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PHYSICS & CHEMISTRY

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Module 6: Electromagnetism

Topic 3.2: Electromagnetic Induction

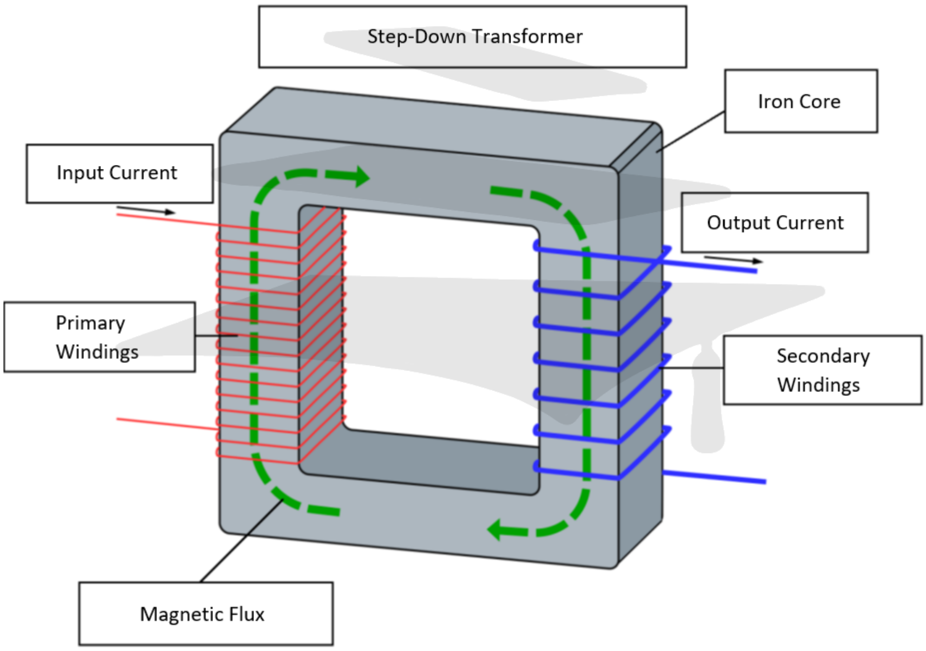
Solutions

Foundation

1. State the purpose of transformers and identify the two types of transformers.

   Transformers are used to either increase or decrease the voltage of electricity flowing through a circuit. The two types are step-up and step-down transformers.

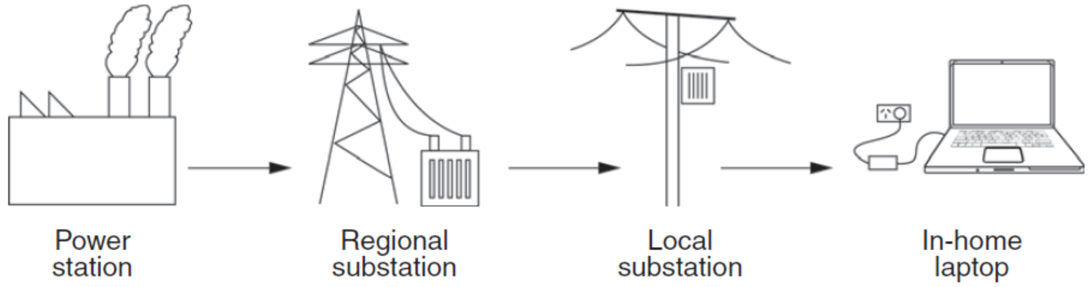
2. Label each component of the transformer below and identify the type of transformer in the top box.



3. Define flux linkage and include a relevant formula in your definition.

   Flux linkage is the total magnetic flux passing through the turns of a coil. It is mathematically represented by the formula: $\lambda = N\Phi$.

4. Circle the appropriate options to represent the correct use of transformers in the following electrical transfer.



Step-up/Step-down   Step-up/**Step-down**   Step-up/**Step-down**   Step-up/**Step-down**

5. Identify which transformer is used before transmitting energy between the power station and local substations and outline why it is used.

   Step-up transformers are used because they decrease output current from a power station, thereby decreasing power loss when transmitting to local substations ($P_{loss} = I^2R$).

Development

1. Eddy currents are a major source of energy loss in an iron core transformer.

   What is one way to minimise this energy loss?

   (a) **Laminating the iron core with an insulator**

   (b) Decrease the number of turns in the primary coil

   (c) Replace the iron core with a copper core

   (d) Decrease the distance between the primary and secondary coils

2. A transformer changes 240 V to 24000 V.

   Which of the following statements is true?

   (a) It is a step-down transformer

   (b) The primary coil has more turns than the secondary coil

   (c) There is a greater current flowing through the secondary coil than in the primary coil

   (d) **The ratio of turns in the primary coil to the secondary coil is 1:100**

3. The primary coil of a transformer contains 5000 turns. The primary AC voltage is 5×10^4 V and the output voltage is 9.9×10^5 V .

   (a) Calculate the number of turns on the secondary winding. **1**

$$\frac{V_p}{V_s} = \frac{n_p}{n_s}$$

$$n_s = \frac{n_p V_s}{V_p}$$

$$= \frac{5000 \times 990000}{50000}$$

$$= 99000$$

1 mark – Calculates the correct number of turns

(b) Given the input current is 100 A, and the secondary winding has a resistance of 2500 Ω, calculate the power loss in the secondary winding, assuming there is zero power loss in the primary winding. **3**

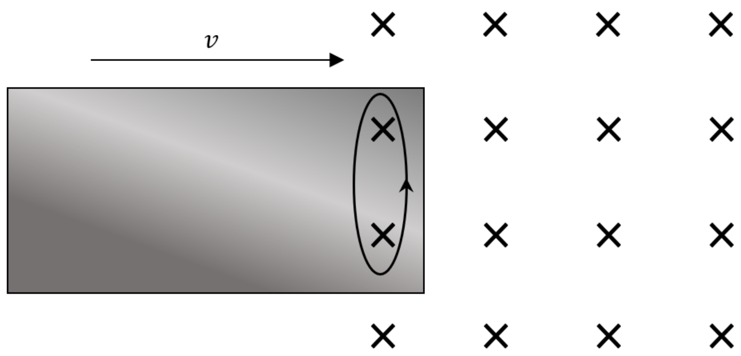
$$
\begin{aligned}
\frac{I_s}{I_p} &= \frac{n_p}{n_s} \\
I_s &= \frac{n_p I_p}{n_s} \\
&= \frac{5000 \times 100}{9.9 \times 10^5} \\
I_s &= 5.05 \text{ A}
\end{aligned}
$$

$$
\begin{aligned}
P_{loss} &= I^2 R \\
&= (5.05)^2 \times 2500 \\
&= 63769 \text{ W}
\end{aligned}
$$

2 marks – Calculates the correct secondary current

1 mark – Calculates the correct power loss

4. A metallic sheet enters a magnetic field which runs into the page as shown.



(a) Draw the induced eddy current on the diagram above and clearly indicate the direction of the eddy current. **1**

1 mark – Draws an eddy current with an anticlockwise direction

(b) Explain the change in motion experienced by the sheet upon entering the magnetic field. **2**

Upon entering the magnetic field, the metallic sheet experiences a change in magnetic flux, thus resulting in the production of eddy currents as predicted by Faraday's law. These eddy currents are produced in such a way to oppose the initial change in flux, in accordance to Lenz's law, thereby slowing the metallic sheet down.

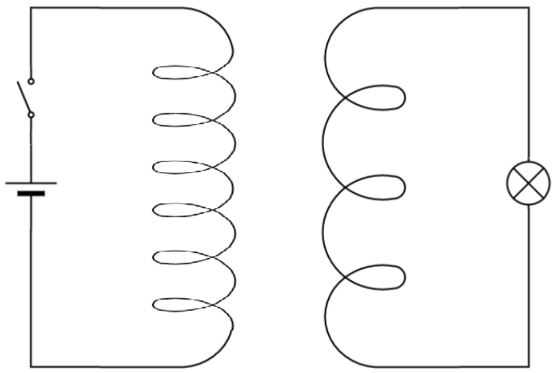
2 marks – Explains that the metal sheet will slow down in terms of Faraday's law and Lenz's law

(c) Explain what would be observed if a plastic sheet was used instead of a metallic sheet. **1**

Since plastic cannot conduct electricity, no eddy currents would be formed and thus the plastic sheet will move through the magnetic field unaffected.

1 mark – Explains that the motion of the plastic sheet would not be affected

5. An early physicist patents his prototype transformer where two coils are situated in vicinity, with one connected to a DC supply and the other to a light bulb as shown below. The switch is initially open.



(a) Explain why the bulb lights up only for a brief moment when the switch closes. **2**

As the switch closes, current flows through the left circuit, producing a magnetic field around the coil. As a result, the right coil experiences a change in magnetic flux, so a current is induced in the circuit by Faraday's law, thus lighting up the bulb. However, since the circuit is supplied DC current, the magnetic field produced does not change, so no further current is induced due to a lack of flux change which causes the bulb to quickly stop glowing.

1 mark – Explains why the bulb lights up initially

1 mark – Explains why the bulb is only lit up for a brief moment

(b) The DC supply is now changed to an AC supply. **2**

Given that the secondary coil has half the turns of the primary coil, and that the input current is 50 A, calculate the current flowing through the bulb.

$$\frac{I_s}{I_p} = \frac{n_p}{n_s}$$
$$\frac{I_s}{50} = \frac{2}{1}$$
$$I_s = 100 \text{ A}$$

2 marks – Calculates the correct current

6. One of the many limitations of the iron core transformer is the unwanted production of eddy currents. **4**

Explain the effect of eddy currents on an iron core transformer and the strategies employed to alleviate the problem.

Eddy currents decrease operation efficiency of iron core transformers. Since iron is a conductor, the changing magnetic flux from the AC voltage induces large eddy currents (by Faraday's law), resulting in great resistive heating and power loss. The size of eddy currents may be reduced through laminations and ferrites.

Laminations limit the size and strength of eddy currents, meaning less power loss and heat production occurs. Ferrites are excellent for flux conduction but are poor electrical conductors, thereby preventing almost any flow of eddy currents. Both strategies may be employed to reduce resistive heating and increase transformer efficiency.

2 marks – Explains how eddy currents arise and why they are unwanted

2 marks – Describes and explains at least TWO strategies used to reduce eddy currents and their consequent power loss

7. An air core transformer has an input power of 500 MW and an efficiency of 33.33%.

(a) If the primary current is 300 kA, calculate the primary voltage. **1**

$$\begin{aligned} P_p &= V_p I_p \\ V_p &= \frac{P_p}{I_p} \\ &= \frac{500 \times 10^6}{300 \times 10^3} \\ &= 1667 \text{ V} \end{aligned}$$

1 mark – Calculates the correct voltage

(b) Given the secondary voltage is 3.2 kV, calculate the secondary current. **2**

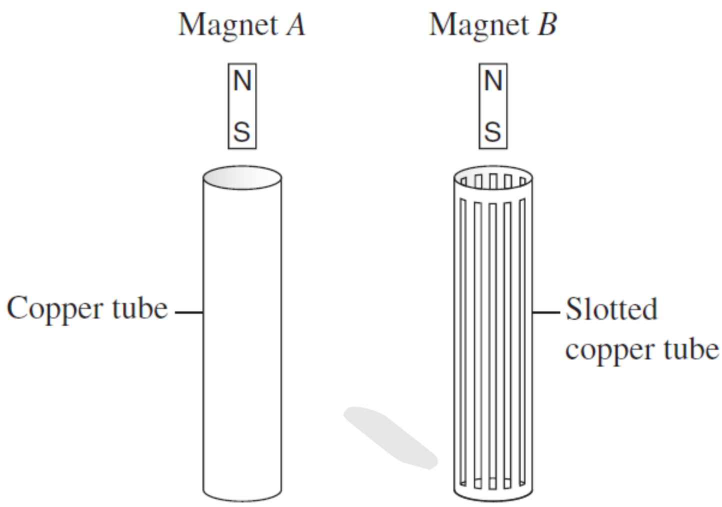
$$\begin{aligned} P_s &= \frac{1}{3} P_p \\ &= \frac{1}{3} \times 500 \\ &= 167 \text{ MW} \\ I_s &= \frac{P_s}{V_s} \\ &= \frac{167 \times 10^6}{3200} \\ &= 52083 \text{ A} \end{aligned}$$

1 mark – Correctly calculates the current

(c) What is the output power if an ideal transformer with 100% efficiency was used instead? **1**

> 500 MW because energy is conserved when power is transmitted in an ideal transformer.
>
> 1 mark – Identifies the output power as 500 MW

8. Identical magnets A and B are suspended above vertical copper tubes as shown in the diagram. **4**

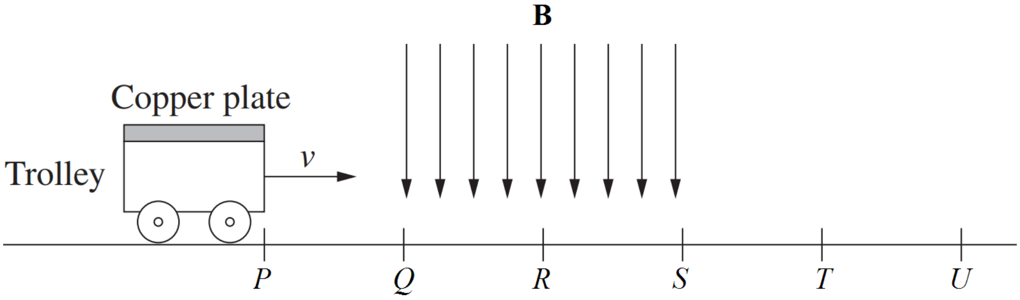


The magnets are dropped simultaneously. Each magnet falls straight through its tube without touching the tube walls.

Identify which magnet leaves the tube first and explain why with reference to relevant physics principles.

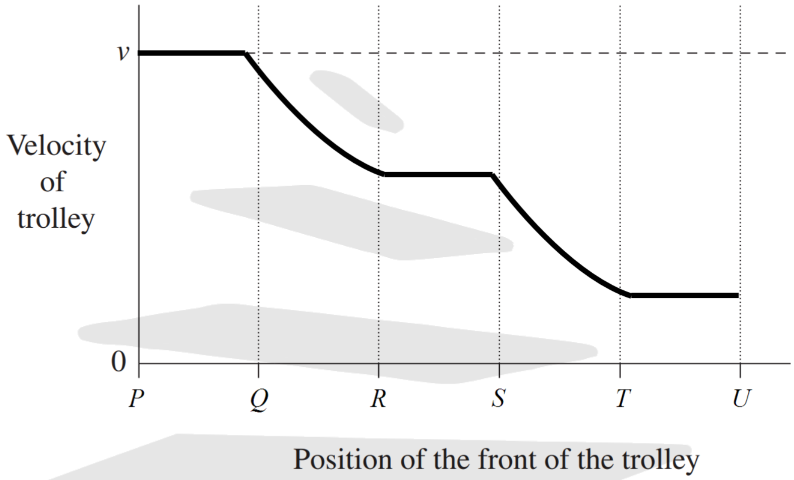
> Magnet B leaves the tube first. By letting the magnets fall through the tubes, their relative motion results in the copper tubes experiencing a change in magnetic flux, so eddy currents are induced by Faraday's law. By Lenz's law, these currents flow in such a way to minimise the change in magnetic flux, thereby creating a magnetic field to oppose the magnets' motion, slowing them down. However, due to the slots on the right tube, smaller eddy currents are induced, thus reducing the overall opposing force on magnet B when compared to A. As such, B will fall faster and leave its tube first.
>
> 1 mark – Identifies that magnet B leaves the tube first
>
> 2 marks – Explain how eddy currents arise in the copper tubes and significantly slow the magnets down with reference to Faraday's law and Lenz's law
>
> 1 mark – Identifies that the slotted copper tube has smaller eddy currents and explains their effect on B

9. A copper plate is attached to a lightweight trolley. The trolley moves at an initial velocity, v, across a smooth table. There is a strong magnetic field **B** pointing downwards in between positions Q and S. **5**



The dashed line on the graph shows the velocity of the trolley when the magnetic field is not present.

On the axes, sketch the graph of the velocity of the trolley as it travels from P to U under the magnetic field, and justify your graph.



The velocity of the trolley decreases as it passes through the beginning (Q) and end (S) of the magnetic field because its kinetic energy is transformed into heat energy in the copper plate. This occurs because of the flux change produced by the movement of the copper plate as it enters and leaves the magnetic field. This induces eddy currents in the copper plate (by Faraday's law) that produce a magnetic field that opposes the changing flux (by Lenz's law) and hence produces a force that decelerates the trolley.

In the interval RS, the copper plate stays entirely immersed in the magnetic field and experiences no change in flux; hence there is no decelerating force here. Similarly, in PQ and TU, the copper plate experiences no change in flux so the velocity remains constant.

2 marks – Sketches a correct graph that is flat at PQ, RS and TU and decreasing at QR and ST

2 marks – Explains that eddy currents arise in the Cu plate and slow it down, referencing Faraday's law and Lenz's law

1 mark – Explains why there is no deceleration at RS