20. Magnetic Fields

20.5 Electromagnetic induction

Paper 4

Question Paper

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

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..... [2]

(b) Fig. 7.1 shows a coil at rest in a uniform magnetic field that is parallel to the axis of the coil.

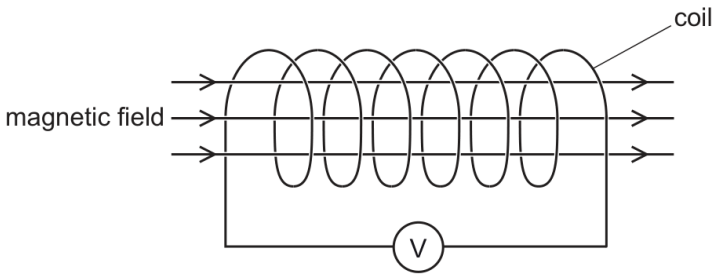


Fig. 7.1

The coil is connected to a centre-zero voltmeter.

The flux density B of the uniform magnetic field varies with time t as shown in Fig. 7.2.

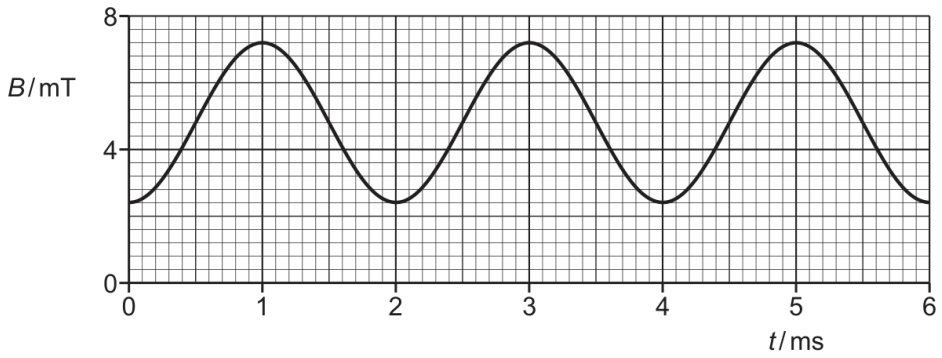


Fig. 7.2

The coil consists of 340 turns, each of cross-sectional area $3.2 \times 10^{-4}\,m^2$.

(i) Calculate the maximum magnetic flux through **one** turn of the coil.

maximum magnetic flux = ... Wb [2]

(ii) Determine the maximum rate of change of magnetic flux linkage in the coil.

maximum rate of change of flux linkage = ... $Wb\,s^{-1}$ [3]

(iii) State the maximum electromotive force (e.m.f.) V_0 induced across the coil.

V_0 = ... V [1]

(iv) On Fig. 7.3, sketch the variation of the e.m.f. V induced across the coil with t from $t = 0$ to $t = 6.0$ ms.

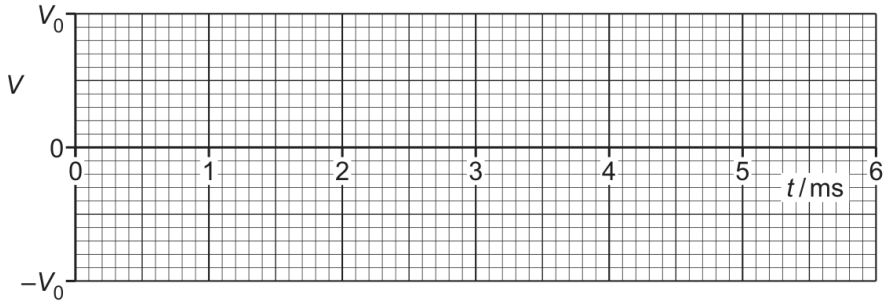


Fig. 7.3

[3]

2 A metal wheel consists of an axle A, eight spokes and a rim, as shown in Fig. 1.1.

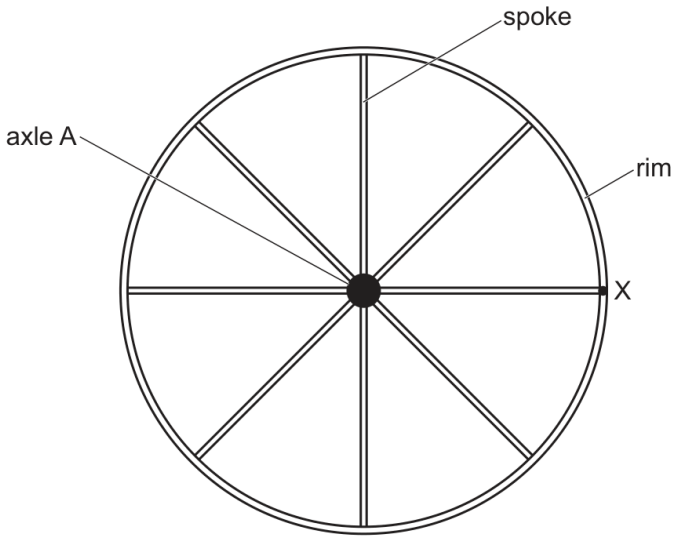


Fig. 1.1

Point X is on the rim at the end of one of the spokes.

The rim has a radius of 0.85 m.
The wheel is rotating clockwise with an angular speed of 140 rad s^{-1}.

(b) There is a uniform magnetic field of flux density 0.18 T into the plane of the page.

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

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..... [2]

(iii) Calculate the magnetic flux cut by spoke AX during one revolution of the wheel.
Give a unit with your answer.

magnetic flux = ... unit ..... [3]

(iv) Determine the magnitude of the electromotive force (e.m.f.) induced across spoke AX.

induced e.m.f. = ... V [2]

3 A heavy aluminium disc has a radius of 0.36 m. The disc rotates with the wheels of a vehicle and forms part of an electromagnetic braking system on the vehicle.

In order to activate the braking system, a uniform magnetic field of flux density 0.17 T is switched on. This magnetic field is perpendicular to the plane of rotation of the disc, as shown in Fig. 6.1.

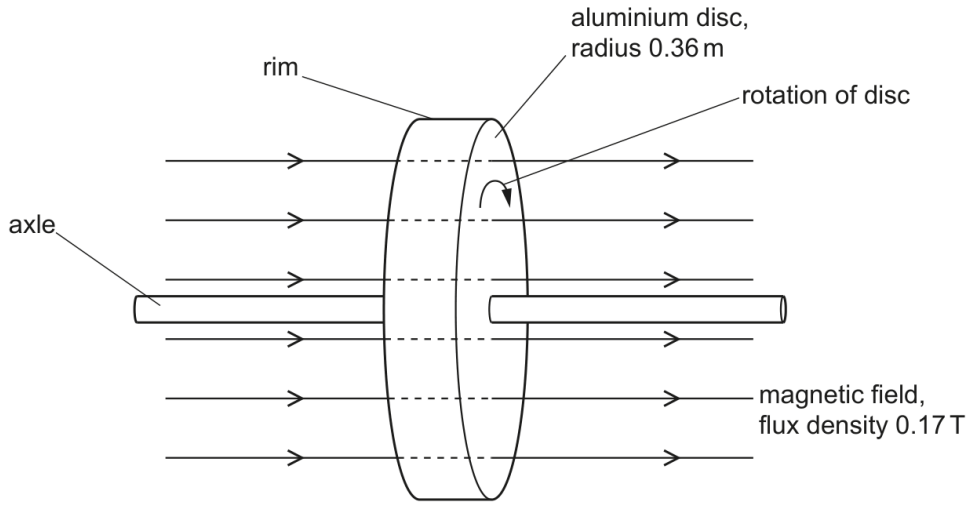


Fig. 6.1

(a) (i) Define magnetic flux.

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..... [2]

(ii) Calculate the magnetic flux through the disc. Give a unit with your answer.

magnetic flux = ... unit ..... [2]

(b) The disc is rotating at a rate of 25 revolutions per second.

Calculate the magnitude of the electromotive force (e.m.f.) induced between the axle and the rim of the disc.

e.m.f. = ... V [3]

4 **(a)** A Hall probe containing a thin slice of semiconducting material is placed in a uniform magnetic field of flux density *B*. The largest faces of the slice are perpendicular to the magnetic field, as shown in Fig. 7.1.

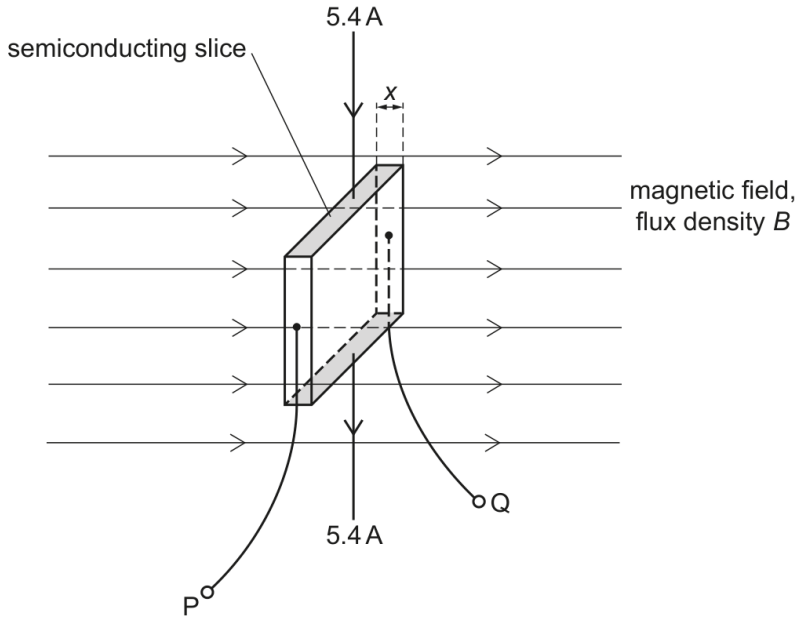


Fig. 7.1

The thickness *x* of the slice is 1.8 mm. The number density of charge carriers in the semiconducting material is $1.5 \times 10^{16}\,m^{-3}$.
A constant current of 5.4 A is passed through the slice between the shaded faces.
The Hall voltage V_H that is developed between the terminals PQ is recorded.

Fig. 7.2 shows the variation with time *t* of *B*.

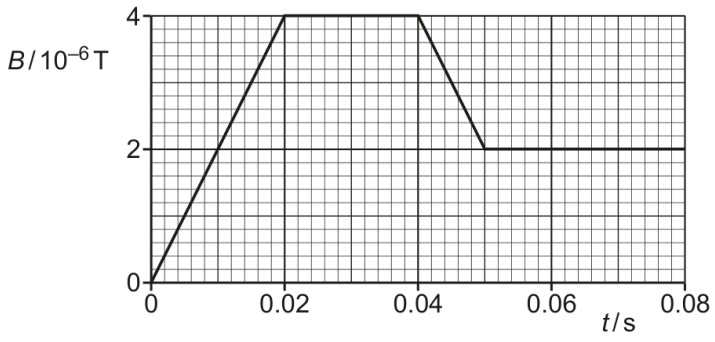


Fig. 7.2

(b) The Hall probe in **(a)** is replaced with a small flat coil that has 3000 turns. The cross-sectional area of the coil is $3.4 \times 10^{-4}\,m^2$.
The plane of the coil is perpendicular to the magnetic field. The electromotive force (e.m.f.) *E* induced between the terminals of the coil is recorded as *B* varies as shown in Fig. 7.2.

(i) Show that the magnitude of E at time $t = 0.010\,\text{s}$ is $2.0 \times 10^{-4}\,\text{V}$.

[3]

(ii) On Fig. 7.4, sketch the variation of E with t between $t = 0$ and $t = 0.080\,\text{s}$.

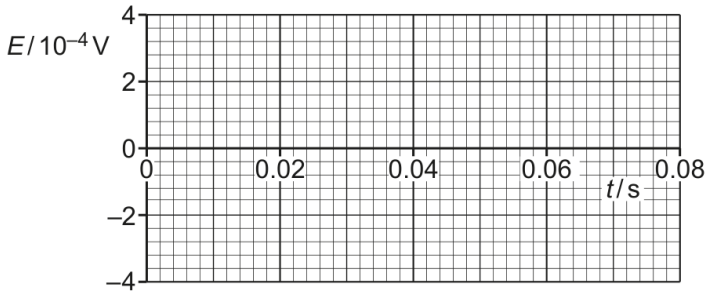


Fig. 7.4

[4]

5 **(a)** Define magnetic flux.

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..... [2]

(b) A square coil of wire of side length 12 cm consists of 8 insulated turns. The coil is stationary in a uniform magnetic field. The plane of the coil is perpendicular to the magnetic field, as shown in Fig. 6.1.

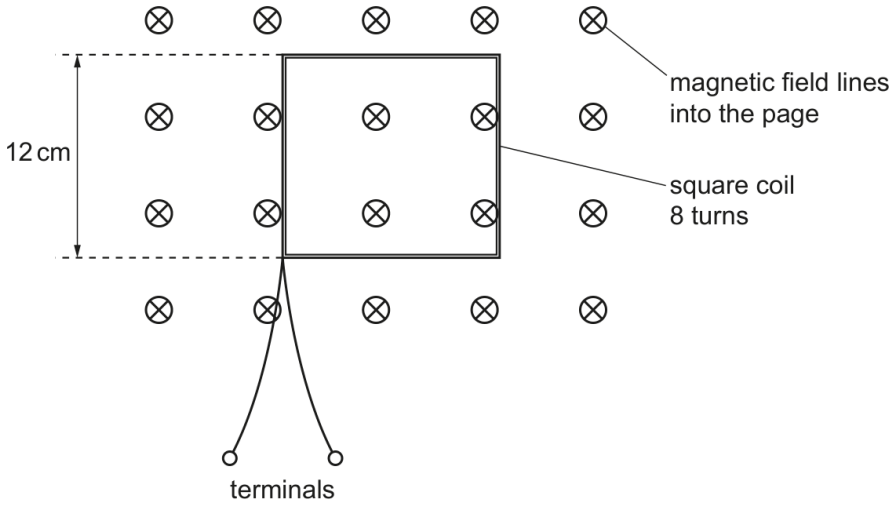


Fig. 6.1

The flux density B of the magnetic field varies with time t as shown in Fig. 6.2.

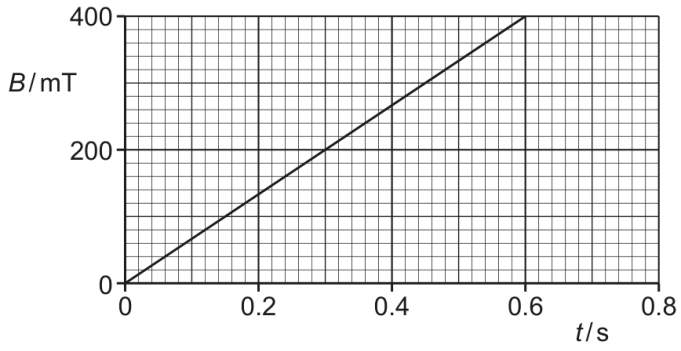


Fig. 6.2

(i) Determine the magnetic flux linkage inside the coil at time $t = 0.60\,s$. Give a unit with your answer.

magnetic flux linkage = ... unit ..... [3]

(ii) State how Fig. 6.2 shows that the electromotive force (e.m.f.) E induced across the terminals between $t = 0$ and $t = 0.60\,s$ is constant.

..... [1]

(iii) Calculate the magnitude of E.

E = ... V [2]

(c) The procedure in **(b)** is repeated, but this time the terminals of the coil are connected together.

State and explain the effect on the coil of connecting the terminals together during the change of magnetic flux density shown in Fig. 6.2.

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..... [3]

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

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..... [2]

(b) Two coils are wound on an iron bar, as shown in Fig. 7.1.

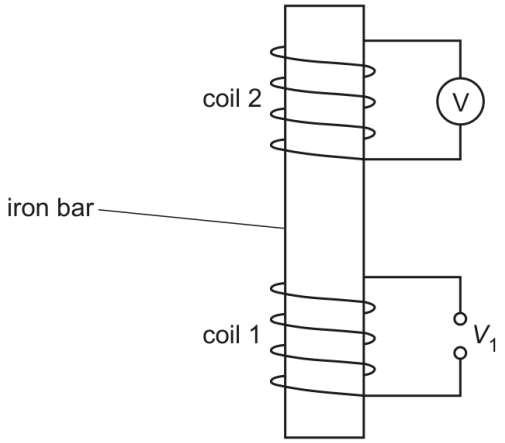


Fig. 7.1

Coil 1 is connected to a potential difference (p.d.) V_1 that gives rise to a magnetic field in the iron bar.

Fig. 7.2 shows the variation with time t of the magnetic flux density B in the iron bar.

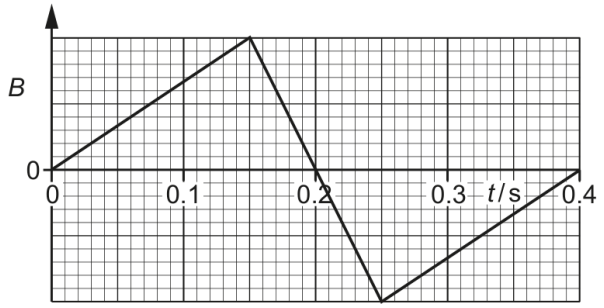


Fig. 7.2

A voltmeter measures the electromotive force (e.m.f.) V_2 that is induced across coil 2.

On Fig. 7.3, sketch the variation with t of V_2 between $t = 0$ and $t = 0.40$ s.

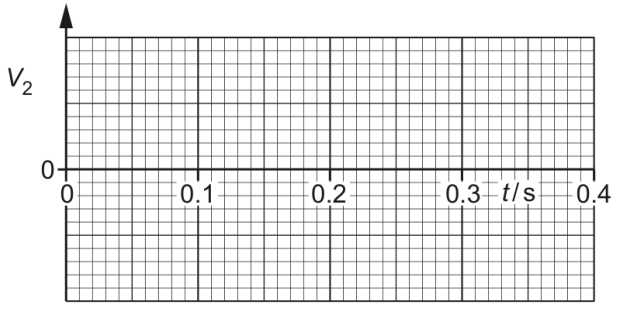


Fig. 7.3

[4]

(c) Coil 2 in **(b)** is now replaced with a copper ring that rests loosely on top of coil 1. The supply to coil 1 is replaced with a cell and a switch that is initially open, as shown in Fig. 7.4.

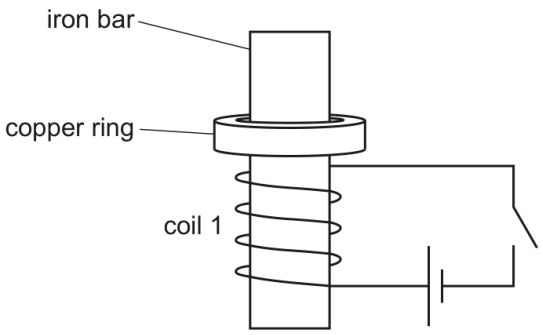


Fig. 7.4

(i) The switch is now closed. As it is closed, the copper ring is observed to jump upwards.

Explain why this happens.

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..... [3]

(ii) Suggest, with a reason, what would be the effect of repeating the procedure in **(c)(i)** with the terminals of the cell reversed.

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7 A capacitor of capacitance 470 μF is connected to a battery of electromotive force (e.m.f.) 24 V in the circuit of Fig. 5.1.

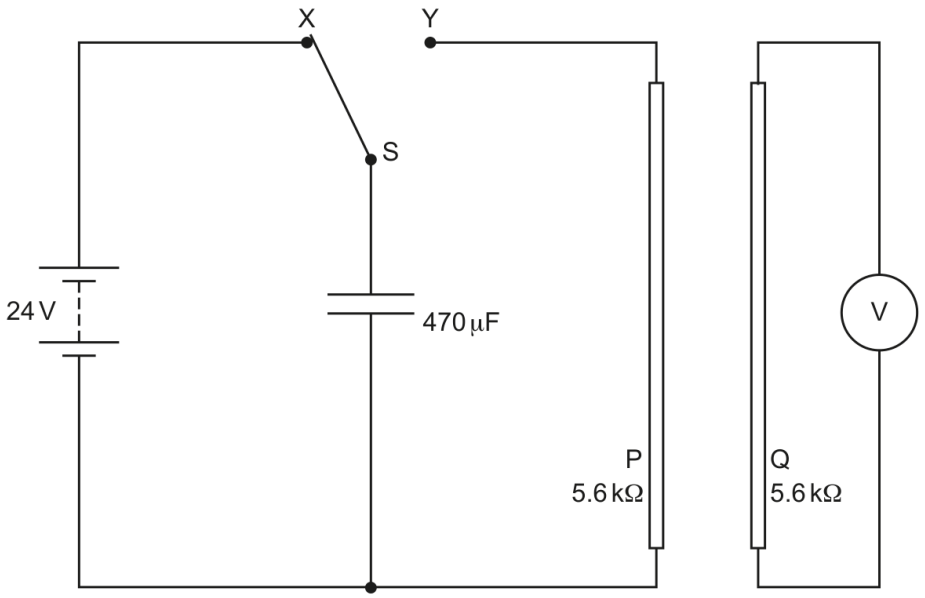


Fig. 5.1

The two-way switch S is initially at position X.

P and Q are identical long straight wires, each with a resistance of 5.6 kΩ. These wires are placed near to, and parallel to, each other. Wire Q is connected to a voltmeter.

At time t = 0, switch S is moved to position Y so that the capacitor discharges through wire P.

(b) (i) Explain why there is an induced e.m.f. across wire Q during the discharge of the capacitor.

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..... [3]

(ii) On Fig. 5.3, sketch a line to suggest the variation with *t* of the voltmeter reading *V*.



Fig. 5.3

[1]

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

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..... [2]

(b) Two coils of insulated wire are wound on an iron bar, as shown in Fig. 8.1.

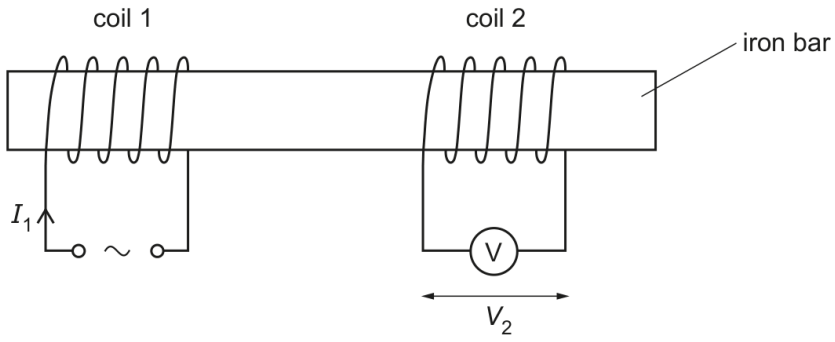


Fig. 8.1

There is a current I_1 in coil 1 that varies with time *t* as shown in Fig. 8.2.

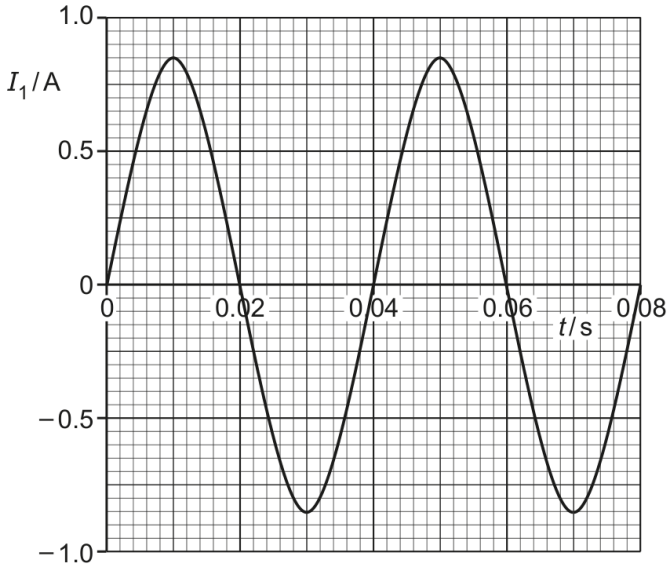


Fig. 8.2

(ii) The current in coil 1 gives rise to a magnetic field in the iron bar.
Assume that the flux density of this magnetic field is proportional to I_1.

An alternating electromotive force (e.m.f.) is induced across coil 2. The p.d. across coil 2 is measured using the voltmeter and has a root-mean-square (r.m.s.) value of 4.6 V.

On Fig. 8.3, sketch a line to show the variation with t of V_2 between $t = 0$ and $t = 0.08$ s.

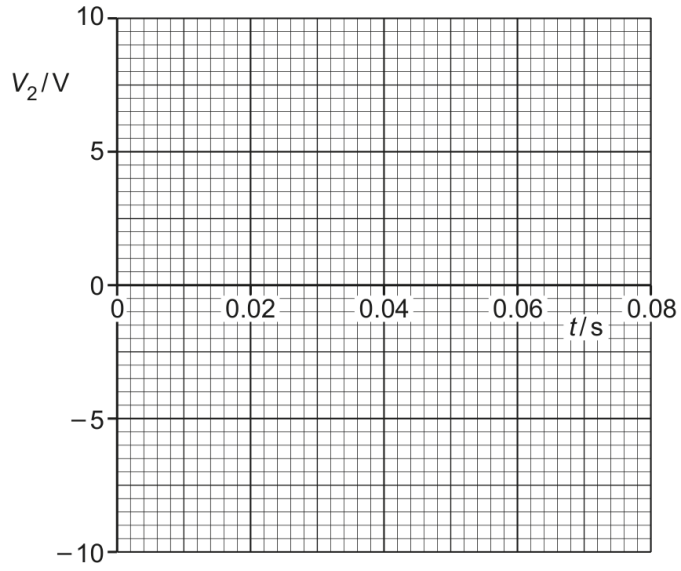


Fig. 8.3

[3]

(iii) Use the laws of electromagnetic induction to explain the shape of your line in **(b)(ii)**.

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..... [3]

9 **(a)** State Lenz's law.

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..... [2]

(b) A metal ring is suspended from a fixed point P by means of a thread, as shown in Fig. 10.1.

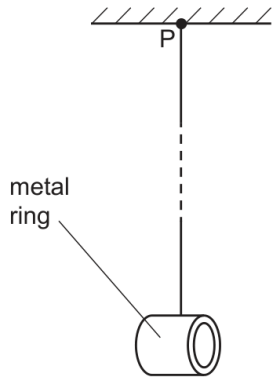


Fig. 10.1

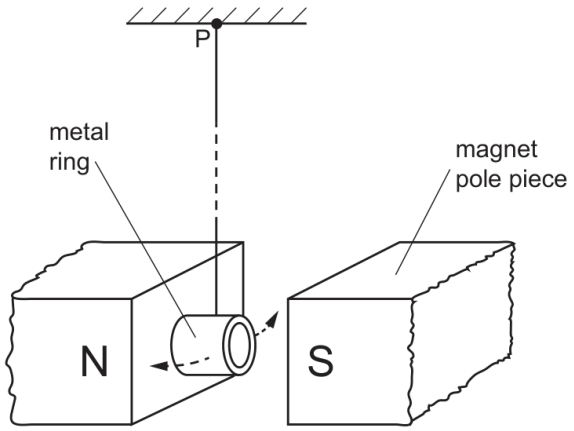


Fig. 10.2

The ring is displaced a distance *d* and then released. The ring completes many oscillations before coming to rest.

The poles of a magnet are now placed near to the ring so that the ring hangs midway between the poles of the magnet, as shown in Fig. 10.2.

The ring is again displaced a distance *d* and then released.
Explain why the ring completes fewer oscillations before coming to rest.

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..... [4]

(c) The ring in **(b)** is now cut so that it has the shape shown in Fig. 10.3.



Fig. 10.3

Explain why, when the procedure in **(b)** is repeated, the cut ring completes more oscillations than the complete ring when oscillating between the poles of the magnet.

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..... [3]

10 (c) With the switch in **(b)** closed, the small mass on the free end of the spring is now made to oscillate vertically.

Use the principles of electromagnetic induction to explain why small fluctuations in the current in the spring are found to occur.

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..... [3]

11 **(b)** A coil is rotating freely, on frictionless bearings, at constant speed in a uniform magnetic field. This rotation causes an induced alternating electromotive force (e.m.f.) across the open terminals of the coil. The induced e.m.f. has r.m.s. value 12 V and frequency 50 Hz.

The speed of rotation of the coil is now doubled.

(i) State and explain, with reference to the principles of electromagnetic induction, the effect of the increased speed of rotation on the r.m.s. value of the induced e.m.f.

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..... [2]

(c) State and explain the effect on the motion of the coil in **(b)** of connecting a load resistor across its terminals.

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..... [2]

12 (a) A coil of wire is situated in a uniform magnetic field of flux density B.
The coil has diameter 3.6 cm and consists of 350 turns of wire, as illustrated in Fig. 9.1.

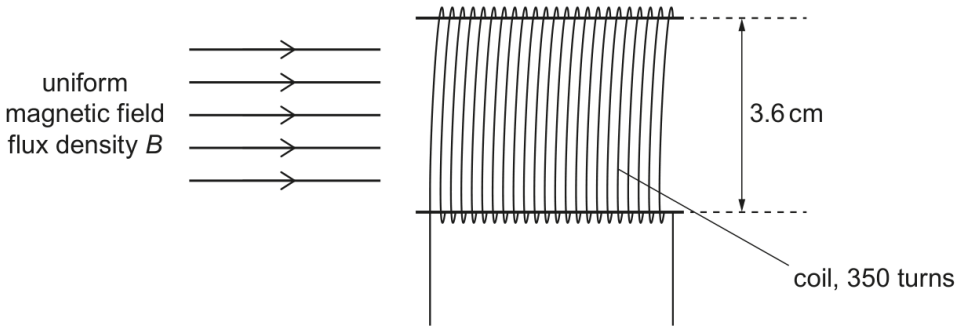


Fig. 9.1

The variation with time t of B is shown in Fig. 9.2.

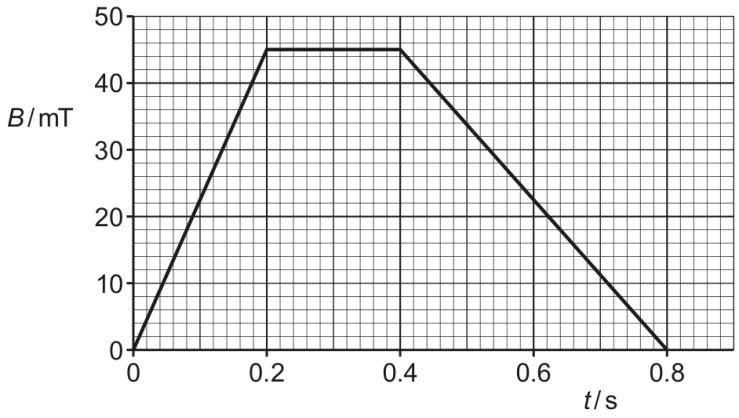


Fig. 9.2

(i) Show that, for the time t = 0 to time t = 0.20 s, the electromotive force (e.m.f.) induced in the coil is 0.080 V.

[2]

(ii) On the axes of Fig. 9.3, show the variation with time t of the induced e.m.f. E for time $t = 0$ to time $t = 0.80$ s.

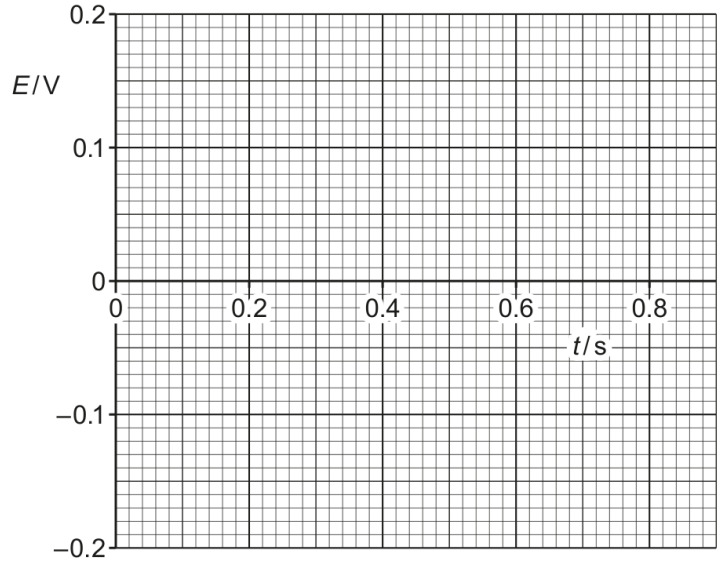


Fig. 9.3

[4]

(b) A bar magnet is held a small distance above the surface of an aluminium disc by means of a rod, as illustrated in Fig. 9.4.

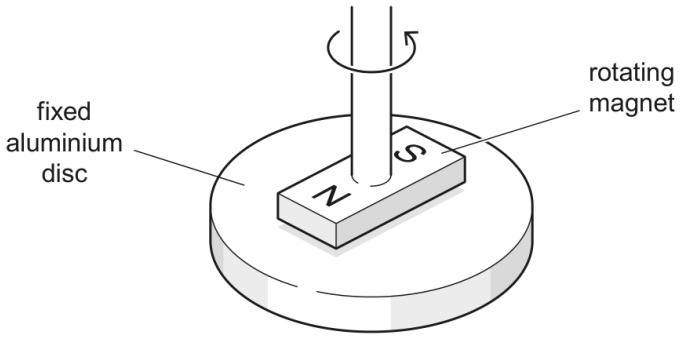


Fig. 9.4

The aluminium disc is supported horizontally and held stationary.

The magnet is rotated about a vertical axis at constant speed.

Use laws of electromagnetic induction to explain why there is a torque acting on the aluminium disc.

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..... [4]

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

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(b) A simple iron-cored transformer is illustrated in Fig. 10.1.

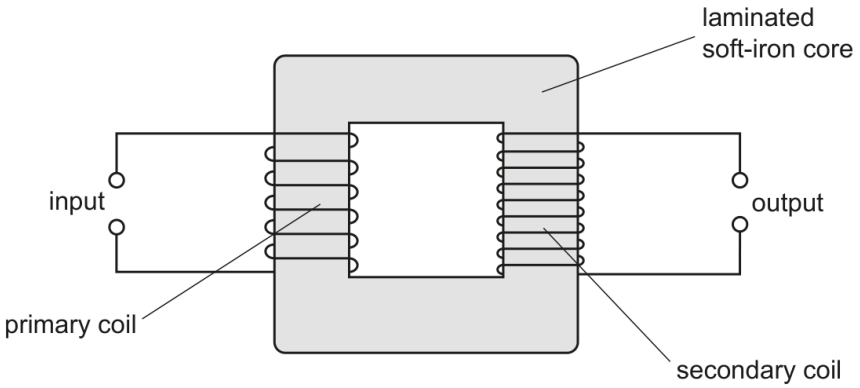


Fig. 10.1

(ii) A sinusoidal alternating current in the primary coil gives rise to a varying magnetic flux linking the secondary coil.

Use Faraday's law to explain why the output from the transformer is an electromotive force (e.m.f.) that is alternating.

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..... [3]

14 (a) Define *magnetic flux*.

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..... [2]

(b) A simple transformer consists of two coils of wire wound on a soft-iron core, as illustrated in Fig. 9.1.

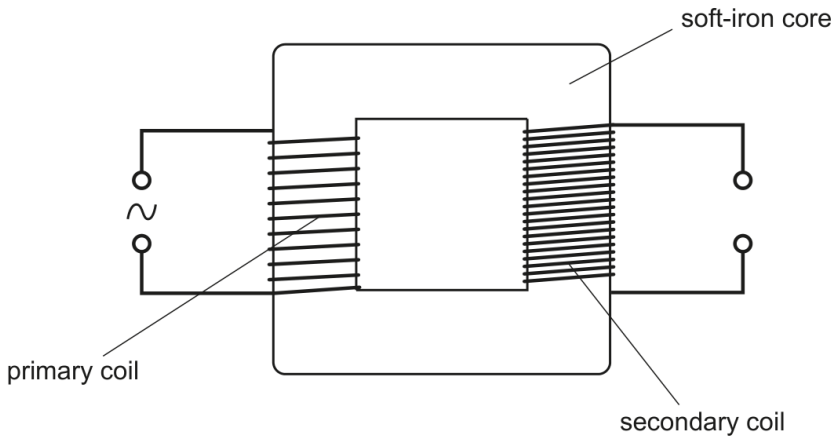


Fig. 9.1

There is a sinusoidal current in the primary coil.

Explain:

(i) how this current gives rise to an induced electromotive force (e.m.f.) in the secondary coil

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..... [3]

(ii) why the e.m.f. induced in the secondary coil is not constant.

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15 (a) A small coil is placed close to one end of a solenoid connected to a power supply. The plane of the small coil is normal to the axis of the solenoid, as illustrated in Fig. 9.1.

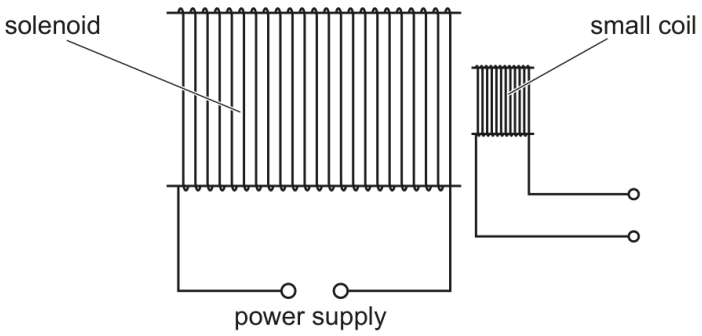


Fig. 9.1

The power supply causes the current I in the solenoid to vary with time t as shown in Fig. 9.2.

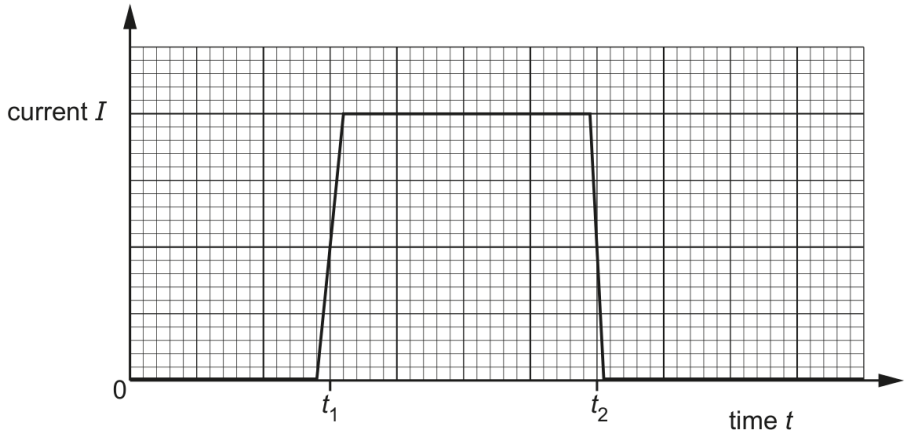


Fig. 9.2

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

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..... [2]

(ii) On the axes of Fig. 9.3, sketch a graph to show the variation with time t of the electromotive force (e.m.f.) induced in the small coil.

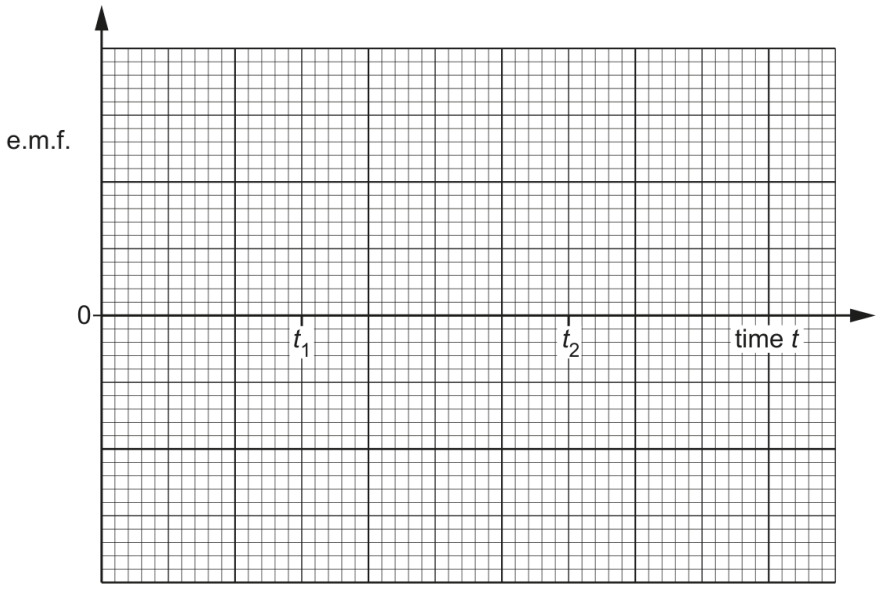


Fig. 9.3

[4]

16 A solenoid is connected in series with a battery and a switch, as illustrated in Fig. 8.1.

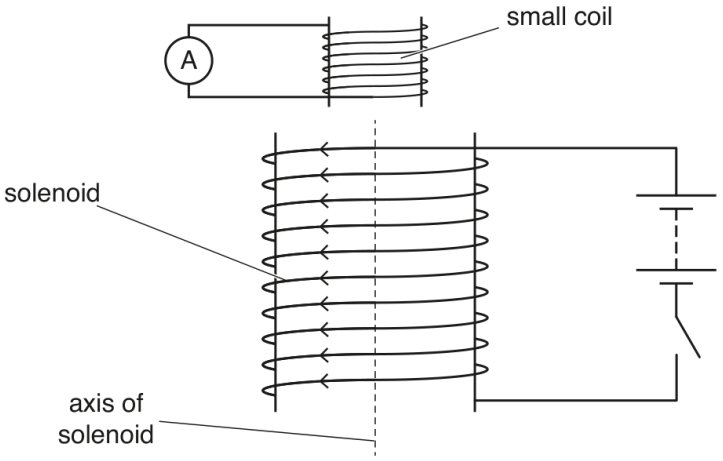


Fig. 8.1

A small coil, connected to a sensitive ammeter, is situated near one end of the solenoid.

As the current in the solenoid is switched on, there is a changing magnetic field inside the solenoid.

(b) As the current in the solenoid is switched on, there is a current induced in the small coil. This induced current gives rise to a magnetic field in the small coil.

(i) State Lenz's law.

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..... [2]

(ii) Use Lenz's law to state and explain the direction of the magnetic field due to the induced current in the small coil. On Fig. 8.1, mark this direction with an arrow inside the small coil.

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..... [3]

(c) The small coil has an area of cross-section $7.0 \times 10^{-4}\,m^2$ and contains 75 turns of wire.

A constant current in the solenoid produces a uniform magnetic flux of flux density 1.4 mT throughout the small coil.

The direction of the current in the solenoid is reversed in a time of 0.12 s.

Calculate the average e.m.f. induced in the small coil.

e.m.f. = ...V [3]

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

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.....[2]

(b) An ideal transformer is illustrated in Fig. 10.1.

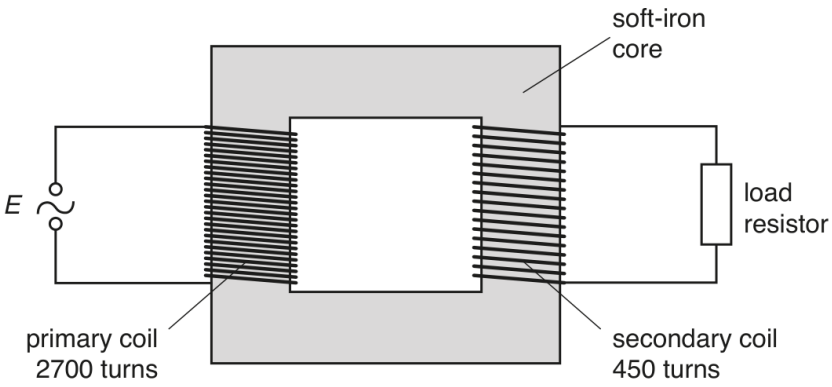


Fig. 10.1

Explain why, when there is an alternating current in the primary coil, there is a current in the load resistor.

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.....[3]

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

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..... [2]

(b) A solenoid S has a small coil C placed near to one of its ends, as shown in Fig. 11.1.

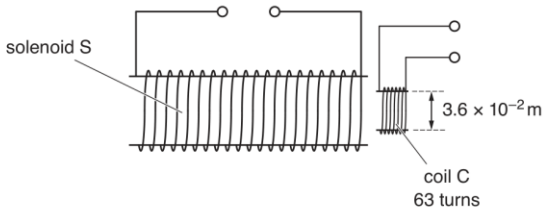


Fig. 11.1

The coil C has a circular cross-section of diameter 3.6×10^{-2} m and contains 63 turns of wire.

The solenoid S produces a uniform magnetic field of flux density B, in tesla, in the region of coil C given by the expression

$$B = 9.4 \times 10^{-4} I$$

where I is the current, in ampere, in the solenoid S.

The variation with time t of the current I in solenoid S is shown in Fig. 11.2.

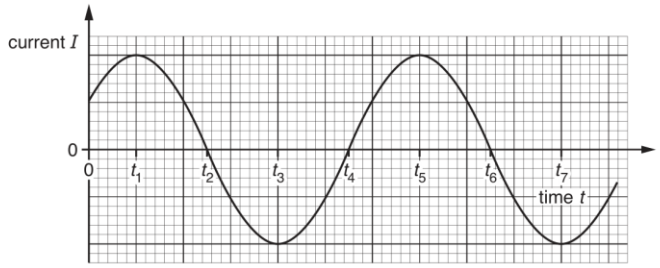


Fig. 11.2

State two times at which:

(i) there is no electromotive force (e.m.f.) induced in coil C

time ..... and time ..... [1]

(ii) the induced e.m.f. in coil C is a maximum but with opposite polarities.

time ..... and time ..... [1]

(c) The alternating current in the solenoid S in **(b)** is replaced by a constant current of 5.0 A.

Calculate the average e.m.f. induced in coil C when the current in solenoid S is reversed in a time of 6.0 ms.

e.m.f. induced = ... V [3]

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

.....

.....

.....

.....[2]

(b) A coil of insulated wire is wound on to one end of a ferrous core and connected to a battery, as shown in Fig. 10.1.

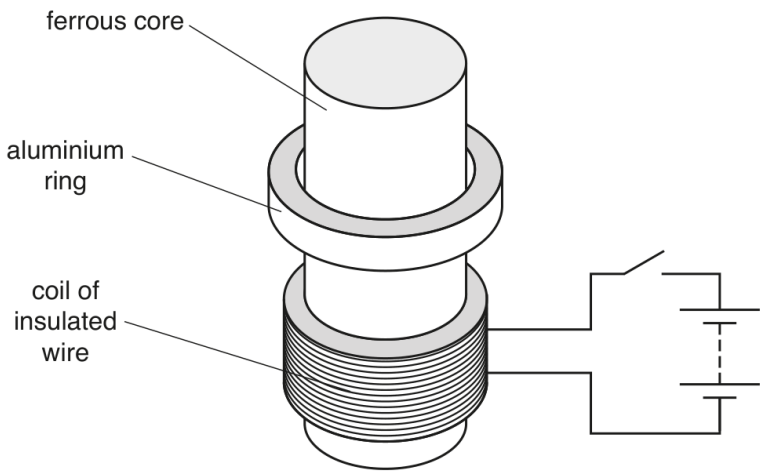


Fig. 10.1

An aluminium ring is placed on the core. The ring can move freely along the length of the core.

The switch is initially open.

Use Faraday's law and Lenz's law to explain why the aluminium ring jumps upwards when the switch is closed.

.....

.....

.....

.....

.....

.....

.....[4]

20 **(a)** State what is meant by the *magnetic flux linkage* of a coil.

.....

.....

.....

.....[3]

(b) A coil of wire has 160 turns and diameter 2.4 cm. The coil is situated in a uniform magnetic field of flux density 7.5 mT, as shown in Fig. 9.1.

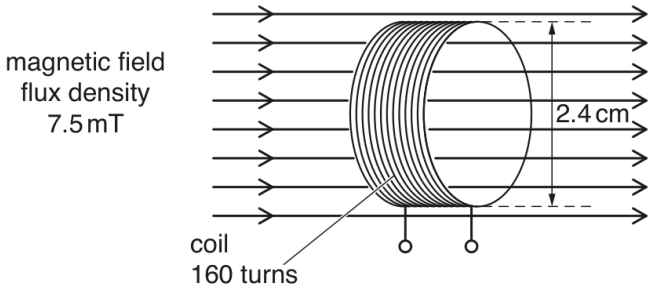


Fig. 9.1

The direction of the magnetic field is along the axis of the coil.

The magnetic flux density is reduced to zero in a time of 0.15 s.

Show that the average e.m.f. induced in the coil is 3.6 mV.

[2]

(c) The magnetic flux density B in the coil in **(b)** is now varied with time t as shown in Fig. 9.2.

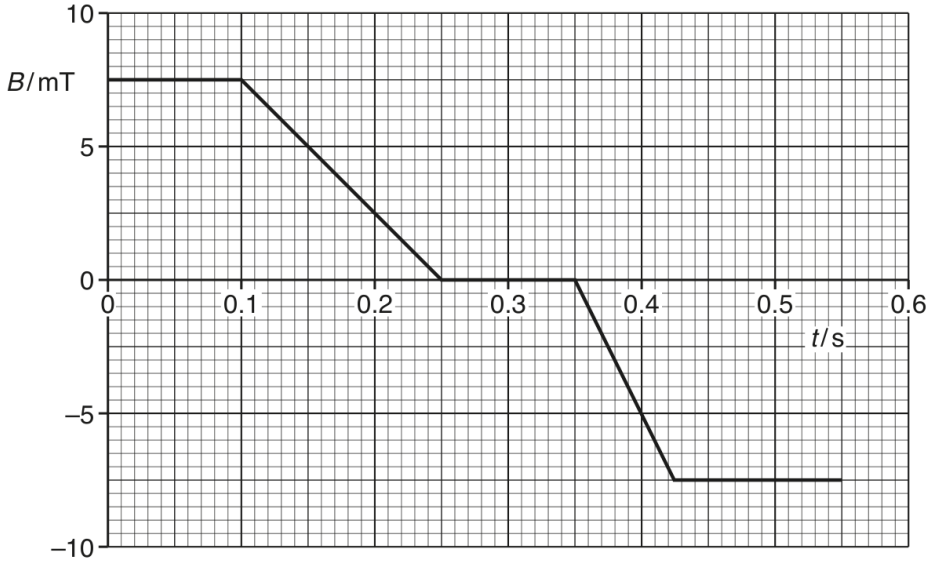


Fig. 9.2

Use data in **(b)** to show, on Fig. 9.3, the variation with time t of the e.m.f. E induced in the coil.

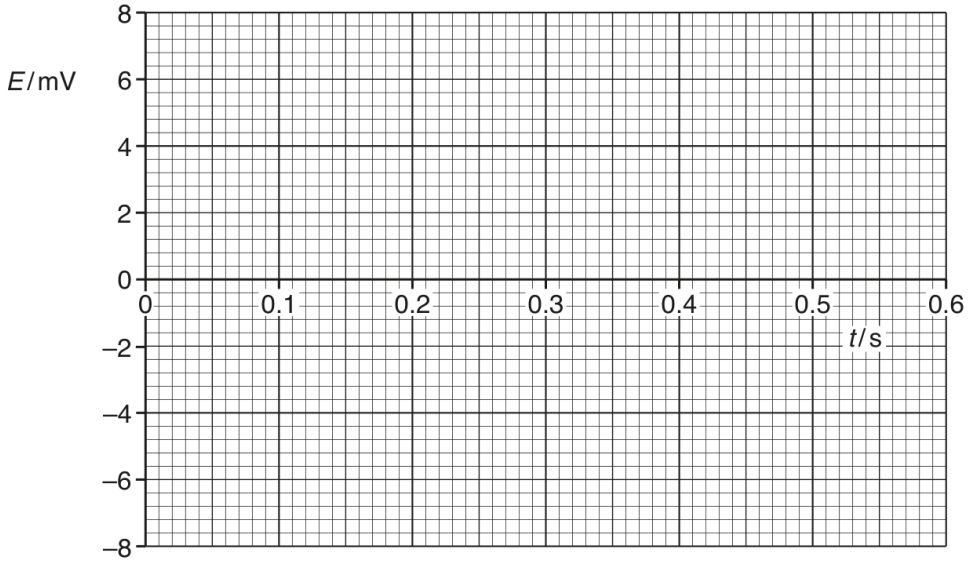


Fig. 9.3

[4]

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

.....

.....

.....[2]

(b) A solenoid S is wound on a soft-iron core, as shown in Fig. 9.1.

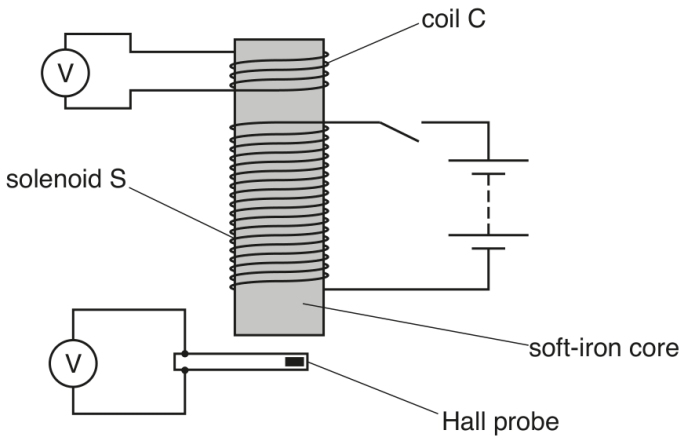


Fig. 9.1

A coil C having 120 turns of wire is wound on to one end of the core. The area of cross-section of coil C is 1.5 cm^2.

A Hall probe is close to the other end of the core.

When there is a constant current in solenoid S, the flux density in the core is 0.19 T. The reading on the voltmeter connected to the Hall probe is 0.20 V.

The current in solenoid S is now reversed in a time of 0.13 s at a constant rate.

(i) Calculate the reading on the voltmeter connected to coil C during the time that the current is changing.

reading = ... V [2]

(ii) Complete Fig. 9.2 for the voltmeter readings for the times before, during and after the direction of the current is reversed.

	before current changes	during current change when current is zero	after current changes
reading on voltmeter connected to coil C / V	.....	.....	.....
reading on voltmeter connected to Hall probe / V	0.20	.....	.....

Fig. 9.2

[4]

22 **(b)** The Hall probe in **(a)** is now replaced by a small coil of wire connected to a sensitive voltmeter, as shown in Fig. 9.4.

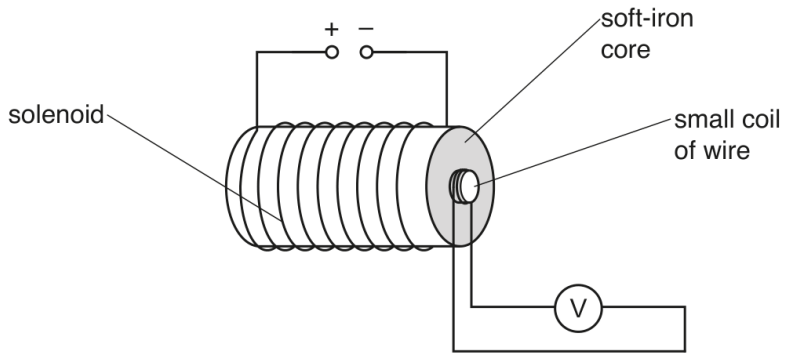


Fig. 9.4

The magnetic flux density, normal to the plane of the small coil, is again varied as shown in Fig. 9.2.

On Fig. 9.5, draw a line to show the variation with time t of the e.m.f. E induced in the small coil for time $t = 0$ to time $t = t_4$.

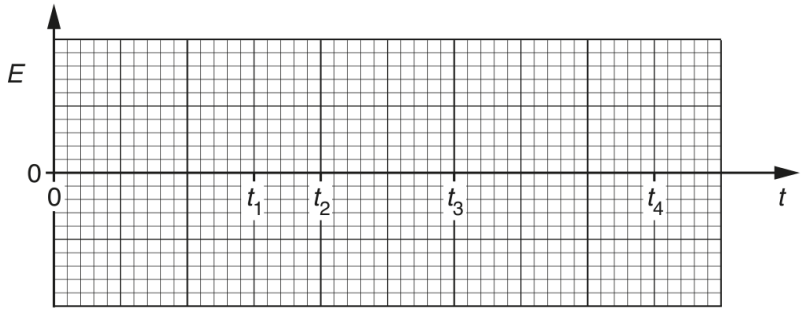


Fig. 9.5

[3]