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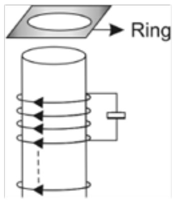
Q1. **Consider a magnet surrounded by a wire with an on/off switch *S* (in figure). If the switch is thrown from the off position (open circuit) to the on position (closed circuit), will a current flow in the circuit? Explain.**



Q2. **Predict the direction of induced current in a metal ring when the ring is moved towards a straight conductor with constant speed *v*. The conductor is carrying current *I* in the direction shown in the figure.**

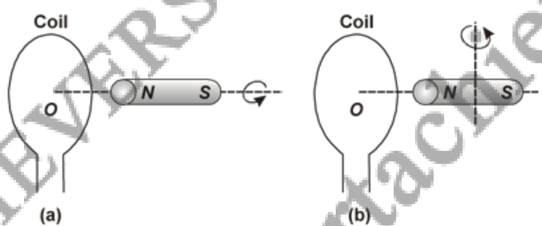
Q3. **Define the term 'wattless current'.**

Q4. **Predict the directions of induced currents in metal rings 1 and 2 lying in the same plane where current *I* in the wire is increasing steadily shown in the figure.**

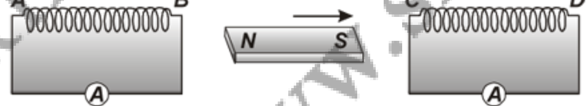
Q5. **Predict the direction of induced current in metal rings 1 and 2 when current *I* in the wire is steadily decreasing?**

Q6. **Explain an experiment which led Faraday to confirm the induction of e.m.f.**

Q7. **A cylindrical bar magnet is kept along the axis of a circular coil and near it as shown in the figure. Will there be any induced e.m.f. at the terminals of the coil, when the magnet is rotated (a) about its own axis and (b) about an axis perpendicular to the length of the magnet?**

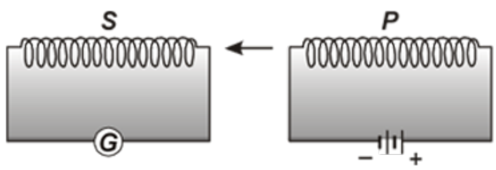


Q8. **A magnet is moved in the direction indicated by an arrow between two coils *AB* and *CD* as shown in figure below. Suggest the direction of current in each coil.**



Q9. **(a) As shown in the figure, when primary coil P is moved towards secondary coil S, the galvanometer shows momentary deflection.**

What can be done to have larger deflection in the galvanometer with the same battery?



(b) State the related law.

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S1. No.

> ***Explanation:*** No part of the wire is moving and so motional e.m.f. is zero. The magnet is stationary and hence the magnetic field does not change with time. This means no electromotive force is produced and hence no current will flow in the circuit.

S2. The direction of the induced current is clockwise by the Lenz law.

S3. Wattless current nothing but component of the current corresponding to which there is no power loss.

S4. In ring 1 the induced current clockwise direction by Lenz law.

In ring 2 the induced current anticlockwise direction by Lenz law.

S5. The direction of induced current in coil 1 clockwise direction by Lenz law.

The direction of induced current in coil 2 anticlockwise direction from Lenz law.

S6. Faraday dealt with an apparatus which consisted of two coils A and B of insulated wire, wound on a wooden core. One coil was connected to a sensitive galvanometer other with a battery source. When Faraday disconnected the battery, he observed that the galvanometer needle got deflected. When he connected the battery back again, he noticed a deflection in opposite direction. He repeatedly connected and disconnected the battery, and got the same result which indicated the existence of momentary currents due to induced e.m.f. in the coil. In this way Faraday confirmed the existence of induced e.m.f. experimentally.

S7. **In figure (a):** When the magnet is rotated about its own axis, there is no change in the magnetic flux liked with the coil. Hence, no induced e.m.f. is produced in the coil.

In figure (b): When the magnet is rotated about an axis perpendicular to its length, the orientation of the magnetic field due to the magnet will change continuously. Due to this, the magnetic flux linked with the coil will also change continuously and it will result in the production of induced e.m.f. in the coil.

S8. **For coli *AB*:** As the *N*-pole of the magnet is moving away from the coil *AB*, the end *B* of the coil will behave as *S*-pole so as to oppose the motion of the magnet. Therefore, looking from the end *A*, the current in the coil *AB* will be in ***anticlockwise direction***.

For coil *CD*: In this case, the end *C* of the coil *CD* should behave as *S*-pole so as to repel the approaching magnet. Looking from the end *D*, the direction of current in coil *CD* will be ***anticlockwise***.

S9. (a) The primary coil *P* should be moved faster towards the secondary coil *S*.

(b) The related law is Faraday's laws of electromagnetic induction.

According to Faraday's law:

(a) Whenever magnetic flux linked with a circuit (a loop of wire or a coil or an electric circuit in general) changes, induced e.m.f. is produced.

(b) The induced e.m.f. lasts as long as the change in the magnetic flux continues.

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

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Q1. The magnetic flux passing through a coil changes from 6×10^{-3} Wb to 8.2×10^{-3} Wb in 0.02 s. Calculate the induced e.m.f.

Q2. What are the SI units of (a) magnetic flux and (b) magnetic field strength?

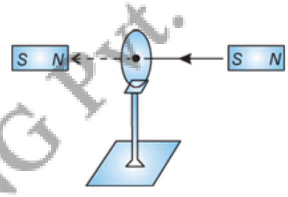
Q3. A Conducting loop is held stationary normal to the field between the *NS* poles of a fixed permanent magnet. By choosing a magnet sufficiently strong, can we hope to generate current in the loop?

Q4. State the Faraday's law of electromagnetic induction.

Q5. Weber is the unit of which physical quantity?

Q6. Explain, whether an induced current will be developed in a conductor, if is moved in a direction parallel to magnetic field.

Q7. Give the direction in which the induced current flows in the coil mounted on an insulating stand when a bar magnet is quickly moved along the axis of the coil from one side to the other as shown in the figure.



Q8. What is meant by magnetic flux? State its SI unit.

Q9. A closed conducting loop moves normal to the electric field between the plates of a large capacitor. Is a current induced in the loop. when it is (a) wholly inside the capacitor, (b) partially outside the plates of the capacitor? The electric field is normal to the plane of the loop.

Q10. What is the basic cause of induced e.m.f.?

Q11. Define electromagnetic induction.

Q12. What factors govern the magnitude of the emf. induced in an electric circuit?

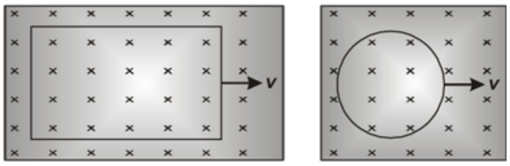
Q13. A square loop of side 10 cm and resistance 0.5 Ω is placed vertically in the east-west plane. A uniform magnetic field of 0.10 *T* is set up across the plane in the north-east direction. The magnetic field is decreased to zero in 0.70 s at a steady rate. Determine the magnitudes of induced e.m.f. and current during the time-interval?

Q14. Current in a 10 mH coil increases uniformly from zero to one ampere in 0.01 second. Find the direction and value of self-induced e.m.f.

Q15. Define magnetic flux and magnetic flux density.

Q16. A long solenoid with 15 turns per cm has a small loop of area 2.0 cm^2 placed inside the solenoid normal to its axis. If the current carried by the solenoid changes steadily from 2.0 A to 4.0 A in 0.1 s, what is the induced e.m.f. in the loop while the current is changing?

Q17. A rectangular loop and a circular loop are moving out of a uniform magnetic field to a field free region with a constant velocity *v* as shown in the figure below.



Explain, in which loop do you expect the induced e.m.f. to be constant during the passage out of the region. The magnetic field is normal to the loops.

Q18. State Faraday's laws of electromagnetic induction.

Q19. A circular coil of radius 10 cm, 500 turns and resistance 2 Ω is paced with its plane perpendicular to the horizontal component of the earth's diameter through 180° in 0.25 s. Estimate the magnitudes of the e.m.f. and current induced in the coil. Horizontal component of the earth's magnetic field at the place is $3.0 \times 10^{-5}\ T$.

Q20. A conducting rod of length *l* is moved in a magnetic field of magnitude *B* with velocity *v* such that the arrangement is mutually perpendicular. Prove that the e.m.f. induced in the rod is $|e| = Blv$.

Q21. A square loop of side 12 cm with its sides parallel to *X* and *Y* axes is moved with a velocity of 8 cm s^{-1} in the positive *x*-direction in an environment containing a magnetic field in the positive *z*-direction. The field is neither uniform in space nor constant in time. It has a gradient of $10^{-3}\ \text{T cm}^{-1}$ along the negative *x*-direction (that is it increases by $10^{-3}\ \text{T cm}^{-1}$ as one moves in the negative *x*-direction), and it is decreasing in time at the rate of $10^{-3}\ \text{T s}^{-1}$. Determine the direction and magnitude of the induced current in the loop if its resistance is 4.50 mΩ.

Q22. The magnetic flux linked with a closed circular loop of radius 20 cm and resistance 2 Ω at any instant of time is

$$\phi = 4t + 3$$

where ϕ is in milli weber and time '*t*' in sec. Find

(a) flux linked with a loop at $t = 3\ s$

(b) induced e.m.f. at $t = 2\ s$

(c) plot a graph between (i) ϕ and *t*; (ii) ε and *t*.

Q23. A metallic rod of length *l* is rotated at a constant angular speed ω, normal to a uniform magnetic field *B*. Derive an expression for the current induced in the rod, if the resistance of the rod is *R*.

Q24. What are the Faraday's Laws of electromagnetic induction? Drive an expression for the induced e.m.f. in terms of self-inductance of a coil.

Q25. It is desired to measure the magnitude of field between the poles of a powerful loud speaker magnet. A small flat search coil of area 2 cm^2 with 25 closely wound turns, is positioned normal to the field direction, and then quickly snatched out of the field region. Equivalently, one can give it a quick 90° turn to bring its plane parallel to the field direction). The total charge flown in the coil (measured by a ballistic galvanometer connected to coil) is 7.5 mC. The combined resistance of the coil and the galvanometer is 0.50 Ω. Estimate the field strength of magnet.

Q26. A coil containing 20 turns of average diameter 0.02 m is placed perpendicular to a magnetic field of intensity 1.6×10^4 T. The magnetic field changes to 1.8×10^3 T in 4 s. A resistor of resistance 15 Ω is connected in series with the coil. If the resistance of the coil is 5 Ω, find the induced current passing through the resistor.

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S1. Here, $\phi_1 = 6 \times 10^{-3}\,\text{Wb}$; $\phi_2 = 8.2 \times 10^{-3}\,\text{Wb}$

and $dt = 0.02$ s

Now, $$e = -\frac{d\phi}{dt} = -\frac{\phi_2 - \phi_1}{dt}$$

$$= -\frac{8.2 \times 10^{-3} - 6 \times 10^{-3}}{0.02} = -\frac{2.2 \times 10^{-3}}{0.02} = \mathbf{-0.11\ V}$$

S2. (a) Weber. (b) Tesla.

S3. No current will be induced in the loop, how so strong a magnet be chosen. It is because, there is no relative motion between the loop and the magnet. The induced current is produced only, if the magnetic flux linked with the loop changes.

S4. The magnitude of the induced e.m.f. is directly proportional to the rate of change of the magnetic flux linked with the circuit.

S5. It is the unit of magnetic flux.

S6. Induced current will not be developed in a conductor, if it is moved in a direction parallel to the magnetic field. As such, Lorentz force on the free electrons in the conductor is zero and consequently no potential difference is produced across the two ends of the conductor.

S7. Induced current in coil is anticlockwise seen from the side opposite to magnet by Lenz law.

S8. The magnetic flux linked with a surface is defined as the number of magnetic field lines passing normally through that surface. Its SI unit is **weber**.

S9. The current is induced, if magnetic flux linked with the loop changes. No current is induced in either case, when the loop is wholly inside or partially inside the electric field.

S10. Whenever magnetic flux linked with a coil changes, induced e.m.f. is produced.

S11. It is the phenomenon of production of e.m.f. in a coil, when the magnetic flux linked with the coil is changed.

S12. The magnitude of induced e.m.f in an electric circuit is directly proportional to the rate of change of magnetic flux linked with the circuit.

S13. Given magnetic field $B = 0.1\,\text{T}$

Area of square $A = 0.01\,\text{m}^2$

$dt = 0.7\,\text{s}$

The angle made by the area vector of the coil with the magnetic field is $\theta = 45°$.

$$\phi_{max} = BA\cos\theta = \frac{0.1\times10^{-2}}{\sqrt{2}}\text{ Wb}$$

From Faraday's law

$$|e| = \frac{d\phi_B}{dt} = \frac{(\phi_{max} - 0)}{dt} = \frac{10^{-3}}{\sqrt{2}\times0.7}\text{1mV}$$

$$I = \frac{|e|}{R} = \frac{10^{-3}}{0.5} = \mathbf{2\ mA}.$$

S14. Given, L = 10 mH = $10\times10^{-3} = 10^{-2}$ H

Initial current in the coil = 0;

final current in the coil = 1 A

Therefore, change in current, dI = 1 – 0 = 1 A

Time in which the current changes, dt = 0.01 second

Now, induced e.m.f., given by

$$e = -L\frac{dI}{dt} = -10^{-2}\times\frac{1}{0.01} = -1\text{ V}.$$

The self-induced e.m.f. will act so as to *oppose the growth of current*.

S15. Magnetic flux through any surface is the total number of magnetic lines of force crossing normally through the surface area. Mathematically

$$\phi = BA\cos\theta = \vec{B}.\vec{A}$$

where, θ = angle between $\vec{B}$ and normal drawn to the surface. Its SI unit is Weber (Wb).

Magnetic flux density (or magnetic induction) is the number of magnetic lines of force passing normally through unit area, *i.e.*,

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

Its SI units Tesla (T) or Weber/m^2.

S16. Number of turns on the solenoid = 15 turns/cm = 1500 turns/m

Number of turns per unit length, n = 1500 turns

The solenoid has a small loop of area, A = 2.0 cm^2 = 2×10^{-4} m^2

Current carried by the solenoid changes from 2 A to 4 A.

$\therefore$ Change in current in the solenoid, $di = 4 - 2 = 2$ A

Change in time, $dt = 0.1$ s

Induced e.m.f. in the solenoid is given by Faraday's law as:

$$e = \frac{-d\phi}{dt} \quad \text{... (i)}$$

Where, ϕ = Induced flux through the small loop

$= BA$ ... (ii)

B = Magnetic field

$= \mu_0 ni$ ... (iii)

μ_0 = Permeability of free space

$= 4\pi \times 10^{-7}$ H/m

Hence, Eq. (i) reduces to:

$$e = \frac{d}{dt}(BA)$$

$$= A\mu_0 n \times \left(\frac{di}{dt}\right)$$

$$= 2 \times 10^{-4} \times 4\pi \times 10^{-7} \times 1500 \times \frac{2}{0.1}$$

$$= 7.54 \times 10^{-6}\,\text{V}$$

Hence, the induced voltage in the loop is 7.54×10^{-6} V.

S17. As the loops move out of the magnetic field, the rate at which the area of the loop decreases inside the field is constant in case of the rectangular loop, while it varies in the case of the circular loop. As a result, the rate of decrease of magnetic flux and hence the induced e.m.f. produced in the ***rectangular loop*** will be constant.

S18. According to Faraday's law:

(a) Whenever magnetic flux linked with a circuit (a loop of wire or a coil or an electric circuit in general) changes, induced e.m.f. is produced.

(b) The induced e.m.f. lasts as long as the change in the magnetic flux continues.

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

S19. Initial flux through the coil at $\theta = 0°$

$$\phi_i = BA\cos\theta$$

$$= 3.0 \times 10^{-5} \times (\pi \times 10^{-2}) \times \cos 0°$$

$$= 3\pi \times 10^{-7}\,\text{Wb.}$$

Final flux at $\theta = 180°$

$$\phi_f = 3.0 \times 10^{-5} \times (\pi \times 10^{-2}) \times \cos 180°$$
$$= -3\pi \times 10^{-7} \text{ Wb.}$$

Change flux, $\Delta\phi = \phi_f - \phi_i = 6\pi \times 10^{-7}$

According to Faraday's law.

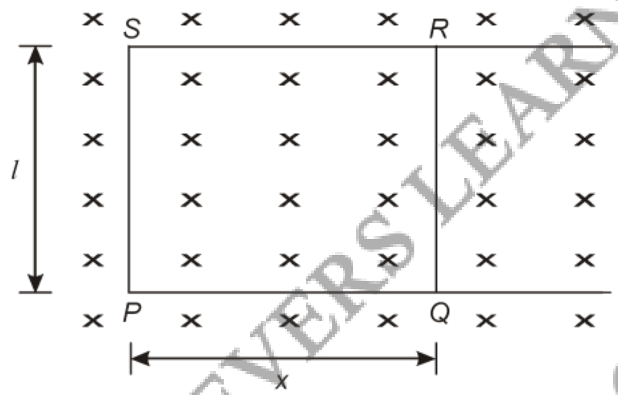
$$e = N\frac{\Delta\phi}{\Delta t} = \frac{500 \times (6\pi \times 10^{-7})}{0.25}$$

$$= 3.8 \times 10^{-3} \text{ V}$$

$$I = \frac{e}{R} = \mathbf{1.9 \times 10^{-3} \text{ A}}.$$

S20. We consider a rectangular conductor placed in a uniform magnetic field normal to its plane. One arm of this conductor is free to more. Let the arm be moved inwards with a speed v. the flux through the loop is Blx.

$$\phi = BA\cos\theta \qquad (\because \ \theta = 0°)$$
$$= BA = Blx.$$



Thus due to motion of the arm e.m.f. induced is given

$$e = -\frac{d\phi}{dt}$$

$$e = -\frac{d}{dt}(Blx) = -Bl\frac{dx}{dt}$$

$$|e| = +Blv,$$

This e.m.f. is called motional e.m.f.

S21. Side of the square loop, $s = 12 \text{ cm} = 0.12 \text{ m}$

Area of the square loop, $A = 0.12 \times 0.12 = 0.0144 \text{ m}^2$

Velocity of the loop, $v = 8 \text{ cm/s} = 0.08 \text{ m/s}$

Gradient of the magnetic field along negative x-direction,

$$\frac{dB}{dx} = 10^{-3}\,\text{T cm}^{-1} = 10^{-1}\,\text{T m}^{-1}$$

And, rate of decrease of the magnetic field,

$$\frac{dB}{dt} = 10^{-3}\,\text{T s}^{-1}$$

Resistance of the loop, $R = 4.5\ \text{m}\Omega = 4.5 \times 10^{-3}\,\Omega$

Rate of change of the magnetic flux due to the motion of the loop in a non-uniform magnetic field is given as:

$$\frac{d\phi}{dt} = A \times \frac{dB}{dx} \times v$$

$$= 144 \times 10^{-4}\,\text{m}^2 \times 10^{-1} \times 0.08$$

$$= 11.52 \times 10^{-3}\,\text{T m}^2\,\text{s}^{-1}$$

Rate of change of the flux due to explicit time variation in field B is given as:

$$\frac{d\phi'}{dt} = A \times \frac{dB}{dx}$$

$$= 144 \times 10^{-4} \times 10^{-3}$$

$$= 1.44 \times 10^{-5}\,\text{T m}^2\,\text{s}^{-1}$$

Since the rate of change of the flux is the induced e.m.f., the total induced e.m.f. in the loop can be calculated as:

$$e = 1.44 \times 10^{-5} + 11.52 \times 10^{-5}$$

$$= 12.96 \times 10^{-5}\,\text{V}$$

$\therefore$ Induced current, $i = \frac{e}{R}$

$$= \frac{12.96 \times 10^{-5}}{4.5 \times 10^{-3}}$$

$$i = 2.88 \times 10^{-2}\,\text{A}$$

Hence, the direction of the induced current is such that there is an increase in the flux through the loop along positive z-direction.

S22. $\phi = 4t + 3$

(a) flux through the loop at $t = 3$ sec.

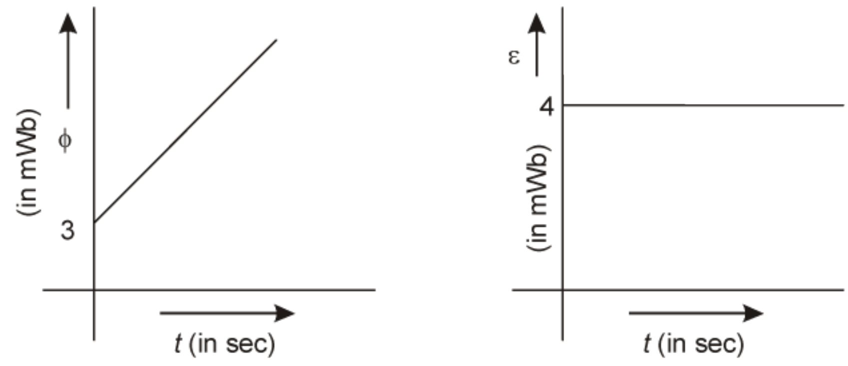
$$\phi = 4 \times 3 + 3$$

$$= 15\,\text{mWb}.$$

(b) $$e = \frac{d\phi}{dt} = 4$$

$$e = 4\,\text{mV}.$$

(c)



S23. When the conducting rod rotates inside the uniform magnetic field, it intercepts magnetic field over a circular area, whose radius is equal to length (l) of the rod.

Therefore, area intercepted by the rod in one rotation,

$$\Delta S = \pi l^2$$

Hence, change in the magnetic flux through the copper rod in one rotation,

$$d\phi = B\Delta S = B \times \pi l^2$$

Since the rod rotates with angular velocity ω, time taken by it to complete one rotation,

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

If e is the induced e.m.f. produced between the two ends of the rod, then

$$e = \frac{d\phi}{dt} = \frac{B \times \pi l^2}{2\pi / \omega}$$

or $$e = \frac{1}{2} B l^2 \omega$$

Hence, current induces in the rod,

$$I = \frac{e}{R} = \frac{\boldsymbol{B l^2} \omega}{\boldsymbol{2R}}.$$

S24. According to Faraday's law:

(a) Whenever magnetic flux linked with a circuit (a loop of wire or a coil or an electric circuit in general) changes, induced e.m.f. is produced.

(b) The induced e.m.f. lasts as long as the change in the magnetic flux continues.

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

As $\phi \propto I$

$\phi = LI$

But $e = -\frac{d\phi}{dt} = -\frac{d}{dt}(LI) = -L\frac{dI}{dt}$

If e = 1 volt $\frac{dI}{dt} = 1A/\text{sec}$ then the self-inductance of a coil is said to be one Henry. In other words, if current is changing at a rate of 1 Ampere per second in a coil induces an e.m.f. of 1 volt in it then the inductance of the coil is one Henry.

S25. Area of the small flat search coil, $A = 2\text{ cm}^2 = 2 \times 10^{-4}\text{ m}^2$

Number of turns on the coil, $N = 25$

Total charge flowing in the coil, $Q = 7.5\text{ mC} = 7.5 \times 10^{-3}\text{ C}$

Total resistance of the coil and galvanometer,

$R = 0.50\,\Omega$

Induced current in the coil,

$$I = \frac{\text{Induced e.m.f.}\ (e)}{R} \quad \text{... (i)}$$

Induced e.m.f. is given as:

$$e = -N\frac{d\phi}{dt} \quad \text{... (ii)}$$

Where, $d\phi$ = Change in flux [N = Total no. of turns]

Combining Eqs. (i) and (ii), we get

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

$$Idt = -\frac{N}{R}d\phi \quad \text{... (iii)}$$

Initial flux through the coil, $\phi_i = BA$

Where, B = Magnetic field strength

Final flux through the coil, $\phi_f = 0$

Integrating Eq. (iii) on both sides, we have

$$\int Idt = \frac{-N}{R}\int_{\phi_i}^{\phi_f} d\phi$$

But total charge, $Q = \int Idt$

$\therefore \qquad Q = \dfrac{-N}{R}(\phi_f - \phi_i) = \dfrac{-N}{R}(-\phi_i) = +\dfrac{N\phi_i}{R}$

$$Q = \frac{NBA}{R}$$

$\therefore \qquad B = \dfrac{QR}{NA} = \dfrac{7.5 \times 10^{-3} \times 0.5}{25 \times 2 \times 10^{-4}} = 0.75\,\text{T}$

Hence, the field strength of the magnet is 0.75 T.

S26. Given, number of turns in the coil, $n = 20$; diameter of the coil, $D = 0.02$ m

Therefore, area of the coil,

$$A = \frac{\pi D^2}{4} = \frac{\pi \times (0.02)^2}{4} = \pi \times 10^{-4}\ \text{m}^2$$

Initial magnetic field intensity, $B_1 = 1.6 \times 10^4$ T.

Therefore, initial magnetic flux linked with the coil,

$$\phi_1 = nB_1 A = 20 \times 1.6 \times 10^4 \times \pi \times 10^{-4} = 32\pi\ \text{Wb}$$

Final magnetic field intensity, $B_2 = 1.8 \times 10^3$ T

Therefore, final magnetic flux linked with the coil,

$$\phi_2 = nB_2 A = 20 \times 1.8 \times 10^3 \times \pi \times 10^{-4} = 3.6\pi\ \text{Wb}$$

The change in magnetic flux,

$$d\phi = \phi_2 - \phi_1 = 3.6\pi - 32\pi = -28.4\pi\ \text{Wb}$$

Time during which the change in magnetic flux takes place,

$$dt = 4\ \text{s}$$

Therefore, induced e.m.f. produced in the coil,

$$e = -\frac{d\phi}{dt} = -\frac{-28.4\pi}{4} = 22.3\ \text{V}$$

Total resistance of the circuit,

$$R = 15\,\Omega + 5\,\Omega = 20\,\Omega$$

Therefore, induced current passing through the resistor,

$$I = \frac{e}{R} = \frac{22.3}{20} = \mathbf{1.115\ A}.$$

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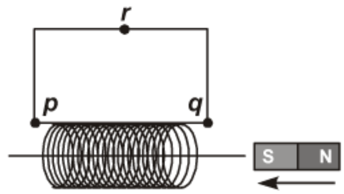
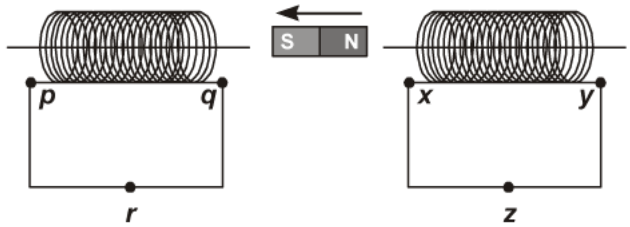
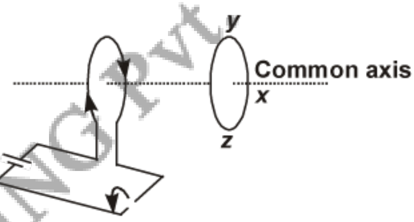
Q1. **Predict the direction of induced current in the situations described by the following figure:**



Q2. **Predict the direction of induced current in the situations described by the following figure:**

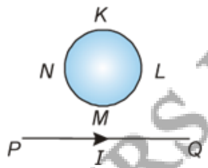


Q3. **Predict the direction of induced current in the situations described by the following figure:**



(Tapping key just closed)

Q4. **What is the magnitude of the induced current in the circular loop *KLMN*, of radius '*r*' if the straight wire *PQ* carries a steady current of magnitude '*I*' ampere?**

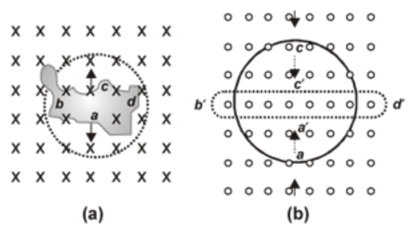


Q5. **State the law that explains the energy conservation in magnetic induction.**

Q6. **Use Lenz's law to determine the direction of induced current in the situations described by (as shown in the figure):**

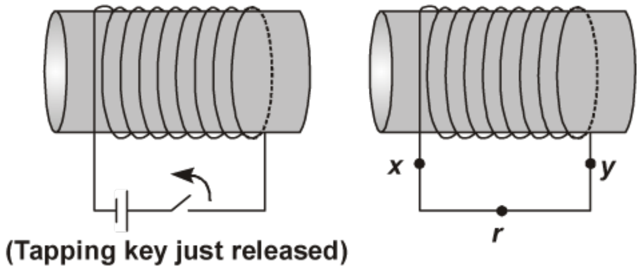
(a) A wire of irregular shape turning into a circular shape;

(b) A circular loop being deformed into a narrow straight wire.



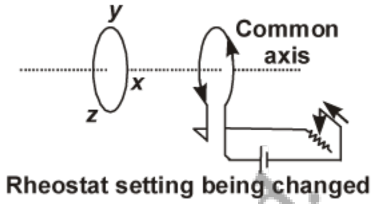
Q7. **A straight conductor 1 m long moves at right angles to both its length and a uniform magnetic field. If the speed of the conductor is 2.0 ms^{-1} and the strength of the magnetic field is 10^4 gauss, find the value of induced e.m.f. un volt.**

Q8. Predict the direction of induced current in the situations described by the following figure:

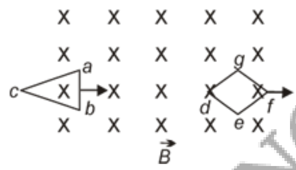


Q9. Predict the direction of induced current in the situations described by the following figure.

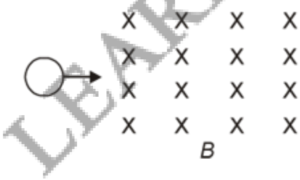
Q10. Predict the direction of induced current in the situations described by the following figure:



Q11. Two loop of different shapes are moved in a region of uniform magnetic field in the directions marked by arrows as shown in the figure. What is the direction of the induced current in each loop?

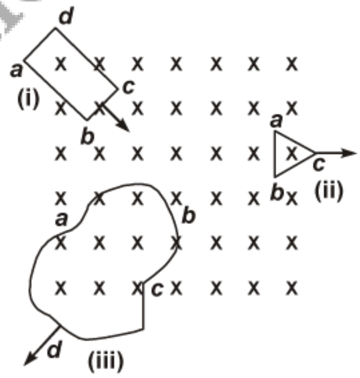


Q12. A circular loop is moved through the region of uniform magnetic field. Find the direction of induced current (clockwise or anticlockwise) when the loop moves: (a) into the field, and (b) out of the field.

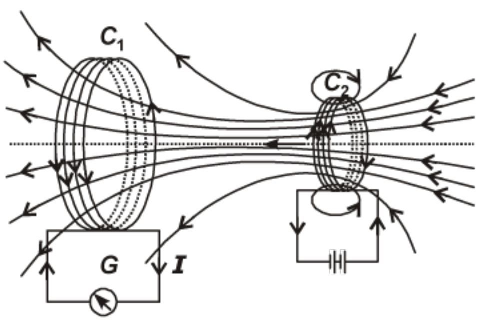


Q13. The induced e.m.f. is sometimes named as back e.m.f. Why?

Q14. Figure shows planar loops of different shapes moving out of or into a region of a magnetic field which is directed normal to the plane of the loop away from the reader. Determine the direction of induced current in each loop using Lenz's law.

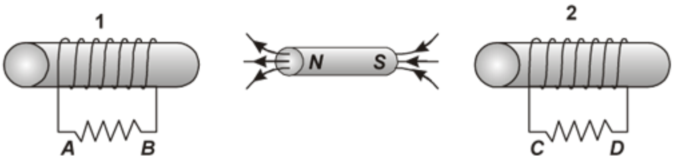


Q15. Consider Experiment 6.2 (NCERT). (a) What would you do to obtain a large deflection of the galvanometer? (b) How would you demonstrate the presence of an induced current in the absence of a galvanometer?

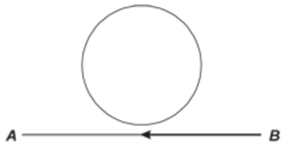


Q16. A coil has inductance of 8 H and resistance 25 ohm. An e.m.f. of 120 volt is applied to it. What is the energy stored in the magnetic field, when the current has reached its final steady value?

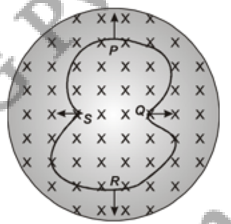
Q17. In the figure given below, a bar magnet moving towards the right or left induces an e.m.f. in the coils (1) and (2). Find giving reason, the directions of the induced currents through the resistors AB and CD, when the magnet is moving (a) towards the right and (b) towards the left.



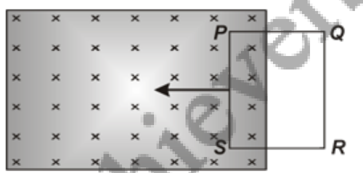
Q18. The electric current in a wire in the direction from *B* to *A* is increasing. What is the direction of induced current in the metallic loop kept above the wire as shown in the figure below.



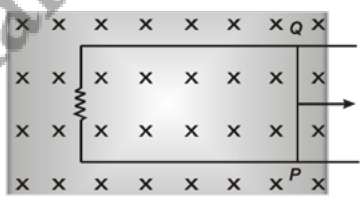
Q19. An irregular shaped wire *PQRS* (as shown in the figure) placed in a uniform magnetic field perpendicular to the plane of the paper changes into a circular shape. Show with reason the direction of the induced current in the loop.



Q20. The closed loop *PQRS* is moving into a uniform magnetic field acting at right angles to the plane of the paper as shown in the figure. State the direction in which the induced current flows in the loop.



Q21. A 0.5 m long metal rod *PQ* completes the circuit as shown in the figure below. The area of the circuit is perpendicular to the magnetic field of flux density 0.15 T. If the resistance of the total circuit is 3 Ω. Calculate the force needed to move the rod in the direction as indicated with a constant speed of 2 ms^{-1}.



Q22. State Lenz's law. Show that the Lenz's law is in accordance with law of conservation of energy.

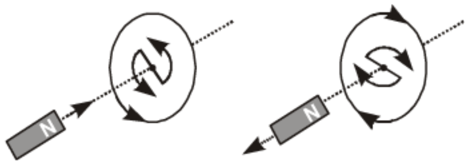
Q23. State Lenz's law. Two identical loops, one of copper and the other of aluminium are rotated with the same speed, in a uniform magnetic field acting normal to the plane of the loops. State with reason, for which of the coils (a) induced e.m.f. (b) induced current, will be more.

Date: 21/10/2021

S1. The direction of the induced current in a closed loop is given by Lenz's law. The given pairs of figures show the direction of the induced current when the North pole of a bar magnet is moved towards and away from a closed loop respectively.

Using Lenz's rule, the direction of the induced current in the given situations can be predicted as follows:

The direction of the induced current is along **qrpq**.



S2. The direction of the induced current in a closed loop is given by Lenz's law. The given pairs of figures show the direction of the induced current when the North pole of a bar magnet is moved towards and away from a closed loop respectively.

Using Lenz's rule, the direction of the induced current in the given situations can be predicted as follows:

The direction of the induced current is along **prqp**.

S3. The direction of the induced current in a closed loop is given by Lenz's law. The given pairs of figures show the direction of the induced current when the North pole of a bar magnet is moved towards and away from a closed loop respectively.

Using Lenz's rule, the direction of the induced current in the given situations can be predicted as follows:

The direction of the induced current is along ***yzxy***.

S4. No current induced in the loop.

Explanation: From Faraday law

$$e = \frac{d\phi}{dt} = 0$$

Since no e.m.f. in the loop therefore no current available in the loop.

S5. It states that the induced e.m.f. (or current) produced in a circuit always acts so that it opposes the change or the cause that produces it.

S6. According to Lenz's law, the direction of the induced e.m.f. is such that it tends to produce a current that opposes the change in the magnetic flux that produced it.

(a) When the shape of the wire changes, the flux piercing through the unit surface area increases. As a result, the induced current produces an opposing flux. Hence, the induced current flows along *adcb*.

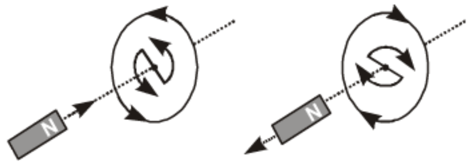
(b) When the shape of a circular loop is deformed into a narrow straight wire, the flux piercing the surface decreases. Hence, the induced current flows along *a′b′c′d′*.

S7. Given, $l = 1$ m; $v = 2.0$ ms^{-1};

$B = 10^4$ gauss = 1 tesla

We know, $e = Bvl = 1 \times 2.0 \times 1 =$ **2.0 V**

S8. The direction of the induced current in a closed loop is given by Lenz's law. The given pairs of figures show the direction of the induced current when the North pole of a bar magnet is moved towards and away from a closed loop respectively.



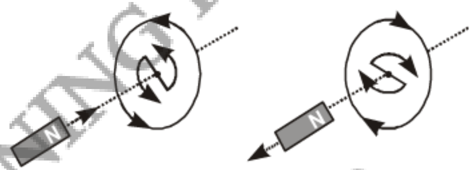
Using Lenz's rule, the direction of the induced current in the given situations can be predicted as follows:

The direction of the induced current is along ***xryx***.

S9. Using Lenz's rule, the direction of the induced current in the given situations can be predicted as follows:

No current is induced since the field lines are lying in the plane of the closed loop.

S10. The direction of the induced current in a closed loop is given by Lenz's law. The given pairs of figures show the direction of the induced current when the North pole of a bar magnet is moved towards and away from a closed loop respectively.



Using Lenz's rule, the direction of the induced current in the given situations can be predicted as follows:

The direction of the induced current is along ***zyxz***.

S11. The induced current in loop *abc* is anticlockwise direction from the Lenz law.

The induced current in loop *defg* is clockwise direction.

S12. (a) If the field is downward direction the induced current is anticlockwise direction by Lenz law.

(b) If the field is upward direction the induced current is clockwise direction by Lenz law.

S13. It is because, the induced e.m.f. is opposes the applied voltage.

S14. (a) The magnetic flux through the rectangular loop abcd increases, due to the motion of the loop into the region of magnetic field, The induced current must flow along the path bcdab so that it opposes the increasing flux.

(b) Due to the outward motion, magnetic flux through the triangular loop abc decreases due to which the induced current flows along bacb, so as to oppose the change in flux.

(c) As the magnetic flux decreases due to motion of the irregular shaped loop abcd out of the region of magnetic field, the induced current flows along cdabc, so as to oppose change in flux.

Note that there are no induced current as long as the loops are completely inside or outside the region of the magnetic field.

S15. (a) To obtain a large deflection, one or more of the following steps can be taken: (i) Use a rod made of soft iron inside the coil C_2, (ii) Connect the coil to a powerful battery, and (iii) Move the arrangement rapidly towards the test coil C_1.

(b) Replace the galvanometer by a small bulb, the kind one finds in a small torch light. The relative motion between the two coils will cause the bulb to glow and thus demonstrate the presence of an induced current.

S16. Given, $L = 8\,\text{H}$; $R = 25\,\Omega$ and $E = 120\,\text{V}$

The steady value of current in the circuit,

$$I = \frac{E}{R} = \frac{120}{25} = 4.8\,\text{A}$$

Therefore, energy stored in the inductor,

$$U = \frac{1}{2}LI^2 = \frac{1}{2} \times 8 \times (4.8)^2 = \mathbf{92.16\ J}.$$

S17. When magnet is moved towards right:

In resistor *AB*, from end *A* to *B* and in *CD*, From *D* to *C*.

When magnet is moved towards left:

In resistor *AB*, from end *B* to *A* and in *CD*, from *C* to *D*.

S18. When the increasing current flows through the wire in the direction from point *B* to *A*, the increasing magnetic field is produced; which is directed perpendicular to the plane of the loop (or the plane of paper) and in inward direction. Due to this, induced e.m.f. is produced in the loop which opposes the magnetic field produced due to the current flowing through the wire *i.e.*, induced current in the loop should flow in a direction so that it produces magnetic field perpendicular to the plane of the loop and in outward direction. Maxwell's cork screw rule tells that induced current in the loop will flow in ***anticlockwise direction***.

S19. When an irregular shaped wire *PQRS* changes to circular loop, the magnetic flux linked with the wire increases due to increase in area of the loop. The induced e.m.f. will cause current to flow in the direction, so that the wire is pulled inward from all sides. According to Fleming's left hand rule, force on wire *PQRS* will act inward from all sides, if the current flows in the direction *PSRQP*.

S20. As the closed loop *PQRS* moves into the uniform magnetic field, magnetic flux linked with the loop will increases. According to Lenz's law, induced e.m.f. produced in the loop should act so that the coil is opposed from moving in the loop should act so that the coil is opposed from moving into the magnetic field. For this to occur, force on the arm *PS* of the coil should act towards right. It requires that current through the arm *PS* should be form the end *P* to *S*. *i.e.*, current in the coil should be in the direction of *PSRQP*.

S21. Given: $B = 0.15\,\text{T}$; $v = 2\,\text{m s}^{-1}$; $l = 0.5\,\text{m}$;

The induced e.m.f. produced across the rod,

$$e = Blv = 0.15 \times 0.5 \times 2 = 0.15\,\text{V}$$

The resistance of the circuit, $R = 3\,\Omega$.

Hence, induced current passing through the circuit,

$$I = \frac{e}{R} = \frac{0.15}{3} = 0.05\,\text{A}.$$

Therefore, the force needed to move the rod,

$$F = BIl = 0.15 \times 0.05 \times 0.5 = 3.75 \times 10^{-3}\,\text{N}.$$

S22. According to Lenz's law due to change in flux through a coil e.m.f. is induced in such a way that it opposes the cause which produces it.

It is this opposition against which we perform mechanical work in causing the change in flux. So, it is the mechanical energy which is converted into electrical energy. For example, when north pole of magnet approaches a coil, a north pole is induced on the face of the coil. Now mechanical energy is spent in further moving the magnet towards the coil. It is this energy which appears as induced e.m.f. or electrical energy. Hence Lenz's law is in accordance with law of conservation of energy.

S23. According to Lenz's law due to change in flux through a coil e.m.f. is induced in such a way that it opposes the cause which produces it.

(a) Induced e.m.f. will be same in both the loops because rate of change of magnetic flux through each loop is same.

(b) Resistivity of copper is lesser than that of aluminium. So induced current in copper loop will be more.

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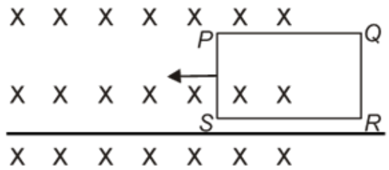
Q1. The closed loop (*PQRS*) of wire is moved into a uniform magnetic field at right angles to the plane of the paper as shown in the figure. Predict the direction of the induced current in the loop, as shown in figure.



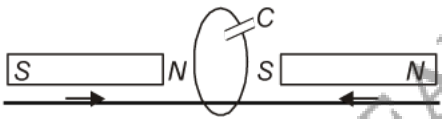
Q2. When a coil is rotated in a uniform magnetic field at constant angular velocity, will the magnitude of induced e.m.f. set up in the coil be constant? Why?

Q3. The magnetic flux threading a coil changes from 12×10^{-3} Wb to 6×10^{-3} Wb in 0.01 s. Calculate the induced e.m.f.

Q4. A metallic wire 1.5 m in length is moving normally across a field of 0.5 T with a speed of 5 ms^{-1}. Find the e.m.f. between the ends of the wire.

Q5. A wire cuts across a flux of 0.6×10^{-2} weber in 0.8 second. What is the e.m.f induced in the wire?

Q6. Two bar magnets are quickly moved towards a metallic loop connected across a capacitor '*C*' shown in the figure. Predict the polarity of the capacitor.



Q7. A rectangular wire loop of sides 8 cm and 2 cm with a small cut is moving out of a region of uniform magnetic field of magnitude 0.3 T directed normal to the loop. What is the e.m.f. developed across the cut if the velocity of the loop is 1 cm s^{-1} in a direction normal to the (a) longer side, (b) shorter side of the loop? For how long does the induced voltage last in each case?

Q8. A 1.0 m long metallic rod is rotated with an angular frequency of 400 rads^{-1} about an axis normal to the rod passing through its one end. The other end of the rod is in contact with a circular metallic ring . A constant and uniform magnetic field of 0.5 T parallel to the axis exist everywhere. Calculate the emf developed between the centre and the ring.

Q9. A circular coil of radius 8.0 cm and 20 turns is rotated about its vertical diameter with an angular speed of 50 rad s^{-1} in a uniform horizontal magnetic field of magnitude 3.0×10^{-2} T. Obtain the maximum and average emf induced in the coil. If the coil forms a closed loop of resistance 10 Ω, calculate the maximum value of current in the coil. Calculate the average power loss due to Joule heating. Where does this power come from?

Q10. A horizontal straight wire 10 m long extending from east to west is falling with a speed of 5.0 m s^{-1}, at right angles to the horizontal component of the earth's magnetic field, 0.30×10^{-4} Wb m^{-2}.

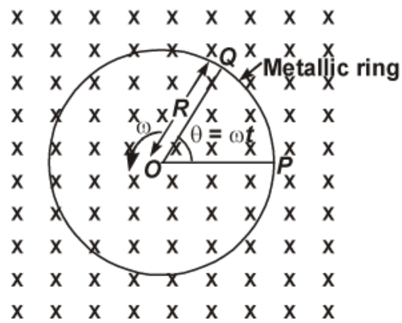
What is the instantaneous value of the e.m.f. induced in the wire?

What is the direction of the e.m.f.?

Which end of the wire is at the higher electrical potential?

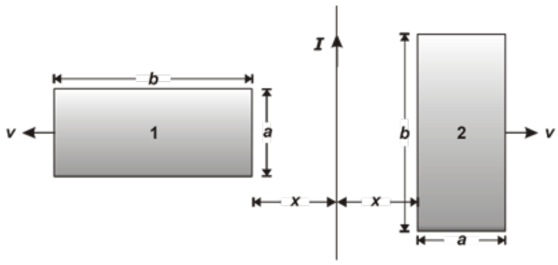
Q11. A jet plane is travelling towards west at a speed of 1800 km/h. What is the voltage difference developed between the ends of the wing having a span of 25 m, if the Earth's magnetic field at the location has a magnitude of 5×10^{-4} T and the dip angle is 30°.

Q12. A metallic rod of 1 m length is rotated with a frequency of 50 rev/s, with one end hinged at the centre and the other end at the circumference of a circular metallic ring of radius 1 m, about an axis passing through the centre and perpendicular to the plane of the ring (see figure). A constant and uniform magnetic field of 1 T parallel to the axis is present everywhere. What is the e.m.f. between the centre and the metallic ring?



Q13. A coil has a self inductance of 15 mH. What is the maximum magnitude of the induced e.m.f. in the inductor, when a current $I = 0.1 \sin 150\, t\ A$ is sent through it?

Q14. The figure shows two identical rectangular loops (1) and (2), placed on a table along with a straight long current carrying conductor between them.



(a) What will be the directions of the induced currents in the loops, when they are pulled away from the conductor with same velocity?

(b) Will the e.m.f. induced in the two loops be equal? Justify your answer.

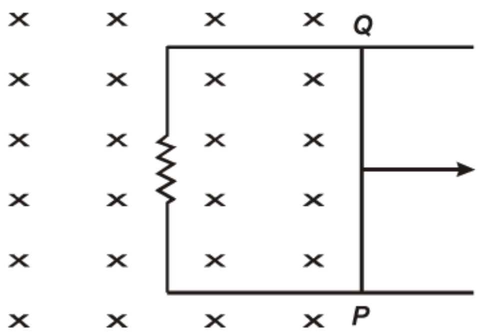
Q15. Suppose the loop is stationary but the current feeding the electromagnet that produces the magnetic field is gradually reduced so that the field decreases from its initial value of 0.3 T at the rate of 0.02 T s^{-1}. If the cut is joined and the loop has a resistance of 1.6 Ω how much power is dissipated by the loop as heat? What is the source of this power?

Q16. An air-cored solenoid with length 30 cm, area of cross-section 25 cm^2 and number of turns 500, carries a current of 2.5 A. The current is suddenly switched off in a brief time of 10^{-3} s. How much is the average back e.m.f. induced across the ends of the open switch in the circuit? Ignore the variation in magnetic field near the ends of the solenoid.

Q17. Deduce an expression for the motional e.m.f

Q18. A wheel with 10 metallic spokes each 0.5 m long is rotated with a speed of 120 rev/min in a plane normal to the horizontal component of earth's magnetic field B_H at place. If B_H = 0.4 G at the place, what is the induced e.m.f. between the axle and the rim of the wheel?

Q19. A 0.5 m long metal rod *PQ* completes the circuit as shown in the figure below. The area of the circuit is perpendicular to the magnetic field of flux density 0.15 *T*. If the resistance of the total circuit is 3 Ω. Calculate the force needed to move the rod in the direction as indicated with a constant speed of $2\ ms^{-1}$.



Q20. A metallic rod of length *l* is rotated at an angular speed ω, normal to a uniform magnetic field *B*. Derive expressions for the (a) e.m.f. induced in the rod (b) heat dissipation, if the resistance of the rod is *R*.

Q21. (a) Obtain the expression for the magnetic energy stored in a solenoid in terms of magnetic field *B*, area *A* and length *l* of the solenoid.

(b) How does this magnetic energy compare with the electrostatic energy stored in a capacitor?

Q22. A coil of number of turns *N*, area *A*, is rotated at a constant angular speed ω, in a uniform magnetic field *B*, and connected to a resistor *R*. Deduce expressions for:

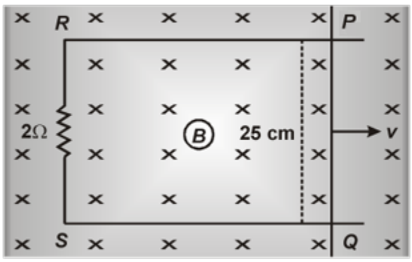
(a) Maximum em.f. induced in the coil

(b) Power dissipation in the coil

Q23. A circular copper disc 10 cm in radius rotates at 20π rad s^{-1} about axis through its centre and perpendicular to the disc. A uniform magnetic field of 0.2 T acts perpendicular to the disc. (a) Calculate the potential difference developed between the axis of the disc and the rim (b) What is the induced current, if the resistance of the disc is 2 Ω?

Q24. A rectangular coil of dimensions $0.10\ m \times 0.5\ m$ consisting of 2000 turns rotates about an axis parallel to its long side, making 2,100 revolutions per minute in a field of 0.1 T. What is the maximum e.m.f. induced in the coil? Also find the instantaneous e.m.f. when the coil is at 30° to the field.

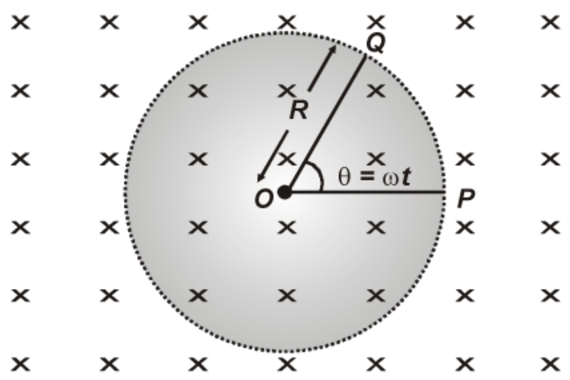
Q25. As shown in figure below, a conducting rod *PQ* in contact with metal rails *RP* and *SQ*, which are 25 cm apart in a uniform field of flux density 0.4 *T* acting perpendicular to the plane of the paper. Ends *R* and *S* connected through a 5 Ω resistance. What is the e.m.f., when the rod moves to the right with a velocity of $5\ ms^{-1}$? What is the magnitude and the direction of the current through the 5 Ω resistor?



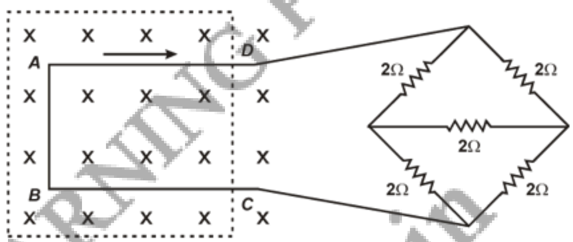
Q26. A circular coil of radius 10 cm, 500 turns and resistance 2 Ω is placed with its plane perpendicular to the horizontal component of the earth's magnetic field. It is rotated about its vertical diameter through 180° in 0.25 s. Estimate the magnitudes of the e.m.f. and current induced in the coil. Horizontal component of the earth's magnetic field at the place is $3.0 \times 10^{-5}\ T$.

Q27. A conducting rod of length l with one end pivoted is rotated with a uniform angular speed ω in a vertical plane, normal to a uniform magnetic field B. Deduce expression for the e.m.f. induced in this rod.

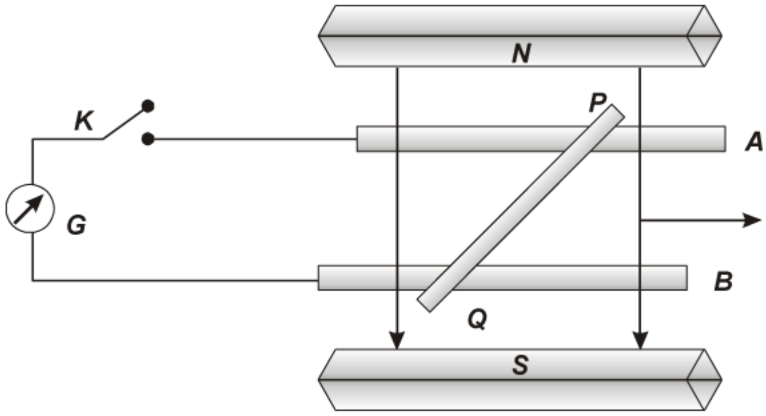
Q28. A metallic rod 1 m length is rotated with a frequency of 50 rev/s, with one end hinged at the centre and the other end at the circumference of a circular metallic ring of radius 1 m, about an axis passing through the centre and perpendicular to the plane of the ring. A constant and uniform magnetic field of 1 T and parallel to the axis is present everywhere. What is the e.m.f. between the centre and the metallic ring?



Q29. A metallic square loop $ABCD$ of size 15 cm and resistance 1.0 Ω is moved at a uniform velocity of v m/s, in a uniform magnetic field of 2 tesla, the field lines being normal to the plane of the paper. The loop is connected to an electrical network of resistors, each of resistance 2 Ω. Calculate the speed of the loop, for which 2 mA current flows in the loop.



Q30. Figure given below shows a metal rod *PQ* resting on the smooth rails *AB* and positioned between the poles of a permanent magnet. The rails, the rod, and the magnetic field are in three mutual perpendicular directions. A galvanometer *G* connects the rails through a switch *K*. Length of the rod = 15 cm, *B* = 0.50 T, resistance of the closed loop containing the rod = 9.0 mΩ. Assume the field to be uniform.



(a) Suppose *K* is open the rod is moved with a speed of 12 cm s^{-1} in the direction shown in the figure. Give the polarity and magnitude of the induced e.m.f.

(b) Is there an excess charge built up at the ends of the rods when *K* is open? What if *K* is closed?

(c) With *K* open and the rod is moving uniformly, there is no net force on the electrons in the rod *PQ* even though they do experience magnetic force due to the motion of the rod. Explain.

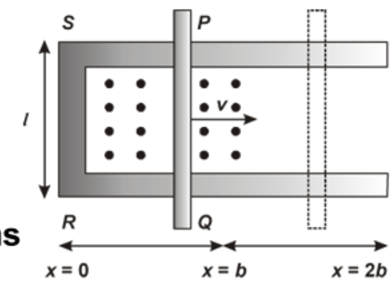
(d) What is the retarding force on the rod when *K* is closed?

(e) How much power is required (by an external agent) to keep the rod moving at the same speed (= 12 cm s^{-1}) when K is closed? How much power is required when *K* is open?

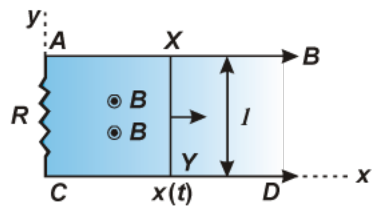
(f) How much power is dissipated as heat in the closed circuit? What is the source of this power?

(g) What is the induced e.m.f. in the moving rod if the magnetic field is parallel to the rails instead of being perpendicular?

Q31. Refer to figure. The arm *PQ* of the rectangular conductor is moved from *x* = 0 to the right side. The uniform magnetic field is perpendicular to the plane and extends from *x* = 0 to *x* = *b* and is zero *x* > *b*. Only the arm *PQ* possesses substantial resistance *r*. Consider the situation when the arm *PQ* is pulled outwards from *x* = 0 with constant speed *v*. Obtain expressions for the flux, the induced e.m.f. the force necessary to pull the arm and the power dissipated as Joule heat. Sketch the variation of these quantities with distance.



Q32. A conducting wire *XY* of mass *m* and negligible resistance slides smoothly on two parallel conducting wires as shown in figure. The closed circuit has a resistance *R* due to *AC*. *AB* and *CD* are perfect conductors. There is a magnetic field $B = B(t)\hat{k}$.



(a) Write down equation for the acceleration of the wire *XY*.

(b) If *B* is independent of time, obtain $v(t)$, assuming $v(0) = u_0$.

(c) From (b), shown that the decrease in kinetic energy of *XY* equals the heat lost in *R*.

Date: 21/10/2021

S1. In loop *PQRS* induced current is anticlockwise by the Lenz law.

S2. Given:

$$\omega = \text{constant}$$

e.m.f. is not constant because the induced e.m.f. vary with time and it will be sinusoidal due the change of the orientation of the coil w.r.t. the magnetic field.

S3. Given: $t = 0.01$ sec, $\phi_1 = 12 \times 10^{-3}$ Wb, $\phi_2 = 6 \times 10^{-3}$ Wb

$$\Delta\phi = \phi_2 - \phi_1 = -6 \times 10^{-3} \text{ Wb}$$

$$e = \frac{\Delta\phi}{\Delta t} = \frac{6 \times 10^{3}}{0.01} = \mathbf{0.6\ V}$$

S4. Given: Wire length $l = 1.5$ m, Magnetic field $B = 0.5$ T and Speed is $v = 5$ m/sec

We know, Induced e.m.f.,

$$e = Bvl = 0.5 \times 5 \times 1.5 = \mathbf{3.75\ V}$$

S5. We know that Induced e.m.f.,

$$e = -\frac{d\phi}{dt} = -\frac{0.6 \times 10^{-2}}{0.8} = \mathbf{-7.5 \times 10^{-3}\ V}$$

S6. Upper plate of the capacitor is positive and lower plate of the capacitor is negative by Lenz law.

S7. Length of the rectangular wire, $l = 8$ cm $= 0.08$ m

Width of the rectangular wire, $b = 2$ cm $= 0.02$ m

Hence, area of the rectangular loop,

$$A = lb$$
$$= 0.08 \times 0.02$$
$$= 16 \times 10^{-4} \text{ m}^2$$

Magnetic field strength, $B = 0.3$ T

Velocity of the loop, $v = 1$ cm/s $= 0.01$ m/s

E.m.f. developed in the loop is given as:

$$e = Blv$$
$$= 0.3 \times 0.08 \times 0.01 = 2.4 \times 10^{-4} \text{ V}$$

Time taken to travel along the width,

$$t = \frac{\text{Distance travelled}}{\text{Velocity}} = \frac{b}{v}$$

$$= \frac{0.02}{0.01} = 2\,\text{s}$$

Hence, the induced voltage is 2.4×10^{-4} V which lasts for 2 s.

E.m.f. developed, $e = Bbv$

$$= 0.3 \times 0.02 \times 0.01 = 0.6 \times 10^{-4}\,\text{V}$$

Time taken to travel along the length,

$$t = \frac{\text{Distance travelled}}{\text{Velocity}} = \frac{l}{v}$$

$$= \frac{0.08}{0.01} = 8\,\text{s}$$

Hence, the induced voltage is 0.6×10^{-4} V which lasts for 8 s.

S8. $l = 1.0\,\text{cm}$ $\omega = 400\,\text{rad/s}$

$B = 0.5\,\text{T}$

$$\varepsilon = \frac{d\Phi}{dt} = \frac{d}{dt}\left(B\,\frac{\pi r^2\theta}{2\pi}\right) = B\left(\frac{1}{2}r^2\omega\right)$$

$$= 100\,\text{V}.$$

S9. Here, Max induced e.m.f. = 0.603 V

Average induced e.m.f. = 0 V

Max current in the coil = 0.0603 A

Average power loss = 0.018 W

(Power comes from the external rotor)

Radius of the circular coil, $r = 8\,\text{cm} = 0.08\,\text{m}$

Area of the coil, $A = \pi r^2 = \pi \times (0.08)^2\,\text{m}^2$

Number of turns on the coil, $N = 20$

Angular speed, $\omega = 50\,\text{rad/s}$

Magnetic field strength, $B = 3 \times 10^{-2}\,\text{T}$

Resistance of the loop, $R = 10\,\Omega$

Maximum induced e.m.f. is given as:

$$e = N\omega AB$$

$$= 20 \times 50 \times \pi \times (0.08)^2 \times 3 \times 10^{-2}$$

$$= 0.603\,V$$

The maximum e.m.f induced in the coil is 0.603 V.

Over a full cycle, the average *emf* induced in the coil is zero.

Maximum current is given as:

$$I = \frac{e}{R} = \frac{0.603}{10} = 0.0603\ A$$

Average power loss due to joule heating:

$$P = \frac{eI}{2} = \frac{0.603 \times 0.0603}{2} = 0.018\,W.$$

The current induced in the coil produces a torque opposing the rotation of the coil. The rotor is an external agent. It must supply a torque to counter this torque in order to keep the coil rotating uniformly. Hence, dissipated power comes from the external rotor.

S10. Length of the wire, $l = 10$ m

Falling speed of the wire, $v = 5.0$ m/s

Magnetic field strength, $B = 0.3 \times 10^{-4}$ Wb m^{-2}

E.m.f. induced in the wire,

$$e = Blv$$

$$= 0.3 \times 10^{-4} \times 5 \times 10$$

$$= 1.5 \times 10^{-3}\,V$$

Using Fleming's right hand rule, it can be inferred that the direction of the induced e.m.f. is from West to East.

The eastern end of the wire is at a higher potential.

S11. Speed of the jet plane, $v = 1800$ km/h $= 500$ m/s

Wing span of jet plane, $l = 25$ m

Earth's magnetic field strength, $B = 5.0 \times 10^{-4}$ T

Angle of dip, $\delta = 30°$

Vertical component of Earth's magnetic field,

$$B_V = B \sin \delta$$

$$= 5 \times 10^{-4} \sin 30°$$

$$= 2.5 \times 10^{-4}\,T$$

Voltage difference between the ends of the wing can be calculated as:

$$e = (B_V) \times l \times v$$

$$= 2.5 \times 10^{-4} \times 25 \times 500$$
$$= 3.125\,V$$

Hence, the voltage difference developed between the ends of the wings is 3.125 V.

S12. **Method I:** As the rod is rotated, free electrons in the rod move towards the outer end due to Lorentz force and get distributed over the ring. Thus, the resulting separation of charges produces an e.m.f. across the ends of the rod. At a certain value of e.m.f., there is no more flow of electrons and a steady state is reached. Using Eq. (6.5), the magnitude of the e.m.f. generated across a length d*r* of the rod as it moves at right angles to the magnetic field is given by

$d\varepsilon = Bvdr$. Hence,

$$\varepsilon = \int d\varepsilon = \int_0^R Bvdr = \int_0^R B\omega r\,dr = \frac{B\omega R^2}{2}$$

Note that we have used $v = \omega r$. This gives

$$\varepsilon = \frac{1}{2} \times 1.0 \times 2\pi \times 50 \times (1^2) = 157\text{ V}$$

Method II: To calculate the emf, we can imagine a closed loop *OPQ* in which point *O* and *P* are connected with a resistor *R* and *OQ* is the rotating rod. The potential difference across the resistor is then equal to the induced emf and equals $B \times$ (rate of change of area of loop). If θ is the angle between the rod and the radius of the circle at *P* at time *t*, the area of the sector *OPQ* is given by

$$\pi R^2 \times \frac{\theta}{2\pi} = \frac{1}{2} R^2\theta$$

where *R* is the radius of the circle. Hence, the induced e.m.f. is

$$\varepsilon = B \times \frac{d}{dt}\left[\frac{1}{2}R^2\theta\right] = \frac{1}{2}BR^2\frac{d\theta}{dt} = \frac{B\omega R^2}{2}$$

[Note: $\frac{d\theta}{dt} = \omega = 2\pi\nu$]

This expression is identical to the expression obtained by Method I and we get the same value of ε. i.e.,induced e.m.f.

S13. Given: $L = 10\text{ mH} = 15 \times 10^{-3}\text{ H}$ and $I = 0.1 \sin 150\,t$

$$\therefore \quad \frac{dI}{dt} = \frac{d}{dt}(0.1 \sin 150\,t) = (0.1 \cos 150\,t) \times 150$$
$$= 15 \cos 150\,t$$

Now, $$\left(\frac{dI}{dt}\right)_{max} = 15 \times 1 = 15\,\text{As}^{-1} \qquad \text{(if } \theta = 0°\text{)}$$

$$\therefore \quad e_{max} = L\left(\frac{dI}{dt}\right)_{max} = 15 \times 10^{-3} \times 15 = \mathbf{0.2\,V}.$$

S14. (a) According to Lenz's law, the direction of current through a loop will be such that change in magnetic flux through the coils is opposed. For this, current through the loop 1 and 2, will be in ***anticlockwise*** and ***clockwise directions*** respectively.

(b) No. The e.m.f. induced in the loop 2 will be ***more***. It is because, rate of change of magnetic flux through the loop 2 will be greater than that through the loop 1.

S15. Sides of the rectangular loop are 8 cm and 2 cm.

Hence, area of the rectangular wire loop,

$$A = \text{length} \times \text{width}$$
$$= 8 \times 2 = 16 \text{ cm}^2$$
$$= 16 \times 10^{-4} \text{ m}^2$$

Initial value of the magnetic field, $B = 0.3\text{ T}$

Rate of decrease of the magnetic field,

$$\frac{dB}{dt} = 0.02 \text{ T/s}$$

E.m.f. developed in the loop is given as:

$$e = \frac{-d\phi}{dt}$$

Where, $d\Phi$ = Change in flux through the loop area = AB

$\therefore$ $$e = \frac{d(AB)}{dt} = \frac{AdB}{dt}$$
$$= 16 \times 10^{-4} \times 0.02 = 0.32 \times 10^{-4} \text{ V}$$

Resistance of the loop, $R = 1.6\,\Omega$

The current induced in the loop is given as:

$$i = \frac{e}{R} = \frac{0.32 \times 10^{-4}}{1.6} = 2 \times 10^{-5} \text{ A}$$

Power dissipated in the loop in the form of heat is given as:

$$P = i^2 R$$
$$= (2 \times 10^{-5})^2 \times 1.6 = 6.4 \times 10^{-10} \text{ W}$$

The source of this heat loss is an external agent, which is responsible for changing the magnetic field with time.

S16. Length of the solenoid, $l = 30 \text{ cm} = 0.3 \text{ m}$

Area of cross-section, $A = 25 \text{ cm}^2 = 25 \times 10^{-4} \text{ m}^2$

Number of turns on the solenoid, $N = 500$

Current in the solenoid, $I = 2.5\text{ A}$

Current flows for time, $t = 10^{-3}$ s

Average back e.m.f., $e = \frac{-d\phi}{dt}$ ... (i)

Where, $d\phi$ = Change in flux

$= NAB$ ... (ii)

Where, B = Magnetic field strength

$= \mu_0 \frac{NI}{l}$ ... (iii)

Where, μ_0 = Permeability of free space

$= 4\pi \times 10^{-7}$ T m A^{-1}

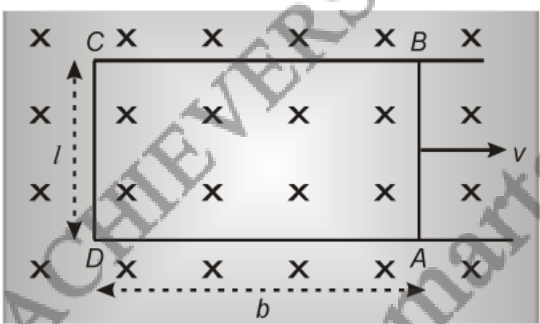
Using Eqns. (ii) and (iii) in Eq. (i), we get

$$e = \frac{\mu_0 N^2 I A}{lt}$$

$$= \frac{4\pi \times 10^{-7} \times (500)^2 \times 2.5 \times 25 \times 10^{-4}}{0.3 \times 10^{-3}} = 6.5\text{ V}$$

Hence, the average back e.m.f. induced in the solenoid is 6.5 V.

S17. Consider a rectangular loop *ABCD* placed in a uniform magnetic field *B*, pointing into the plane of paper. The arm *AB* slides towards right with velocity *v*. As the conductor moves towards right, the area of the loop increases. The magnetic flux linked with the loop increases and an induced current begins to flow in the anticlockwise direction, as shown in figure.



If *e* is the induced e.m.f. across the ends of the conductor, then the electric field set-up across the end is

$$E = \frac{e}{l}$$

Magnitude of electric force on an electron is given by

$$F_e = qE = q\,\frac{e}{l}$$

force experienced by an electron due to magnetic field,

$$F_m = Bqv$$

So in equilibrium,

$$Bqv = q\,\frac{e}{l}$$

or $$Bv = \frac{e}{l}$$

or $$e = Bvl$$

S18. $N = 10$, $r = 0.50$ m, $v = 120$ rev/min = 2 rev/s, $B = 0.4$ G $= 0.4 \times 10^{-4}$ T, e = ?

Area swept by each spoke per second, $A = \pi r^2 v$

Magnetic flux cut by each spoke per second

$$\frac{d\phi}{dt} = BA = B\pi r^2 v$$

$$e = B\pi r^2 v = 0.4 \times 10^{-4} \times \pi \times (0.50)^2 \times 2$$

$$= \mathbf{6.28 \times 10^{-5}}.$$

As the spokes are connected in parallel net e.m.f. developed across the 10 spokes is the same.

S19. Given: $l = 0.5$ m $\quad B = 0.15$ T

$R = 3\,\Omega \quad v = 2$ ms^{-1}

e.m.f. induced in the circuit

$$E = vBl$$

Current in the circuit

$$I = \frac{E}{R} = \frac{vBl}{R}$$

Force needed to move the rod is

$$F = BIl$$

$$F = B\left(\frac{vBl}{R}\right)l = \frac{vB^2l^2}{R}$$

$$F = \frac{2 \times (0.15)^2 \times (0.5)^2}{3}$$

$$F = \mathbf{3.75 \times 10^{-3}\ N}.$$

S20. (a) e.m.f. induced across a small section (dr) of the rod

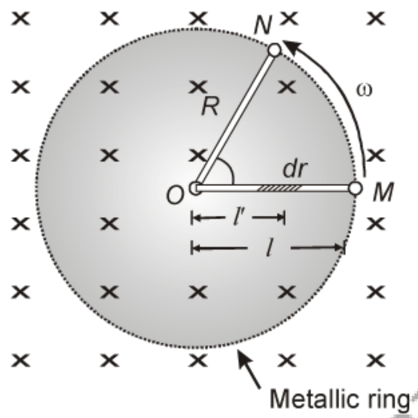
$$de = Bvdr$$

$$de = B\omega rdr \qquad (\because \; v = r\omega)$$

Net e.m.f. induced across the length 'l' of the rod.

$$e = \int_0^l B\omega rdr$$

$$e = \frac{B\omega l^2}{2}$$



(b) If resistance of the rod is 'R' current induced is

$$I = \frac{e}{R} = \frac{B\omega l^2}{8R}$$

Alternatively

In case, axis of the rod is assumed to pass through its mid-point. Hence $l' = l/2$

$$e = \frac{B\omega l^2}{8}$$

and $$I = \frac{B\omega l^2}{8R}.$$

S21. (a) Magnetic energy stored in an inductor is

$$U_B = \frac{1}{2}LI^2 = \frac{1}{2}L\left(\frac{B}{\mu_0 n}\right)^2 \qquad (\because \; B = \mu_0 nI)$$

$$= \frac{1}{2}(\mu_0 n^2 Al)\left(\frac{B}{\mu_0 n}\right)^2 = \frac{1}{2\mu_0} B^2 Al \qquad (\because\ L = \mu_0 n^2 Al)$$

(b) Energy density is

$$u_m = \frac{U_B}{V} = \frac{1}{2\mu_0}\frac{B^2 \cancel{Al}}{\cancel{V}} \qquad (\because\ Al = V)$$

If we make the substitution,

$$\frac{1}{\mu_0} \to \varepsilon_0$$

$$\vec{B} \to \vec{E}$$

We get energy density in a parallel plate capacitor

$$\mu_e = \frac{1}{2}\varepsilon_0 E^2.$$

In both cased energy is proportional to the square of the field strength.

S22. We know, induced e.m.f.

(a)
$$e = -\frac{d\phi}{dt}$$

$$e = -\frac{d}{dt}(NBA \cos \omega t)$$

$$e = NBA\ \omega \sin \omega t \qquad (\text{when } \omega t = 90°)$$

where

$$E_{\max} = NBA\,\omega$$

(b) Power dissipation,

$$P = \frac{e_{\text{rms}}^2}{R} = \frac{N^2B^2A^2\omega^2 \sin^2 \omega t}{R}$$

Power dissipated over a complete cycle is

$$\langle P \rangle = \frac{N^2B^2A^2\omega^2}{2R}.$$

S23. Given, $B = 0.2$ T;

Radius of the circular disc, $r = 10$ cm $= 0.1$ m

Resistance of the Disc, $R = 2\ \Omega$

Angular speed of rotation of the disc, $\omega = 20\,\pi\,\text{rad s}^{-1}$

Therefore, frequency of rotation of the disc,

$$f = \frac{\omega}{2\pi} = \frac{20\pi}{2\pi} = 10\,\text{r.p.s.}$$

(a) If e is the induced e.m.f. produced between the axis of the disc and its rim, then

$$e = -B \times \pi r^2 \times n$$

$$= -0.2 \times \pi \times (0.10)^2 \times 10 = \mathbf{-0.0628\,V}.$$

(b) Induced current, $I = \frac{e}{R} = \frac{0.0628}{2}$ = **0.0314 A**.

S24. Given, $B = 0.1$ T; $n = 2000$;

area of the coil, $A = 0.10\text{ m} \times 0.5\text{ m} = 0.05\text{ m}^2$;

angular velocity, $\omega = 2{,}100$ r.p.m

$$= \frac{2\pi \times 2{,}100}{60} = \mathbf{220\ rad\,s^{-1}}$$

Maximum e.m.f. induced in the coil,

$$e_0 = nBA\omega$$

$$= 2{,}100 \times 0.1 \times 0.05 \times 220 = \mathbf{2.310\,V}.$$

The e.m.f. induced in the coil, when it makes an angle ωt with the vertical is given by

$$e = e_0 \sin \omega t$$

Therefore, the angle, which the coil makes with the vertical,

$\therefore$ $\omega t = 90° - 30° = 60°$

$$e = 2{,}310 \sin 60° = \mathbf{2{,}000.5\,V}.$$

S25. Given: $B = 0.4\,T$; $v = 5\,\text{ms}^{-1}$; $l = 25\,\text{cm} = 0.25\,\text{m}$

Induced e.m.f. produced,

$$e = Blv = 0.4 \times 0.25 \times 5 = 0.5\,\text{V}. \qquad (\because\ \theta = 90°)$$

Current through the 5 Ω resistance,

$$I = \frac{e}{R} = \frac{0.5}{5} = \mathbf{0.1\ A}.$$

According to Lenz's law, when the rod PQ moves towards right, the induced current should flow in a direction so that the rod PQ experiences force towards left. According to Fleming's left hand rule, then the current through the rod PQ will flow from the end Q to P *i.e.*, from the end R to S through the resistance of 5 Ω.

S26. Given: $B = 30 \times 10^{-5}$ T ; A = 0.01 πm^2; $N = 500$; $R = 2\Omega$; $\Delta t = 0.25$ sec.

Initial flux through the coil, $\theta = 0°$

$$\Phi_{B\,(\text{initial})} = BA\cos\theta$$
$$= 3.0 \times 10^{-5} \times (\pi \times 10^{-2}) \times \cos 0°$$
$$= 3\pi \times 10^{-7}\ \text{Wb}$$

Final flux after the rotation, $\theta = 180°$

$$\Phi_{B\,(\text{final})} = 3.0 \times 10^{-5} \times (\pi \times 10^{-2}) \times \cos 180°$$
$$= -3\pi \times 10^{-7}\ \text{Wb}$$

Hence, estimated value of the induced e.m.f. is,

$$e = N\frac{\Delta\Phi}{\Delta t}$$

$$= 500 \times \frac{3\pi \times 10^{-7} - (-3\pi \times 10^{-7})}{0.25}$$

$$= 3.8 \times 10^{-3}\ \text{V}$$

$$I = e/R = \mathbf{1.9 \times 10^{-3}\ A}.$$

S27. When the conducting rod rotates inside the uniform magnetic field, it intercepts magnetic field over a circular area. whose radius is equal of length (l) of the rod.

Therefore, area intercepted by the rod in one rotation,

$$\Delta S = \pi l^2$$

Hence, change in the magnetic flux through the copper rod in one rotation,

$$d\phi = B\Delta S = B \times \pi l^2$$

Since the rod rotates with angular velocity ω, time taken by it to complete one rotation,

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

If e is the induced e.m.f. produced between the two ends of the rod, then

$$e = -\frac{d\phi}{dt} = \frac{B \times \pi l^2}{2\pi/\omega}$$

or $$e = -\frac{1}{2}Bl^2\omega$$

Note: If f is frequency of rotation of the rod, then

$$\omega = 2\pi f$$

$\therefore$ $$e = -\frac{1}{2} B l^2 \times 2\pi f$$

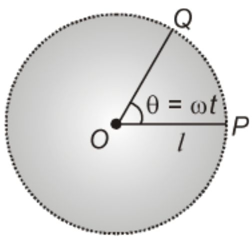
or $$e = - B \times \pi l^2 \times f.$$

S28. Given: $B = 1.0\,\text{T}$, $l = 1.0$ m; $\omega = 50$ rev/s

Flux at any instant of time $\phi = B \times$ area at that instant of time swept out by the rod.

$$\phi = B \times \frac{1}{2} l^2 \theta$$

$$\frac{d\phi}{dt} = B \times \frac{1}{2} l^2 \frac{d\theta}{dt}$$



$$e = \frac{1}{2} B l^2 \omega = \frac{1}{2} B l^2 2\pi f = \frac{1}{2} \times 1.0 \times (1.0)^2 \times 2\pi \times 50 = \mathbf{157\ V}$$

S29. Given $B = 2\,T$, $l = 15 \times 10^{-2}$ m, $I = 2 \times 10^{-3}$ A, $R = 3\,\Omega$

e.m.f. induced in the loop $(e) = Blv$

Current in the loop, $$I = \frac{e}{R} = \frac{Blv}{R} \quad \text{... (i)}$$

Hence, R = resistance of the loop + resistance of the network

$R = (1.0 + 2)$ (Network is balanced wheatstone bridge)

From Eqn. (i), we get

$$v = \frac{IR}{Bl}$$

$$v = \frac{2 \times 10^{-3} \times 3}{2 \times 15 \times 10^{-2}}$$

$$v = \mathbf{2 \times 10^{-2}\ m/s}.$$

S30. (a) We know $$e = Bl\text{v}$$

$$= 0.50 \times 0.12 \times 0.15 \text{ volt}$$

$$e = 9 \times 10^{-3}\ \text{V}$$

with p is positive and Q is negative end as per Fleming's left hand rule.

(b) Yes, excess change built up at the both ends of the rod when K is open.

If K is closed, these excess charge is takes the form of induced current.

Induced current,

$$I = \frac{e}{R}$$

or $$I = \frac{9 \times 10^{-3}}{9 \times 10^{-3}} = \mathbf{1\ A}.$$

(c) **Reason:** The presence of excess charge at the ends of metallic rod PQ set-up an electric field. This electric force ($q\vec{E}$) is balanced by the Lorentz magnetic force $e(\vec{v} \times \vec{B})$.

$$qE = e(v \times B)$$

(d) Retarding force = BIl $(\because\ \theta = 90°)$

$$F = 0.5 \times 1 \times 0.15\ \text{N}$$
$$= 75 \times 10^{-3}\ \text{N}.$$

(e) Power consumed by the external agent

we Know $$P = Fv$$

$$= 75 \times 10^{-3} \times 12 \times 10^{-2}$$
$$= 9.0 \times 10^{-3}\ \text{W}$$

When K is open, no power is required.

(f) Power dissipated as heat = I^2R

$$= (1)^2 \times (9 \times 10^{-3})$$

$$= 9 \times 10^{-3}\ \text{W}$$

Source of power: External agent

(g) No. e.m.f is induced

Motion of the rod does not cut across the field lines.

S31. The flux ϕ_B linked with the circuit $SPQR$ when PQ at x, is

$$\phi_B = \begin{cases} B\,l\,x & 0 \le x < b \\ B\,l\,b & b \le x < 2b \end{cases}$$

The induced e.m.f. is, the magnetic flux ϕ_B differentiate w.r.t. t,

$$e = -\frac{d\phi_B}{dt}$$

$$= \begin{cases} Blv & 0 \le x < b \\ 0 & b \le x < 2b \end{cases}$$

For, non-zero induced e.m.f., the current I is (in magnitude)

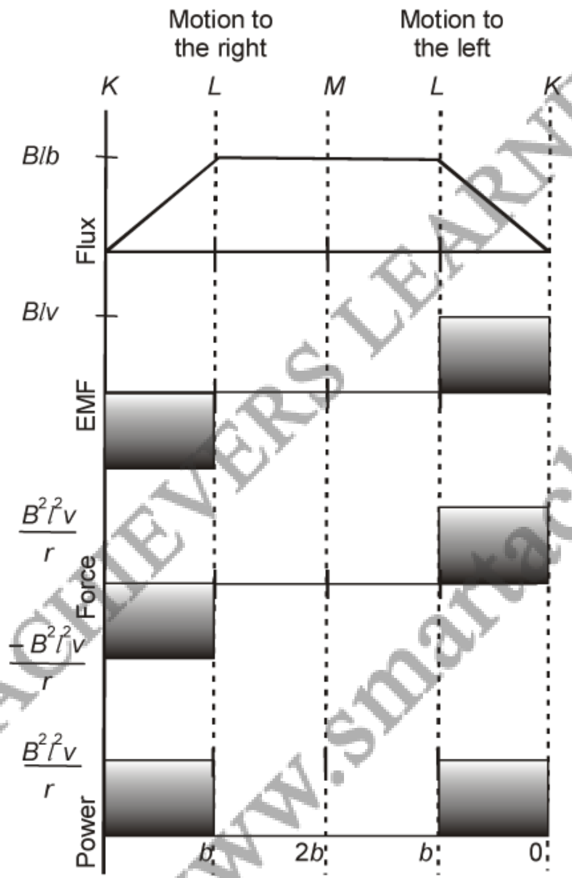
$$I = \frac{e}{r} = \frac{Blv}{r} \qquad \text{...(i)}$$

The force required to keep the arm PQ in constant motion is IlB. Its direction is to the left. Its magnitude

we know $F = IlB$ $\{\because \theta = 90°\}$

Put the value I in form Eq (i) we get

$$F = \begin{cases} \dfrac{B^2l^2v}{r} & 0 \le x < b \\ 0 & b \le x < 2b \end{cases}$$



In case of forward motion from $x = 0$ to $x = 2b$. According to Joule's law, heating loss is

$$P_J = I^2 r$$

$$= \begin{cases} \dfrac{B^2 l^2 v^2}{r} & 0 \le x < b \\ 0 & b \le x < 2b \end{cases}$$

One obtains similar expressions can be obtained for the inward motion from $x = 2b$ to $x = 0$.

S32. (a) Let the wire be $x = x(t)$ at time t.

Flux = $B(t)\, l x(t)$

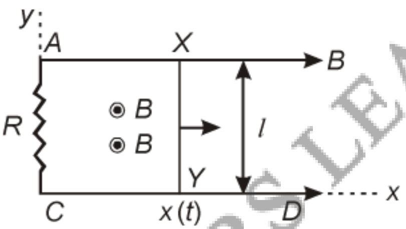
$$E = -\frac{d\phi}{dt}$$

$$= -\frac{dB(t)}{dt} l x(t) - B(t) l y(t) \quad \text{(second term due to motional e.m.f.)}$$

$$I = \frac{1}{R} E$$

$$\text{Force} = \frac{lB(t)}{R}\left[-\frac{dB}{dt} l x(t) - B(t) l v(t)\right]\hat{i}$$

$$m\frac{d^2x}{dt^2} = \frac{l^2 B}{R}\frac{dB}{dt}x(t) - \frac{l^2B^2}{R}\frac{dx}{dt}$$



(b) $$\frac{dB}{dt} = 0, \quad \frac{d^2x}{dt^2} + \frac{l^2B^2}{mR}\frac{dx}{dt} = 0$$

$$\frac{dv}{dt} + \frac{l^2B^2}{mR}v = 0$$

$$v = A\exp\left(\frac{-l^2B^2t}{mR}\right)$$

At $t = 0, \quad v = u$

$$v(t) = u \exp(-2l^2B^2t/mR).$$

(c) $$I^2R = \frac{B^2 l^2 v^2(t)}{R^2} \times R$$

$$= \frac{B^2 l^2}{R} u^2 \ \exp(-2l^2B^2t/mR)$$

Power lost $$= \int_0^t I^2 R dt$$

$$= \frac{B^2 l^2}{R} u^2 \frac{mR}{2l^2B^2}[1 - e^{-(l^2B^2t/mR)}]$$

$$= \frac{m}{2} u^2 - \frac{m}{2} v^2(t)$$

= decrease in kinetic energy.

Date: 21/10/2021

Q1. What are eddy currents? How are they produced?

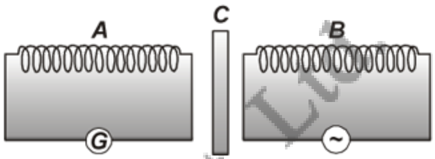
Q2. When an alternating current is passed through a moving coil galvanometer, it shows no deflection. Why?

Q3. Mention any one useful application of eddy currents produced.

Q4. The oscillations of a copper disc in a magnetic field are lightly damped. Why?

Q5. A coil *A* is connected to a voltmeter *V* and the other coil *B* to an alternating current source shows in the figure.

If a large copper sheet *C* is placed between the two coils, how does the induced e.m.f. in the coil *A* change due to current in coil *B*?



Q6. Why is the coil of a dead beat galvanometer wound on a metal frame?

Q7. How are eddy currents produced? Give two applications of eddy currents.

Q8. What are eddy currents? How are these produced? In what sense are eddy currents considered undesirable in a transformer and how are these reduced in such a device?

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S1. The eddy currents are caused in a metallic conductor, when the magnetic flux linked with the conductor changes.

S2. Because, a moving coil galvanometer measure the average value of current which is zero in a.c. Therefore no deflection is shown by moving coil galvanometer.

S3. In dead beat galvanometers.

S4. The eddy currents produced in the copper disc (due to its motion in magnetic field) always oppose its oscillatory motion and as such, the motion is damped.

S5. In the absence of copper sheet, induced e.m.f. will be produced in the coil *A* due to mutual induction between the coils *A* and *B*. As a result, voltmeter will show deflection depending on the magnitude of the induced e.m.f.

When the copper sheet is placed between the two coils, eddy currents will be set up in the coil. Since the eddy currents have opposing effect, the magnetic flux linked with the coil *S* due to eddy currents will always be opposite to that due to the alternating current through the coil *B*. Hence, induced e.m.f. will get reduced.

S6. On switching off the current in a galvanometer, the coil of the galvanometer does not come to rest immediately. It oscillates about its equilibrium position. But the coil of a dead beat galvanometer comes to rest immediately. It is due to the reason that the eddy currents are setup in the metallic frame, over which the coil is wound and the eddy currents oppose the oscillatory motion of the coil.

S7. Eddy currents are produced in a metallic conductor, when magnetic flux linked with the conductor changes.

Two applications are:

(a) In energy meters. (b) In dead beat galvanometers.

S8. It is the current induced in a thick conductor when it is paced in non-uniform *i.e.*, changing magnetic field.

Eddy currents are produced in a metal plate when it is placed in changing magnetic field, such that, magnetic field is perpendicular to the plane of paper and directed inwards in the form of concentric circles of “eddies” or “whirlpools” form.

To reduce eddy currents, we use identical slotted iron strips. Case them with vanish for insulation and join together to from thick core transformer. As resistance of such a core much larger than that of single thick core eddy currents get reduced to a good amount.

Date: 21/10/2021

Q1. A solenoid is connected to a battery so that a steady current flows through it. If an iron core is inserted into the solenoid, with the current increase or decrease? Explain.

Q2. How will you convert an a.c. generator into a d.c. generator?

Q3. At wire in the form of tightly wound solenoid is connected to a d.c. source, and carries a current. If the coil is stretched so that there are gaps between successive elements of the spiral coil, will the current increase or decrease?

Q4. What is the self inductance of a coil? Is it a scalar or vector quantity.

Q5. At which position of the rotating coil in the magnetic field, the induced e.m.f. is maximum?

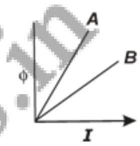
Q6. What is the self inductance? Write Its unit.

Q7. Two identical loops, one of copper and another of constantan are removed from a magnetic field within the same time interval. In which loop will the induced current be greater?

Q8. State the principle of a.c. generator.

Q9. Magnetic flux of 15 μWb is linked with a coil, when a current of 2 mA flows through it. What is the self-inductance of the coil?

Q10. A plot of magnetic flux (ϕ) versus current (I) is shown in the figure for two inductors A and B. Which of the two has larger value of self inductance?.



Q11. Why is spark produced in the switch of a fan, when it is switched off?

Q12. Why a lamp connected in parallel with a large inductor glows brilliantly before going off, when the switch is put off?

Q13. Why resistance coils are usually double wound?

Q14. Define mutual inductance. Give its SI units.

Q15. A coil is wound on an iron core and looped back on itself so that the core has two sets of closely wound wires in series carrying current in the opposite senses. What do you expect about its self-inductance? Will it be large or small?

Q16. Why the inductance coils are made of copper?

Q17. If the self-inductance of an air core inductor increases from 0.01 mH to 10 mH on introducing an iron core into it, what is the relative permeability of the core used?

Q18. What is the unit of mutual inductance?

Q19. Two concentric circular coils, one of small radius r_1 and the other of large radius r_2, such that $r_1 << r_2$, are placed co-axially with centres coinciding. Obtain the mutual inductance of the arrangement.

Q20. A 100 turn coil of area 0.1 m^2 rotates at half a revolution per second. It is placed in a uniform magnetic field of 0.01 *T* perpendicular to the axis of rotation of the coil. Calculate the maximum voltage generated in the coil?

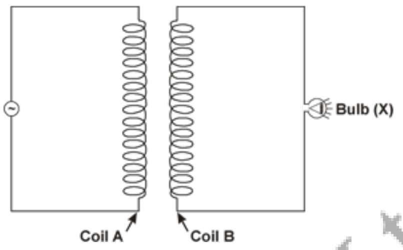
Q21. The self-inductance of a coil having 300 turns is 15 mH. Compute the total flux linked with the coil. Also determine the magnetic flux through the cross-section of the coil corresponding to current of 5 mA.

Q22. Calculate the mutual inductance between the two coils, when a current of 4 A changes to 8 A in 0.5 s and induces an e.m.f. of 50 mV in the secondary coil.

Q23. The circuit arrangement given below shows that when an a.c. passes through the coil *A*, the current starts flowing in the coil *B*.

(a) State the underlying principle involved.

(b) Mention two factors on which the current produced in the coil *B* depends



Q24. Current in a circuit falls steadily from 5.0 A to 0.0 A in 100 ms. If an average e.m.f. of 200 V is induced. Calculate the self-inductance of the circuit.

Q25. An a.c. generator consists of a coil of 100 turns and cross-sectional area of 3 m^2, rotating at a constant angular speed of 60 rad s^{-1} in a uniform magnetic field 0.04 *T*. The resistance of the coil is 500 Ω. Calculate (a) maximum current drawn from the generator and (b) maximum power dissipation in the coil

Q26. Define the term 'self-induction'. Write its SI unit. Write two factors on which the self-inductance of a coil depends.

Q27. Two concentric circular coils C_1 and C_2, radius r_1 and r_2 ($r_1 \ll r_2$) respectively are kept co-axially an expression for mutual inductance between the two coils.

Q28. How does the self-inductance of a coil change, when: (a) the number of turns in the coil is decreaded; (b) an iron rod is introduced into it? Explain your answer in each case.

Q29. Define the term mutual inductance. Write its SI units. Give two factors on which the coefficient of mutual inductance between a pair of coil depends.

Q30. Define mutual inductance of a pair of coils. A secondary coil of N_2 turns is wound on a long solenoid of cross-section *A* and having a primary coil n_1 turns per unit length. What is the mutual inductance of the two coils?

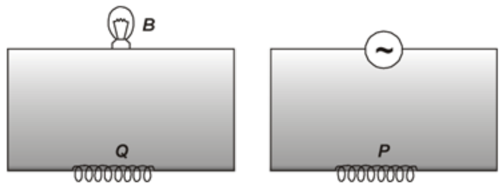
Q31. A solenoid with an iron core and a bulb are connected to a d.c. source. How does the brightness of the bulb change, when the iron core is removed from the solenoid?

Q32. A coil *Q* is connected to a low voltage bulb *B* and placed near another coil *P* as shown in figure below.

Give reasons to explain the following observations:

(a) The bulb *B* lights.

(b) The bulb *B* gets dimmer, if the coil *Q* is moved towards left.



Q33. Distinguish between self-inductance and mutual induction.

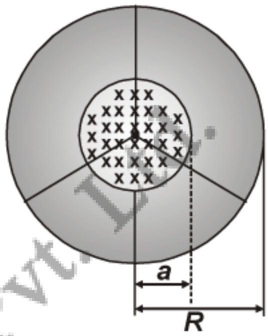
Q34. How does the mutual inductance of a pair of coils change, when (a) the distance between the coils is increased? (b) the number of turns in each of the two coils is decreased? Justify your answer in each case.

Q35. A pair of adjacent coils has a mutual inductance of 1.5 H. If the current in one coil changes from 0 to 20 A in 0.5 s, what is the change of flux linkage with the other coil?

Q36. A solenoidal coil has 50 turns per cm along its length and a cross-sectional area of 4 cm^2. 200 turns of another wire is wound round the first solenoid coaxially. The two coils are electrically insulated from each other. Calculate the mutual inductance between the two coils. Given, $\mu_0 = 4\pi \times 10^{-7}\ NA^{-2}$.

Q37. Derive an expression for the mutual inductance of two long solenoids.

Q38. A line charge λ per unit length is lodged uniformly onto the rim of a wheel of mass M and radius R. The wheel has light non-conducting spokes and is free to rotate without friction about its axis (see figure). A uniform magnetic field extends over a circular region within the rim. It is given by,



$$B = -B_0 k \ (r \leq a;\ a < R)$$
$$= 0 \ \text{(otherwise)}$$

What is the angular velocity of the wheel after the field is suddenly switched off?

Q39. Explain, with the help of diagram, the principle and working of an a.c. generator. Write the expression for the e.m.f generated in the coil in terms of its speed of rotation.

Q40. Deduce an expression for the self-inductance of a long solenoid of N turns, having a core of relative permeability μ_r.

Q41. A series LCR circuit with $R = 20\ \Omega$, $L = 15$ H and $C = 35\ \mu F$ is connected to a variable-frequency 200 V a.c. supply. When the frequency of the supply equals the natural frequency of the circuit, what is the average power transferred to the circuit in one complete cycle?

Q42. An a.c. generator consists of a coil of 50 turns and area 2.5 m^2 rotating at an angular speed of 60 rad s^{-1} in a uniform magnetic field $B = 0.30$ T between two fixed pole pieces. The resistance of the circuit including that of the coil is 500 Ω.

(a) What is the maximum current drawn from the generator?

(b) What is the flux through the coil, when the current is zero? What is the flux, when the current is maximum?

(c) Would the generator work, if the coil were stationary and instead of the pole pieces rotated together with the same speed as above?

Q43. Two circular coils one of radius r and the other of radius R are placed coaxially with their centers coinciding. For $R \gg r$, obtain an expression for the mutual inductance of the arrangement.

Q44. There is an inductor of 5 mH. Current flowing through the inductor art any instant of time is given by the relation.

$$I = t^2 + 4$$

If, 'I' is in ampere and 't' in sec, find out

(a) e.m.f. induced in the inductor at $t = 1$ and $t = 3$ s.

(b) plot e v/s t graph.

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S1. The current will decrease. As the iron core is inserted in the solenoid. The magnetic field increase and the flux increase. Lenz's law implies that induced e.m.f. should resist this increase, which can be achieved by a decrease in current.

S2. By replacing the two slip rings of a.c. generator by two half slip rings, it can be converted into a d.c. generator.

S3. The current will increase. As the wires are pulled apart the flux will leak through the gaps. Lenz's law demands that induced e.m.f. resist this decrease, which can be done by an increase in current.

S4. The self-inductance of a coil is numerically equal to the magnetic flux linked with the coil, when a unit current flows through it.

It is a scalar quantity.

S5. The induced e.m.f. is maximum, when the plane of the coil is parallel to magnetic field lines.

S6. The self-inductance of a coil is said to be one henry, if a rate of change of current of one ampere per second induces an e.m.f of one volt in it.

The SI unit of self inductance is **henry**.

S7. In copper loop has more induced current compare to constantan.

S8. It is based on the principle of the electromagnetic induction.

When a coil is rotated about an axis perpendicular to the direction of uniform magnetic field, an induced e.m.f. is produced across it.

S9. Given, $\phi = 15\ \mu\text{Wb} = 15 \times 10^{-6}$ Wb;

$I = 2\text{ mA} = 2 \times 10^{-3}$ A

We know, $\phi = LI$,

$$L = \frac{\phi}{I} = \frac{15 \times 10^{-6}}{2 \times 10^{-3}} = \mathbf{7.5 \times 10^{-3}\ H}$$

S10. We know,

$$L = \frac{Q}{I} \qquad \dots \text{(i)}$$

The Eq. (i) show the slope of line *A* and *B* which line more slope that is show more inductance. Hence *A* has more inductance compare to *B*.

S11. Due to the sudden break, a large induced e.m.f. is set up across the gap in the switch. Due to this, sparking takes place in the switch.

S12. As the switch is put off, a large e.m.f. is set up in the inductor due to break in the current through the inductor. This large e.m.f. makes the bulb glow brilliantly.

S13. It is done so as to cancel the effect of self-induced e.m.f. in the coil. In the coil made of doubled up wire, the inductive effect in the two wires will be opposite to each other.

S14. The mutual inductance of two coils is said to be one henry, if a rate of change of current of 1 ampere per second in one coil induces an e.m.f. of 1 volt in the neighbouring coil.

S15. The self-inductance will be small due to cancellation of inductive effects. It is because, currents in two sets of wires flow in opposite directions and produce flux in opposite directions.

S16. The inductance coils made of copper will have very small ohmic resistance. Due to change in magnetic flux, a large induced current will be produced in such an inductance, which will offer appreciable opposition to the flow of current due to the applied e.m.f.

S17. Relative permeability,

$$\mu_r = \frac{10}{0.01} = \mathbf{1{,}000}$$

S18. Henry.

S19. Let a current I_2 flow through the outer circular coil. The field at the centre of the coil is $B_2 = \mu_0 I_2/2r_2$. Since the other co-axially placed coil has a very small radius, B_2 may be considered constant over its cross-sectional area. Hence,

$$\Phi_1 = \pi r_1^2$$

$$= \frac{\mu_0 \pi r_1^2}{2r_2} I_2 = M_{12} I_2$$

Thus, $$M_{12} = \frac{\mu_0 \pi r_1^2}{2r_2}$$

From Eq. (6.14) $$M_{12} = M_{21} = \frac{\mu_0 \pi r_1^2}{2r_2}$$

Note that we calculated M_{12} from an approximate value of Φ_1, assuming the magnetic field B_2 to be uniform over the area πr_1^2. However, we can accept this value because $r_1 << r_2$.

S20. Given: $B = 0.01$ T; $n = 100$; $A = 0.1\,\text{m}^2$; frequency of rotation of the coil, $\nu = 0.5\,\text{s}^{-1}$.

The maximum voltage generated in the coil, is given by

$$e_0 = nBA\omega = nBA \times (2\pi\nu)$$

$$= 100 \times 0.01 \times 0.1 \times 2\pi \times 0.5 = \mathbf{0.314\ V}.$$

S21. Given, self-inductance of coil,

$$L = 15\,\text{mH} = 15 \times 10^{-3}\,\text{H}$$

current through the coil,

$$I = 5\,\text{mA} = 5 \times 10^{-3}\,\text{A}$$

Number of turns in the coil,

$$N = 300$$

$$\phi = \frac{LI}{N} = \frac{15 \times 10^{-3} \times 5 \times 10^{-3}}{300} = \mathbf{2.5 \times 10^{-7}\ weber}.$$

S22. Given, $e = -50\text{ mV} = -50 \times 10^{-3}\text{ V}$, $dI = 8 - 4 = 4\text{ A}$ and $dt = 0.5\text{ s}$

We know, $$e = -M\frac{dI}{dt} \Rightarrow M = -e\frac{dt}{dI}$$

or $$M = \frac{50 \times 10^{-3} \times 0.5}{4} = 6.25 \times 10^{-3}\text{ H}$$

S23. (a) It is based on the principle of “mutual induction”.

(b) Two factors are:

(i) distance between the coils.

(ii) orientation of the coils.

S24. Given, e.m.f. $e = 200\,\text{V}$

Change current $dI = 5 - 0 = 5\,\text{A}$

Time $dt = 100 \times 10^{-3} = 0.1\,\text{s}$

$$|e| = L\frac{dI}{dt}$$

$$L = \frac{|e| \times dt}{dI} = \frac{200 \times 0.1}{5}$$

$$= \mathbf{4\,H}.$$

S25. Given: $n = 100$; $A = 3\,\text{m}^2$; $\omega = 60\,\text{rad s}^{-1}$; $B = 0.04\,\text{T}$

(a) Maximum e.m.f. produced in the coil,

$$e_0 = nBA\omega = 100 \times 0.04 \times 3 \times 60 = 720\,\text{V}.$$

Since resistance of the coil is 500 Ω, the maximum current drawn from the generator,

$$I_0 = \frac{e_0}{R} = \frac{720}{500} = \mathbf{1.44\,A}.$$

(b) Maximum power dissipation in the coil, is given by P

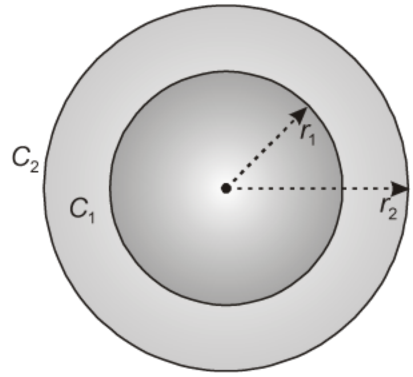
$$e_0 I_0 = 720 \times 1.44 = \mathbf{1{,}036.8\,W}.$$

S26. The phenomenon, according to which an opposing induced e.m.f. is produced in a coil as a result of change in current or magnetic flux linked with the coil, is called ***self-induction***.

Its SI units is ***Henry***.

The self-inductance of a coil depends upon its area of cross-section, the number of turns and the permeability of the material of the core.

S27. Consider the two co-axial circular unit of radius r_1 and r_2 placed co-axial shown in figure below ($r_1 \ll r_2$). Let n_1 and n_2 be the number of turn per unit length in the coil, Let a current I be passed through the outer coil. It will produce a magnetic field B on the coil of radius r_1. This magnetic field is given by



$$B = \frac{\mu_0 I}{2r_2} \qquad (\because \ n_1 = 1)$$

The magnetic flux associated with the inner coil of radius r_1 will grow to

$$\phi_1 = B \times \text{area of the inner coil}$$

$$= \frac{\mu_0 I}{2r_2} \pi r_1^2 \qquad (\because \ n_2 = 1)$$

$$\phi_1 = \frac{\mu_0 \pi r_1^2}{2r_2} I$$

Now, $$M = \frac{\phi_1}{I} = \frac{\mu_0 \pi r_1^2}{2r_2}.$$

S28. Self inductance of a coil, $L = \mu_0 n^2 l A$.

(a) When the number of turns is decreased, the self inductance will decrease. It is because,

$$L \propto n^2.$$

(b) On introducing the iron rod into the coil, the self inductance will become

$$L' = \mu_0 \mu_r n^2 l A,$$

Where μ_r is the relative permeability of iron. Since $\mu_r > 2$, self-inductance of the coil will increase.

S29. Mutual-inductance of the two coils is numerically equal to the magnetic flux linked with one coil, when a unit current flows through the neighbouring coil.

The SI unit of mutual inductance is ***Henry***.

The mutual inductance between two coils depends upon the number of turns of the two coils, their relative orientations and the permeability of the material of the core.

S30. Mutual-inductance of the two coils is numerically equal to the magnetic flux linked with one coil, when a unit current flows through the neighbouring coil.

Mutual inductance of the two coils,

$$M = \mu_0 n_1 N_2 A.$$

S31. When the iron core is removed from the solenoid, the magnetic flux linked with the coil changes (decreases). As a result, induced e.m.f. is produced in the coil, which according to the Lenz's law, opposes the removal of the iron core from the solenoid. The opposing induced e.m.f. so produced decreases the steady current in the solenoid. As lesser current flows through the solenoid, the brightness of the bulb ***decreases***.

S32. (a) As coil P is connected to an a.c. source, the magnetic flux linked with it keeps on changing with time. Due to the mutual induction between the two coils, an induced e.m.f. is produced in the coil Q. As a result, the bulb B lights.

(b) When the coil Q is moved to the left, the separation between the two coils increases. It results into a decrease in mutual induction between the two coils and hence a decrease in the induced e.m.f. in the coil Q. As a result, the bulb B gets dimmer.

S33. The self-inductance of a coil is the induced e.m.f. set-up in it when the current through it is changing at as unit rate. The SI unit of self-inductance is Henry (H).

The mutual inductance of two coils is defined as the induced e.m.f. set-up in one coil due to a unit rate of change of current in the neghouring coil. The SI unit of mutual inductance is Henry (H).

S34. (a) On increasing distance between the coil, the magnetic flux linked with secondary coil due to current flowing through the primary coil will decrease. Hence, mutual inductance of the two coils will ***decrease***.

(b) Mutual inductance of two coils,

$$M = \mu_0 n_1 n_2 Al.$$

Obviously, the mutual inductance of the two coils will ***decrease*** on decreasing the number of turns in each coil.

S35. Mutual inductance of a pair of coils, $\mu = 1.5\,\text{H}$

Initial current, $I_1 = 0\,\text{A}$

Final current $I_2 = 20\,\text{A}$

Change in current, $dI = I_2 - I_1 = 20 - 0 = 20\,\text{A}$

Time taken for the change, $t = 0.5\,\text{s}$

Induced e.m.f., $$e = \frac{-d\phi}{dt} \quad \text{... (i)}$$

Where $d\phi$ is the change in the flux linkage with the coil.

E.m.f. is related with mutual inductance as:

$$e = \mu \frac{-dI}{dt} \quad \text{... (ii)}$$

Equating equations (i) and (ii), we get

$$\frac{d\phi}{dt} = \mu \frac{dI}{dt}$$

$$d\phi = 1.5 \times (20) = 30\,\text{Wb}.$$

Hence, the change in the flux linkage is 30 Wb.

S36. Here, number of turns per unit length of the solenoid S_1,

$$n_1 = 50 \text{ turns cm}^{-1} = 5000 \text{ turn/m}$$

area of cross-section of the solenoid S_1,

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

total number of turns of the solenoid S_2,

$$n_2 l = 200$$

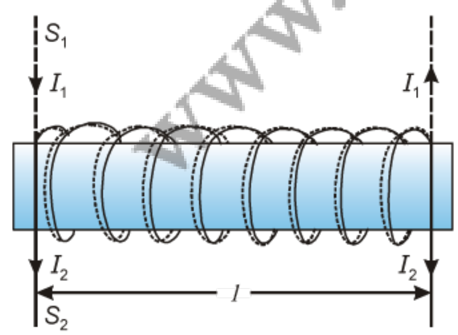
Also, $\mu_0 = 4\pi \times 10^{-7}\,\text{NA}^{-2}$

Therefore, mutual inductance of two coils,

$$M = \mu_0 n_1 n_2 A l = \mu_0 n_1 (n_2 l) A$$

$$= 4\pi \times 10^{-7} \times 5{,}000 \times 200 \times 4 \times 10^{-4} = \mathbf{5.027 \times 10^{-4}\,H}.$$

S37. Consider two long solenoids of length l. One of turns N_1 carrying current I_1 (solenoid S_1) completely surrounds the other coil having turns N_2 and carrying current I_2 (solenoid S_2). The first coil is closely wound over the other so that they have common cross-sectional area A, as shown in figure.



∴ Flux linked with second solenoid due to current in first solenoid is

$$\phi_2 = B_1 \times A \times N_2$$

Where B_1 is the magnetic field produced by solenoid S_1.

As $B_1 = \mu_0 n_1 I_1$

∴ $\phi_2 = \mu_0 n_1 I_1 A N_2$

As $n_1 = \frac{N_1}{l}$

∴ $\phi_2 = \frac{\mu_0 N_1 N_2 I_1 A}{l}$ ... (i)

Also, $\phi_2 = I_1 M_{21}$ ... (ii)

Comparing Eqs. (i) and (ii), we get

$$M_{21} = \frac{\mu_0 N_1 N_2 A}{l}$$

Similarly, $M_{12} = \frac{\mu_0 N_1 N_2 A}{l}$.

If n_1 and n_2 are the number of turns per unit length in the two solenoids so that $N_1 = n_1 l$ and $N_2 = N_2 l$, and r be the radius of each circular coil so that $A = \pi r^2$, then

$$M_{21} = M_{12} = \mu_0 n_1 n_2 l \pi r^2.$$

If the space inside the solenoids is filled with a material of relative permeability μ_r, then

$$M_{21} = M_{12} = \mu_r \mu_0 n_1 n_2 l \pi r^2.$$

S38. Line charge per unit length $\lambda = \frac{\text{Total charge}}{\text{Length}} = \frac{Q}{2\pi r}$

Where, r = Distance of the point within the wheel

Mass of the wheel = M

Radius of the wheel = R

Magnetic field, $\vec{B} = -B_0 \hat{k}$

At distance r, themagnetic force is balanced by the centripetal force *i.e.*,

$$BQv = \frac{Mv^2}{r}$$

Where, v = linrar velocity of the wheel

∴ $B 2\pi r \lambda = \frac{Mv}{r}$

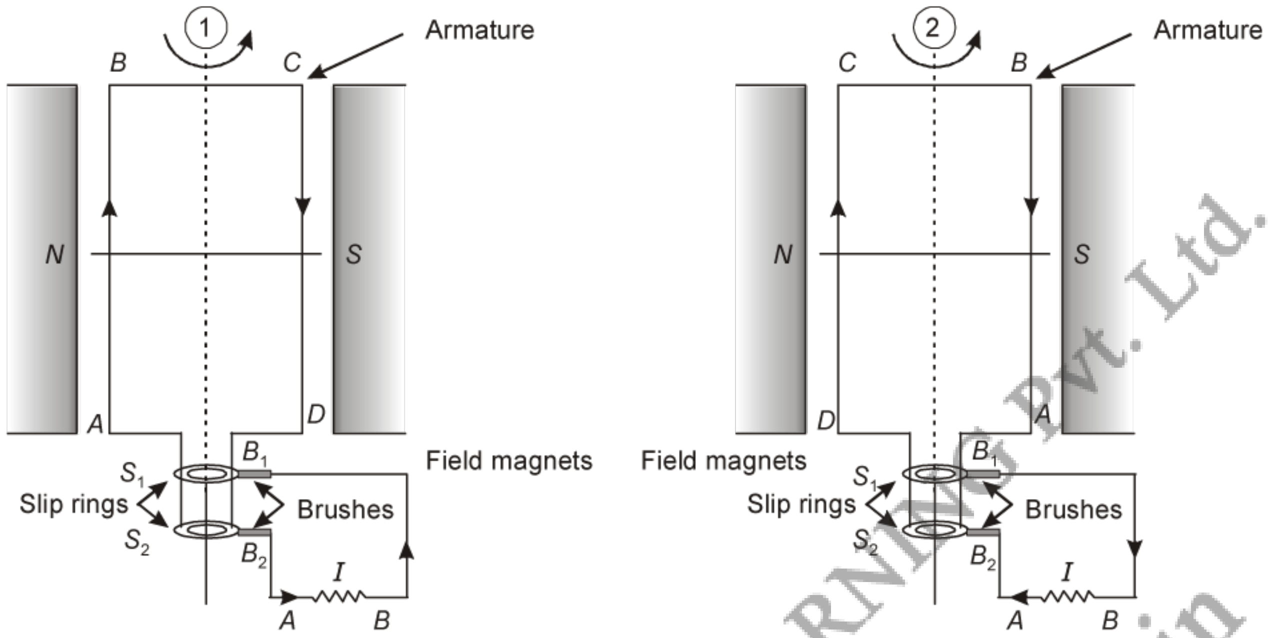
$$v = \frac{B 2\pi \lambda r^2}{M}$$

$\therefore$ Angular velocity, $\qquad \omega = \dfrac{v}{R} = \dfrac{B2\pi\lambda r^2}{MR}$

For $r \leq$ and $a < R$, we get

$$\omega = -\frac{2B_0 a^2 \lambda}{MR}\hat{k}$$

S39. **Principle:** A.C. generator is based on the phenomenon of electromagnetic induction.



Fleming's right hand rule indicates the direction of current induced in the coil.

As the orientation of the coil changes in the uniform magnetic field, there is a change in flux through the coil. This change in flux induces a current in the circuit. e.m.f. generated in the coil is given by

$$e = NAB\,\omega \sin \omega t$$

S40. Consider a long solenoid having N turns and a core of relative permeability μ_r. When current I flows through the solenoid, the magnetic field B at any point inside a such solenoid is given by

$$B = \frac{\mu_r \mu_0 NI}{l}$$

Magnetic flux linked with the solenoid is

$$\phi = (BA)N = \left(\frac{\mu_r \mu_0}{l} NIA\right)N \qquad \text{... (i)}$$

where 'A' is area of cross-section of the solenoid. If L is the coefficient of self inductance of a long solenoid, then

$$\phi = LI \qquad \text{... (ii)}$$

From (i) and (ii), we get

$$LI = \frac{\mu_r \mu_0 N^2 I A}{l}$$

or $$L = \frac{\mu_r \mu_0 N^2 A}{l}.$$

S41. At resonance $Z = R$ and $\phi = 0°$

Thus, $Z = 20\ \Omega$

$$P_{av} = E_v I_v \cos\phi$$

$$= E_v \times \frac{E_v}{Z} \qquad [\because \cos\phi = 1$$

$$= \frac{(200)^2}{20} = 2000\,\text{W}$$

$$P_{av} = 2\,\text{kW}.$$

S42. Given: $n = 50$; $A = 2.5\,\text{m}^2$; $\omega = 60\ \text{rad s}^{-1}$; $B = 0.30\,\text{T}$; $R = 500\ \Omega$.

(a) Maximum e.m.f. produced,

$$e_0 = nBA\omega = 50 \times 0.30 \times 2.5 \times 60 = 2{,}250\ \text{V}.$$

Therefore, maximum current drawn from the generator,

$$I = \frac{e_0}{R} = \frac{2{,}250}{500} = \mathbf{4.5\ A}.$$

(b) The current is zero, when the coil is vertical. In this position, flux through the coil is maximum. On the other hand, the current is maximum, when the coil is horizontal. In this position, flux through the coil is minimum.

(c) Yes, For generation of electricity, there should be relative motion between magnetic field and the coil.

S43. Let C_1 and C_2 be the two coils of radii R and r respectively. The two coils are placed coaxially with their centres coinciding. Suppose that a current I is passed through the coil C_1. Then, magnetic flux linked with the coil C_2,

$$\phi = MI, \qquad \text{... (i)}$$

where M is mutual induction between the two coils.

Now, magnetic field produced at the centre of coil C_1,

$$B_1 = \frac{\mu_0 I}{2R}$$

Since $R >> r$, the magnetic field over the whole area of coil C_2 can be assumed to be uniform and equal to B_1. Therefore, magnetic flux linked with the coil C_2,

$$\phi = B_1 \times \text{area of coil } C_2 = \frac{\mu_0 I}{2R} \times \pi r^2$$

or $$\phi = \frac{\mu_0 \pi r^2 I}{2R} \quad \dots \text{(ii)}$$

From the equation (i) and (ii), we get

$$MI = \frac{\mu_0 \pi r^2 I}{2R}$$

or $$M = \frac{\mu_0 \pi \boldsymbol{r}^2}{\mathbf{2R}}.$$

S44. (a)

$$\varepsilon = L\frac{dI}{dt}$$

$$I = t^2 + 4$$

$$\frac{dI}{dt} = L(2t)$$

At $t = 1$ sec

$$e_1 = 5 \times 10^{-3} \times 2 \times 1 = 10^{-2} \text{ volt}$$

At $t = 3$ sec

$$e_2 = 5 \times 10^{-3} \times 2 \times 3 = 3 \times 10^{-2} \text{ volt}$$

(b)

$$e = 2Lt = 2 \times 5 \times 10^{-3} t = 10^{-2} t$$

t (in sec.)	t (in volts)
0	0
1	1×10^{-2}
2	2×10^{-2}
3	3×10^{-2}
4	4×10^{-2}