaneous induced e.m.f } E = \frac{-d(N\phi)}{dt}$$

$$\text{Instantaneous current } I = \frac{E}{R} = -\frac{1}{R} \frac{d(N\phi)}{dt}$$

$$\text{But } I = \frac{dQ}{dt}$$

$$\therefore \frac{dQ}{dt} = \frac{-N}{R} \frac{d\phi}{dt}$$

$$dQ = \frac{-N}{R} d\phi$$

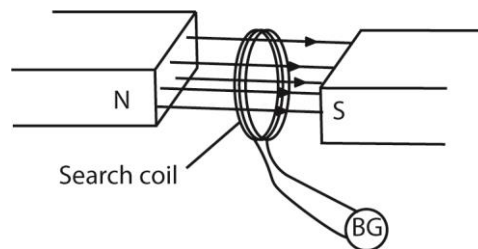
Suppose when time is zero flux linkage is ϕ_0

And when time is t, flux linkage is ϕ_1 . Then total

$$\begin{aligned} \text{Induced charge } Q &= -\frac{N}{R} \int_{\phi_0}^{\phi_1} d\phi \\ &= \frac{N}{R} (\phi_0 - \phi_1) \end{aligned}$$

- (b) (i) Describe how a ballistic galvanometer of an unknown charge sensitivity can be used to measure magnetic flux density in a region between the poles of a magnet. (05marks)

Solution



A search coil is connected in series with a ballistic galvanometer, B.G and a resistor.

The search coil is placed between the poles pieces of the magnet with its plane normal to the magnetic field.

When the ballistic galvanometer pointer settles, the coil is completely withdrawn from the field and the first deflection θ of the B.G is noted.

A capacitor of known capacitance C is charged to a p.d V and then discharged through the ballistic galvanometer and the corresponding θ' is noted.

The magnetic flux density B is now calculated from $B = \frac{CVR\theta}{NA\theta'}$ where A is the area of the coil, N is the number of turns in the coil and R is the resistance of the coil circuit.

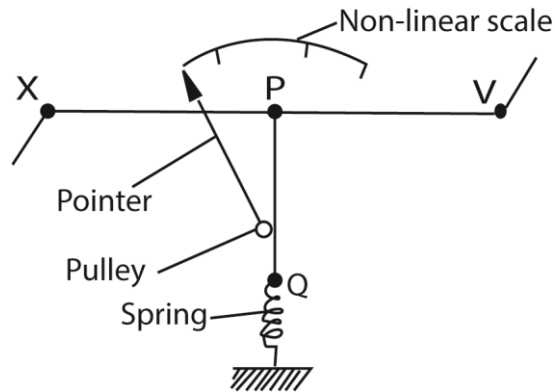
- (ii) State the possible sources of error in above experiment. (02mark)

- It may not be possible to get the coil completely out of the field
- Improper position of the search coil
- Inaccuracy of ballistic galvanometer
- Influence of earth's magnetic flux

- (c) A flat circular coil with 2000turns, each of radius 50cm, is rotated at a uniform rate of 600 revolutions per minute about its diameter at right angle to a uniform magnetic flux density 5×10^{-4} T. Calculate the amplitude of the induced e.m.f. (03marks)

$$\begin{aligned} E_0 &= 2\pi fNAB \\ &= 2\pi \times \frac{600}{60} \times 2000 \times \pi \times 0.5^2 \times 5 \times 10^{-4} = 49.3V \end{aligned}$$

(d) Describe with the aid of a labelled diagram, the structure and action of a hot wire ammeter. (06marks)

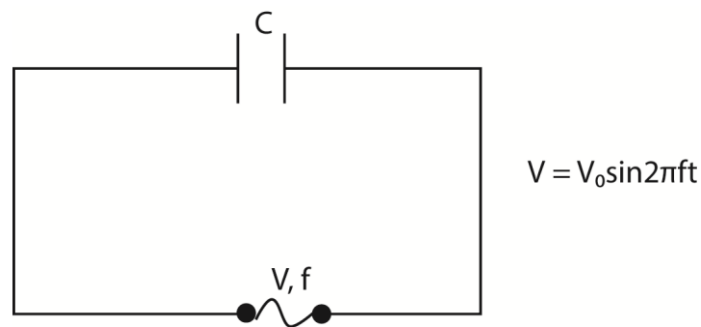


- The current flows through a fine resistance-wire XY, which it heats.
- The wire warms up to such a temperature that it loses heat-mainly by convection-at a rate equal to the average rate at which heat is developed in the wire.
- The rise in temperature of the wire makes it expand and sag; the sag is taken up by a second fine wire PQ, which is held taut by a spring.
- The wire PQ passes round a pulley attached to the pointer of the instrument, which rotates as the wire XY sags.
- The deflection of the pointer is roughly proportional to the average rate at which heat is developed in the wire XY; it is therefore roughly proportional to the average value of the square of the alternating current, and the scale is a square-law one.

34. (a) (i) what is meant by peak value of a sinusoidal current? (01mark)

The peak current of a sinusoidal current is the maximum value of the current.

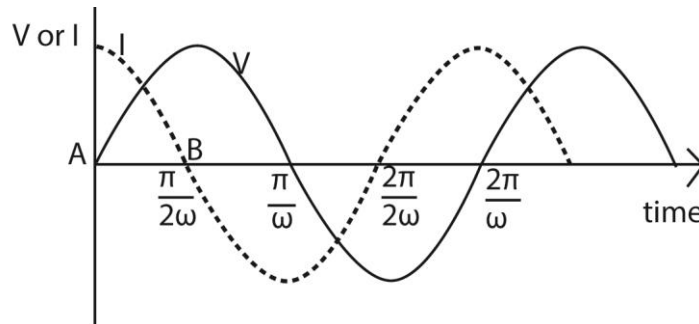
(ii) A source of sinusoidal voltage of amplitude V_0 and frequency f is connected across a capacitor of capacitance, C . Derive an expression for instantaneous current which flows (03marks)



Instantaneous charge on the capacitor, $Q = CV = CV_0 \sin 2\pi ft$

$$\begin{aligned} \text{But } I &= \frac{dQ}{dt} = \frac{d(Cv_0 \sin 2\pi ft)}{dt} \\ &= 2\pi fCV_0 \cos 2\pi ft \end{aligned}$$

(iii) With reference to the circuit in (a)(ii), sketch using the same axes, graphs to show the variation of voltage and current with time. (02marks)



Explanation

The current I through (not across) a capacitor is $C \frac{dV}{dt}$. This is the slope of the voltage.

When a capacitor is connected to an AC voltage (at the zero crossing) the maximum current flow will occur immediately, i.e. $t = 0, \frac{dV}{dt}$ will approach infinity instantly and then repeat as a sinusoidal waveform.

There will be a peak current at every zero crossing of the voltage waveform. The current waveform will lead the voltage waveform 90 degrees.

Or

When $V = V_0, I = 0$ the capacitor is fully charged, and opposition to the flow of charge is maximum

When $V = 0, I$ is maximum because the opposition to the flow of charge is minimum or zero

(b)(i) Explain why an alternating current apparently flows through a capacitor whereas a direct current does not. (03marks)

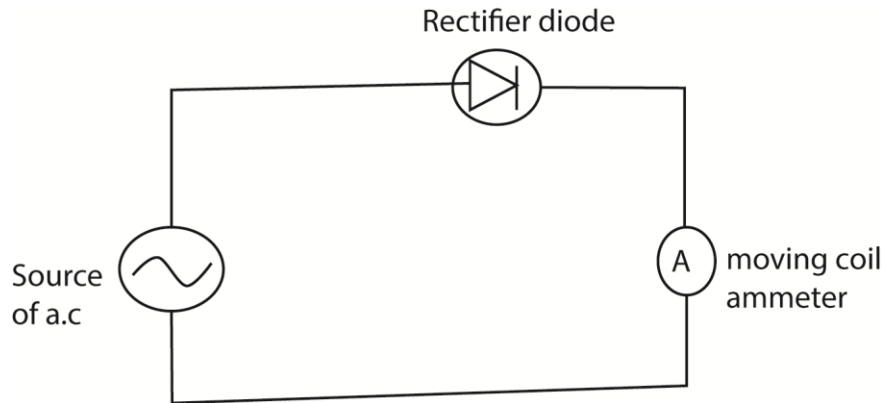
When a capacitor is connected to a d.c source, the capacitor charges fully and current stops flowing.

When the capacitor is connected to a.c voltage supply, the voltage increases and decreases alternatively. When the voltage increases the capacitor charges and when the voltage decreases the capacitor discharges. Hence continuous flow of charge (current) in the circuit.

(ii) Explain the advantages of a.c over d.c in power transmissions. (02marks)

- a.c can easily be stepped up and down
- a.c is easy to generate
- a.c can be transmitted with low power loss.

(c) With the aid of a diagram, describe how a half wave rectifier type of meter works. (04marks)



Current to be measured is fed to the meter through rectifier diode in which current flows in only one direction. So a direct current of varying magnitude flows through the meter. The moving coil meter is calibrated to measure the average current (or $I_{r.m.s}$)

(c) A sinusoidal voltage $V = 339\sin 100\pi t$ is connected across 40Ω resistor. Find the;
(i) amplitude of the current through the resistor. (02marks)

$$I_0 = \frac{V_0}{R} = \frac{339}{40} = 8.475A$$

(ii) average power developed in the resistor. (03marks)

$$\text{Average power, } P = \frac{V_0 I_0}{2} = \frac{V_0^2}{2R} = \frac{339^2}{2 \times 40} = 1436.5W$$

35. (a) Define:

(i) The tesla (01mark)

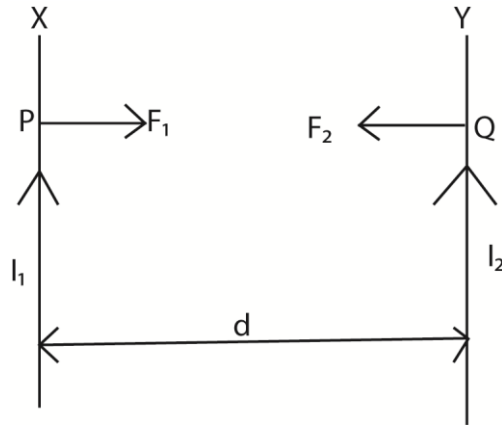
A tesla (1 T) is defined as the magnetic field intensity generating one newton (N) of force per ampere (A) of current per meter of conductor:

(ii) Magnetic flux (01mark)

Magnetic flux is the product of the magnitude of the magnetic flux density and the area perpendicular to the magnetic field.

(b) Two infinitely long straight wire carrying currents, I_1 and I_2 respectively are placed parallel to each other in a vacuum at a distance, d , meters apart. Derive an expression for the force per meter between the wires. (05marks)

Consider two infinitely long parallel wires X and Y carrying currents I_1 and I_2 respectively. The conductors are separated by a distance, d .



Magnitude of magnetic flux density, B_1 at any point, Say Q on Y due to the current in X is given by $B_1 = \frac{\mu_0 I_1}{2\pi d}$

Force acting per meter length of Y = $B_1 I_2$

$$= \frac{\mu_0 I_1 I_2}{2\pi d}$$

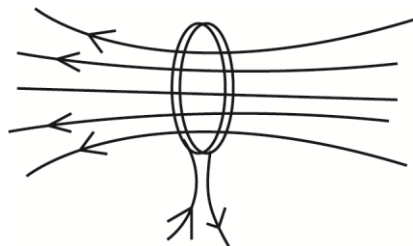
Magnitude of magnetic flux density, B_2 at any point, Say P on X due to the current in Y is given by $B_2 = \frac{\mu_0 I_2}{2\pi d}$

Force acting per meter length of X = $B_2 I_1$

$$= \frac{\mu_0 I_1 I_2}{2\pi d}$$

Hence $F_1 = F_2 = \frac{\mu_0 I_1 I_2}{2\pi d}$

(c)(i) Sketch the magnetic field pattern due to a current flowing in a circular coil. (02mark)



(ii) Write an expression for magnetic field flux density, B , at the center of circular coil of N turns of radius, r , and carrying a current I (01 mark)

$$B = \frac{\mu_0 NI}{2r}$$

- (iii) A wire of length 7.85m is wound into a circular coil, find the magnetic flux density at the center of the coil of radius 0.05m. If the current of 2A passes through the coil, find the magnetic flux density at the center of the coil. (04marks)

Solution

$$\begin{aligned} \text{Number of turns, } N &= \frac{\text{length of wire}}{\text{circumference of each turn}} \\ &= \frac{L}{2\pi r} = \frac{7.85}{2\pi \times 0.05} = 25 \text{ turns} \end{aligned}$$

$$\text{But } B = \frac{\mu_0 NI}{2r} = \frac{4\pi \times 10^{-7} \times 25 \times 2}{2 \times 0.05} = 6.28 \times 10^{-4} \text{ T}$$

- (d) (i) Explain the term back e.m.f in a d.c motor. (02mark)

As the motor rotates the magnetic field, the flux linking changes. This induces an e.m.f in the coil. The e.m.f acts in opposition to applied voltage, hence back e.m.f

- (ii) Show how the back e.m.f in a motor is related to efficiency of motor (04marks)

Suppose E_b , V , and r are the magnitudes of back e.m.f, applied p.d and total resistance respectively.

If I is the current flowing, the power supplied = $VI = I^2R + IE_b$

IE_b is the rate at which the motor does mechanical work, I^2r is the power dissipated in the coil and VI is the power supplied by the motor.

$$\text{Efficiency of the motor, } \eta = \frac{\text{Mechanical power got}}{\text{Power supplied}} \times 100\%$$

$$= \frac{IE_b}{VI} \times 100\%$$

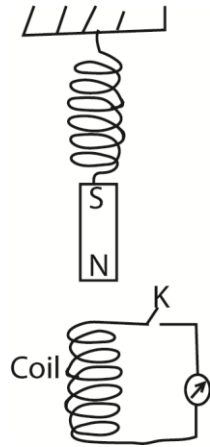
$$= \frac{E_b}{V} \times 100\%$$

36. (a)(i) Define the terms amplitude and root mean square (r.m.s) value of an alternating current. (02marks)

Amplitude of an alternating current is the maximum value of alternating current.

Root mean square value of an alternating current is the value of steady current that dissipates heat at the same rate as alternating current.

- (b)



A small magnet is attached to a spring as shown above. Switch, K is closed and the magnet is displaced downwards slightly and released to oscillate vertically. Explain

(i) The observation made (03marks)

The galvanometer deflects in one direction when the magnet approaches the coil and deflects in opposite direction when it recedes.

This is because as the magnet moves toward the coil, the flux linking it changes and e.m.f is induced in the coil. Since the circuit is complete, current flows in the direction of the induced e.m.f.

As the magnet moves away from the coil, an e.m.f is induced in the opposite direction.

(ii) Why the magnet takes long to come to rest when K is opened (03marks)

When the switch is open, there will be no flow of induced current that would cause an opposing magnetic field that produce electromagnetic damping. Consequently, the oscillation take long to stop.

(c) A sinusoidal voltage of r.m.s value 10V is supplied across a 50 μ F capacitor.

(i) Find the peak value of the charge on the capacitor. (02marks)

$$\text{From } Q = CV$$

$$\Rightarrow Q = CV_0 \sin \omega t = Q_0 \sin \omega t$$

$$\text{Where } Q_0 = CV_0$$

$$\text{So the peak value of charge, } Q_0 = CV_0$$

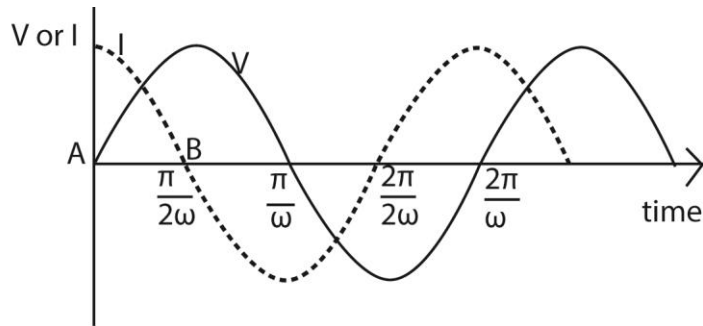
$$= CV_{\text{r.m.s}} \sqrt{2}$$

$$= 50 \times 10^{-6} \times 10 \times \sqrt{2}$$

$$= 7.07 \times 10^{-4} \text{C}$$

(ii) Draw a sketch graph of charge Q on the capacitor against time. (01mark)

(iii) Draw on the same sketch in (c)(i) a graph of voltage against time. (01mark)



Explanation

The current I through (not across) a capacitor is $C \frac{dV}{dt}$. This is the slope of the voltage.

When a capacitor is connected to an AC voltage (at the zero crossing) the maximum current flow will occur immediately, i.e. $t = 0, \frac{dV}{dt}$ will approach infinity instantly and then repeat as a sinusoidal waveform.

There will be a peak current at every zero crossing of the voltage waveform. The current waveform will lead the voltage waveform 90 degrees.

- (iv) If the a.c supply has a frequency of 50Hz, calculate the r.m.s value of the current through the capacitor. (04marks)

Solution

$$\text{Capacitive resistance} = \frac{V_{r.m.s}}{I_{r.m.s}}$$

$$I_{r.m.s} = \frac{V_{r.m.s}}{X_C} \dots\dots\dots (i)$$

$$\text{Also, } X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 50 \times (50 \times 10^{-6})} = 63.66\Omega$$

$$\text{Thus, } I_{r.m.s} = \frac{10}{63.66} = 0.15A$$

- 37. (a) (i) Distinguish between self-induction and mutual induction (02marks)

Self-induction is a type of electromagnetic induction where by an e.m.f is induced in a coil due to change in the current flowing in the same coil.

Mutual induction is a type of electromagnetic induction where by change in current in one coil or induces e.m.f in the neighboring coil or circuit.

- (ii) An aired cored inductor is connected in series with a switch and d.c. source. The switch is closed and left for some time. Explain why a spark is observed across the switch contacts when the switch is reopened. (03marks)

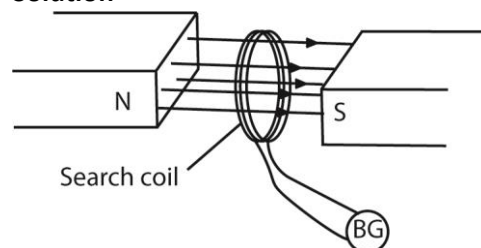
When the switch is opened, the falling current causes a change in the magnetic flux linking the inductor coil.

A change in the magnetic flux linking the coil, induce a large e.m.f in the circuit and leads to high the electric field intensity between the contact points causing ionization of gases.

When the oppositely charged ions collide, a spark is produced.

(b) Describe, with the aid of a diagram, how the magnetic flux density between the poles of a strong magnet can be measured. (06marks)

Solution



A search coil is connected in series with a ballistic galvanometer, B.G and a resistor.

The search coil is placed between the poles pieces of the magnet with its plane normal to the magnetic field.

When the ballistic galvanometer pointer settles, the coil is completely withdrawn from the field and the first deflection θ of the B.G is noted.

A capacitor of known capacitance C is charged to a p.d V and then discharged through the ballistic galvanometer and the corresponding θ' is noted.

The magnetic flux density B is now calculated from $B = \frac{CVR\theta}{NA\theta'}$ where A is the area of the coil, N is the number of turns in the coil and R is the resistance of the coil circuit.

(c)(i) Explain how eddy currents can be produced. (02marks)

Eddy currents are currents induced in a conductor moving across magnetic field; these currents oppose the motion of a solid conductor.

When a piece of metal moves in a magnetic field, a force acts on delocalized electrons in accordance with Fleming's left hand rule. The electrons deficient atoms also attract electrons from other atoms. This movement of electrons cause current loops that are called Eddy currents.

(iii) Explain the application of eddy currents. (03marks)

- Damping a 'galvanometer. In the galvanometer the coil is wound on a metal former. Eddy currents in the metal slow down the turning of the coil towards its eventual position, and also suppress its swings about that position; in the end the coil comes to rest sooner than if it were not damped.
- Cause overheating in dynamos and motors damaging the insulation of windings.
- Speedometer
- Electric brakes

(d) A coil of 500 turns and mean area $4.0 \times 10^{-2} \text{m}^2$ is rotated at a uniform rate of 600 revolution per minute about an axis perpendicular to a uniform magnetic field of flux density 0.2T. Calculate the maximum value of the e.m.f induced in the coil. (04marks).

$$E = BAN\omega \sin \omega t$$

$$E_{\text{max}} = BAN\omega$$

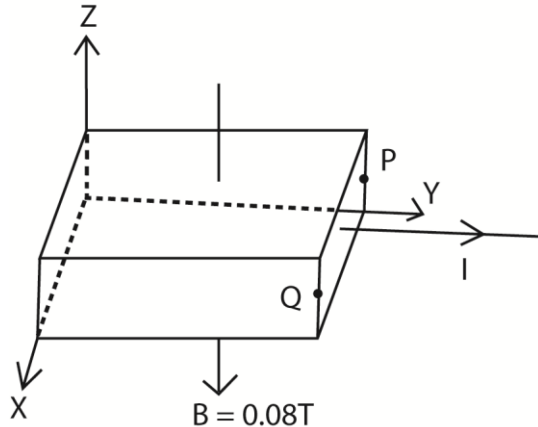
$$\text{But } \omega = \frac{2\pi \times 600}{60} = 20\pi \text{ rads}^{-1}$$

$$\therefore E = 0.2 \times 4.0 \times 10^{-2} \times 500 \times 20\pi = 251.3\text{V}$$

38. (a)(i) What is a magnetic field? (01marks)

Magnetic field is a region of space in which a magnetic dipole experiences a force.

(b)



A magnetic field of flux density 0.08T is applied to a metal strip carrying current, I, as shown above

(i) Account for the occurrence of potential difference (p.d) between points P and Q.

When a current begins flowing in the y-direction, by Fleming's left hand rule, a magnetic force acts on the conduction electrons in the direction PQ.

The electrons are deflected towards P, since there is high concentration of negative charge on side P and positive charge on side Q, a p.d develops between sides P and Q.

- (ii) Calculate the electric field intensity between P and Q if the drift velocity of the conduction electrons is $4.0 \times 10^{-4} \text{ m/s}$ (03marks)
 In equilibrium, electric force on electrons = magnetic force on the electron

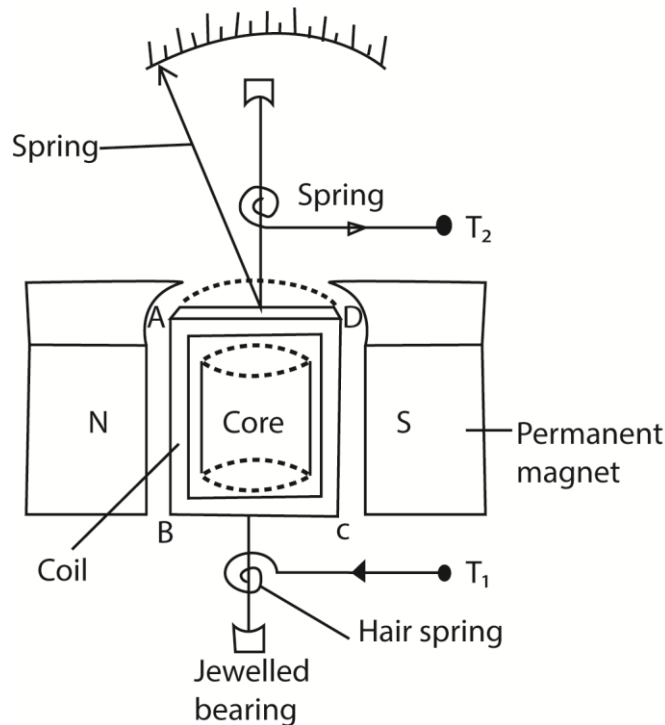
i.e. $eE = VeB$

$\therefore E = BV$

$= 0.08 \times 4 \times 10^{-4}$

$= 3.2 \times 10^{-5} \text{ Vm}^{-1}$

- (c)(i) Describe with the aid of a diagram the structure and mode of action of moving coil galvanometer. (03marks)



Structure

- It consists of a rectangular coil of fine insulated copper wire wound on an aluminium frame to provide electromagnetic damping.
- The coil together with the frame of aluminium are mounted over a soft iron cylindrical core and freely pivoted on jewelled bearing to minimize friction at contact.
- The suspension torsion wire suspending the coil is attached to a pair of control hair springs T_1 and T_2 for feeding current in and out of the coil and control rotation of the coil.
- The coil is then suspended between concave pieces of a strong magnet to provide magnetic field.

Mode of action

- Current I to be measured is passed into the coil via hair spring T_1 .

- The current then causes the coil to experience a deflection torque, $\tau = NABl$ due to a couple force causing rotation in a radial magnetic field.
- The coil turns with the pointer through angle θ until stopped by restoring torque, $\tau = k\theta$ provided by a pair of hair springs T_1 and T_2 .
- At equilibrium, $NABl = k\theta$
- \therefore current $I = \left(\frac{k}{NAB}\right)\theta$
- $I \propto \theta$, hence the instrument has a linear scale

Where B = magnetic field strength between the poles of the magnets

A = area of the plane of the coil

N = number of turns of the coil

k = torsion constant of suspension wire

- (ii) Explain how the design of the moving coil galvanometer can be modified to produce a ballistic galvanometer. (03marks)

The light metal former is replaced by a heavy insulating former. The former is an insulator to minimize eddy currents. The former is made heavy and the suspension fine to achieve a longer period of oscillation.

- (e) A flat circular coil X of 30 turns and mean diameter 30cm is fixed in a vertical plane and carries a current of 3A.

Another coil Y of 2cm x 2cm and having 2000 turns is suspended in a vertical plane at the center of the circular coil. Initially the plane of the two coils coincides. Determine the torque on the coil Y when a current of 2.0A is passed through it. (04marks)

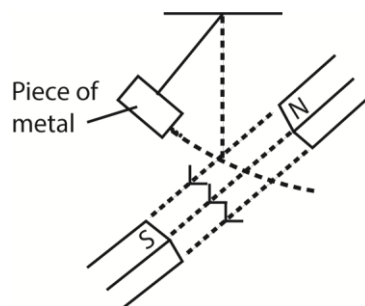
Magnetic flux density at the center of the larger coil $B = \frac{\mu_0 NI}{2R}$

Initial torque on the small coil, $\tau = NBI A \cos\theta$

$$= 200 \times \left(\frac{4 \times 3.14 \times 10^{-4} \times 30 \times 3}{2 \times 15 \times 10^{-2}} \right) \times 2 \times 2 \times 10^{-4} \cos 90^\circ$$

$$= 0$$

39. (a)(i) Describe an experiment to demonstrate the damping effect of eddy current, (04marks)



A metal plate is suspended in a magnetic field so that its plane is perpendicular to the magnetic field. The plane is set to oscillate such that its plane cuts the magnetic field, and the time taken for the oscillation to die out is noted.

The experiment is repeated without a magnetic field.

It is noted that in absence of magnetic field when no eddy currents are induced oscillations take longer to stop.

(ii) Give two practical applications of this effect. (01mark)

- damping of moving coil meters
- melting metals in induction furnaces
- braking in electric train
- speedometer

(b) What is meant by:

(i) self induction? (01mark)

Self-induction is a type of electromagnetic induction where by an e.m.f is induced in a coil due to change in the current flowing in the same coil.

(ii) mutual induction? (01mark)

Mutual induction is a type of electromagnetic induction where by change in current in one coil or induces e.m.f in the neighboring coil or circuit.

(c) Discuss the factors which determine the maximum e.m.f generated by a dynamo. (04mark)

Induced e.m.f, $E = 2\pi fNB A \sin 2\pi ft$

Maximum e.m.f, $E_0 = 2\pi fNB A$

Thus maximum e.m.f increases with increase in

- frequency or angular velocity
- number of turns in the coil
- area of the coil
- magnetic flux density.

(d) A transformer has 2000 turns in the primary coil. The primary coil is connected to a 240V mains. A 12 V, 36W lamp is connected to the secondary coil. If the efficiency of the transformer is 90%, determine the

(i) number of turns in the secondary coil (02marks)

$$N_S = \frac{V_S}{V_P} \times N_P = \frac{12}{240} \times 2000 = 100$$

(ii) current flowing in the primary coil (03marks)

$$I_S V_S = 0.9 I_P V_P$$

$$I_P = \frac{I_S V_S}{0.9 V_P} = \frac{36}{0.9 \times 240} = 0.167 \text{ A}$$

(e) Explain any two factors which lead to energy losses in the transformer.

- Hysteresis – energy spend in turning the magnetic domains, dissipated as heat.
- Eddy currents- Eddy currents circulating in metal dissipate heat by I^2R mechanism
- Flux leakage- all the magnetic flux associated with the primary does not pass through secondary coil
- Resistance of winding lead to I^2R heat loss minimized by use of thick copper wires

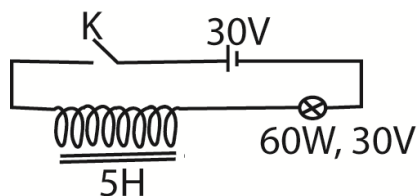
40. (a) (i) Define root mean square value of alternating current. (01mark)

Root mean square value of an alternating current is the value of steady current that dissipates heat at the same rate as alternating current.

(ii) A resistor of 400Ω is connected to 240V a.c. supply. What is the peak value of current flowing through the resistor? (03marks)

$$\begin{aligned} \text{From } V_{r.m.s} &= I_{r.m.s} \times R \\ I_{r.m.s} &= \frac{V_{r.m.s}}{R} = \frac{240}{400} = 0.6 \text{ A} \end{aligned}$$

(b)



A 60W , 30V bulb, and a coil of inductance 5H are connected in series to a battery of 30V as shown above.

(i) What is observed when switch K is closed and when it is opened? (02marks)

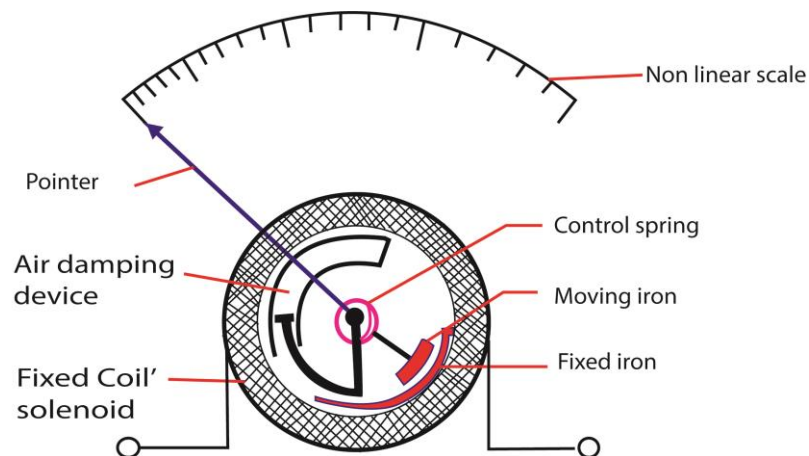
When the switch is closed, the bulb increases slowly to full brightness. When the switch is opened, the bulb dims gradually until it goes off.

(ii) Explain your observation in (b)(i) (04marks)

When the switch is closed, a large back e.m.f is induced in the coil which opposes the flow of current in the circuit. Due to low current the bulb produces dim light. The rate of change of current reduces gradually and the back e.m.f reduces to zero. This leads to maximum current in the circuit causing the bulb to light brightest.

When the switch is opened, the decaying magnetic field in the coil induces an e.m.f in the circuit which tend to reinforce the decaying current. The glow of the bulb gradually reduces before going off.

(c) With the aid of a labelled diagram, describe how a repulsive type of moving iron ammeter works. (05marks).



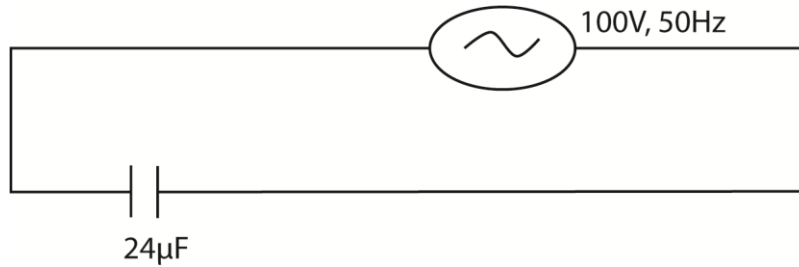
When a current is passed through the coil, the iron rods magnetize in the same poles adjacent to each other in whatever the direction of current. Hence they repel and the pointer move in the same direction until it is stopped by the restoring spring.

Since the magnetic force is proportional to the square of the average current, hence, the deflection is proportional to the square of average current.

Advantage: it measured both direct and alternating current.

Disadvantage: it has nonlinear scale

(d)

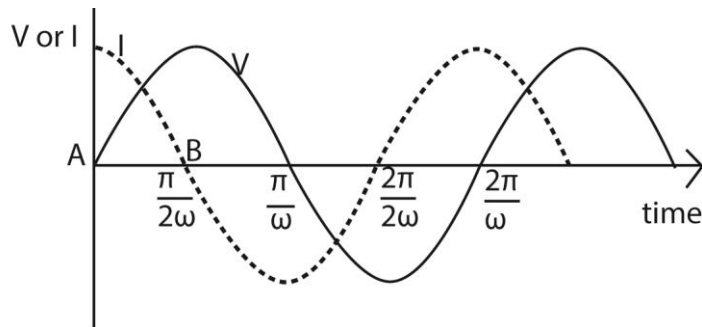


A 100V, 50Hz a.c. supply is connected across a capacitor of 24μF as shown in figure above,

- (i) Calculate the reactance of the circuit (03marks)

$$\text{Capacitive reactance, } X_c = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 50 \times 24 \times 10^{-6}} = 132.6\Omega$$

- (ii) Sketch graphs to show the time-dependence of supplied voltage and the current in the circuit. (02marks)



Explanation

The current I through (not across) a capacitor is $C \frac{dV}{dt}$. This is the slope of the voltage.

When a capacitor is connected to an AC voltage (at the zero crossing) the maximum current flow will occur immediately, i.e. $t = 0, \frac{dV}{dt}$ will approach infinity instantly and then repeat as a sinusoidal waveform.

There will be a peak current at every zero crossing of the voltage waveform. The current waveform will lead the voltage waveform 90 degrees.

41. (a) Define magnetic flux density and state its units (02marks)

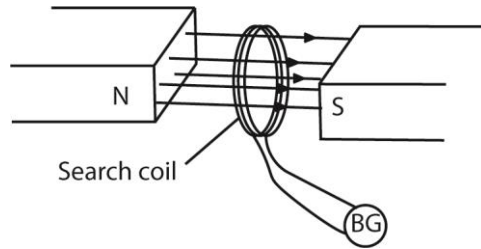
This is the force acting perpendicularly on a conductor carrying a current in a direction normal to the field.

The S.I unit of B is tesla (T)

This is the force acting perpendicularly on a conductor of length one meter carrying a current of one ampere in a direction normal to the field.

(b) Describe how the magnetic flux density between the poles of a powerful magnet can be determined. (03marks)

Solution



A search coil is connected in series with a ballistic galvanometer, B.G and a resistor.

The search coil is placed between the poles pieces of the magnet with its plane normal to the magnetic field.

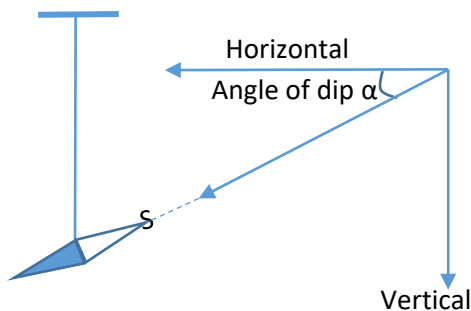
When the ballistic galvanometer pointer settles, the coil is completely withdrawn from the field and the first deflection θ of the B.G is noted.

A capacitor of known capacitance C is charged to a p.d V and then discharged through the ballistic galvanometer and the corresponding θ' is noted.

The magnetic flux density B is now calculated from $B = \frac{CVR\theta}{NA\theta'}$ where A is the area of the coil, N is the number of turns in the coil and R is the resistance of the coil circuit.

(c)(i) Explain with the aid of sketch, the terms angles of dip and declination. (04marks)

Angle of dip (inclination) α : Angle of dip is the angle that the axis of a freely suspended bar magnet makes with the horizontal when the magnet settles.



(ii) Explain what happens to the angle of dip as one moves along the same longitude from the equator to the North Pole. (02marks)

At the equator, the earth's magnetic force is parallel to the surface of the earth and thus the angle of dip is zero.

From the equator towards the North Pole, the field lines the angle of dip increases from zero to 90° . As the field lines bend away from the horizontal. At the North Pole the field lines are perpendicular to the earth's surface.

- (iii) Find the force per unit length on a straight horizontal wire carrying a current of 2.0A in the direction north to south if the angle of dip is 70° and the earth's horizontal field component is 1.6×10^{-5} T. (04marks)

$$B_v = B_H \tan \theta$$

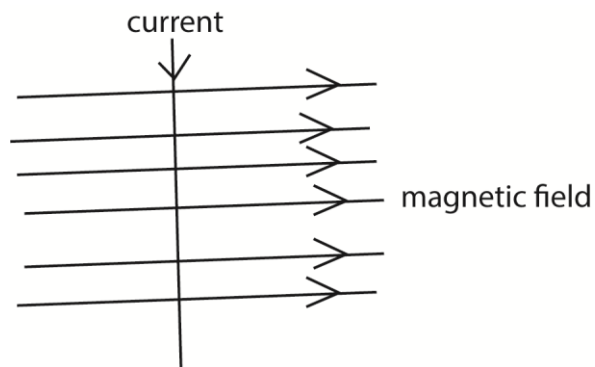
$$\frac{F}{L} = B_v I$$

$$= B_H \tan \theta \times I$$

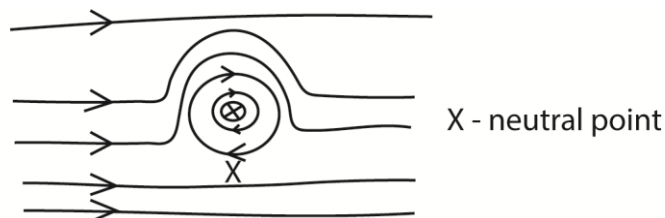
$$= 1.6 \times 10^{-5} \tan 70^\circ \times 2$$

$$= 8.8 \times 10^{-5} \text{ Nm}^{-1}$$

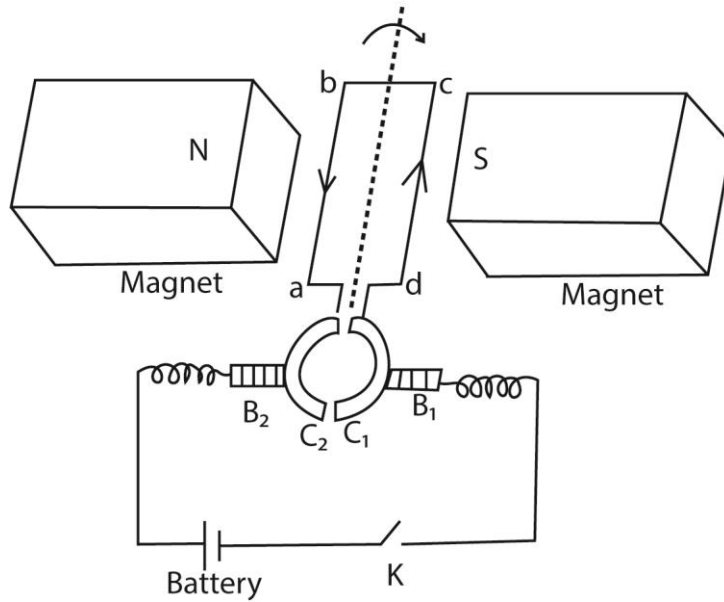
(d)



A wire is placed vertically in a horizontal magnetic field as shown in figure above. Sketch the resultant magnetic field pattern (03marks)



42. (a) (i) With the aid of diagram, describe how a simple d.c. motor works (06marks)



It consists of a rectangular coil abcd of wire pivoted between curved poles of a strong magnet and free to rotate about its axis with a uniform velocity.

The ends of the coil are connected to two halves of split ring (commutators) which press lightly against the carbon brush.

Mode of operation

The switch K is closed and current flows in the coil in the direction shown

Applying Fleming's left hand rule, ab experiences an upward force and side cd a downward force. The two forces constitute a couple which rotates the coil in a clockwise direction.

When the coil passes over the vertical position, the commutators change contact with the carbon brushes and current in the coil is immediately reversed. The force acting on the sides thus change and the coil continues to rotate in the same direction.

Because the conductor cuts the magnetic field, an e.m.f that oppose the supply voltage is induced in it called back e.m.f

If V is the supply voltage and E is the back e.m.f, then the current I_a is given by

$$I_a = \frac{V - E}{R_a} \text{ where } R_a \text{ is the armature resistance}$$

(ii) Explain the significance of back e.m.f. in the operation of a d.c. motor (02marks)

The back e.m.f in a d.c. motor provides the useful power of the motor.

back e.m.f also reduces the heating effect in motor by reducing the current, since

$$I = \frac{V - E_b}{r} \text{ where } E_b = \text{back e.m.f}$$

- (b) A motor of armature resistance 0.75Ω is operated from a 240V d.c. supply.
 (i) When the motor turns freely without a load, the current in the armature is 4.0A and the motor makes 400 revolution per minute. Calculate the back e.m.f. (02marks)

$$V = 240V, R = 0.75\Omega, I = 4.0A$$

$$E_b = V - IR = 240 - 4 \times 0.75 = 240 - 3 = 237V$$

- (ii) When a load is placed on the motor, the armature current increases to 60.0A. Find the new speed of rotation of the motor (04marks)

$$E_{b1} = 237V$$

$$E_b \propto \omega$$

$$\Rightarrow E_{b1} = k\omega_1 \dots\dots\dots (i)$$

$$E_{b2} = k\omega_2 \dots\dots\dots (ii)$$

$$\text{Eqn (ii)} \div \text{Eqn (i)}$$

$$\frac{E_{b2}}{E_{b1}} = \frac{k\omega_2}{k\omega_1}$$

$$\omega_2 = \frac{E_{b2}}{E_{b1}} \times \omega_1$$

$$\text{But } E_{b2} = 240 - 60 \times 0.75 = 195V$$

$$\therefore \omega_2 = \frac{195}{237} \times 400 = 329.1 \text{ revolution per minute}$$

- (c) (i) A circular coil of 10 turns and radius 5.0cm carries a current of 1.0A. Find the magnetic flux density at its center. (02marks)

$$B = \frac{\mu_0 NI}{2R} = \frac{4\pi \times 10^{-7} \times 10 \times 1}{2 \times 5 \times 10^{-3}} = 1.26 \times 10^{-4}T$$

- (ii) A copper wire of cross section area 1.5mm^2 carries a current of 5.0A. The wire is placed perpendicular to magnetic field of flux density 0.2T. If the density of free electrons in the wire is 10^{29}m^{-3} , calculate the force on each electron. (04marks)

$$V = \frac{1}{nLA}$$

Force on the rod, $F = BIL$
 But $I = nevA$, where n = number of electrons per unit volume and v is the drift velocity... (i)
 $F = BnevA$
 \therefore Force of each electron, $F' = \frac{F}{N} = Bev \dots\dots\dots (ii)$

$$\text{From } v = \frac{1}{neV}$$

Putting into EQn

$$F' = \frac{Ble}{neA} = \frac{BI}{nA} = \frac{0.2 \times 5}{10^{29} \times 1.5 \times 10^{-6}} = 6.67 \times 10^{-24}N$$

43. (a) Define the terms root mean square, peak of an alternating current and derive the relation between them for a sinusoidal a.c. (06marks)

Peak of an alternating current is the maximum value of alternating current.

Root mean square value of an alternating current is the value of steady current that dissipates heat at the same rate as alternating current.

(b) A sinusoidal alternating current, $I = I_0 \sin \omega t$, passes through a pure inductor of inductance, L

(i) Derive an expression for the reactance of the inductor. (04marks)

$$\text{Induced e.m.f} = -L \frac{dI}{dt}$$

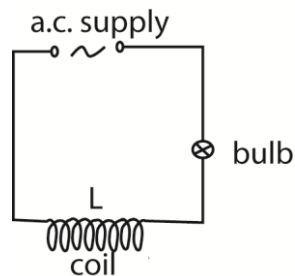
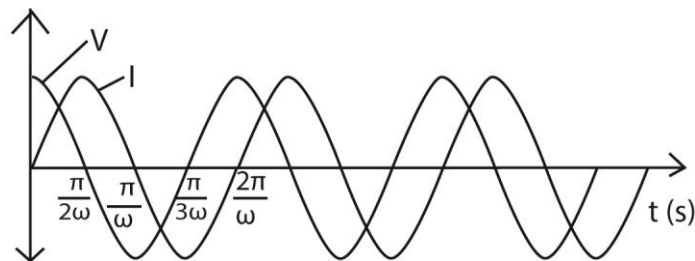
$$E = -L \frac{d(I_0 \sin \omega t)}{dt} = -\omega L I_0 \cos \omega t$$

Current flow in a pure inductor, $V = -E = \omega L I_0 \cos \omega t$

Hence $V = V_0 \cos \omega t$ where $V_0 = \omega L I_0$

$$\text{Inductance} = X_L = \frac{V_0}{I_0} = \frac{\omega L I_0}{I_0} = \omega L$$

(ii) Using the axes, sketch graphs to show the relative phases of the current and voltage across the inductor. (02marks)



The figure above is a circuit consisting of an air coil, L , a bulb, X and an alternating voltage source connected in series, an iron core is introduced into the coil. Explain why the

(i) Bulb becomes dimmer (03marks)

When the iron core is introduced in the coil, the magnetic flux linking the coil is enhanced. The rate of change of magnetic flux linking the coil thus increases,

leading to increase in back e.m.f. High e.m.f. leads to low current flowing through the bulb, hence dim light.

(ii) Iron core becomes warm. (02marks)

The iron core warms up due to:

- Hysteresis: E energy used to turn the magnetic domains of the core is dissipated as heat.
- Eddy currents induced in the core are dissipated as heat by I^2R mechanism.

(d) Explain why a moving coil ammeter cannot be used to measure alternating current from the mains. (03marks)

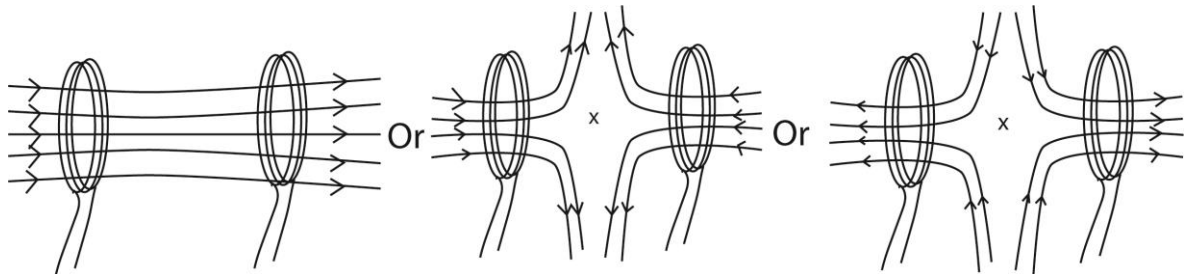
The coil rotates about a vertical axis between the north and south concave poles of strong magnet. This provides a radial magnetic field. When an alternating current is passed through the coil, the torque on the coil reverses direction at the same frequency as current. The pointer vibrates with very small amplitude about the mean position hence a steady current reading cannot be taken

44. (a) Define magnetic flux density. (01mark)

Magnetic flux density is the force acting on a 1m long conductor carrying current of 1A in a direction perpendicular to magnetic field.

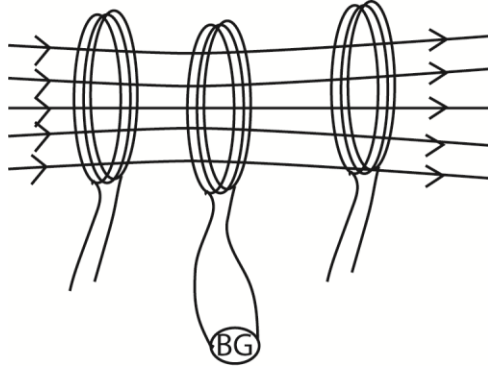
(b) Two identical circular coils are placed coaxially at distance equal to the radius of each coil.

(i) Sketch the magnetic field pattern which results when equal current are passed through the coils. (02marks)



(ii) Describe how you would investigate the variation of magnetic flux density with distance along the axis of the coils. Draw a sketch graph to show the expected results. (06marks)

Solution



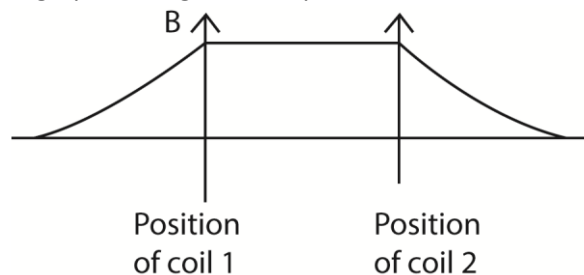
- A search coil is connected in series with a ballistic galvanometer, B.G.
- The search coil is placed such that its plane is parallel to those of the coils.
- When the ballistic galvanometer pointer settles, the coil is completely withdrawn from the field and the first deflection θ of the B.G is noted.
- A capacitor of known capacitance C is charged to a p.d V and then discharged through the ballistic galvanometer and the corresponding θ' is noted.
- The magnetic flux density B is now calculated from $B = \frac{CVR\theta}{NA\theta'}$

Where A = the area of the coil,

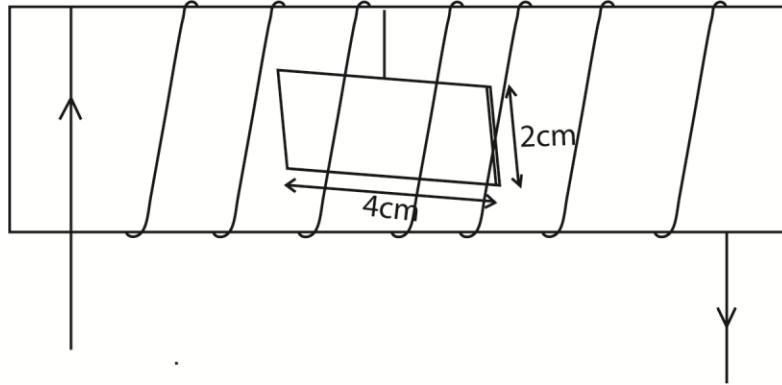
N = the number of turns in the coil and;

R = the resistance of the coil circuit.

- The procedure is repeated for different distances, X , from the coils
- A graph of B against X is plotted.



(c) A small rectangular coil of 10 turns and dimensions 4cm by 2cm is suspended inside a long solenoid of 1000 turns per meter so that its plane lies along the axis of the solenoid as shown in the figure below. The coil is connected in series with solenoid.



The coil deflects through 30° when a current of 2.0A is passed through the solenoid. Find the torsion constant of the suspension. (05mark)

$$n = 1000, I = 2A, N = 10 \text{ A} = 4 \times 2 \times 10^{-4} = 8 \times 10^{-4} \text{ m}^2$$

$$\begin{aligned} \text{Magnetic flux density in the center of the coil, } B &= \mu_0 n I \\ &= 4\pi \times 10^{-7} \times 1000 \times 2 \\ &= 2.512 \times 10^{-3} \end{aligned}$$

$$\text{Deflection torque} = \tau = BAN I$$

This torque is equal to opposing, $\tau' = C\theta$ where C is the torsion constant.

At equilibrium

$$BAN I = C\theta$$

$$C = \frac{BAN I}{\theta} = \frac{2.512 \times 10^{-3} \times (8 \times 10^{-4}) \times 10 \times 2}{\pi/6} = 7.68 \times 10^{-5} \text{ Nmrad}^{-1}$$

(d) A moving coil galvanometer reads 15mA when it is connected in series with a source of e.m.f of negligible internal resistance is replaced with one of resistance 100Ω .

The galvanometer reads 10mA when the 100Ω resistor is replaced with one of resistance 200Ω . Find the

(i) Resistance of the galvanometer

Let r be the resistance of the galvanometer

$$\text{From } V = (R + r)I$$

$$V = 15 \times 10^{-3} (100 + r) = 10 \times 10^{-3} (200 + r)$$

$$r = 100\Omega$$

(ii) E.m.f of the source.

Substituting for r,

$$V = 15 \times 10^{-3} (100 + 10) = 3,0V$$

45. (a) State the laws of electromagnetic induction (02marks)

Faraday's law of electromagnetic induction states that magnitude of induced in a circuit is directly proportional to the rate of change of magnetic flux linkage in the circuit.

Lenz's Laws states that the direction of the induced current is such as to oppose the change causing it.

- (b) A coil of 100turns is wound round the middle of a long solenoid of 500 turns per meter and radius 8.0cm
 A sinusoidal current $I = 10\sin(120\pi t)$, amperes, is passed through the solenoid winding.
 Find the amplitude of e.m.f induced across the terminals of the coil. (05mark)

Solution

$$|E| = \frac{d(N\phi)}{dt} = N \frac{d(BA)}{dt}$$

$$\text{But } B = \mu_0 n I$$

$$\therefore |E| = NA\mu_0 n \frac{d}{dt}(10\sin 120\pi t)$$

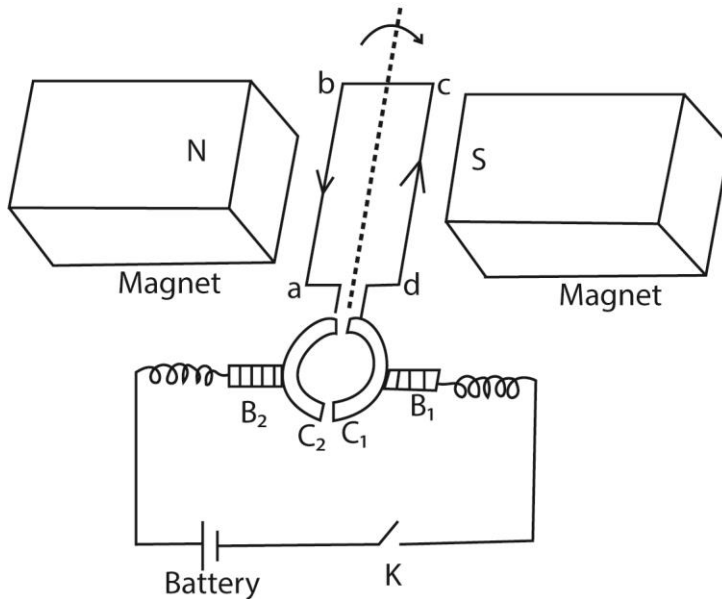
$$= NA\mu_0 n \cdot 120\pi \cdot \cos 120\pi t$$

$$\text{Amplitude of induced e.m.f, } E_0 = NA\mu_0 n \cdot 120\pi$$

$$= 100 \times (\pi \times 8^2 \times 10^{-4}) \times 4\pi \times 10^{-7} \times 500 \times 120 \pi$$

$$= 4.75V$$

- (c)(i) With the aid of labelled diagram, describe the structure and action of a simple d.c. motor. (07marks)



It consists of a rectangular coil abcd of wire pivoted between curved poles of a strong magnet and free to rotate about its axis with a uniform velocity.

The ends of the coil are connected to two halves of split ring (commutators) which press lightly against the carbon brush.

Mode of operation

The switch K is closed and current flows in the coil in the direction shown

Applying Fleming's left hand rule, ab experiences an upward force and side cd a downward force. the two forces constitute a couple which rotates the coil in a clockwise direction.

When the coil passes over the vertical position, the commutators change contact with the carbon brushes and current in the coil is immediately reversed. The force acting on the sides thus change and the coil continues to rotate in the same direction.

Because the conductor cuts the magnetic field, an e.m.f that oppose the supply voltage is induced in it called back e.m.f

If V is the supply voltage and E is the back e.m.f, then the current I_a is given by

$$I_a = \frac{V-E}{R_a} \text{ where } R_a \text{ is the armature resistance}$$

- (ii) Explain the term back e.m.f in a motor and derive its relation to the efficiency of the motor. (03marks)

When the armature coil of a motor rotates in magnetic field, an, e.m.f is induced in the coil. The induced e.m.f opposes the applied p.d. and is therefore a back e.m.f.

If V , E and r are applied p.d, induced e.m.f and resistance to the armature coil respectively, then the current flowing in the coil is given by

$$I = \frac{V-E}{r}$$

$$\Rightarrow V - E = Ir$$

Multiplying through by I

$$VI = EI + I^2r$$

Since I^2r is the power dissipated as heat in the armature, EI is the mechanical power output and VI is the power supplied.

$$\text{Efficiency of the motor, } \eta = \frac{EI}{VI} \times 100\%$$

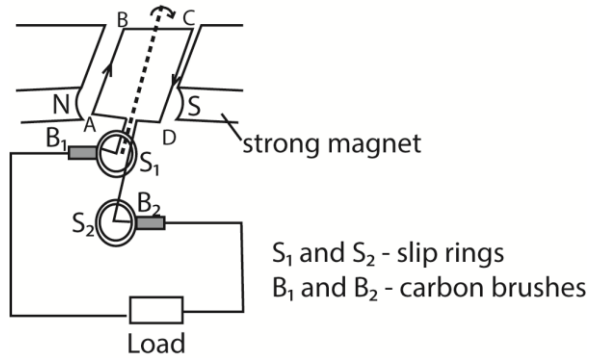
$$= \frac{E}{V} \times 100\%$$

- (d) Briefly explain one application of eddy currents (03marks)

- Damp and slow down the oscillation of a pointer of the galvanometer.
- Melting of metals in induction furnace
- Electric brakes

46. (a) (i) Describe with the aid of a diagram, the structure and mode of operation of a.c. generator. (05marks)

Solution



How it works

- The coil is rotated in a magnetic field, the magnetic field linked with it changes and hence e.m.f. is induced by means of slip rings which press slightly against the carbon brushes.
- Applying Fleming's right hand rule, the induced current enters the coil AB and leaves the coil via CD.
- Starting with the coil in the vertical position, the magnetic flux linking it is maximum and hence no induced e.m.f.
- The induced e.m.f. increases with the position of the coil in the magnetic field until it becomes maximum with the coil in horizontal position and then decreases to zero as the coil rotates to the vertical position.
- The force acting on the sides of the coil changes as the coil passes over the position and hence the current flowing in the coil reverses. Hence an alternating e.m.f. or current flows through the load.

- (ii) Explain the structural modifications needed to convert an a.c. generator to a d.c. generator. (02marks)

To convert an a.c. generator to a d.c. generator, the ends of the rectangular coil are connected to commutators instead of a pair of slip rings.

- (b)(i) Define the terms peak value and root mean square (r.m.s) value of alternating voltage (02marks)

Root mean square value is the value of direct current which dissipates heat in a given resistor at the same rate as the a.c.

- (ii) An electric kettle draws $1.5 \times 10^3 \text{ W}$ from a 240V mains supply. Find the peak value of the current drawn by the kettle, if the voltage is sinusoidal. (03marks).

$$P = 1.5 \times 10^3 \text{ W}, V_{r.m.s} = 240 \text{ V}$$

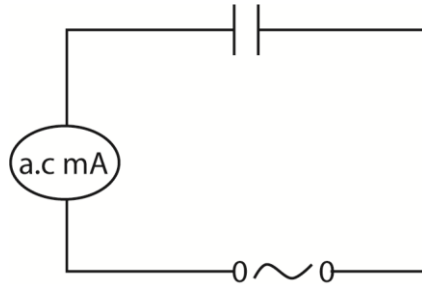
$$P = I_{r.m.s} \times V_{r.m.s}$$

$$I_{r.m.s} = \frac{1.5 \times 10^3}{240} = 6.25 \text{ A}$$

$$I_0 = \sqrt{2} \times I_{r.m.s} = \sqrt{2} \times 6.25 = 8.84A$$

(c) An alternating voltage of 12V and variable frequency, f , is connected in series with a capacitor of capacitance, C .

(i) Explain why current apparently flows through the capacitor. (05marks)



During the first quarter cycle, the capacitor charges in one direction until the p.d. between the plates is equal to supply voltage.

In the second quarter a cycle, the supply voltage decreases and the p.d between the capacitor plates drives charge in opposite direction.

The charge gets depleted from the plates but the flow of charge continues in the same direction, thus charging in opposite sense.

In the fourth quarter cycle, voltage begins to decrease and capacitor drives charge in the circuit in opposite direction.

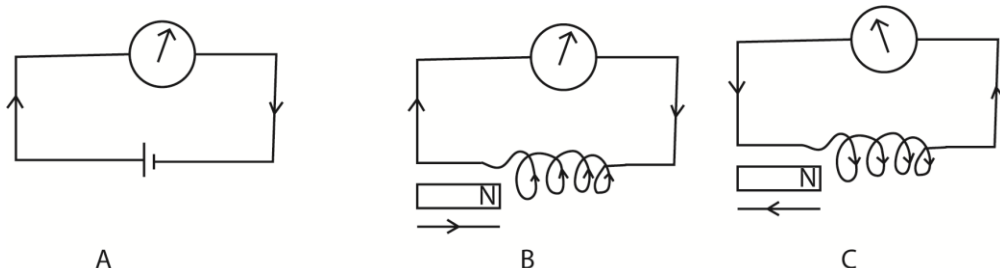
The process is repeated many times per second such that the millimeter shows continuous flow of current.

(ii) Calculate the value of the current in the circuit when f and C are 1kHz and $0.5\mu F$ respectively. (03marks)

$$\text{From } \frac{V_{r.m.s}}{I_{r.m.s}} = \frac{1}{2\pi f C}$$

$$I_{r.m.s} = V_{r.m.s} \times 2\pi f C = 12 \times 2\pi \times 1000 \times 0.5 \times 10^{-6} = 3.77 \times 10^{-2}A$$

47. (a) with the aid of a diagram, describe briefly an experiment to illustrate Lenz's law of electromagnetic induction (05marks)



- The galvanometer is first connected in series with a battery and the direction for a given direction of current is determined.
- The battery is disconnected and is replaced by a coil of known winds.
- A strong permanent magnet is brought towards the coil with N-pole facing the coil, the galvanometer deflects in a direction for which the side of the coil facing the magnet is N-pole.
- When the magnet is move away from the coil, the galvanometer deflects in opposite direction, implying that the pole near the coil is a S-pole.
- In the first case, the pole due to the induced current was repelling the approaching magnet, while in the second case, the pole was attracting the receding magnet.
- The induced current therefore is in such as to oppose the change causing it, which is Lenz's law.

(b) Explain the main precautions taken in the construction of an a.c. transformer.

(04marks)

The main precaution

- Low resistance copper wire are used to reduce I^2R losses.
- Laminated core reduce Eddy currents
- Use of soft iron core reduce hysteresis
- Winding secondary coil on top of primary to reduce magnetic flux leakage.

(c) Explain the effect of the following on the voltage across the secondary coil of a.c transformer.

(i) A fall in the supply frequency of the current in the primary (04marks)

Transformer works on the principal of mutual induction i.e. induced e.m.f in the secondary.

$$E_s = \frac{d(N\phi)}{dt} = \frac{d(NAB)}{dt}$$

But $B = \mu_0 I_0 \sin 2\pi ft$

$$\therefore E_s = NAI_0 \frac{d(\sin 2\pi ft)}{dt}$$

$$= NAKI_0 \cdot 2\pi f \cos 2\pi ft$$

$$E_0 = NAKI_0 \cdot 2\pi ft$$

Hence when the supply frequency falls, the output voltage also falls.

(iii) A reduction in the primary turns. (02marks)

$$\frac{N_p}{N_s} = \frac{V_p}{V_s}$$

$$V_s = \frac{N_s V_p}{N_p}$$

Hence a reduction in primary turns causes an increase in secondary voltage.

- (d) A transformer whose secondary coil has 60 turns and primary 1200 turns, has its secondary connected to a 3Ω resistor. If its primary is connected to a 240V a.c supply, calculate the current flowing in the primary assuming that the transformer is 80% efficient. (05marks)

$$V_S = \frac{N_S V_P}{N_P} = \frac{60 \times 240}{1200} = 12V$$

$$I_S = \frac{V_S}{R} = \frac{12}{3} = 4.0A$$

$$V_S I_S = 0.8 V_P I_P$$

$$12 \times 4 = 0.8 \times 240 \times I_P$$

$$I_P = 0.25A$$

48. (a) When can an alternating current be referred to as being sinusoidal?(01mark)
An alternating current is referred to as sinusoidal when its variation with time can be represented by a sine wave.

(b) Define

- (i) the root mean square value of an alternating current (01mark)

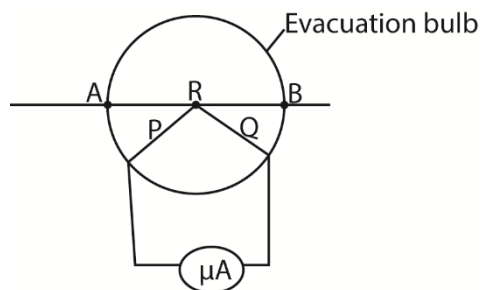
Root mean square value of an a.c is the value of steady current which dissipates heat at the same rate in a given resistor as a.c.

- (ii) reactance (01mark)

Reactance is non resistive opposition to the flow of a.c through an inductor or capacitor.

- (c) Describe the structure and action of a meter that makes use of a thermocouple in measuring the root mean square value of an alternating current. Why this meter does has high sensitivity. (05marks)

Solution



P and Q are dissimilar wires

Current to be measured is passed through the wire AB and heats the junction R of the thermocouple. The thermoelectric effect generated at R causes a direct current to flow through the micrometer calibrated to measure the r.m.s value of current.

The meter has high sensitivity because of its low inductance and capacitance

(d) (i) Show that current leads voltage by 90° when a sinusoidal voltage is applied across a capacitor. (05marks)

Solution

Let p.d across the capacitor at time t be V

$$V = V_0 \sin 2\pi ft$$

Charge on the capacitor is $Q = CV$, where C is the capacitance of the capacitor.

The instantaneous current flowing through the capacitor,

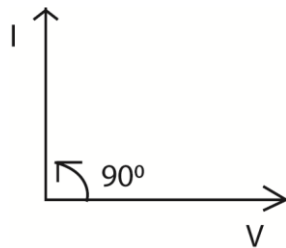
$$\begin{aligned} I &= \frac{dQ}{dt} \\ &= \frac{d(CV_0 \sin 2\pi ft)}{dt} \\ &= 2\pi f CV_0 \cos 2\pi ft \end{aligned}$$

From trigonometry, $\cos 2\pi ft = \sin (2\pi ft + \frac{\pi}{2})$

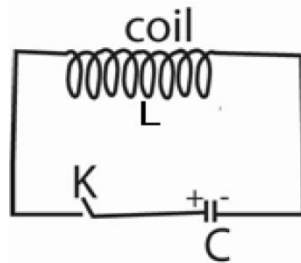
$$\Rightarrow I = 2\pi f CV_0 \sin(2\pi ft + \frac{\pi}{2})$$

Hence current leads voltage by $\frac{\pi}{2} = 90^\circ$.

(ii) Sketch a phase diagram to illustrate the orientation of the current vector with respect to voltage vector in (d)(i) above. (01mark)



(e)



An inductor, L, a capacitor, C and switch, K, are connected as shown above. Explain, briefly what happens when the switch K is closed (06marks)

When switch K is closed, the charged capacitor begins to discharge and current flows. A magnetic field now begins to build up around L, and by Lenz's law, an e.m.f is induced in L so as to oppose the current, C therefore discharges slowly. When it is completely

discharged, the electrical energy originally stored in the electric field between the capacitor plates has been transferred to magnetic field around L.

At this instant, the magnetic field begins to collapse and a p.d is induced in L which tries to maintain the field. Current therefore flows in the same direction as before and C gets charged in the reverse sense creating a magnetic field of opposite polarity.

Discharge again occurs in opposite direction to attain the initial charge on either plates and the whole process is repeated over and over again.

49. (a) What is meant by magnetic meridian? (01mark)

Magnetic meridian is the vertical plane through the earth containing the earth's magnetic axis. Or it is a vertical plane in which a freely suspended magnet sets.

(b)(i) Describe the effect of eddy currents in a dynamo and state how they can be reduced? (03mark)

Eddy currents cause heating up of the dynamo armature core. This reduces efficiency since some of the energy input is converted into heat. This problem is reduced by laminating the core to prevent circulation of these currents.

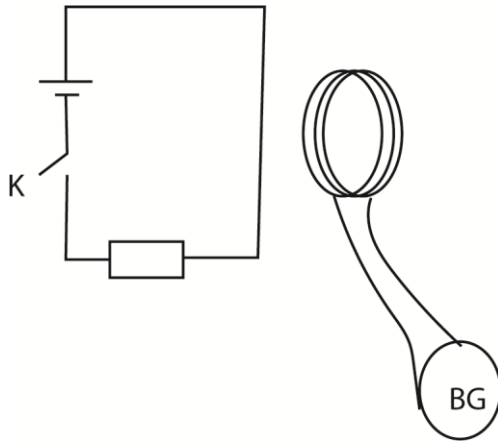
(ii) Explain why eddy currents are useful in a moving coil galvanometer. (03marks)

In a moving coil galvanometer, eddy currents damp the oscillation of the coil. This makes the pointer to settle at point quickly. It is desirable for quick and accurate reading.

(iii) What is the difference between a motor and dynamo? (02marks)

A motor converts electrical into mechanical energy while a dynamo converts mechanical into electrical energy.

(c) Describe how a search coil and calibrated ballistic galvanometer can be used to measure magnetic flux density at a given point near a wire carrying current. (06marks)



A search coil of known geometry connected in series with a ballistic galvanometer BG is placed close and with its plane parallel to the wire under test.

Switch K is closed and deflection θ_1 on BG is taken.

K is then opened and deflection θ_2 on BG is taken again.

The average $\theta = \frac{\theta_1 + \theta_2}{2}$ is determined

Now $Q = k\theta$

Also, $Q = \frac{BAN}{R}$

$\therefore B = \frac{kR}{AN}$

Where A = Area of the coil

N = Number of turns

R- total resistance of the circuit

k = calibration constant

(d) An aircraft is flying horizontally at 800kmh^{-1} at a point where the earth's magnetic flux density is $2.31 \times 10^{-5}\text{T}$ and angle of dip is 60° . If the distance between the wing tips is 50m, calculate the potential difference induced between its wing tips. (05marks)

$$B_v = 2.31 \times 10^{-5} \sin 60^\circ = 2 \times 10^{-5} \text{ T}$$

$$\text{e.m.f induced} = BLu = B_v Lu = 2 \times 10^{-5} \times 50 \times 800 \times \frac{1000}{3600} = 0.22\text{V}$$

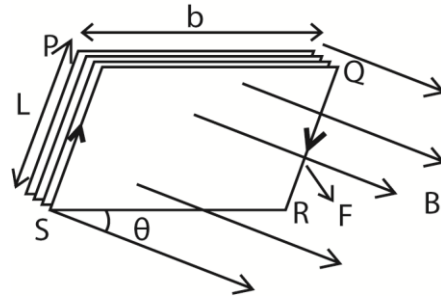
u = velocity in m/s

50. (a) (i) Write down the expression for the force exerted on a straight wire of length, L meter carrying a current, I amperes at right angles to magnetic field of flux density B tesla (01marks)

$$F = BIL$$

- (ii) A rectangular coil of N -turns and area $A \text{ m}^2$ is suspended in a uniform magnetic field of flux density B tesla. Initially the plane of the coil is at right angles to the magnetic field. Derive an expression for the initial couple on the coil when a current I amperes flows through the coil. (05marks).

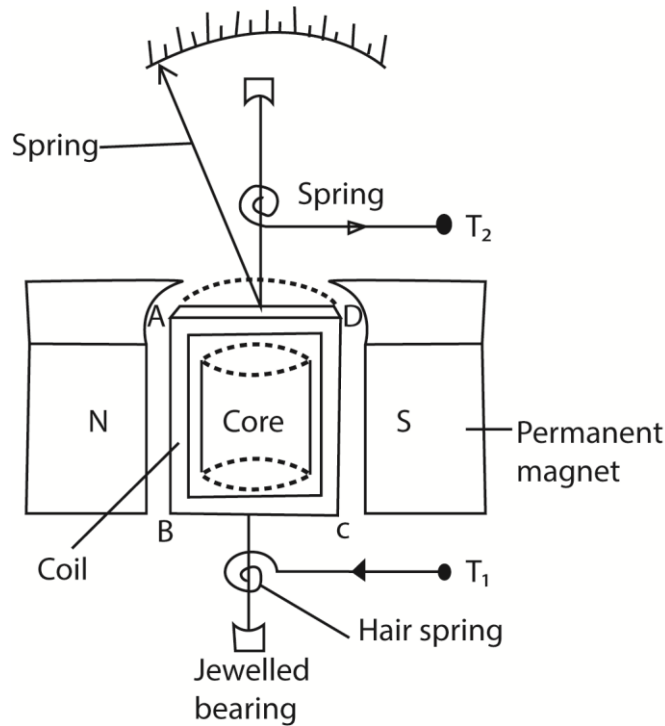
Solution



- When current flows through the coil, the conductor experiences a magnetic force.
- Force on side PQ = $NBIb$ (downwards) while Force on side RS = $NBIN$ (upwards). The two forces cancel out due to rigidity of the coil.
- Side PS experiences force $NBIL$ perpendicularly into the page while RQ experiences force $NBIL$ perpendicularly out of page. The two forces constitute a couple whose moment of force

$$\begin{aligned} \tau &= F \times b \\ &= NBILb \\ &= NBIA \text{ (where is the area = } L \times b \text{)} \end{aligned}$$

- (b) Draw a labelled diagram of a moving coil galvanometer and explain how it works (06 marks)



Structure

- It consists of a rectangular coil of fine insulated copper wire wound on an aluminium frame to provide electromagnetic damping.
- The coil together with the frame of aluminium are mounted over a soft iron cylindrical core and freely pivoted on jewelled bearing to minimize friction at contact.
- The suspension torsion wire suspending the coil is attached to a pair of control hair springs T_1 and T_2 for feeding current in and out of the coil and control rotation of the coil.
- The coil is then suspended between concave pieces of a strong magnet to provide magnetic field.

Mode of action

- Current I to be measured is passed into the coil via hair spring T_1 .
- The current then causes the coil to experience a deflection torque, $\tau = NABl$ due to a couple force causing rotation in a radial magnetic field.
- The coil turns with the pointer through angle θ until stopped by restoring torque, $\tau = k\theta$ provided by a pair of hair springs T_1 and T_2 .

At equilibrium, $NABl = k\theta$

$$\therefore \text{current } I = \left(\frac{k}{NAB} \right) \theta$$

- $I \propto \theta$, hence the instrument has a linear scale

Where B = magnetic field strength between the poles of the magnets

A = area of the plane of the coil

N = number of turns of the coil

k = torsion constant of suspension wire

- (c) A small circular coil of 10 turns and mean radius 2.4cm is mounted at the center of a long solenoid of 750 turns per meter with its axis at right angles to the axis of the solenoid. If the current in the solenoid is 2.0A, calculate the initial torque on the circular coil when a current of 1.0A is passed through it. (05marks)

Solution

For a solenoid, $B = \mu_0 n I = 4\pi \times 10^{-7} \times 750 \times 2 = 1.88 \times 10^{-3} \text{T}$

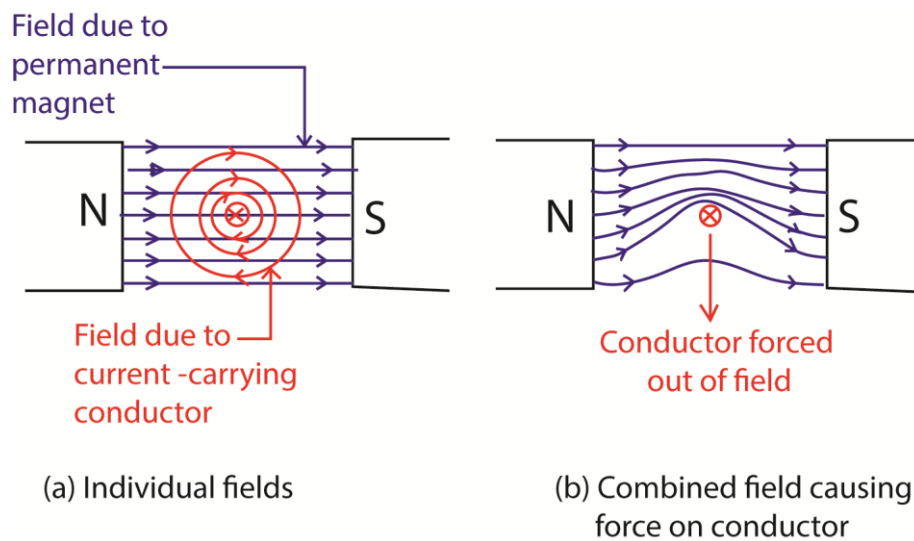
Initial torque, $\tau = B I A N$

$$= 1.88 \times 10^{-3} \times 1 \times (\pi (2.4 \times 10^{-2})^2) \times 10$$

$$= 3.69 \times 10^{-5} \text{Nm}$$

- (d) Explain why a current carrying conductor placed in a magnetic field experience a force. (03marks)

Solution



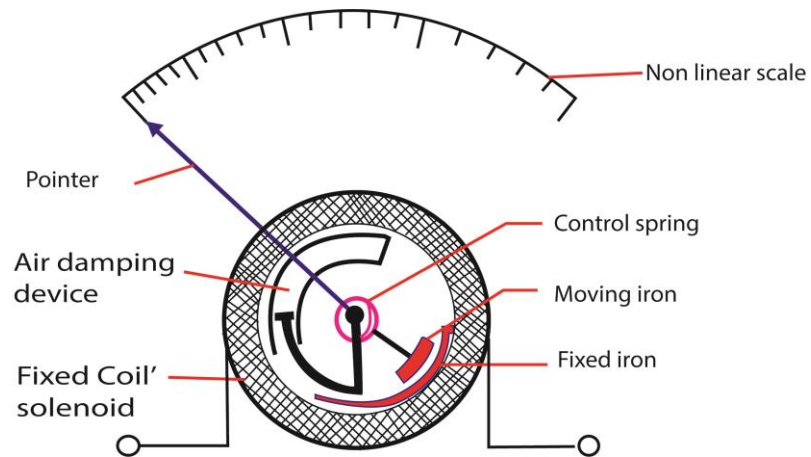
The current in the wire setup a magnet field around the wire. When the field due to the wire interacts with the external magnetic field. The resultant magnetic field has greater flux density above the wire than below it.

The wire moves from a region of greater magnetic flux density. Hence the wire moves downwards.

51. (a) (i) What is meant by the root mean square value of alternating current? (01mark)

Root mean square value of an a.c is the value of steady current which dissipates heat at the same rate in a given resistor as a.c.

- (ii) Describe with the aid of a labelled diagram, the structure and action of a moving iron meter. (05marks)



When a current is passed through the coil, the iron rods magnetize in the same poles adjacent to each other in whatever the direction of current. Hence they repel and the pointer move in the same direction until it is stopped by the restoring spring.

Since the magnetic force is proportional to the square of the average current, hence, the deflection is proportional to the square of average current.

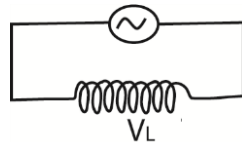
Advantage: it measured both direct and alternating current.

Disadvantage: it has nonlinear scale

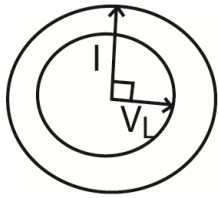
- (iii) What is meant by the term reactance? (01mark)

Reactance is the opposition to the passage of alternating current through a capacitor.

- (b) In the diagram below, V_L is the voltage drop across the inductor.

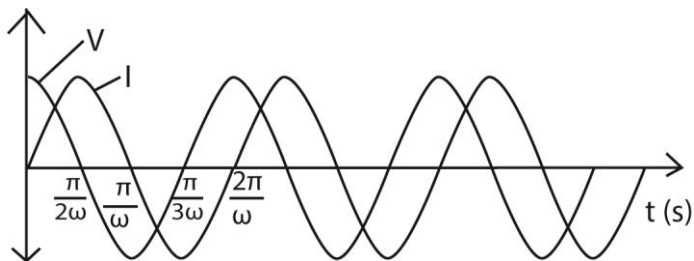


- (i) Draw a vector diagram to show the orientation of V_L with respect to current I (01mark)

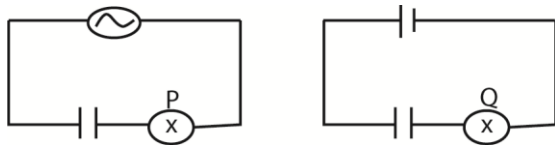


Note that vector diagrams are also called phase diagrams since they indicate phase angle and quantities. In this case V_L leads I by $\pi/2$

- (ii) Using the same axes, sketch graphs to show the variation of V_L with current I with time (02marks)

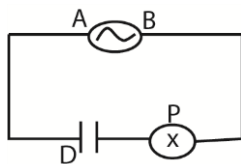


- (c)



The bulb P and Q have the same rating. P is connected in series with a capacitor across an a.c source while Q is connected in series with an identical capacitor across a d.c., source of e.m.f equal to root mean square voltage of the a.c as shown in the figure above. Explain why bulb P light continuously while bulb Q does not. (05marks)

Solution

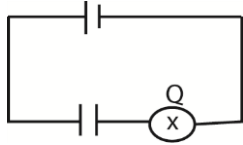


During the half cycle when end A is positive, plate D of the capacitor is charged positively.

During the next half cycle, plate D loses its positive charge and becomes negatively charged.

Current moves to and fro in the wires connected to the capacitor.

Since the filament of the bulb heats up regardless of the direction of current through it, the bulb light continuously.



Q lights initially because the initial rate of charge flow is high and then goes out because the p.d that develops across the plates of the capacitor oppose flow of current. In fact when the capacitor is fully charged no current flows through it.

(d) A 240V, 60W alternating voltage is applied across a capacitor of capacitance $10\mu\text{F}$. Calculate the

(i) root mean square value of the current which flows (04marks)

$$I_{r.m.s} = \frac{V_{r.m.s}}{X_C}$$

$$\text{But } X_C = \frac{1}{2\pi fC}$$

$$\Rightarrow I_{r.m.s} = 2\pi fC V_{r.m.s}$$

$$\text{Also, } V_{r.m.s} = \frac{V_0}{\sqrt{2}}$$

$$\text{Thus, } I_{r.m.s} = 2\pi fC \frac{V_0}{\sqrt{2}} = \frac{2\pi \times 60 \times (10 \times 10^{-6}) \times 240}{\sqrt{2}} = 0.64\text{A}$$

(ii) power expended. (01marks)

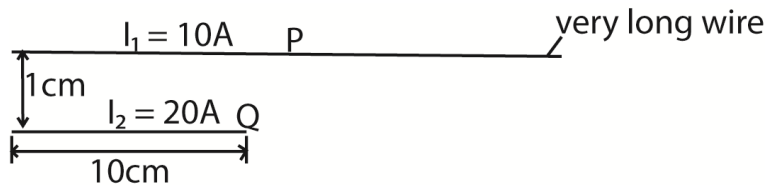
$$\text{Power expended} = 0$$

A capacitor is worthless component in an a.c. circuit

52. (a) (i) Define ampere (01mark)

The ampere is the current which when maintained in two parallel conductors of negligible cross section area and a separation of 1m cause a force of $2 \times 10^{-7}\text{N}$ per meter between them.

(ii)



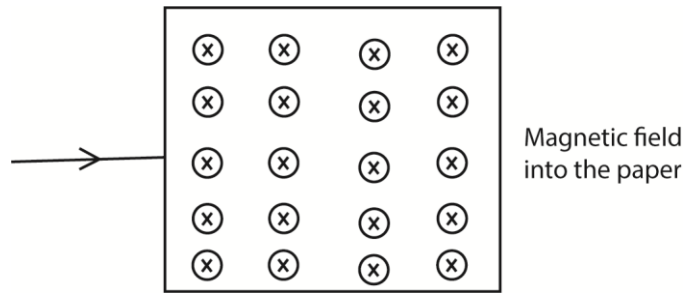
The diagram in the figure above show a parallel wire P and Q placed 1cm apart and carrying current currents of 10A and 20A respectively in the same direction. If wire Q is 10cm long, find the magnetic force acting on it. (04marks)

Force, $F = BI_1L$

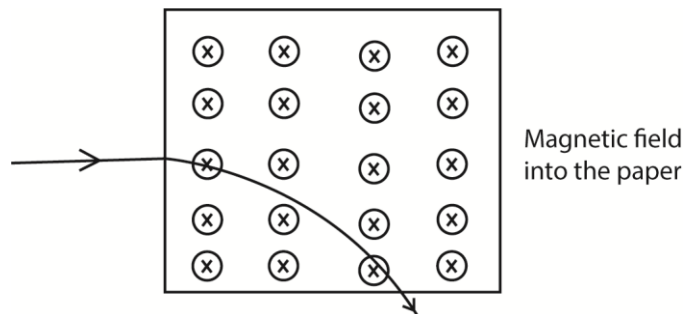
$$\text{But } B = \frac{\mu_0 I_2}{2\pi r}$$

$$\text{Thus, } F = \frac{\mu_0 I_1 I_2 L}{2\pi r} = \frac{4\pi \times 10^{-7} \times 10 \times 20 \times 10 \times 10^{-2}}{2\pi \times 1 \times 10^{-2}} = 4 \times 10^{-4} \text{N (from Q towards P)}$$

(b) A stream of electrons enter normally, a uniform magnetic field which is perpendicular to and directed into the plane of the page as shown below



Explain, with the aid of a diagram, the path of electrons while inside the field and after leaving it (06marks)



Current flows in the direction opposite to that of electrons. Applying Fleming's left hand rule, electrons are deflected downwards, i.e. electrons are deflected downwards describing a circular path.

When electrons move out of the field, the magnetic force become zero. The electrons now move in a straight line tangential to the circle at the point of exit

(c) Explain why, when a current is switched off in some circuits, a spark is seen across the gap of the switch. (03mark)

When current is switched off, there is a sudden change in magnetic flux from a large value to zero in a very short time.

Consequently, a high voltage is induced across the open switch. The high voltage ionizes the air in the gap. Then positive ions and negative ions combine violently causing a spark.

(d) Show that the total charge which passes through a coil depends only on the resistances of the coil and the total flux linked. (06marks)

Consider a coil of N turns and total resistance, $R\Omega$, in which the flux linking each turn is changing and has a value of ϕ at time t .

The induced e.m.f, $E = -\frac{d(N\phi)}{dt}$

Induced current, $I = \frac{E}{R} = -\frac{N}{R} \left(\frac{d\phi}{dt} \right)$

But I is the rate of change of charge,

$$\therefore I = \frac{dQ}{dt}$$

$$\Rightarrow \frac{dQ}{dt} = -\frac{N}{R} \left(\frac{d\phi}{dt} \right)$$

If the flux changes, say from ϕ_1 to ϕ_2 , the total charge, Q , that passes is given by

$$\int_0^Q dQ = -\frac{N}{R} \int_{\phi_1}^{\phi_2} d\phi$$

$$Q = -\frac{N(\phi_2 - \phi_1)}{R} = -\frac{\text{change in magnetic flux}}{R}$$

Therefore the total charge which passes through a coil depends only on the resistance of the coil and the total flux linkage.

53. (a) Distinguish between self-induction and mutual induction. (03marks)

Self-induction is the process by which e.m.f is induced in a circuit due to changing current in the same circuit.

Mutual induction is the process by which e.m.f is induced in a circuit due change in current in the nearby circuit.

(b) (i) explain the factors which affect the efficiency of a transformer. (04marks)

- Joule heat loss in the winding. Current in the winding leads to dissipation of electrical energy as heat by I^2R mechanism.
- Eddy currents loss. When the magnetic flux linking the core of transformer changes, currents called eddy currents are induced in the core. The currents cause dissipation of electrical energy in form of heat.
- Hysteresis loss. When alternating currents flow in the primary coil, movement of magnetic domains in the core leads to dissipation of energy known as hysteresis loss.
- Loss of magnetic flux. Not all the magnetic flux linking the primary links the secondary which results in energy loss.

(ii) Power of 6000W is produced at 100V is to be transmitted over a distance of 2km through cables of resistance 0.2Ω . Determine the voltage at the output of transformer needed to transmit the power so that only 5% of it is lost. (assume the transformer is 100% efficient) (05 marks)

Solution

$$\begin{aligned} \text{Power} &= I^2 R \\ &= 12 \times 0.2 \times 2000 \\ &= 400 I^2 \end{aligned}$$

$$\text{Hence } \frac{400 I^2}{6000} = \frac{5}{100}$$

$$\Rightarrow I^2 = \frac{60}{4} \times \frac{5}{100} = 0.75$$

$$I = 0.866 \text{A}$$

Current in secondary of the transformer is 0.866A

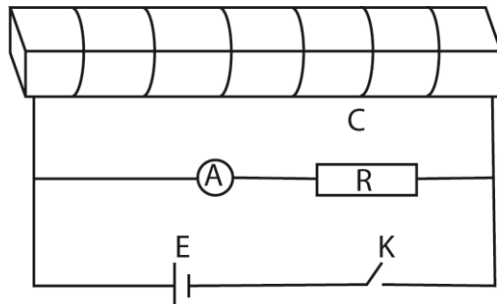
Assuming 100% efficient

$$V_p I_p = V_s I_s$$

$$6000 = V_s (0.866)$$

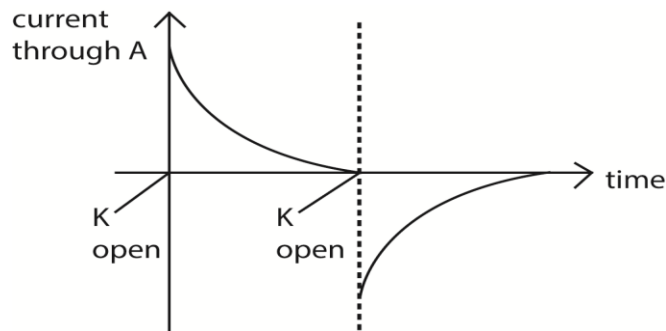
$$V_s = 6930 \text{V}$$

(c)



In the diagram above, C is a coil of large number of turns connected in series with a center zero meter, A and a resistor R across cell E. The switch K is closed for some time and then opened.

- (i) Sketch a graph to show the variation of current with time observed on the ammeter from the moment K was first closed. (01mark)



- (ii) Explain the variation of current observed in in (c)(i) (05marks)

When the switch is first closed, growth of current in the coil causes varying magnetic flux and hence an induced e.m.f in the coil.

The direction of the induced e.m.f is such as to oppose the applied e.m.f. initially most of the current flows through the ammeter because the back e.m.f is very high.

As current in the coil increases, its rate of change decreases and the induced e.m.f decrease to zero and nearly all current flows through the coil. The current through the ammeter tends to zero.

When K is opened, the collapsing magnet field in the coil leads to an induced e.m.f in the coil which tends to maintain current in the coil. Current flows through the ammeter in opposite direction and in the coil current decays to zero as the magnetic field in the coil decays to zero.

(iii) Describe the effect of placing a bunch of soft iron wire inside the coil, on the observations in (c)(i) and (c)(ii) (02marks)

- The initial current flows in the ammeter at closing and opening the switch higher
- The time taken for the current through the ammeter to decay to zero is longer.

54. (a) (i) Write down the expression for the force on a charge q coulombs moving with velocity V at an angle, θ , to a uniform magnetic field of flux density, B .

$$F = qBV\sin\theta$$

(ii) Use the expression in (a)(i) above to deduce the force on a conductor carrying a current in magnetic field. (03marks)

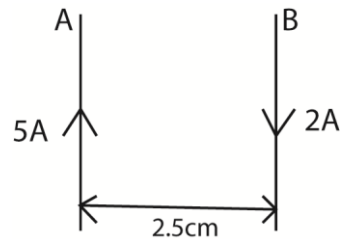
Suppose N electrons pass through the wire of length L in time t .

$$\text{Force on the electrons} = (Ne)B\left(\frac{L}{t}\right)\sin\theta$$

$$\text{But } \frac{Ne}{t} = I$$

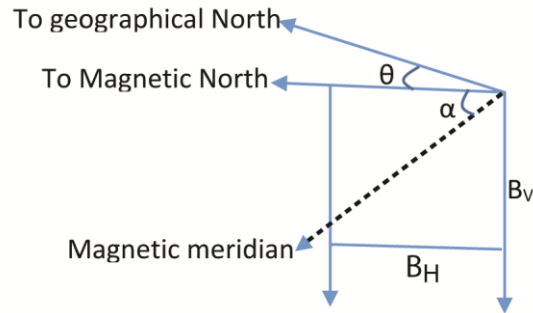
$$\text{Force on the electrons and communicated to the wire} = IBL\sin\theta$$

(iii) Two thin, long parallel wires A and B carry current of 5A and 2A respectively in opposite directions, if the wires are separated by a distance of 2.5cm in vacuum, calculate the force exerted by wire B on 1m of wire A (03 marks)



$$\text{From } F = \frac{\mu_0 I_a I_b}{2\pi a} = \frac{4\pi \times 10^{-7} \times 5 \times 2}{2\pi \times 2.5 \times 10^{-2}} = 8.0 \times 10^{-5} \text{ Nm}^{-1}$$

(b) With the aid of a diagram, explain the terms angle of dip and magnetic meridian, as applied to earth's magnetic field. (04marks)



α = angle of dip

θ = angle of declination

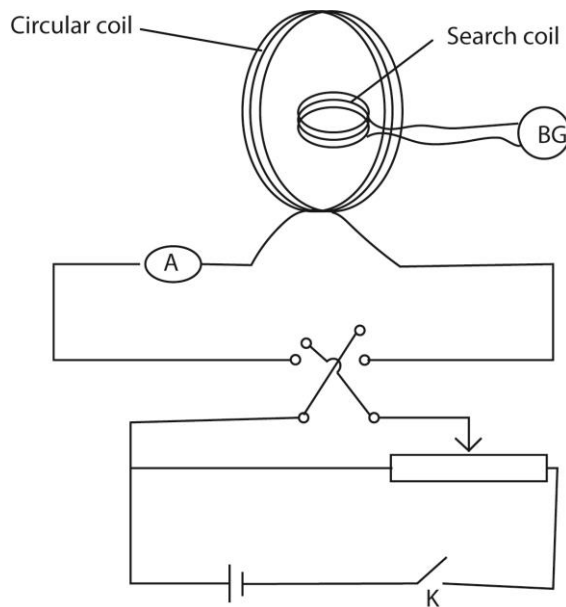
B_H = horizontal component of the earth's magnetic field

B_V = vertical component of magnetic field

Angle of dip (inclination) α : Angle of dip is the angle that the axis of a freely suspended bar magnet makes with the horizontal when the magnet settles

Magnetic meridian: This is the vertical plane containing the magnetic axis

(c)(i) Describe, using an appropriate circuit diagram, an expression to investigate the dependence of magnetic flux density at the center of circular coil on the current through the coil. (07mark)



The circuit is set up as above

The search coil is placed in the center of the coil such that their planes coincide.

Current in the circular coil is adjusted using a potential divider. K is closed. Current is reversed in the circular coil. The deflection θ of the BG is noted.

The procedure is repeated for several currents in the circular coil and corresponding angles θ of deflection in BG are noted.

A graph of θ against I is plotted and straight line graph through the origin is obtained.

Since θ is proportional to B , then B is proportional to I (current)

(ii) State two other factors on which the magnetic flux density in (c)(i) depends.
(02marks)

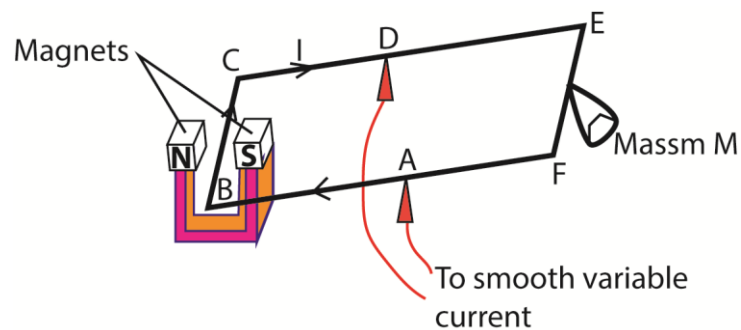
- Radius of the coil
- Number of turns of the coil

55. (a)(i) Define magnetic flux. (01mark)

Magnetic flux is thus, a product of magnitude of magnetic flux density and area of projection normal to magnetic field lines

(ii) Describe an experiment to investigate the relationship between the force on a current conductor situated in a uniform magnetic field and the current, using the ampere/current balance. (06marks)

Solution

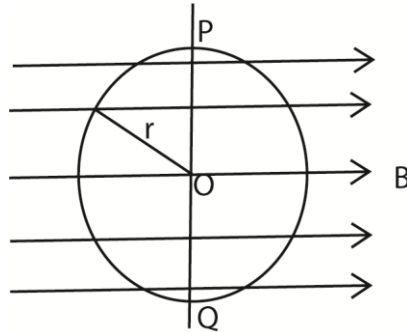


The apparatus setup is as above, $AB = AF$, length $BC = L$

- The Coil BDEF is adjusted to balance in a horizontal position
- Mass M is placed on the scale pan and the current required to restore the balance is determined.

- The mass is varied and corresponding currents to maintain the balance are determined.
- A plot of the graph of I against M gives a straight line showing that force on BC is proportional to current.

(b)



A circular loop of wire of radius, r , is placed in a uniform magnetic field of flux density, B , with the axis to the field as shown above. Explain what happens to the loop when current starts to flow in it a clockwise direction if the loop is pivoted about the axis POQ. (04marks)

Solution

The right hand side experiences an outward force. The left hand side experiences an equal but inward force.

The two forces constitute a couple which causes the coil to turn about PQ in an anticlockwise direction.

(c) A vertical square coil of the side 5cm has 100 turns and carries a current of 1A. Calculate the torque on the coil when it is placed in a horizontal magnetic field of flux density 0.2T with its plane making an angle of 30° to the field. (03marks)

$$\begin{aligned}\tau &= BANi\cos 30^\circ \\ &= 0.2 \times (5 \times 5 \times 10^{-4}) \times 100 \times 1 \times \cos 30^\circ \\ &= 4.33 \times 10^{-2} \text{Nm}\end{aligned}$$

(d) Explain why a moving coil galvanometer should have a radial magnetic field, fine springs and many turns. (06marks)

Radial magnetic field ensures that the Force, F , remains normal to the plane of the coil when it turns through an angle i.e.

Torque on the coil $\tau = BANIsin\alpha$, where α is the angle between the normal to the coil and magnetic field this is balanced by restoring torque = $k\theta$ due to current, where θ is the angle turned through

Thus, current sensitivity given by $\frac{\theta}{I} = \frac{BANIsin\alpha}{k}$

For a linear scale, $\sin \alpha = 1 \Rightarrow$ radial field

For current sensitivity, k must be small; i.e. the springs must be fine

For current sensitivity, N , must be large

56. (a)(i) Define the ampere (2marks)

An ampere is a current when maintained in two parallel conductors of negligible cross section area and separation of 1m cause a force of $2 \times 10^{-7}N$ per meter between them.

(ii) Write down the expression for the force on a conductor carrying current which is inclined at an angle θ to a uniform magnetic field (02mark)

Force, $F = BIL \sin\theta$

Where B = magnetic flux density
 L = length of the conductor
 I = current

(b)

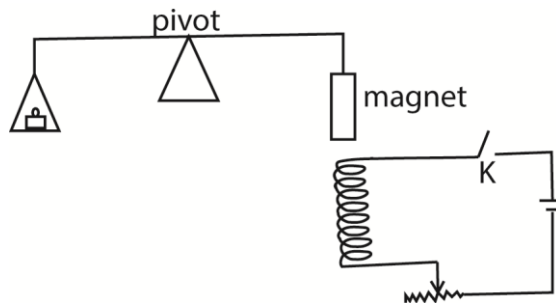


Figure above represents a current balance. When switch, K , is open the force required to balance the magnet is 0.2N. When switch, K , is closed and a current of 0.5A flows, a force of 0.22N is required for balance.

(i) Determine the polarity at the end of the magnet closest to the coil (03marks)

Solution

When K is closed, current observed from end of the coil near the magnet will be flowing in an anticlockwise direction implying that it becomes a north pole.

Since a large force is needed to balance the magnet on closing K, there attraction between the magnet and the coil hence the end of the magnet near the coil is a South Pole.

- (ii) Calculate the weight required for balance when a current of 2A flows through the coil (03marks)

If W_m is the weight of the magnet, F_m is the magnetic force due to the coil, and W is the weight required, then

$$W = W_m + F_m \dots\dots\dots (i)$$

But $W_m = 0.2$ and $F_m = kI^2$

When $I = 0.5$, $F_m = (0.22 - 0.2) = 0.02$

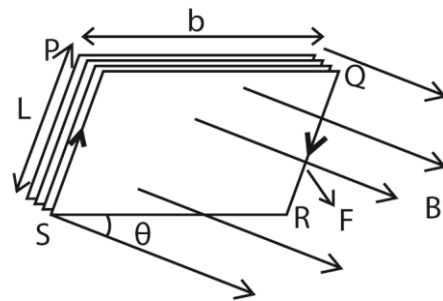
Hence $k = \frac{0.02}{0.5^2} = 0.08$

When $I = 2$, $k = 0.08$, $F_m = 0.08 \times 2^2 = 0.32$

Substituting F_m in eqn.

$$W = 0.2 + 0.32 = 0.52\text{N}$$

- (c) A rectangular coil of N turns each of dimensions $L \times b$ is inclined at an angle θ to uniform magnetic field of flux density, B . derive an expression for torque on the coil if a current I is passed through it.



- When current flows through the coil, the conductor experiences a magnetic force.
- Force on side PQ = $NBIb\sin\theta$ (downwards) while Force on side RS = $NBIb\sin\theta$ (upwards). The two forces cancel out due to rigidity of the coil.
- Side PS experiences force $NBIL\cos\theta$ perpendicularly into the page while RQ experiences force $NBIL\cos\theta$ perpendicularly out of page. The two forces constitute a couple whose moment of force

$$\begin{aligned} \tau &= F \times b \\ &= NBILb\cos\theta \\ &= NBI A \cos\theta \text{ (where } A \text{ is the area } = L \times b) \end{aligned}$$

- (d) A ballistic galvanometer of sensitivity 2 divisions per μC is connected across a coil of 10 turns wound tightly round the middle of a solenoid of 10^3 turns per meter and diameter 5.0cm. When the current in the solenoid is reversed, the ballistic

galvanometer deflects through 8 divisions. If the total resistance of the coil and galvanometer is 20Ω , find the current in the coil.

Solution

$$Q = \frac{8}{2} \times 10^{-6} = 4 \times 10^{-6} \text{C}; r = 20\Omega, n = 10^3$$

$$A = \frac{\pi d^2}{4} = \frac{\pi(5 \times 10^{-2})^2}{4} = 1.96 \times 10^{-2} \text{m}^2$$

$$B \text{ in the solenoid} = \mu_0 n I$$

$$\text{Magnetic flux linking the coil} = \phi_1 = \mu_0 n I \times N A$$

$$\text{When current is reversed, magnetic flux linking the coil, } \phi_2 = -\mu_0 n I \times N A$$

$$\text{Change in magnetic flux linking the coil, } \phi_1 - \phi_2 = 2\mu_0 n I N A$$

$$\text{Charge, } Q = \frac{\Delta\phi}{R}$$

$$I = \frac{QR}{2\mu_0 n N A} = \frac{4 \times 10^{-6} \times 20}{2 \times 4\pi \times 10^{-7} \times 10 \times 10^3 \times 1.96 \times 10^{-2}} = 1.62 \text{A}$$

57. (a) State the laws of electromagnetic induction. (02marks)

Faraday's law of electromagnetic induction states that the magnitude of induced e.m.f in a circuit is directly proportional to the rate of change in magnetic flux linking the circuit.

Lenz's law of electromagnetic induction states that the induced e.m.f is in such a direction as to oppose the change causing it.

- (b) A circular coil of 100 turns and cross sectional area 0.2m^2 is placed with its plane perpendicular to horizontal magnetic field of flux density $1.0 \times 10^{-2}\text{T}$.

The coil is rotated about a vertical axis so that it turns through 60° in 2s.

Calculate:

- (i) The initial flux linkage through the coil (02mark)

$$\text{Initial flux linkage, } \phi_1 = N B A = 100 \times 0.2 \times 1 \times 10^{-2} = 0.2 \text{Wb}$$

- (ii) The e.m.f induced in the coil (03marks)

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

$$\phi_1 = N B A \cos 60^\circ = 100 \times 0.2 \times 1 \times 10^{-2} \times 0.5 = 0.1 \text{Wb}$$

$$\text{e.m.f} = \frac{\Delta Q}{\Delta t} = \frac{-(\phi_1 - \phi_2)}{\Delta t} = \frac{-(0.1 - 0.2)}{2} = 0.05 \text{V}$$

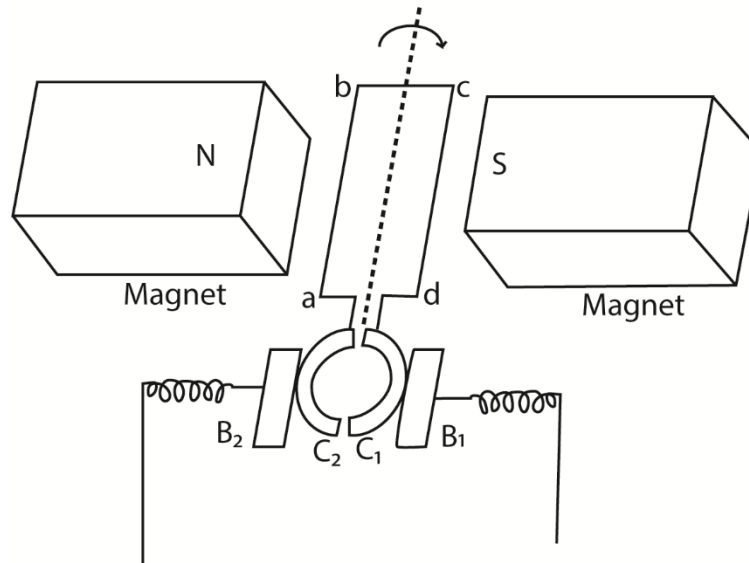
- (c)(i) Explain the origin of the back e.m.f in an electric motor (02mark)

When the armature of an electric motor rotating, the wires are cutting the lines of force and an e.m.f is induced in the armature. The direction of the induced e.m.f is such that it opposes the applied e.m.f and hence back e.m.f.

- (ii) A motor whose armature resistance is 2Ω is operated on 240V mains supply. If the back e.m.f in the motor is 220V, calculate the armature current. (03marks)

$$I = \frac{V-E}{r} = \frac{240-220}{2} = 10A$$

- (d) (i) Describe with the aid of a diagram the mode of action of a simple d.c. generator. (06marks)

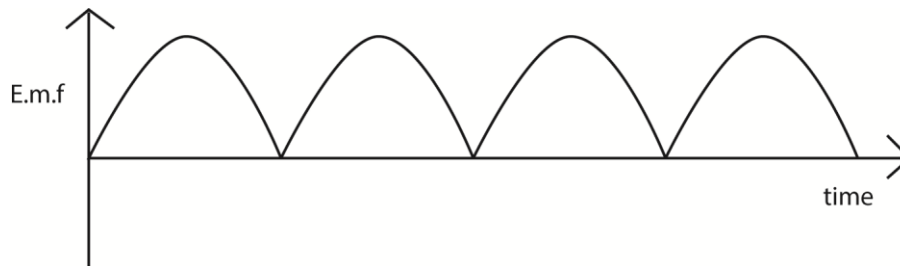


B_1 and B_2 are carbon brushes, C_1 and C_2 are split ring commutators and abcd is a rectangular coil

When the coil rotates at uniform velocity in magnetic field, e.m.f is induced in it. When the coil is in vertical position, the commutators change brushes C_1 to B_2 and C_2 to B_1 .

E.m.f reverses direction but the current does not change direction. Hence current flows in the same direction in a resistor.

- (ii) Sketch the output of a d.c. generator. (01mark)



- (iii) What is the major difference between a d.c. motor and a.c. generator? (01mark)

In a d.c. motor, electrical energy is converted into mechanical energy while for a d.c. generator mechanical energy is converted into electrical energy.

58. (a) Define root mean square value (r.m.s) of an alternating current. (01mark)

Root mean square value of an a.c is the value of steady current which dissipates heat at the same rate in a given resistor as a.c.

(b) A sinusoidal alternating voltage $V = 170\sin 120\pi t$, voltage, is applied across a resistor of resistance 100Ω

Determine

(i) The r.m.s value of current which flows. (03marks)

$$I_{r.m.s} = \frac{V_{r.m.s}}{R} \text{ but } \frac{V_0}{\sqrt{2}}$$

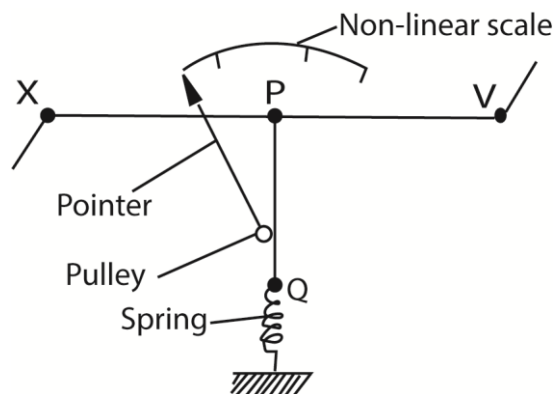
$$\therefore I_{r.m.s} = \frac{V_0}{R\sqrt{2}} = \frac{170}{100\sqrt{2}} = 1.2 \text{ A}$$

(ii) The frequency of the current through the resistor. (02marks)

$$\omega = 2\pi f; \omega = 120\pi$$

$$\therefore f = \frac{\omega}{2\pi} = \frac{120\pi}{2\pi} = 60\text{Hz}$$

(c) With the aid of a labelled diagram describe the structure and action of hot wire ammeter. (06mark)



- The current flows through a fine resistance-wire XY, which it heats.
- The wire warms up to such a temperature that it loses heat-mainly by convection-at a rate equal to the average rate at which heat is developed in the wire.
- The rise in temperature of the wire makes it expand and sag; the sag is taken up by a second fine wire PQ, which is held taut by a spring.

- The wire PQ passes round a pulley attached to the pointer of the instrument, which rotates as the wire XY sags.
- The deflection of the pointer is roughly proportional to the average rate at which heat is developed in the wire XY; it is therefore roughly proportional to the average value of the square of the alternating current, and the scale is a square-law one.

(d) Explain the term self-induction and mutual induction. (03 marks)

Self-induction is the process by which e.m.f is induced in a circuit due to changing current in the same circuit.

Mutual induction is the process by which e.m.f is induced in a circuit due change in current in the nearby circuit.

(e) A coil of self-inductance, L and negligible resistance is connected across a source of alternating voltage, $V = V_0 \cos \omega t$.

(i) Find the expression for the current which flows in the coil. (03marks)

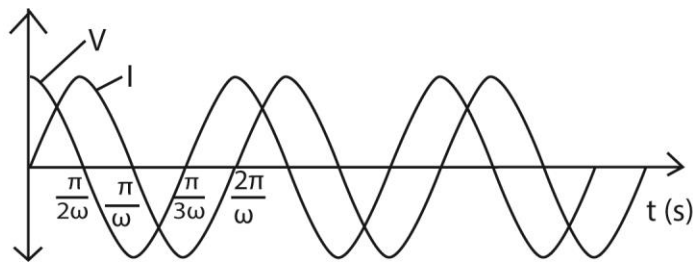
If E is induced e.m.f and V is the applied voltage, then $V = -E$

$$E = \frac{LdI}{dt}; \text{ since } V = V_m \text{ then } V_0 \sin \omega t = \frac{LdI}{dt}$$

$$\int \cos \omega t dt = \frac{L}{V_0} \int dI$$

$$\frac{1}{\omega} \sin \omega t = \frac{V_0}{L\omega} \sin \omega t$$

(ii) Sketch, using the same axes, the time variation of the applied voltage and the current which flows in the coil (02marks)



59. (a) Write down an expression for the magnetic flux density at

(i) A perpendicular distance, d, from a long straight wire carrying a current I, in vacuum. (01mark)

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

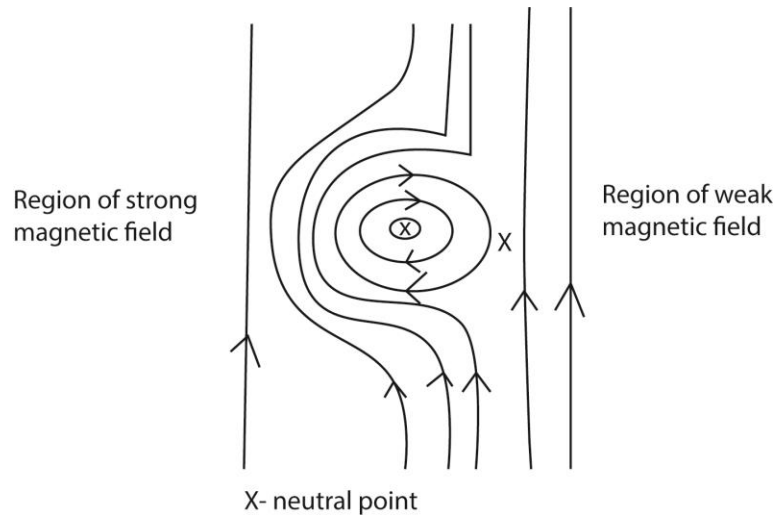
(ii) The center of a circular coil of N turn of radius, R, and carrying a current, I(01mark)

$$B = \frac{\mu_0 NI}{2R}$$

- (iii) The center of an air-cored solenoid of n turns per meter each carrying a current I . (01mark)

$$B = \mu_0 n I$$

- (b) Sketch the magnetic field pattern around a vertical current carrying straight wire in the earth's field and used it to explain a neutral point in a magnetic field. (04marks).



At the neutral point, X, the earth's magnetic field is equal and opposite of the magnetic field due to the current carrying wire.

- (c) What is meant by terms:

- (i) magnetic meridian (01mark)

Magnetic meridian is a vertical plane in which a freely suspended or pivoted magnet rests.

Or

It is the vertical plan containing the earth's magnetic poles.

- (ii) angle of dip? (01marks)

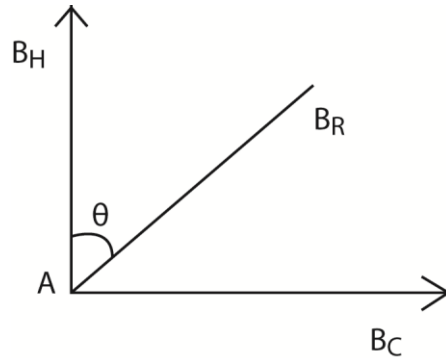
The angle dip is the angle between the horizontal and magnetic axis of freely suspended magnet.

- (d) A circular coil of 10 turn and diameter 12cm carries current I . The coil is placed with its plane in the magnetic meridian. A small magnetic needle placed at the center of the coil makes 30 oscillation per minute about a vertical axis.

When the current is cut off, it makes 15 oscillations per minute. If the horizontal component of the earth's magnetic flux density is $2.0 \times 10^{-5} \text{T}$, calculate the magnitude of I .

(Assume that the square of frequency of oscillation is proportional to the magnetic flux density) (07marks)

Solution



B_H = horizontal component of earth's magnetic field

B_C = magnetic flux density due to current in the coil

B_R = resultant magnetic flux density.

$$\frac{B_R}{B_H} = \frac{30^2}{15^2} = 4$$

$$B_R = \sqrt{B_C^2 + B_H^2}$$

But $B_R = 4B_H$

$$B_R^2 = 16B_H^2$$

$$16B_H^2 = B_C^2 + B_H^2$$

$$B_C^2 = B_H\sqrt{15} = 2 \times 10^{-5}\sqrt{15}$$

But $B_C = \frac{\mu_0 NI}{2R}$

$$2 \times 10^{-5}\sqrt{15} = \frac{4\pi \times 10^{-7} \times 10 \times I}{12 \times 10^{-2}} = 0.74A$$

(e) Explain what is meant by eddy currents and give four of their applications. (04marks)

When the magnetic flux cutting across a metal changes, an e.m.f is induced in the metal. This causes eddy currents to circulate within the metal. These currents flow in a direction as to oppose the magnetic flux threading the metal

Applications

- Damping in the moving coil galvanometer
- Detection of cracks in metal

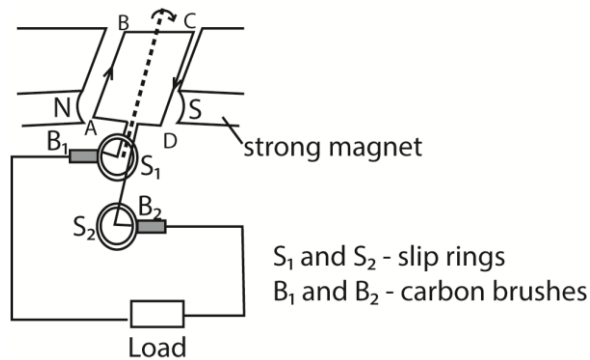
- In electromagnetic brake system
- Used in sorting metallic objects from solid wastes.

60. (a) State laws of electromagnetic induction. (02 marks)

Faradays law states that the magnitude of the induced e.m.f is directly proportional to the rate of change of the magnetic flux linked with the circuit.

Lenz's law states that the e.m.f induced in a circuit is in such a direction so as to oppose the change causing it

(b) (i) With the aid of a labelled diagram, describe the structure and mode of action of a.c. transformer (05mark)



How it works

- The coil is rotated in a magnetic field, the magnetic field linked with it changes and hence e.m.f is led away by means of slip rings which press slightly against the carbon brushes.
- Applying Fleming's right hand rule, the induced current enters the coil AB and leave the coil via CD.
- Starting with the coil in the vertical position, the magnetic flux linking it is maximum and hence no induced e.m.f.
- The induced e.m.f increases with the position of the coil in the magnetic field until it becomes maximum with the coil in horizontal position and then decrease to zero as the coil rotates to the vertical position
- The force acting on the sides of the coil change as the coil passes over the position and hence the current flowing in the coil reverses. Hence an alternating e.m.f or current flows through the load.

(ii) What are the main energy losses in a practical a.c. generator and how are they minimized? (02marks)

- Eddy current loss are minimized by laminating the armature

- I^2R losses are minimized by use of low resistance winding wires
- loss due to friction minimized by lubricating the rubbing parts

(c) An a.c. transformer operates on a 240V mains. The voltage across the secondary which has 900 turns is 20V.

(i) Find the number of turns in the primary. (02marks)

$$V_P = 240V, V_S = 20V, N_S = 960 \text{ turns}$$

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

$$N_P = N_S \frac{V_P}{V_S} = \frac{960 \times 240}{20} = 11520 \text{ turns}$$

(ii) If the efficiency of the transformer is 80%, calculate the current in the primary coil when a resistor of 40Ω is connected across the secondary. (04marks)

$$\text{Efficiency} = \frac{\text{Power output}}{\text{Power input}} \times 100\%$$

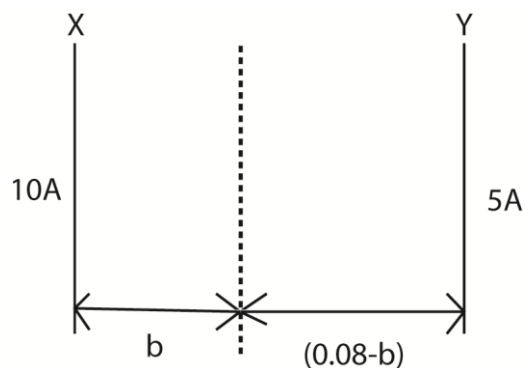
$$= \frac{V_S^2/R}{V_P^2/I_P} \times 100\%$$

$$80 = \frac{20^2/40}{240^2/I_P}$$

$$I_P = 0.052A$$

(d) Two long parallel wires X and Y are separated by 8cm in a vacuum. The wires carry currents of 10A and 5A respectively in the same direction. At What points between the wires is the magnetic flux density is zero? (03marks)

Solution



Let b be the distance from wire X at which the resultant magnetic flux density is zero.

Magnetic flux due to a wire carrying current I is $B = \frac{\mu_0 I}{2\pi r}$

$$B_1 = \frac{10\mu_0}{2\pi b} \quad \text{and} \quad B_2 = \frac{10\mu_0}{2\pi(0.08-b)}$$

But the resultant magnetic flux density is zero when $B_1 = B_2$

$$\text{Then, } \frac{10\mu_0}{2\pi b} = \frac{10\mu_0}{2\pi(0.08-b)}$$

$$B = 0.053$$

Hence the resultant magnetic field is zero at points that are perpendicular distance of 0.053m from a wire carrying 10A.

61. (a) Define the terms amplitude and root mean square (r.m.s) value an alternating current. (02marks)

Amplitude of an a.c is the maximum value of alternating current.

Root mean square value of a.c is the value of a steady current that dissipates heat at the same rate as alternating current in a given resistor.

- (b) A sinusoidal current $I = 4\sin(100\pi t)$ amperes flows through a resistor of resistance 2.0Ω . Find the mean power dissipated in the resistor. Hence deduce the r.m.s value of the current. (04marks)

Solution

$$\text{Power dissipated} = I^2 R = (4\sin(100\pi t))^2 \times 2 = 32\sin^2(100\pi t)$$

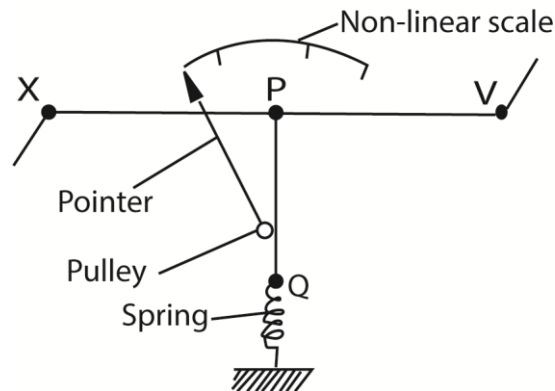
$$\text{But } \sin^2(100\pi t) = \frac{1}{2}$$

$$\text{Then power} = 32 \times \frac{1}{2} = 16\text{W}$$

$$\text{Also, Power} = I_{r.m.s}^2 \times R = 2I_{r.m.s}^2 = 16$$

$$I_{r.m.s}^2 = 8$$

- (c) Describe, with the aid of a labelled diagram, how a hot wire ammeter works. (05marks)



- The current flows through a fine resistance-wire XY, which it heats.
- The wire warms up to such a temperature that it loses heat-mainly by convection-at a rate equal to the average rate at which heat is developed in the wire.
- The rise in temperature of the wire makes it expand and sag; the sag is taken up by a second fine wire PQ, which is held taut by a spring.
- The wire PQ passes round a pulley attached to the pointer of the instrument, which rotates as the wire XY sags.

- The deflection of the pointer is roughly proportional to the average rate at which heat is developed in the wire XY; it is therefore roughly proportional to the average value of the square of the alternating current, and the scale is a square-law one.

(d) An inductor of inductance, L is connected across a source of alternating voltage,
 $V = V_0 \sin \omega t$.

(i) Find the current which flows (03marks)

$$V = V_0 \sin \omega t.$$

The back e.m.f E in the inductor wire due to charging current I is $E = -L \frac{dI}{dt}$

Assuming the inductor has zero resistance, then for current to flow, the applied p.d, D must be equal and opposite to the back e.m.f, hence

$$V = -E$$

$$= -L \frac{dI}{dt}$$

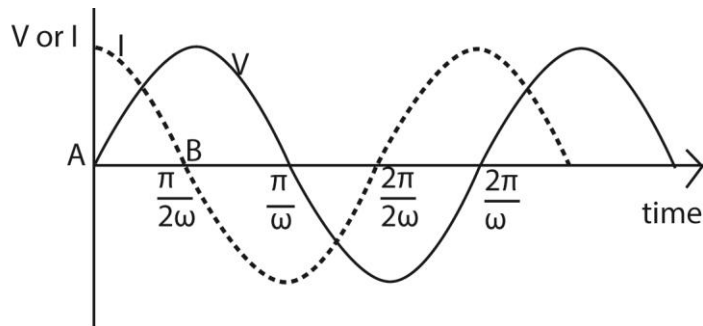
$$dI = -\frac{V}{L} dt = \frac{V_0}{L} \sin \omega t dt$$

$$I = -\frac{V_0}{L} \int \sin \omega t . dt$$

$$I = \frac{V_0}{\omega L} \cos \omega t$$

(ii) Sketch using the same axes, the variation with time of the voltage across the inductor and the current through it, and explain the phase difference between them (06marks)

Solution



$$V = V_0 \sin \omega t \text{ and } I = \frac{V_0}{\omega L} \cos \omega t$$

At A; Current lags behind voltage by a quarter a cycle or 90°

At B; the current is zero but its rate of increase is at maximum, therefore for the inductor of constant inductance, the rate of change of flux is also at a maximum. Hence the back e.m.f is a maximum

Thank you

Compiled by Dr. Bbosa science