A2 Level Physics

Chapter 12 – Magnetic Fields

12.3.2 Electromagnetism

Worked Examples

Electromagnetism

Exam style question 1

(a) Define magnetic flux.

(b) Fig. 4.1 shows a solenoid connected to a battery and the magnetic field through it when the switch S is closed.

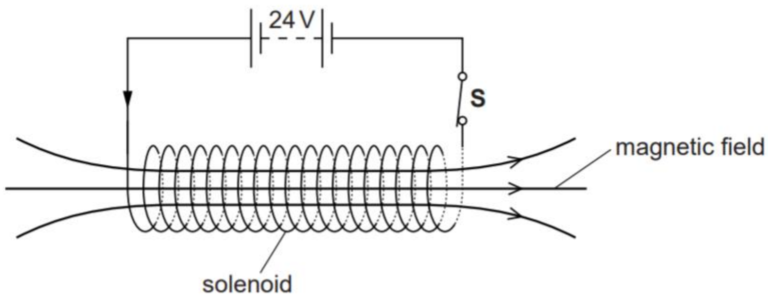

Fig. 4.1

(i) The battery has an e.m.f. of 24 V and negligible internal resistance. The solenoid is made from copper wire. The wire has radius $4.6 \times 10^{-4}\ m$ and total length 130 m. The resistivity of copper is $1.7 \times 10^{-8}\ \Omega\ m$. Calculate the current in the solenoid.

(ii) A tiny electrical spark is created between the contacts of the switch S as it is opened. The spark is produced because an e.m.f. is induced across the ends of the solenoid by the collapse of the magnetic flux linked with the solenoid.

The initial magnetic flux density within the solenoid is 0.090T and may be assumed to be uniform. The solenoid has 1100 turns and cross-sectional area $1.3 \times 10^{-3}\ m^2$.

The average e.m.f. induced across the ends of the solenoid is 150 V. Estimate the time taken for the magnetic flux to collapse to zero.

Electromagnetism

Exam style question 1

(a) Define magnetic flux.

Magnetic flux = magnetic flux density x area normal to the field

(b) (i) Calculate the current in the solenoid.

Step 1: Calculate resistance using $R = \frac{\rho L}{A}$ and as this is a wire the cross-sectional area is $A = \pi r^2$ so sub that in:

$$\therefore\ R = \frac{\rho L}{\pi r^2}$$

$$R = \frac{(1.7 \times 10^{-8}\ \Omega\ m)(130\ m)}{\pi(4.6 \times 10^{-4}\ m)^2}$$

$$R = 3.3245 \ldots \Omega$$

> $R = \frac{\rho L}{A}$
> Where:
> $\rho = resistivity$
> $L = length$
> $A = cross\ sectional\ area$

Step 2: Use $V = IR$ and rearrange for I:

$$I = \frac{V}{R} = \frac{24\ V}{3.3245\ \Omega} = 7.2\ A\ (1\ d.p.)$$

(b) (ii) Estimate the time taken for the magnetic flux to collapse to zero.

e.m.f.= rate of change of magnetic flux linkage

$$\therefore\ \varepsilon = -\frac{N\Delta\Phi}{\Delta t}$$

So first calculate the initial magnetic flux ϕ using:

$$\phi = BA = 0.090\ T \times 1.3 \times 10^{-3}\ m^2$$

Sub the above into the equation $\varepsilon = -\frac{N\Phi}{\Delta t}$

> As we are just estimating the time take for the magnetic flux to collapse to zero the final $\phi = 0$ therefore $\Delta\phi = 0 - (0.090\ T \times 1.3 \times 10^{-3}\ m^2)$

$$150\ V = \frac{(1100\ turns)(0.090\ T \times 1.3 \times 10^{-3}\ m^2)}{\Delta t}$$

$$\Delta t = \frac{(1100\ turns)(0.090\ T \times 1.3 \times 10^{-3}\ m^2)}{150\ V}$$

$$\Delta t = 8.60 \times 10^{-4}\ s\ (2\ s.f.)$$

Exam style question 2

(a) State Faraday's law of electromagnetic induction.

(b) Fig. 5.1 shows a magnet being moved towards the centre of a flat coil.

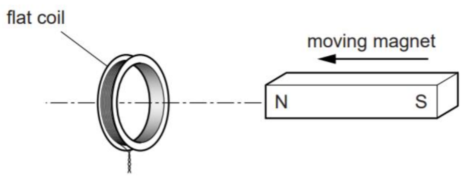

Fig. 5.1

A current is induced in the coil. Use ideas about energy conservation to state and explain the polarity of the face of the coil nearer the magnet.

(c) Fig. 5.2 shows the magnetic field from the north pole of a vertically held bar magnet.

(i) A small flat coil is placed at A. The coil is moved downwards from position A to position B. The plane of the coil remains horizontal between these two positions. Explain why there is no induced e.m.f. across the ends of the coil.

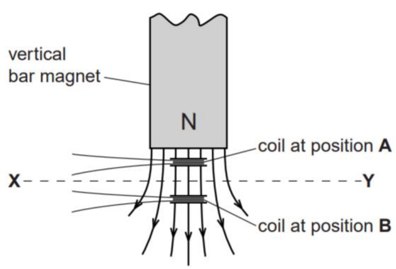

Fig. 5.2

Electromagnetism

(ii) Fig. 5.3 is a graph showing how the magnetic flux density B varies along the horizontal line XY in Fig. 5.2.

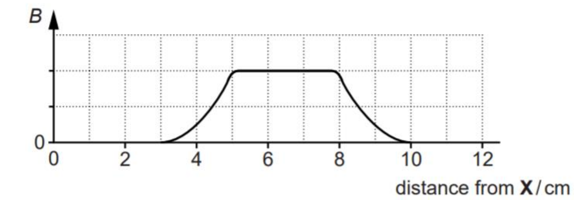

Fig. 5.3

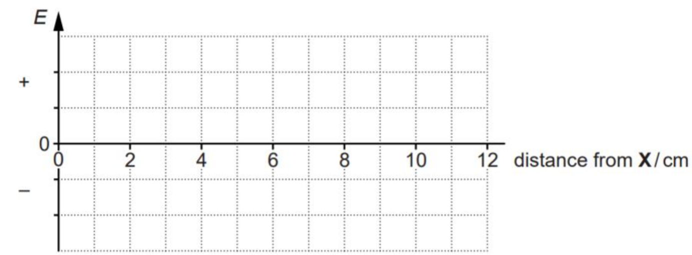

Fig. 5.4

The same small flat coil from (i) is moved at a constant speed from X to Y. The plane of the coil remains horizontal between X and Y.

On the axis provided in Fig. 5.4, sketch a graph to show the variation of the induced e.m.f. E across the ends of the coil with distance from X.

Electromagnetism

Exam style question 2

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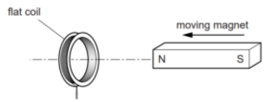

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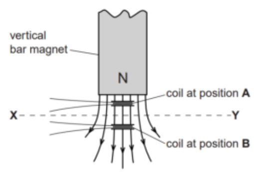

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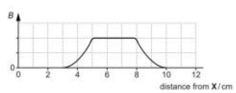

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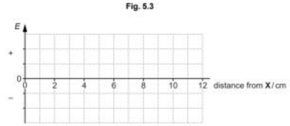

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The same small flat coil from (i) is moved at a constant speed from X to Y. The plane of the coil remains horizontal between X and Y.

On the axis provided in Fig. 5.4, sketch a graph to show the variation of the induced e.m.f. E across the ends of the coil with distance from X.

Electromagnetism

(a)State Faraday's law of electromagnetic induction.

The induced e.m.f. is directly proportional to the rate of change of magnetic flux linkage.

(b) Use ideas about energy conservation to state and explain the polarity of the face of the coil nearer the magnet.

North pole. There is a repulsive force between the magnet and coil and the work done against this repulsive force is transferred to electrical energy in the coil.

A south pole would cause attraction between the coil and magnet or there is a gain in KE of magnet which can not happen hence it must be north pole.

(c) (i) Explain why there is no induced e.m.f. across the ends of the coil.

There is no change in magnetic flux linkage.

Electromagnetism

Exam style question 2

(a) State Faraday's law of electromagnetic induction.

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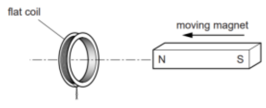

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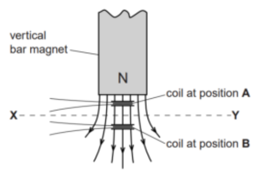

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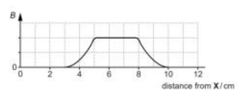
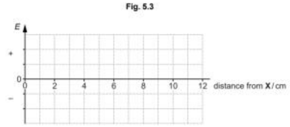


Fig. 5.3



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The same small flat coil from (i) is moved at a constant speed from X to Y. The plane of the coil remains horizontal between X and Y.

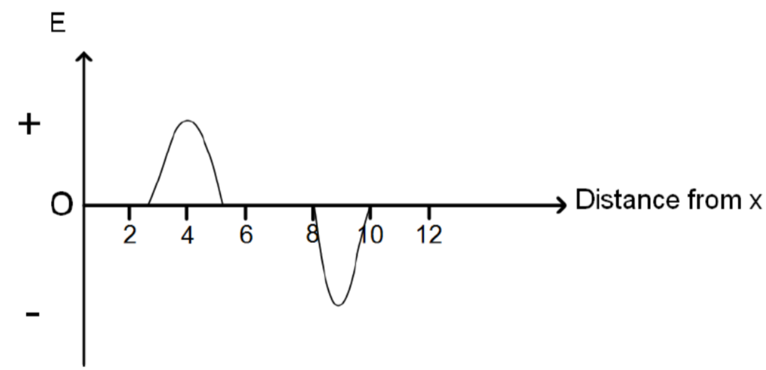
On the axis provided in Fig. 5.4, sketch a graph to show the variation of the induced e.m.f. E across the ends of the coil with distance from X.

Electromagnetism

(c) (ii) On the axis provided in Fig. 5.4, sketch a graph to show the variation of the induced e.m.f. E across the ends of the coil with distance from X.

E is only non-zero when B is changing $\left(E = \frac{N\Delta\Phi}{\Delta t}\right)$ so between 0 – 3 cm, 5 – 8 cm and 10 – 12 cm there is no change in B therefore $\Delta\Phi$ is zero and so is E. However, between 3 to 5 cm there is a positive increase in B and therefore $\Delta\Phi$ is positive and so is E and between 8 to 10 cm $\Delta\Phi$ is negative as B is decreasing and so is the E.

So, you get 2 equal and opposite pulses where B changes value.



Electromagnetism

Exam style question 3

Fig. 3.1 shows the variation of the magnetic flux linkage with time t for a small generator.

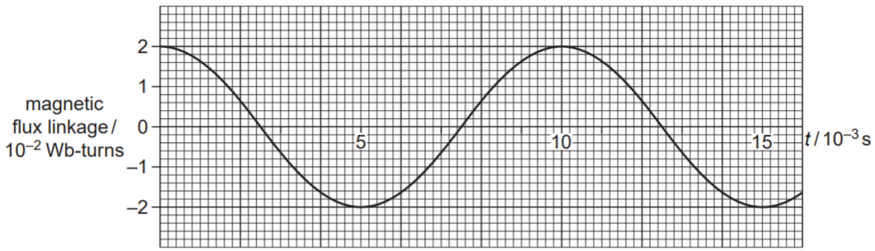


Fig. 3.1

The generator has a flat coil of negligible resistance that is rotated at a steady frequency in a uniform magnetic field. The coil has $400\ turns$ and cross-sectional area $1.6 \times 10^{-3}\ m^2$. The output from the generator is connected to a resistor of resistance $150\ \Omega$.

(a) Use Fig. 3.1 to

(i) calculate the frequency of rotation of the coil

(ii) calculate the magnetic flux density B of the magnetic field

(iii) show that the maximum electromotive force (e.m.f.) induced in the coil is about 12 V.

(b) Hence calculate the maximum power dissipated in the resistor.

Electromagnetism

(a)Use Fig. 3.1 to

(i) calculate the frequency of rotation of the coil

Use $f = \frac{1}{T}$

$$f = \frac{1}{10 \times 10^{-3}\ s} = 100\ Hz$$

(ii) calculate the magnetic flux density B of the magnetic field.

Use $\phi = BAN$ and rearrange for B

$$B = \frac{\phi}{AN} = \frac{2.0 \times 10^{-2}\ Wb}{(1.6 \times 10^{-3}\ m^2)(400\ turns)}$$

$$B = 3.1 \times 10^{-2}\ T\ (2\ s.f.)$$

(iii) show that the maximum electromotive force (e.m.f.) induced in the coil is about 12 V.

The e.m.f induced in the coil is the rate of change of flux linkage with the coil and this is a maximum when the flux linkage is zero. In the diagram above, the induced e.m.f. (ε) is given by the gradient of the flux linkage (Φ) graph.

Therefore, drawn a tangent at 2.5 ms or 7.5 ms or 12.5 ms.

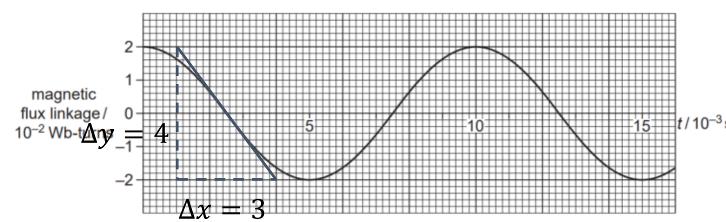


Fig. 3.1

$$\therefore e.m.f. = gradient = \frac{\Delta y}{\Delta x} = \frac{4 \times 10^{-2}\ Wb}{3 \times 10^{-3}\ s} = 13.3\ V\ (1\ d.p.)$$

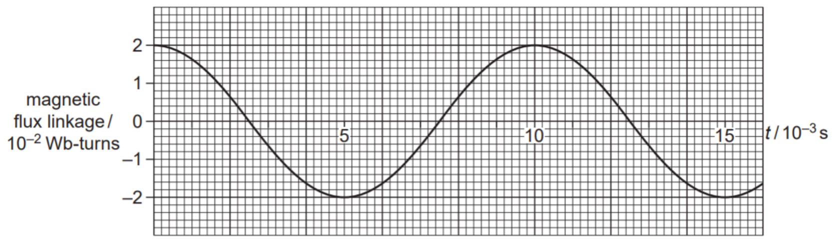
$$\therefore e.m.f. = 13.3\ V \approx 12\ V$$

Mark scheme answer was $12.5 \pm 1.0\ (V)$

Electromagnetism

Exam style question 3

Fig. 3.1 shows the variation of the magnetic flux linkage with time t for a small generator.



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Electromagnetism

(b) Hence calculate the maximum power dissipated in the resistor.

Use $P = \frac{V^2}{R}$

$$P = \frac{(12\ V)^2}{(150\ \Omega)}$$
$$P = 0.96\ W$$

Exam style question 4

(a) Define magnetic flux.

(b) Fig. 4.1 shows a generator coil of $500\ turns$ and cross-sectional area $2.5 \times 10^{-3}\ m^2$ placed in a magnetic field of magnetic flux density $0.035\ T$. The plane of the coil is perpendicular to the magnetic field.

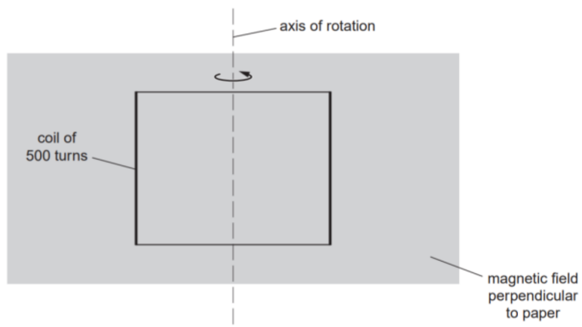

Fig. 4.1

Calculate the magnetic flux linkage for the coil in this position. Give a unit for your answer.

Electromagnetism

(c) The coil is rotated about the axis in the direction shown in Fig. 4.1.

Fig. 4.2 shows the variation of the magnetic flux ϕ against time t as the coil is rotated.

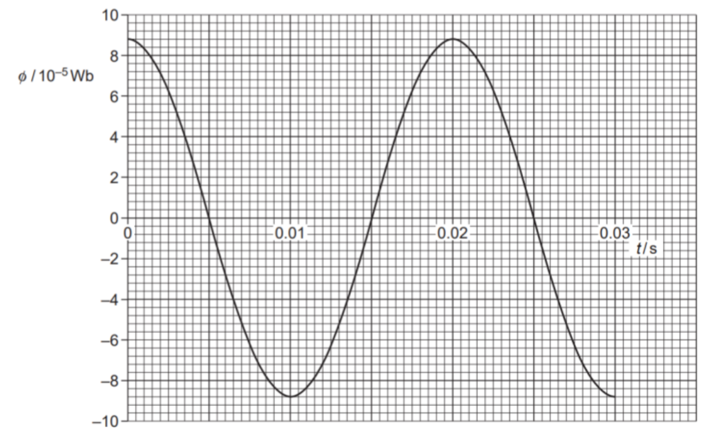

Fig. 4.2

(i) Explain why the magnitude of the magnetic flux through the coil varies as the coil rotates.

(ii) State Faraday's law of electromagnetic induction.

(iii) Use Fig. 4.2 to describe and explain the variation with time of the induced e.m.f. across the ends of the coil.

(iv) Use Fig. 4.2 to determine the magnitude of the average induced e.m.f. for the coil between the times $0\ s$ and $0.005\ s$.

(v) State and explain the effect on the magnitude of the maximum induced e.m.f. across the ends of the coil when the coil is rotated at twice the frequency.

Electromagnetism

Exam style question 4

(a) Define magnetic flux.

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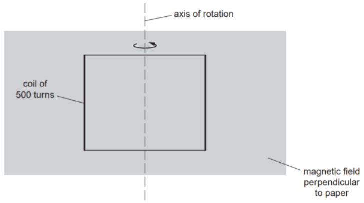

Fig. 4.1

Calculate the magnetic flux linkage for the coil in this position. Give a unit for your answer.

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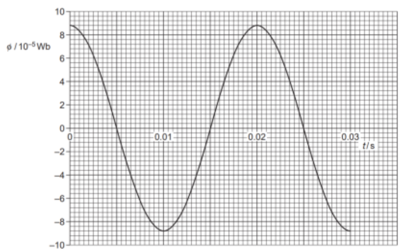

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(v) State and explain the effect on the magnitude of the maximum induced e.m.f. across the ends of the coil when the coil is rotated at twice the frequency.

Electromagnetism

(a)Define magnetic flux.

Magnetic flux = magnetic flux density x cross-sectional area perpendicular to field direction.

(b) Calculate the magnetic flux linkage for the coil in this position. Give a unit for your answer.

Use $\phi = BAN$

$$\phi = (0.035\ T)(2.5 \times 10^{-3}\ m^2)(500\ turns)$$
$$\phi = 0.044\ Wb\ (2\ s.f.)$$

(c) (i) Explain why the magnitude of the magnetic flux through the coil varies as the coil rotates.

The component of B perpendicular to the area varies.
When the plane of the coil is perpendicular to the field, $\theta = 0°$, $cos\theta = 1$ and so the flux linkage is a maximum ($\Phi = BAN$).
When the plane of the coil is parallel to the field, $\theta = 90°$, $cos\theta = 0$ and so the flux linkage is zero ($\Phi = 0$).

(c) (ii) State Faraday's law of electromagnetic induction.

Induced e.m.f. is proportional to the rate of change of magnetic flux.

(c) (iii) Use Fig. 4.2 to describe and explain the variation with time of the induced e.m.f. across the ends of the coil.

E.m.f. max when ϕ is zero and e.m.f zero when ϕ is a max. E.m.f. is the gradient of the graph. E.m.f. follows a sin curve.

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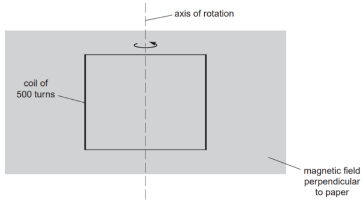
Electromagnetism

Exam style question 4

(a) Define magnetic flux.

(b) Fig. 4.1 shows a generator coil of $500\ turns$ and cross-sectional area $2.5 \times 10^{-3}\ m^2$ placed in a magnetic field of magnetic flux density $0.035\ T$. The plane of the coil is perpendicular to the magnetic field.



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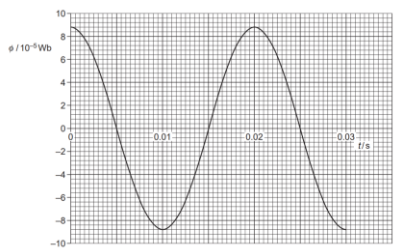

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(iv) Use Fig. 4.2 to determine the magnitude of the average induced e.m.f. for the coil between the times $0\ s$ and $0.005\ s$.

(v) State and explain the effect on the magnitude of the maximum induced e.m.f. across the ends of the coil when the coil is rotated at twice the frequency.

Electromagnetism

(c) (iv) Use Fig. 4.2 to determine the magnitude of the average induced e.m.f. for the coil between the times $0\ s$ and $0.005\ s$.

Use $\varepsilon = \frac{N\Delta\Phi}{\Delta t}$

$$\varepsilon = \frac{[(0.035\ T)(2.5 \times 10^{-3}\ m^2)(500\ turns)] - [0\ Wb]}{0.005\ s - 0\ s}$$

$$\varepsilon = 8.75\ V$$

(c) (v) State and explain the effect on the magnitude of the maximum induced e.m.f. across the ends of the coil when the coil is rotated at twice the frequency.

Use $\varepsilon = BAN\omega\ sin\omega t$ where $\omega = 2\pi f$

Therefore, if the coil is rotated at twice the frequency, max e.m.f. is twice the original value as the rate of flux change is twice the original.

Exam style question 5

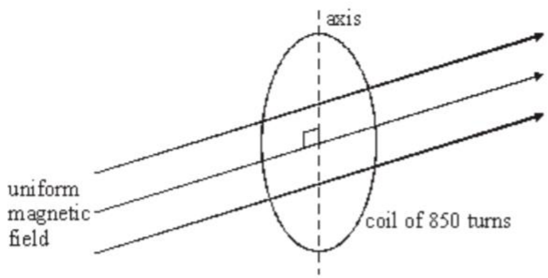


Figure 1

A circular coil of diameter 140 mm has 850 $turns$. It is placed so that its plane is perpendicular to a horizontal magnetic field of uniform flux density 45 mT, as shown in Figure 1.

(a) Calculate the magnetic flux passing through the coil when in this position.

(b) The coil is rotated through 90° about a vertical axis in a time of 120 ms.

Calculate

(i) the change of magnetic flux linkage produced by this rotation,

(ii) the average emf induced in the coil when it is rotated.

Electromagnetism

(a)Calculate the magnetic flux passing through the coil when in this position.

Use $\phi = BA$

$$\phi = (45 \times 10^{-3}\ T)(\pi(70 \times 10^{-3}\ m)^2)$$
$$\phi = 6.9 \times 10^{-4}\ Wb\ (2\ s.f.)$$

(b) (i) the change of magnetic flux linkage produced by this rotation.

Use $N\Delta\Phi = BANcos\theta$

Remember $cos(90°) = 0$ therefore when the coil is rotated through $90°$ $N\phi = 0$

$$\boldsymbol{N\Delta\Phi} = (45 \times 10^{-3}\ T)(\pi(70 \times 10^{-3}\ m)^2)(850\ turns)\cos(0°) - (0)$$
$$N\Delta\phi = 0.588813 \ldots = 0.59\ Wb\ (2\ s.f.)$$

(b) (ii) the average emf induced in the coil when it is rotated.

Use $induced\ emf = N\frac{\Delta\phi}{\Delta t}$

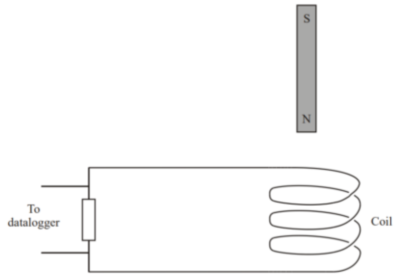
$$induced\ emf = \frac{0.588813 \ldots Wb}{0.12\ s} = 4.91\ V\ (2\ d.p.)$$

Electromagnetism

Exam style question 6

(a) State Lenz's law of electromagnetic induction.

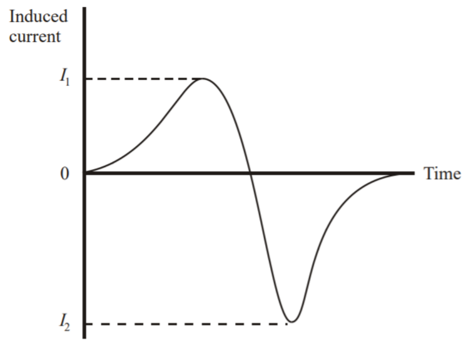
A bar magnet is dropped from rest through the centre of a coil of wire which is connected to a resistor and datalogger.



(b) State the induced magnetic polarity on the top side of the coil as the magnet falls towards it.

(c) Add an arrow to the wire to show the direction of the induced current as the magnet falls towards the coil.

The graph shows the variation of induced current in the resistor with time as the magnet falls.



(d) Explain why the magnitude of I_2 is greater than I_1.

Electromagnetism

(a) State Lenz's law of electromagnetic induction.

The direction of an induced current/emf is such as to oppose the change in flux that produces it.

(b) State the induced magnetic polarity on the top side of the coil as the magnet falls towards it.

North.

(c) Add an arrow to the wire to show the direction of the induced current as the magnet falls towards the coil.

(d) Explain why the magnitude of I_2 is greater than I_1.

The magnet is moving faster and accelerating under gravity. Rate of change of flux is greater and therefore induced emf is greater.

Electromagnetism

Exam style question 7

(a) Define electromotive force.

(b) Define magnetic flux.

(c) Fig. 1.1 shows a simple transformer.

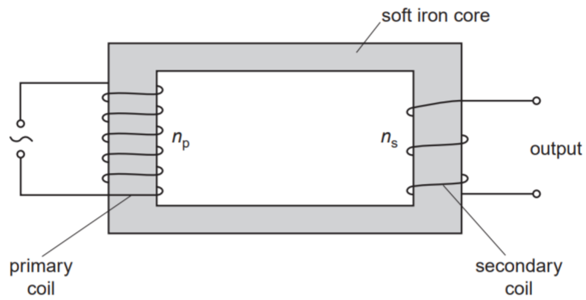


Fig. 1.1

(i) The primary coil is connected to an alternating voltage supply. Explain how an e.m.f. is induced in the secondary coil.

(ii) State how you could change the transformer to increase the maximum e.m.f. induced in the secondary coil.

(d) A transformer with $4200\ turns$ in the primary coil is connected to a $230\ V$ mains supply. The e.m.f. across the output is $12\ V$. Assume the transformer is 100% efficient.

(i) Calculate the number of turns in the secondary coil.

(ii) The transformer output terminals are connected to a lamp using leads that have a total resistance of $0.35\ \Omega$. The p.d. across the lamp is $11.8\ V$. Calculate

1) the current in the leads connected to the lamp

2) the power dissipated in the leads.

Electromagnetism

(a)Define electromotive force.

Electromotive force of an electrical source is the electrical energy given to each coulomb of charge.

(b) Define magnetic flux.

Magnetic flux is the product of the magnetic flux density and the area normal to the field ($\phi = BA$).

(c) (i) Explain how an e.m.f. is induced in the secondary coil.
An alternating voltage applied to the primary coil produces an alternating current which gives rise to an alternating magnetic flux in the iron core. The iron core guides the magnetic flux around the iron core. This varying magnetic flux then links up with the turns of the secondary coil and so induces an alternating e.m.f. (or voltage) across it.

(c) (ii) State how you could change the transformer to increase the maximum e.m.f. induced in the secondary coil.
More coils on secondary.
Less coils on primary.
Laminate the core.

(d) (i) Calculate the number of turns in the secondary coil.

Use $\frac{V_s}{V_p} = \frac{N_s}{N_p}$ and rearrange for N_s

$$N_s = N_p\left(\frac{V_s}{V_p}\right) = (4200\ turns)\left(\frac{12\ V}{230\ V}\right)$$
$$N_s = 219\ turns$$

Electromagnetism

Exam style question 7

(a) Define electromotive force.

(b) Define magnetic flux.

(c) Fig. 1.1 shows a simple transformer.

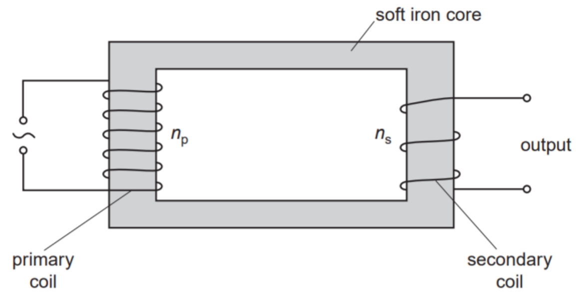


Fig. 1.1

(i) The primary coil is connected to an alternating voltage supply. Explain how an e.m.f. is induced in the secondary coil.

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1) the current in the leads connected to the lamp

2) the power dissipated in the leads.

Electromagnetism

(d) (ii) Calculate

1) the current in the leads connected to the lamp.

Use $V = IR$ and rearrange for I.
Voltage through the leads is:

$$V = 12V - 11.8V = 0.2\ V$$

$$\therefore I = \frac{V}{R} = \frac{0.2\ V}{0.35\ \Omega} = 0.57\ A\ (2\ d.p.)$$

2) the power dissipated in the leads.

You can use: $P = VI$ or $P = I^2R$ or $P = \frac{V^2}{R}$

$$P = IV = (0.57\ A)(0.2\ V)$$

$$P = 0.11\ A\ (2\ d.p.)$$

Exam style question 8

(a) Define magnetic flux.

(b) Fig. 3.1 shows an experiment to demonstrate electromagnetic induction.

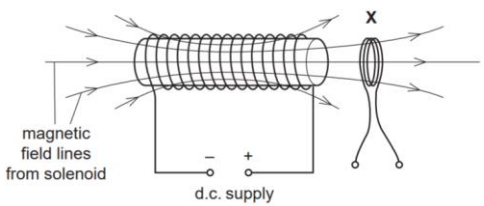

Fig. 3.1

The solenoid is connected to a variable voltage d.c. supply. A coil X is placed close to one end of the solenoid. The current in the solenoid is reduced. Fig. 3.2 shows the consequent variation of the magnetic flux density B at right angles to the plane of the coil X with time t.

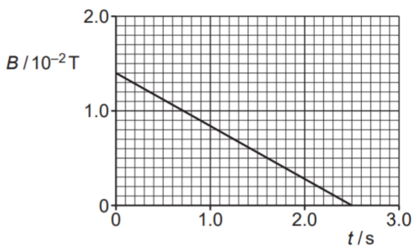

Fig. 3.2

The coil X has radius 3.2 cm and 180 $turns$.

(i) Explain why the induced e.m.f. across the ends of the coil has a constant value from $t = 0\,s$ to $t = 2.5\,s$.

(ii) Calculate the magnitude of the induced e.m.f. across the ends of coil X from $t = 0\,s$ to $t = 2.5\,s$.

Electromagnetism

(c) Fig. 3.3 shows a transformer circuit.

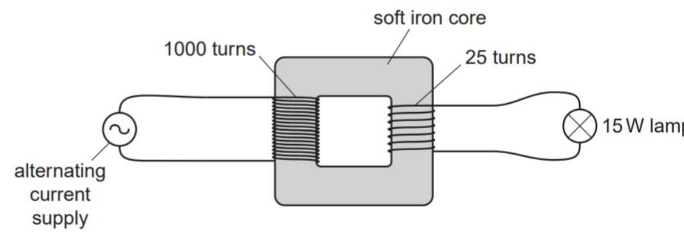

Fig. 3.3

The primary coil has $1000\ turns$ and the secondary coil $25\ turns$. A lamp is connected to the output of the secondary coil. The potential difference across the lamp is $6.0\ V$ and the lamp dissipates $15\ W$. The transformer has an efficiency of 100%.

(i) Calculate the current in the primary coil.

(ii) The alternating voltage supply is replaced by a battery. Explain why the p.d. across the lamp is zero some time after the battery is connected.

Electromagnetism

Exam style question 8

(a) Define magnetic flux.

(b) Fig. 3.1 shows an experiment to demonstrate electromagnetic induction.

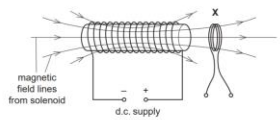

Fig. 3.1

The solenoid is connected to a variable voltage d.c. supply. A coil X is placed close to one end of the solenoid. The current in the solenoid is reduced. Fig. 3.2 shows the consequent variation of the magnetic flux density B at right angles to the plane of the coil X with time t.

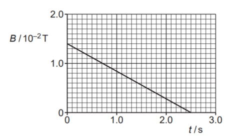

Fig. 3.2

The coil X has radius 3.2 cm and 180 $turns$.

(i) Explain why the induced e.m.f. across the ends of the coil has a constant value from $t = 0\ s$ to $t = 2.5\ s$.

(ii) Calculate the magnitude of the induced e.m.f. across the ends of coil X from $t = 0\ s$ to $t = 2.5\ s$.

(c) Fig. 3.3 shows a transformer circuit.

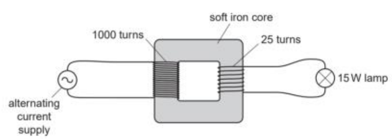

Fig. 3.3

The primary coil has 1000 $turns$ and the secondary coil 25 $turns$. A lamp is connected to the output of the secondary coil. The potential difference across the lamp is 6.0 V and the lamp dissipates 15 W. The transformer has an efficiency of 100%.

(i) Calculate the current in the primary coil.

(ii) The alternating voltage supply is replaced by a battery. Explain why the p.d. across the lamp is zero some time after the battery is connected.

Electromagnetism

(a)Define magnetic flux.
Magnetic flux = magnetic flux density x cross-sectional area perpendicular to field direction.

(b) (i) Explain why the induced e.m.f. across the ends of the coil has a constant value from $t = 0\ s$ to $t = 2.5\ s$.
Constant rate of change of magnetic flux.

(b) (ii) Calculate the magnitude of the induced e.m.f. across the ends of coil X from $t = 0\ s$ to $t = 2.5\ s$.
e.m.f. = rate of change of flux linkage $\left(\text{or } \varepsilon = \frac{N\Delta\Phi}{\Delta t}\right)$

$$e.m.f = \frac{(1.4\times10^{-2}\ T)\left(\pi(3.2\times10^{-2}\ m)\right)(180\ turns)}{2.5}$$

$$e.m.f = 3.2\times10^{-3}\ V\ (2\ s.f.)$$

(c) (i) Calculate the current in the primary coil.
Step 1: Calculate the current in the secondary coil using $P = IV$ and rearrange for I:

$$I_s = \frac{P}{V} = \frac{15\ W}{6.0\ V} = 2.5\ A$$

Step 2: Use $\frac{I_p}{I_s} = \frac{N_s}{N_p}$ and rearrange for I_p:

$$I_p = \left(\frac{N_s}{N_p}\right)(I_s) = \left(\frac{25\ turns}{1000\ turns}\right)(2.5\ A)$$

$$I_p = 0.0625\ A = 6.3\times10^{-2}\ A\ (2\ s.f.)$$

(c) (ii) The alternating voltage supply is replaced by a battery. Explain why the p.d. across the lamp is zero some time after the battery is connected.
There is no change in magnetic flux.

Please see '12.3.1 Electromagnetism notes' pack for revision notes.

For more revision notes, tutorials and worked examples please visit www.tutorpacks.co.uk.