FOUNDATION SCIENCE A

SEMINAR 9: MAGNETISM & INDUCTION

University of Nottingham
UK | CHINA | MALAYSIA

LEARNING OUTCOMES

- To understand the electromagnetism principles, including for parallel straight wires, solenoid, and moving conductor in a given magnetic field.
- To be able to measure the induced EMF.
- To utilise the concepts of back EMF, counter torque, and transformers.

Straight Wires, Magnetic Fields and Forces:

Question 1:

Two straight parallel wires are separated by 6.0 cm. There is a 2.0 A current flowing in the first wire. If the magnetic field strength is found to be 0 T between the two wires at a distance of 2.2 cm from the first wire, what is the magnitude and direction of the current in the second wire?

Answer:

Using the right-hand-rule, if **the currents must flow in the same direction**, **the magnetic fields** will oppose each other between the wires, and **therefore can equal zero** at a given point. Set the sum of the magnetic fields from the two wires = 0 T at the point 2.2 cm from the first wire and use the equation below to solve for the unknown current.

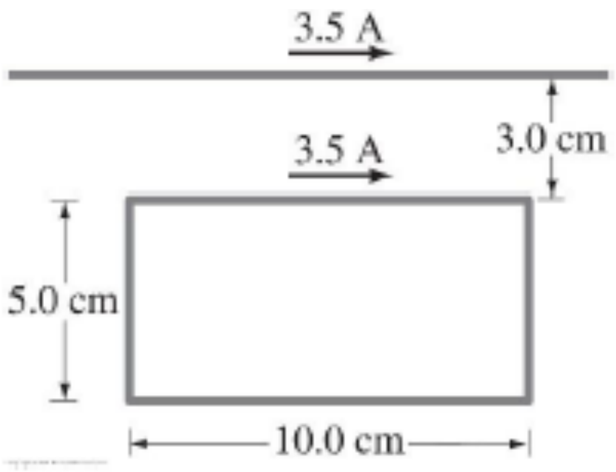
$$B_{net} = 0 = \frac{\mu_0 . I_1}{2.\pi . r_1} - \frac{\mu_0 . I_2}{2.\pi . r_2}$$

$$I_2 = \left(\frac{r_2}{r_1}\right). I_1 = \left(\frac{6.0\ cm - 2.2\ cm}{2.2\ cm}\right) \times 2.0\ \mathrm{A} = 3.5\ A$$

Straight Wires, Magnetic Fields and Forces:

Question 2:

A rectangular loop of wire is placed next to a straight wire. There is a current of 3.5 A in both wires. Determine the magnitude and direction of the net force on the loop.



Answer:

- The magnetic field at the loop due to the long wire is into the page, and can be calculated using the equations on the right.
- The force on the segment of the loop closest to the wire is towards the wire, since the currents are in the same direction.
- The force on the segment of the loop farthest from the wire is away from the wire, since the currents are in the opposite direction.

$$\boxed{\boldsymbol{F_{net} = F_{near} - F_{far}}}$$

$$= \frac{\mu_0}{2\pi}\frac{I_1 I_2}{d_{near}} l_{near} - \frac{\mu_0}{2\pi}\frac{I_1 I_2}{d_{far}} l_{far}$$

Straight Wires, Magnetic Fields and Forces:

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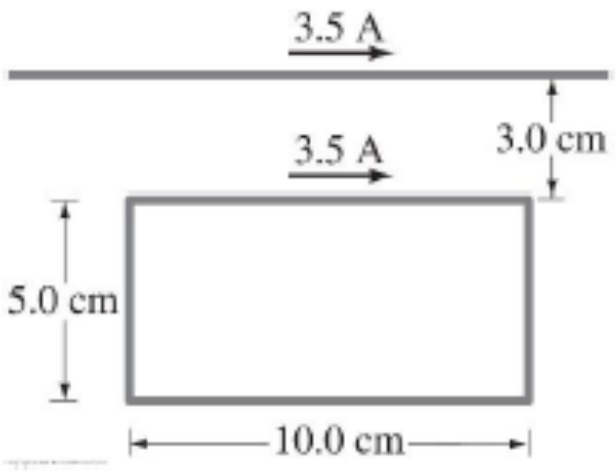


Answer:

- Because the magnetic field varies with distance, it is more difficult to calculate the total force on the left and right segments of the loop.
- Using the right hand rule, the force on each small piece of the left segment of wire is to the left, and the force on each small piece of the right segment of wire is to the right.
- If left and right small pieces are chosen that are equidistant from the long wire, the net force on those two small pieces is zero.
- Thus the total force on the left and right segments of wire is zero, and so only the parallel segments need to be considered in the calculation.

$$\boxed{F_{net} = F_{near} - F_{far}}$$

$$= \frac{\mu_0 I_1 I_2}{2\pi}\, l \left(\frac{1}{d_{near}} - \frac{1}{d_{far}}\right)$$

$$= \frac{4\pi \times 10^{-7}}{2\pi}(3.5)^2(0.10)\left(\frac{1}{0.03} - \frac{1}{0.08}\right)$$

$= 5.1 \times 10^{-6}$ N, towards the wire

Ampere's Law, Solenoids and Toroids:

Question 3:

A 32 cm long solenoid, 1.8 cm in diameter, is to produce a 0.30 T magnetic field at its centre. If the maximum current is 4.5 A, how many turns must the solenoid have?

Answer:

The field inside a solenoid is given by the equation:

$$B = \frac{\mu_0 . I . N}{l}$$

$$N = \frac{B . l}{\mu_0 . I}$$

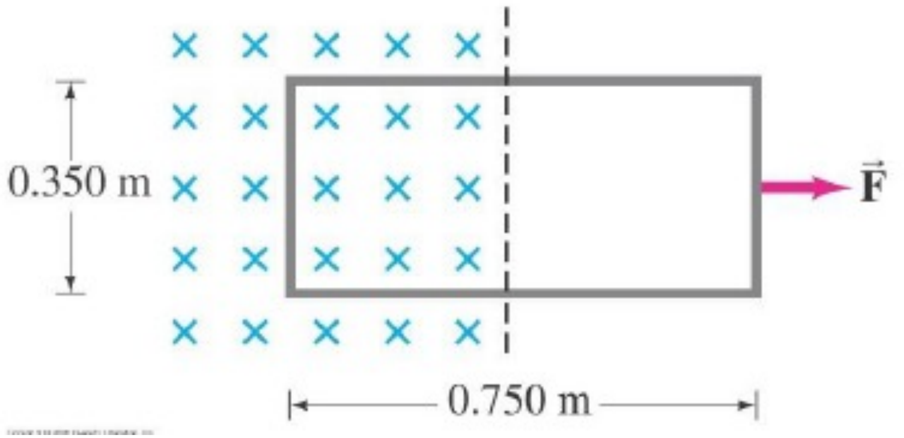
$$= \frac{(0.30\ \mathrm{T}).(0.32\ \mathrm{m})}{(4\pi \times 10^{-7}\ \mathrm{T.m.A^{-1}})(4.5\ \mathrm{A})}$$

N = 1.7 $\times 10^4$ turns

Faraday's Law and Induction:

Question 4:

Part of a single rectangular loop of wire with dimensions shown in the figure below is situated inside a region of uniform magnetic field of 0.650 T. The total resistance of the loop is 0.280 Ω. Calculate the force required to pull the loop from the field (to the right) at a constant velocity of 3.40 m.s^{-1}. Neglect gravity.



Answer:

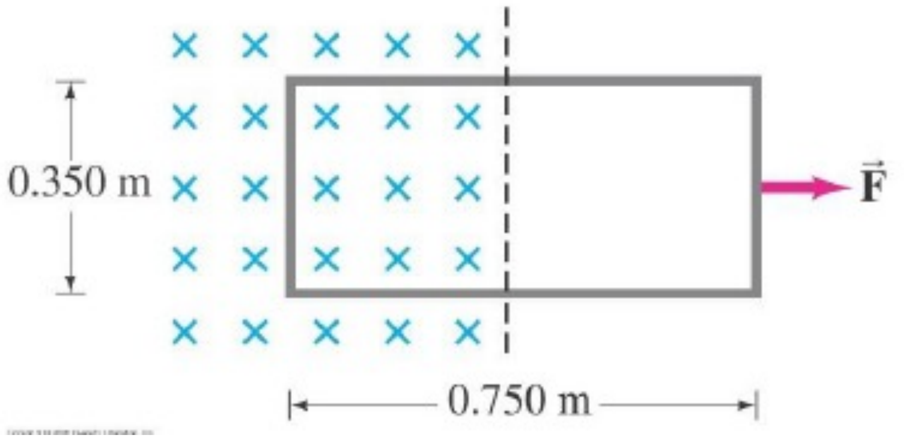
- As the loop is pulled from the field, the flux through the loop decreases, causing an induced EMF whose magnitude is given by $\mathcal{E} = B.l.v$.
- Because the inward flux is decreasing, the induced flux will be into the page, so the induced current is clockwise, given by $I = \mathcal{E}/R$.
- Because this current in the left-hand side of the loop is in a downward magnetic field, there will be a magnetic force to the left.
- To keep the rod moving, there must be an equal external force to the right, given by

$$F = I.l.B$$

Faraday's Law and Induction:

Question 4:

Part of a single rectangular loop of wire with dimensions shown in the figure below is situated inside a region of uniform magnetic field of 0.650 T. The total resistance of the loop is 0.280 Ω. Calculate the force required to pull the loop from the field (to the right) at a constant velocity of 3.40 $m.s^{-1}$. Neglect gravity.



Answer:

- Therefore: $F = I.l.B = \frac{e}{R}.l.B$

$$= \frac{B.l.v}{R} l.B$$

$$= \frac{B^2.l^2.v}{R} = \frac{(0.650\ \mathrm{T})^2.(0.350\ \mathrm{m})^2.(3.40\ \mathrm{m.s^{-1}})}{0.280\ \Omega}$$

$$\boldsymbol{F = 0.628\ \mathrm{N}}$$

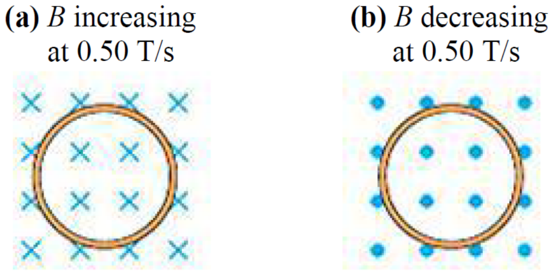
Motional EMF:

Question 5:

The figure below shows a 10-cm-diameter loop in three different magnetic fields. The loop's resistance is 0.20 Ω. For each, what are the size and direction of the induced current?

Answer:

First we need to determine the change in magnetic flux in each case.



$$\varepsilon = -\frac{d\Phi_B}{dt} = -\frac{d(ABcos\theta)}{dt}$$

In this question it is the field strength, B, which is changing with respect to time and the angle θ is constant at 0°. Therefore

$$\varepsilon = -A\frac{dB}{dt}$$

For a)

$$I = \frac{\varepsilon}{R} = -\frac{A}{R}\frac{dB}{dt} = -\frac{(\pi\times 0.05^2)}{0.20}\frac{0.50}{1}$$

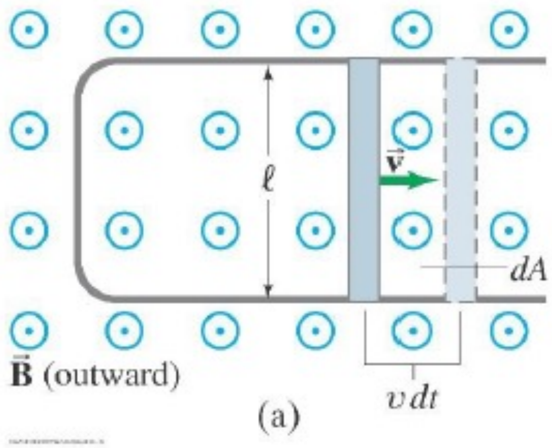
$$= -0.0196 \text{ A Counter Clockwise}$$

For b)

The answer is the same

Motional EMF:

Question 6:



A rod moves to the right with a speed of 1.3 m.s^{-1} and has a resistance 2.5 Ω. The rail separation is l = 25.0 cm. The magnetic field is 0.35 T, an the resistance of the U-shaped conductor is 25.0 Ω at a given instant. Calculate

a) the induced emf,

b) the current in the U-shaped conductor, and

c) the external force needed to keep the rod's velocity constant at that instant.

Answer:

a) Because the velocity is perpendicular to the magnetic field and the rod, the induced emf is calculated as

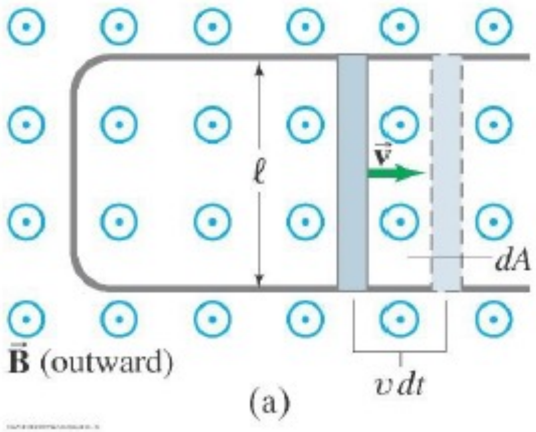
$$\mathcal{E} = B.l.v = (0.35\ \mathrm{T}).(0.250\ \mathrm{m}).(1.3\ \mathrm{m.s^{-1}}) = 0.1138\ \mathrm{V}$$

b) Find the induced current from Ohm's law, using the **total** resistance

$$I = \frac{\mathcal{E}}{R} = \frac{0.1138\ \mathrm{V}}{25.0\ \Omega + 2.5\ \Omega} = 4.138\times10^{-3}\mathrm{A} \approx 4.1\ \mathrm{mA}$$

Motional EMF:

Question 6:



A rod moves to the right with a speed of 1.3 $m.s^{-1}$ and has a resistance of 2.5 Ω. The rail separation is l = 25.0 cm. The magnetic field is 0.35 T, and the resistance of the U-shaped conductor is 25.0 Ω at a given instant. Calculate

a) the induced emf,
b) the current in the U-shaped conductor, and
c) the external force needed to keep the rod's velocity constant at that instant.

Answer:

c) The induced current in the rod will be down. Because this current is in an upward magnetic field, there will be a magnetic force to the left. To keep the rod moving, there must be an equal external force to the right

$$F = I.l.B = (4.138\times10^{-3}\text{ A}).(0.250\text{ m}).(0.35\text{ m.s}^{-1})$$

$$= 3.621\times10^{-4}\text{N} \approx \mathbf{0.36\ mN}$$

Generators:

Question 7:

A 250 loop circular armature coil with a diameter of 10.0 cm rotates at 120 rev.s^{-1} in a uniform magnetic field of strength, 0.45 T.

What is the V_{rms} output of the generator?

What would you do to the rotation frequency in order to double the V_{rms} output?

Answer:

Rms voltage is found from the peak induced emf. The peak induced emf is calculated from the equations

$$\mathcal{E}_{peak} = NB\omega A \quad \rightarrow$$

$$v_{rms} = \frac{\mathcal{E}_{peak}}{\sqrt{2}} = \frac{NB\omega A}{\sqrt{2}} = \frac{(250)(0.45\ \mathrm{T})(2\pi\ \mathrm{rad/rev})(120\ \mathrm{rev/s})\pi(0.05\ \mathrm{m})^2}{\sqrt{2}}$$

$$\boxed{= 471.1\ \mathrm{V} \approx 470\ \mathrm{V}}$$

To double the output voltage, double the rotation frequency to **240 rev/s**.

Back EMF, Counter Torque;

Question 8:

A motor has an armature resistance of 3.05 Ω. If it draws 7.20 A when running at full speed and connected to a 120 V line, how large is the back emf?

Answer:

When the motor is running at full speed, the back emf opposes the applied emf, to give the net emf across the motor.

$$\mathcal{E}_{applied} - \mathcal{E}_{back} = IR \rightarrow$$

$$\mathcal{E}_{back} = \mathcal{E}_{applied} - IR = 120\,V - (7.2\,A)(3.05\,\Omega) = \mathbf{98\,V}$$

Transformers:

Question 9:

A model-train transformer plugs into 120 V ac, and draws 0.35 A while supplying 7.5 A to the train.

a) What voltage is present across the tracks?

b) Is the transformer step-up or step-down?

Answer:

a) Use equations to relate the voltage and current ratios.

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \qquad \frac{I_s}{I_p} = \frac{N_p}{N_s} \qquad \frac{V_s}{V_p} = \frac{I_p}{I_s}$$

$$V_s = V_p . \frac{I_p}{I_s} = (120\ \mathrm{V})\,\frac{0.35\ \mathrm{A}}{7.5\ \mathrm{A}} \qquad \boldsymbol{V_s = 5.6\ \mathrm{V}}$$

b) Because $V_s < V_p$, this is **a step-down** transformer.

Q&A?
OFFICE HOURS: