

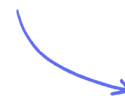
Structured Questions

Induction

Induced Emf (HL) / Magnetic Flux (HL) / Faraday's Law of Induction (HL) / Lenz's Law (HL) / AC Generators (HL)

| | |
|----------------------|-------------|
| Easy (6 questions) | /60 |
| Medium (7 questions) | /64 |
| Hard (5 questions) | /52 |
| Total Marks | /176 |

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Easy Questions

1 (a) Faraday's law of electromagnetic induction can be written as:

$$\varepsilon = \frac{\Delta(N\phi)}{\Delta t}$$

- (i) Name the quantity represented by $\Delta(N\phi)$. [1]
- (ii) State Faraday's law of electromagnetic induction in words. [2]

(3 marks)

(b) The table outlines the standard international (SI) units of the main quantities involved in electromagnetic induction.

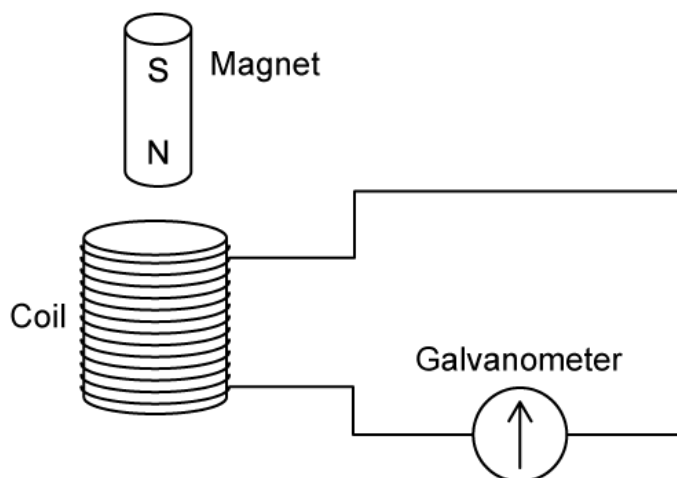
| Quantity | Symbol | SI unit |
|-----------------------|--------|----------|
| Magnetic flux | ϕ | |
| Magnetic flux linkage | | Wb turns |
| Electromotive force | | |
| Magnetic flux density | B | |

Complete the table by filling in the missing symbols and SI units.

(4 marks)

- (c) A galvanometer is an electromagnetic device that can measure small values of current by the deflection of a needle.

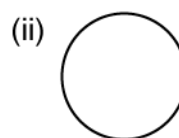
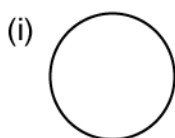
A coil is connected to a galvanometer centered at zero.



A magnet moves vertically into the coil so that the galvanometer deflects to the right as shown.



In the spaces provided, sketch the expected observations of the galvanometer needle when



- (i) The magnet is held at rest in the coil.

[1]

(ii) The magnet is removed from the coil more quickly than it entered

[3]

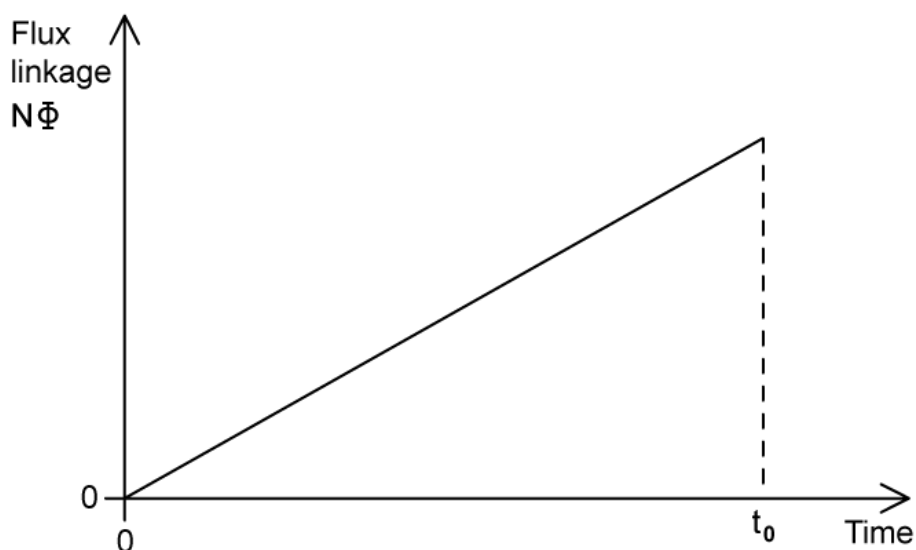
(4 marks)

(d) As the student removes the magnet from the coil, the galvanometer shows a constant value of 1.5 mV for 2.0 s.

Calculate the change in magnetic flux linkage as the student removes the magnet from the coil.

(3 marks)

- 2 (a) The graph shows how magnetic flux linkage $N\Phi$ passing through a coil of wire changes as time t progresses, as it moves into a uniform magnetic field.

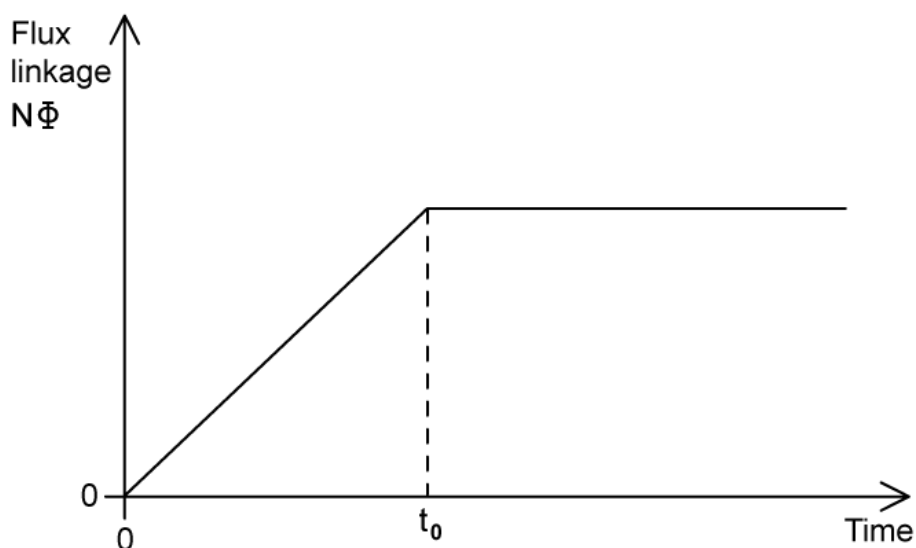


State the quantity represented by the gradient of the graph.

(1 mark)

- (b) After a certain amount of time the coil of wire in part (a) has fully entered the region of uniform magnetic field and moves normally to the flux density within it.

The graph in part (a) is continued so that the graph looks like:



State and explain the value of the induced emf in the coil of wire after time, t_0 .

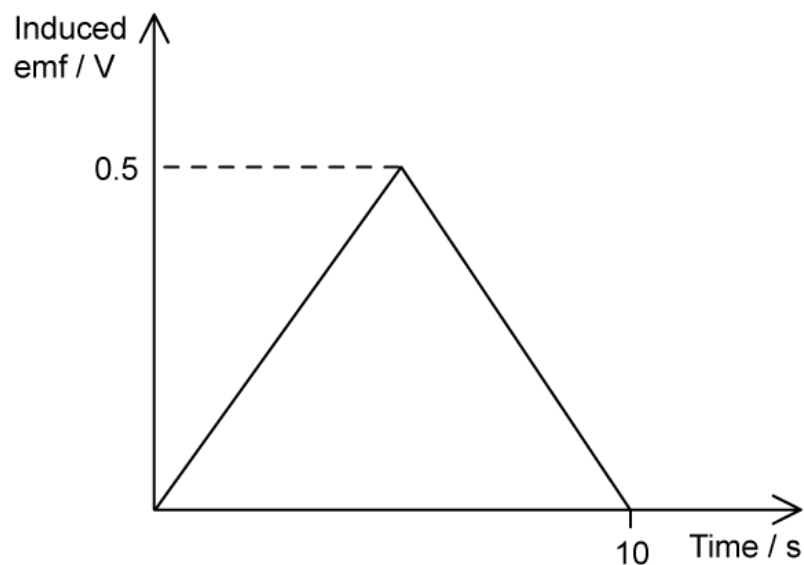
(2 marks)

- (c) The coil of wire in part (b) is made of 5000 turns of wire and has an area of 0.15 m^2 . The uniform magnetic field has a field strength of 2.5 T and is perpendicular to the coil face, such that the angle between the normal line to the coil face and the flux lines is 0° .

Calculate the magnitude of the magnetic flux linkage through the coil in the uniform magnetic field.

(2 marks)

- (d) The graph shows how the induced emf varies with time for a different coil of wire.



- (i) State the quantity represented by the area under the slope. [1]
- (ii) Calculate the area under the slope, giving an appropriate unit with your answer. [3]

(4 marks)

- 3 (a) When a coil of wire rotates in a uniform magnetic field, the magnetic flux is given by the equation

$$\Phi = BA\cos(\theta)$$

State the meaning of the following symbols and an appropriate unit for each.

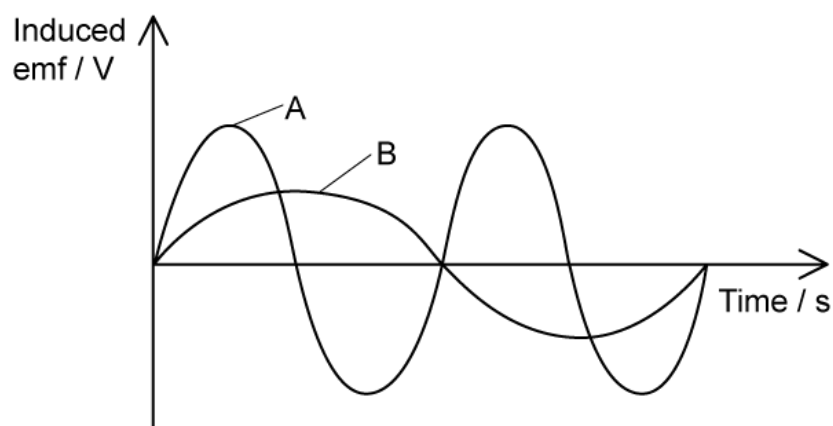
(i) B [1]

(ii) A [1]

(iii) θ [1]

(3 marks)

- (b) The graph represents the variation of induced emf over the progression of time for coils A and B which rotate in the same uniform magnetic field.



For coils A and B

- (i) State which of the two coils experiences the largest maximum induced emf. [1]
- (ii) Hence, or otherwise, state which coil has a faster rate of rotation.

(2 marks)

- (c) Sometimes the equation $\Phi = BA\cos(\theta)$ is simplified to

$$\Phi = BA$$

State the relation between the coil and the magnetic field lines when the magnetic flux is simplified in this way.

(1 mark)

- (d) A rectangular coil with a magnetic flux of 0.15 mWb spins in a uniform magnetic field of flux density 0.50 mT.

Calculate the cross sectional area of the coil.

(4 marks)

4 (a) Lenz's law is sometimes combined with Faraday's law in order to explain important electromagnetic effects.

Choose words from the list below to complete the sentence.

attract density direction linkage oppose

The of an induced emf is always set up in such a way so as to the change in magnetic flux that causes it.

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.....
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(3 marks)

(b) Faraday's law can be combined with Lenz's law in the following mathematical equation

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

State which aspect(s) of the equation shown corresponds to

(i) Faraday's law.

[1]

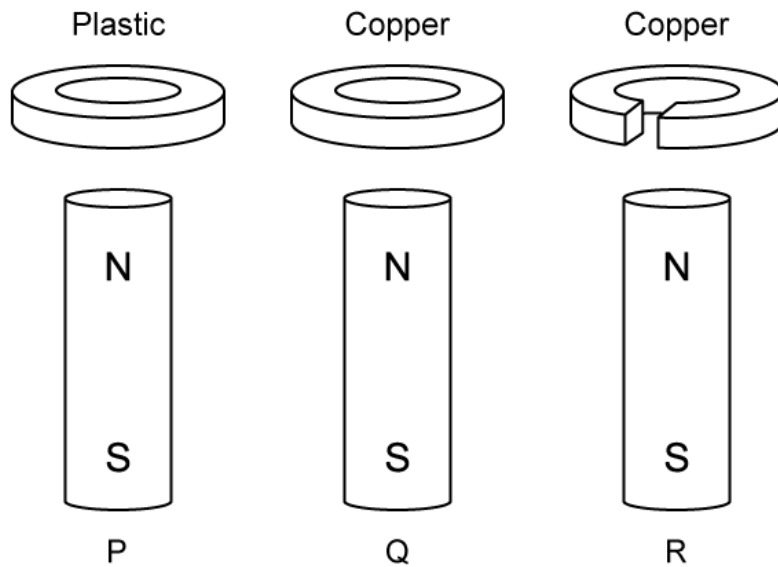
(ii) Lenz's law.

[1]

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(2 marks)

(c) Bar magnets are arranged vertically, with each magnet having a ring of a different material suspended above it.



An analysis of the subsequent motion of each ring involves considering the type of material of each ring, how it is made, and how this affects any induced emfs or currents.

Respond with Y (yes) or N (no) in the table below to complete the analysis of the situation.

| Ring | Conductor | Emf induced? | Current induced? |
|------|-----------|--------------|------------------|
| P | N | N | |
| Q | Y | | |
| R | Y | | |

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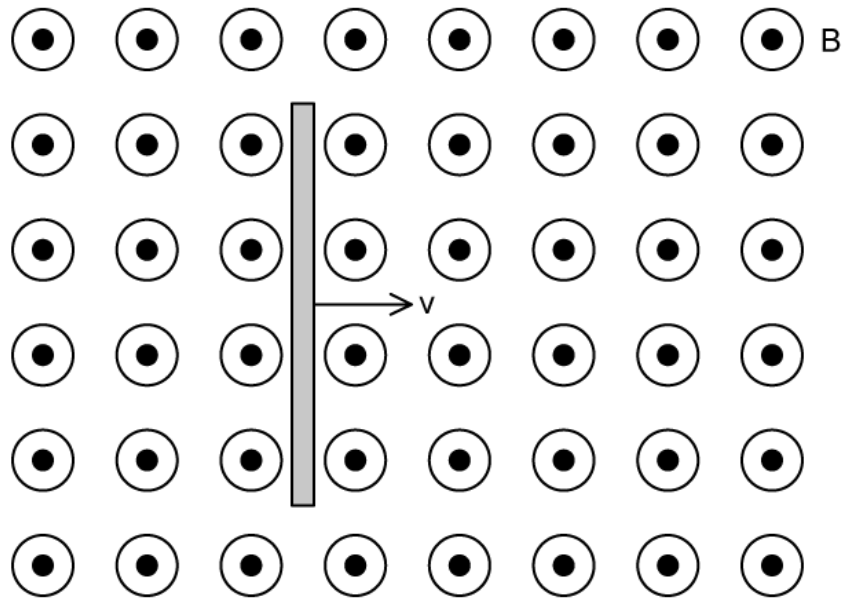
(5 marks)

- (d) Ring Q takes significantly longer to reach the bottom of the magnet compared to rings P and R.

State the law of electromagnetic induction which explains this observation.

(1 mark)

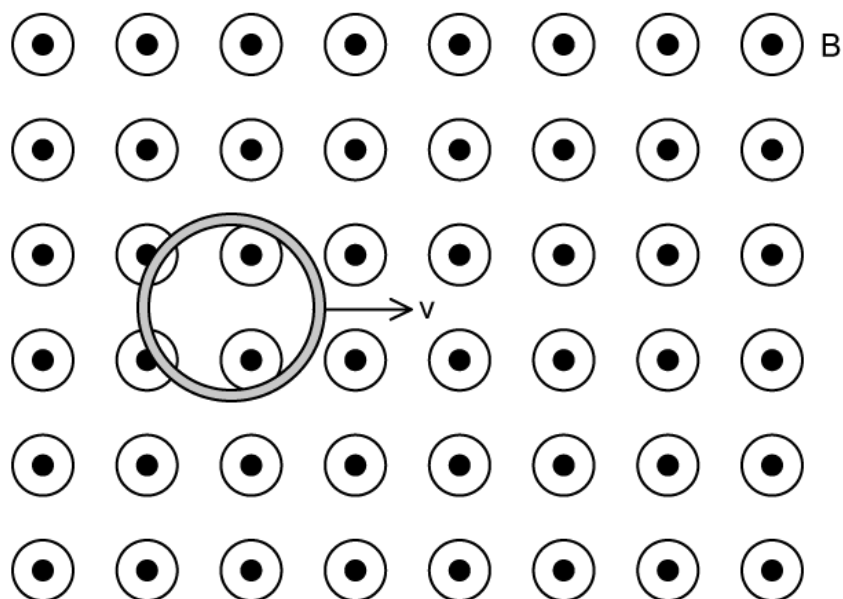
- 5 (a) A straight conductor of length $l = 30$ cm moves normally across a uniform magnetic field of flux density $B = 2.0$ T at a speed v .



Calculate the speed v the conductor would need to have in order to induce an emf of magnitude 1.5 V.

(4 marks)

- (b) The conductor in the diagram is now bent into a single loop of wire and moves normally across the same uniform magnetic field at the same speed v , as shown.



The induced emf in the single loop of wire is now 0 V.

Explain why the induced emf in the single loop of wire is now 0 V.

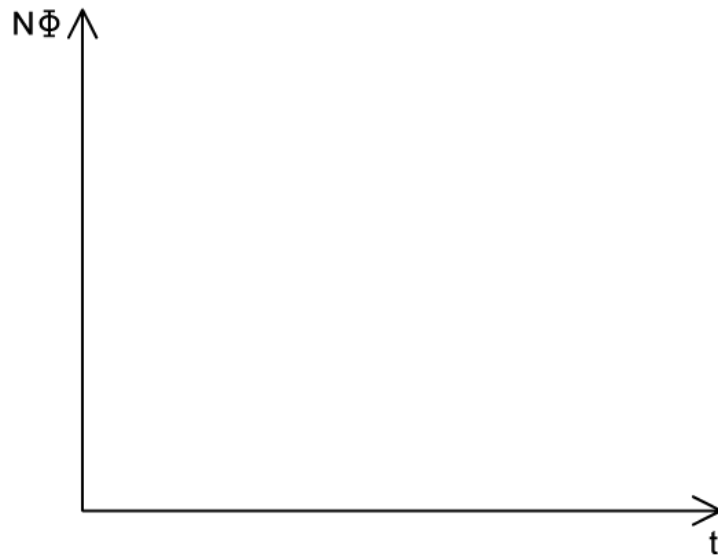
(1 mark)

- (c) The single loop of wire shown in part (b) encloses an area of $7.2 \times 10^{-3} \text{ m}^2$.

Calculate the magnetic flux through the single loop of wire.

(3 marks)

- (d) Sketch a graph on the axes provided below to show how the magnetic flux linkage $N\Phi$ varies with time t as the single loop of wire is removed entirely from the uniform magnetic field. Assume the speed v stays constant.



(2 marks)

6 (a) The following paragraph explains the operation of a basic a.c. generator.

An AC generator consists of a coil rotating in a field.

The ends of the coil are attached to rings that rotate along with the coil.

These touch that transfer the current into an external circuit.

The magnetic changes as the coil rotates and an is induced.

An AC generator converts energy into energy.

Complete the sentences using keywords from below.

You may use any keyword once, more than once, or not at all.

e.m.f. flux electrical field magnetic

brushes mechanical slip electric

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(5 marks)

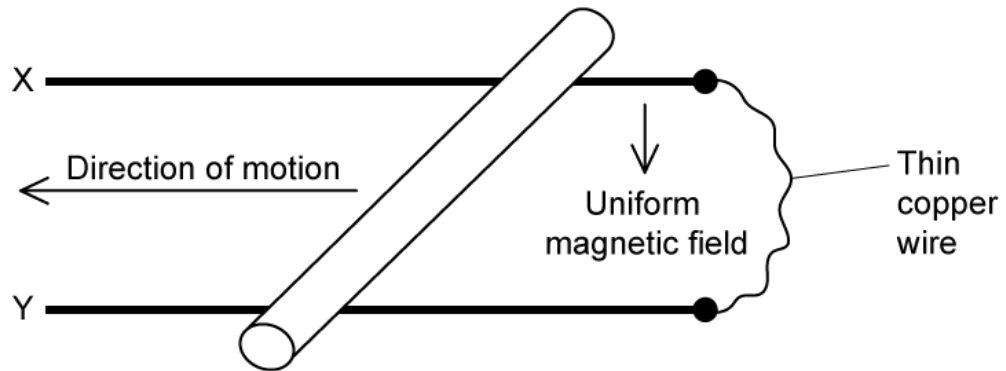
(b) Outline the effect of the output if the frequency of an ac generator is increased.

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(1 mark)

Medium Questions

- 1 (a) A copper rod is placed in a region of uniform magnetic field. The rod is moved horizontally along two parallel conducting rails X and Y.



The rod lies at right angles to the direction of the uniform magnetic field. It moves at constant speed.

The rails are connected at one end by a thin copper wire.

Describe how an emf is induced in the rod. Refer to forces acting on the conduction electrons in the copper of the rod in your answer.

(2 marks)

- (b) State what is meant by rate of change of flux and apply it to this situation.

(2 marks)

- (c) The length of the rod is 0.8 m and it moves at a speed of 5.7 m s^{-1} . The induced emf is 9 mV.

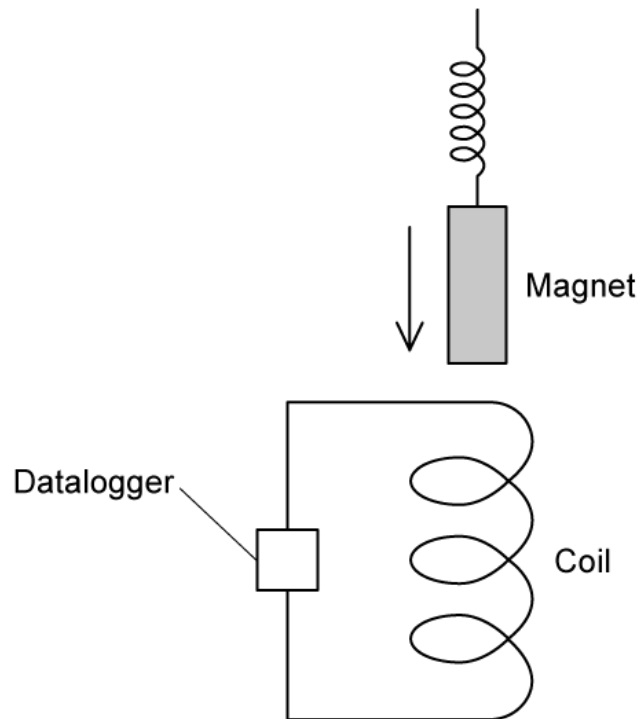
Determine the magnitude of the magnetic field strength.

(2 marks)

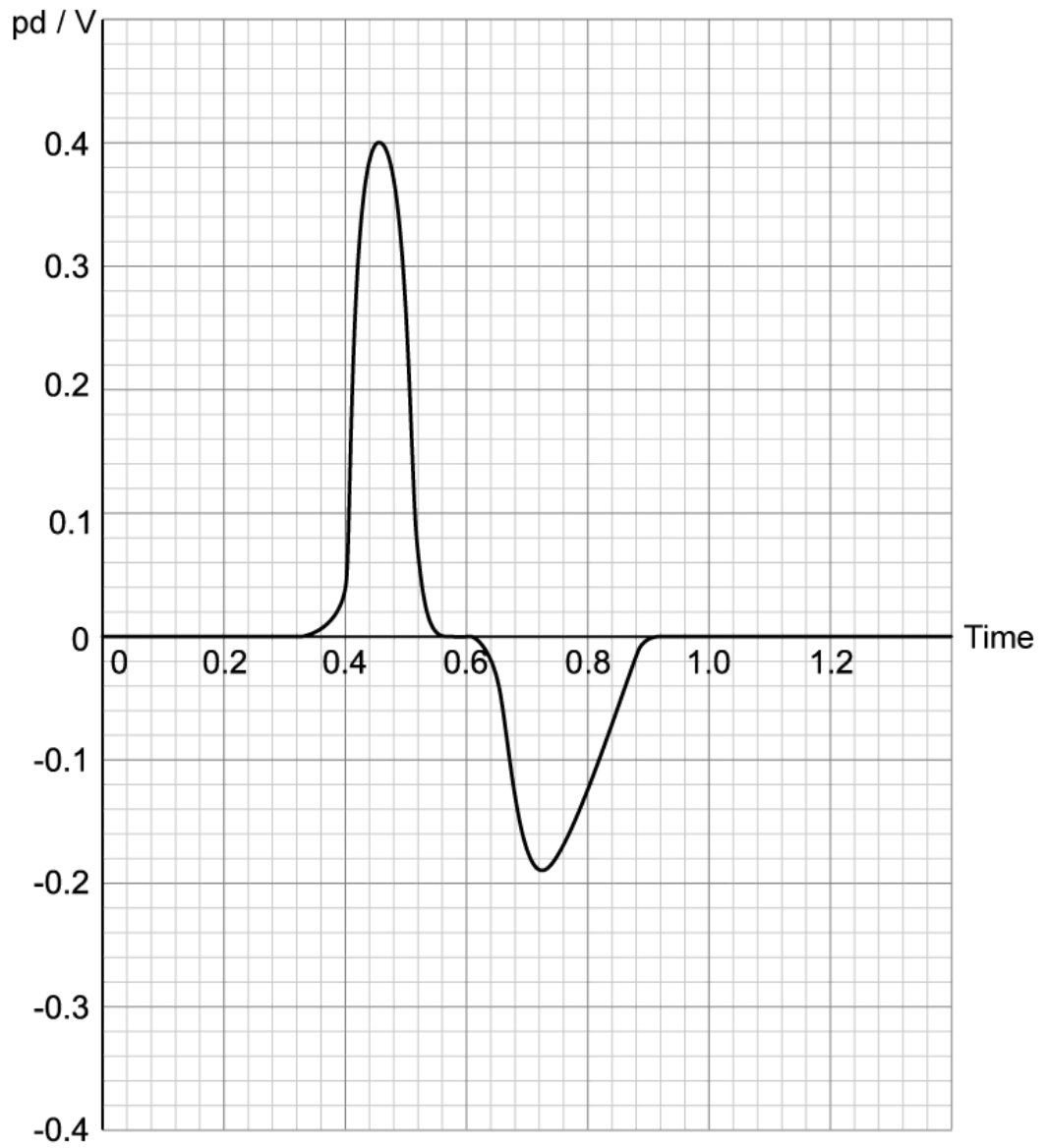
- (d) Explain how Lenz's law relates to the rod moving on the rails.

(3 marks)

- 2 (a)** A bar magnet attached to a spring is allowed to fall vertically from rest through a simple coil of conducting wire. The potential difference (pd) across the solenoid is measured using a datalogger.



The graph shows the variation of the pd across the coil with time.



Explain the shape of the graph by

(i) Making reference to both Faraday's and Lenz's laws.

[2]

(ii) Considering the mass-spring system.

[2]

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(4 marks)

(b) The coil has 2200 turns.

Calculate the magnitude of the maximum rate of change of magnetic flux.

(2 marks)

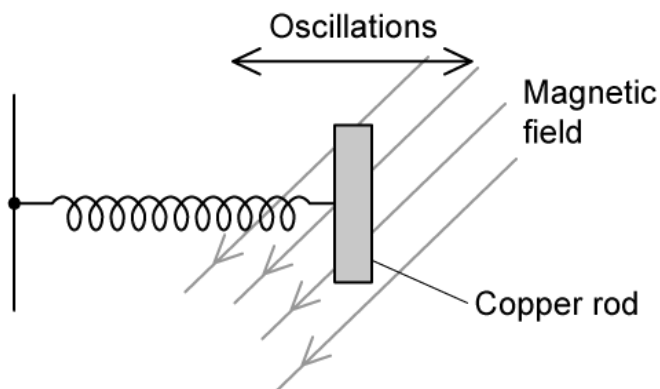
(c) The magnet is displaced vertically so that it initially oscillates with simple harmonic motion. Apply Lenz's law to this situation.

(3 marks)

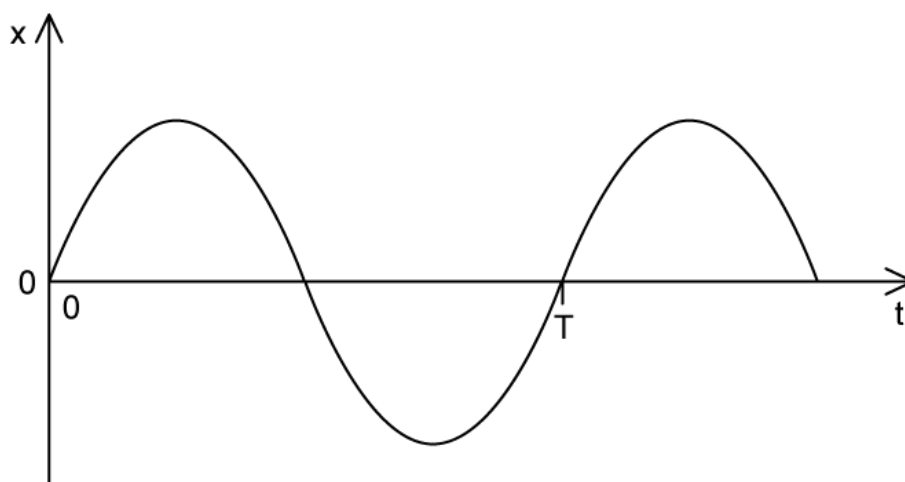
(d) Outline how the simple harmonic motion of the oscillations would be affected by replacing the magnet with one of equal mass but with a greater magnetic field strength.

(3 marks)

- 3 (a)** A vertical copper rod is attached to the mass of a mass-spring system so that it can be made to oscillate with simple harmonic motion with a time period T at right angles to a uniform magnetic field.



The graph shows the variation with time t of the horizontal displacement x of the rod.



Sketch a graph to show

- (i) Variation with time t of the vertical velocity v of the rod.

[2]

- (ii) Variation with time t of the emf generated between the ends of the rod.

[2]

(4 marks)

- (b) The length of the rod is 25 cm and the magnitude of the magnetic field is $68 \mu\text{T}$. At the equilibrium position the rod is moving at 5.1 m s^{-1} .

Determine the magnitude of the maximum emf ϵ_{max} between the ends of the rod.

Explain your reasoning.

(3 marks)

- (c) The frequency of the motion is doubled without any change in the amplitude of the motion.

State and explain the changes this causes to the time, t and the induced emf.

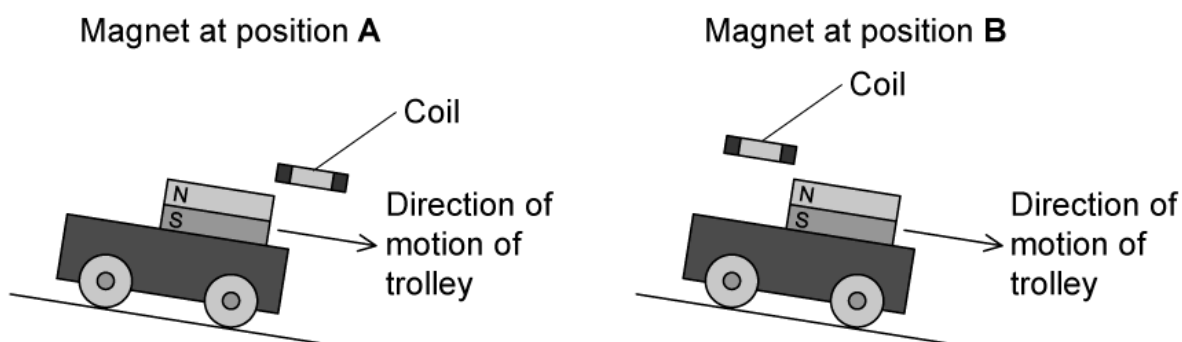
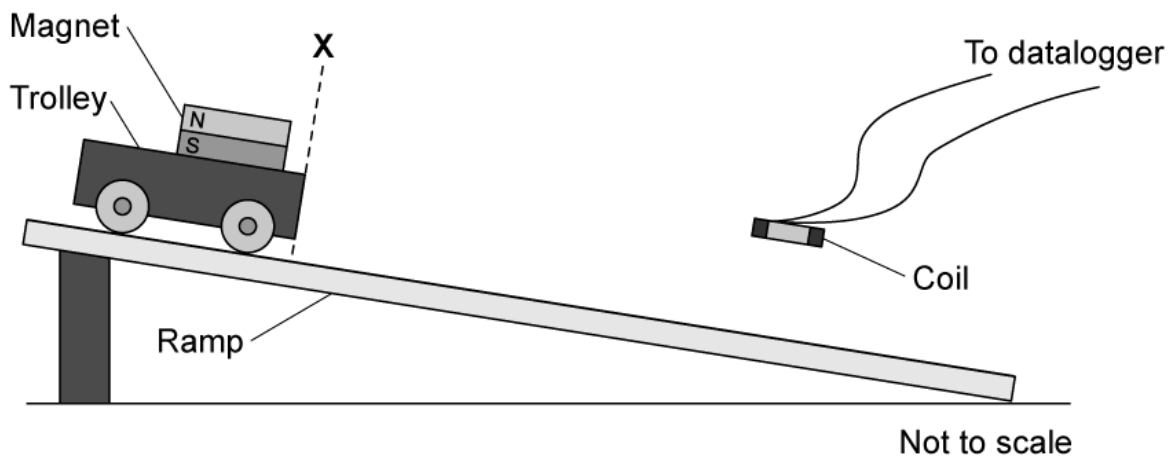
(3 marks)

- (d) Conducting wire is wrapped around a circular disk of diameter 10 cm to create a loop with 145 turns. The loop is held in a constant magnetic field with field strength 0.36 T.

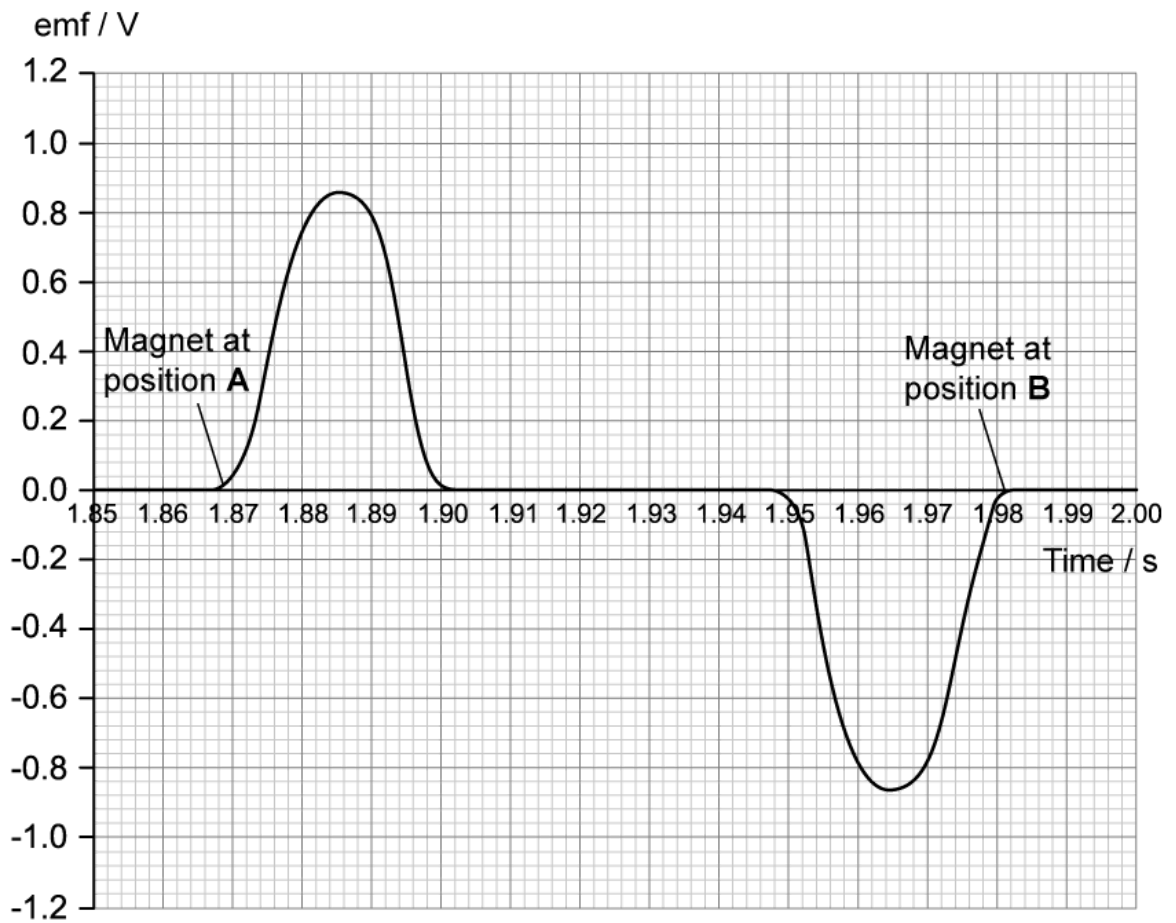
Determine the magnetic flux through the loop when the angle between the disk and the magnetic field is 10° .

(2 marks)

- 4 (a) A toy car with a magnet attached so that the North pole faces upwards is released from the top of a ramp. The car rolls down the ramp at constant speed. An emf is induced in a coil of wire as the toy and magnet pass underneath it.



The induced emf is recorded by a datalogger attached to the coil.



The graph shows the variation of induced emf.

- (i) Determine the maximum rate of change of flux linkage in the coil. [1]
- (ii) Explain the shape of the graph between points A and B. [3]

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(4 marks)

(b) The length of the magnet is 3.0 cm and the diameter of the coil is 1.5 cm.

Using the graph, determine the speed of the car between positions A and B.

(2 marks)

(c) The slope of the ramp is increased, making the car accelerate when released. It reaches point A at 1.86 s.

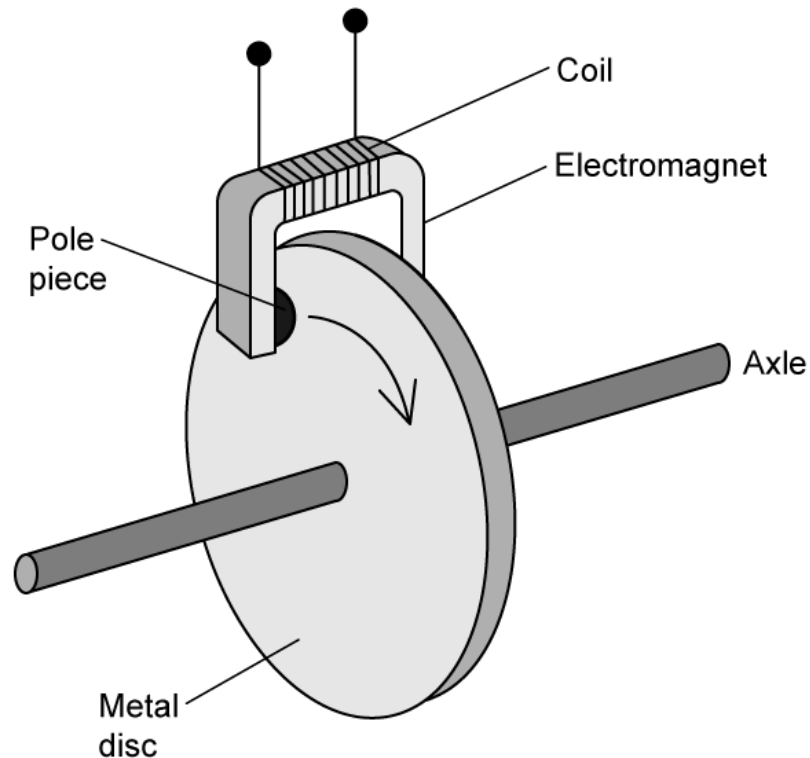
Apply Faraday's Law to explain how this would affect the induced emf at points A and B.

(2 marks)

(d) Sketch a graph to show the new induced emf as the magnet moves from point X to point B.

(4 marks)

- 5 (a) An electromagnetic braking system uses a metal disk, attached to the wheel of the vehicle so that they rotate together. An electromagnet is placed such that the poles are on either side of the rotating disk, but do not touch it.



When the driver applies the brakes a direct current passes through the coil of the electromagnet.

Explain with reference to appropriate laws of electromagnetic induction how this design can produce a braking effect.

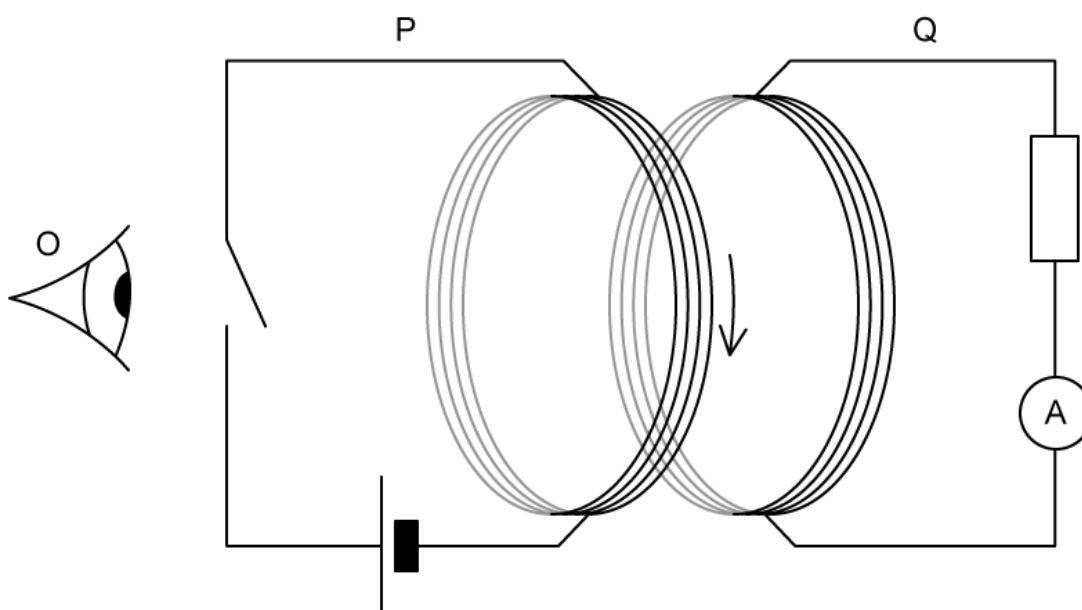
(3 marks)

- (b) Conventional braking systems use friction pads which are brought into contact with a rotating disk to slow down vehicles.

Distinguish between the electromagnetic and conventional braking systems, identifying at least two advantages and two disadvantage of the electromagnetic system.

(4 marks)

- (c) Induced current can be used in switching devices. A current in point P is made to flow in a clockwise direction when viewed from position O.



Outline how Lenz's law applies to the direction of the flow of induced current when the switch is opened and then closed.

(3 marks)

(d) The coil at P has 50 turns and an area of 15.8 cm^2 . It produces a constant magnetic field of 0.26 T . The two coils are identical.

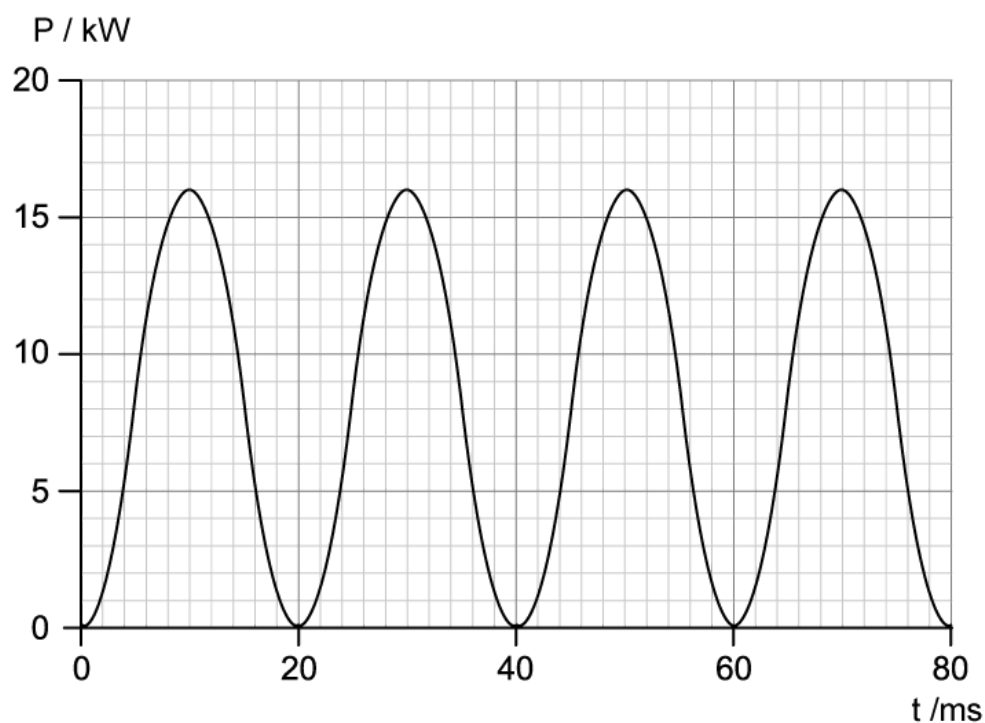
For coil Q

(i) Determine the magnetic flux when Q is positioned at 45° to the field produced by P. [1]

(ii) Calculate and explain the induced emf when the magnetic field is changing at a rate of 4.0 T s^{-1} . [2]

(3 marks)

6 (a) The graph shows the variation with time of the power delivered by an ac generator.



Determine the frequency of rotation of the generator.

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(2 marks)

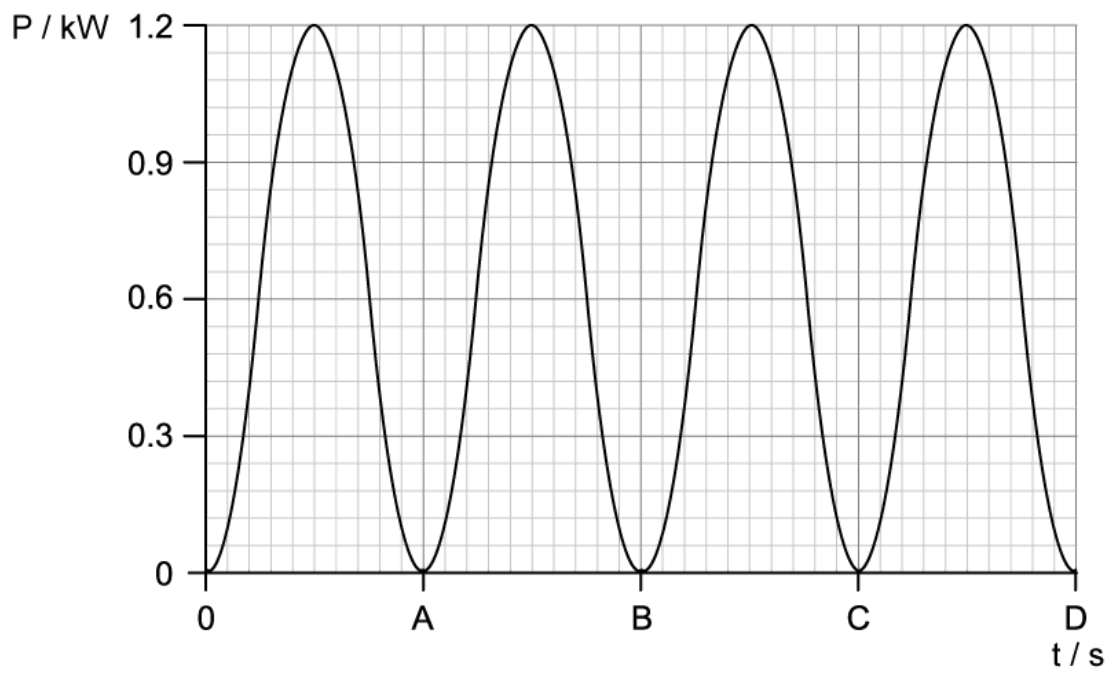
(b) Sketch a graph to show the power delivered when the frequency is halved.

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(2 marks)

7 A coil rotates in a magnetic field with a frequency of 50 Hz.



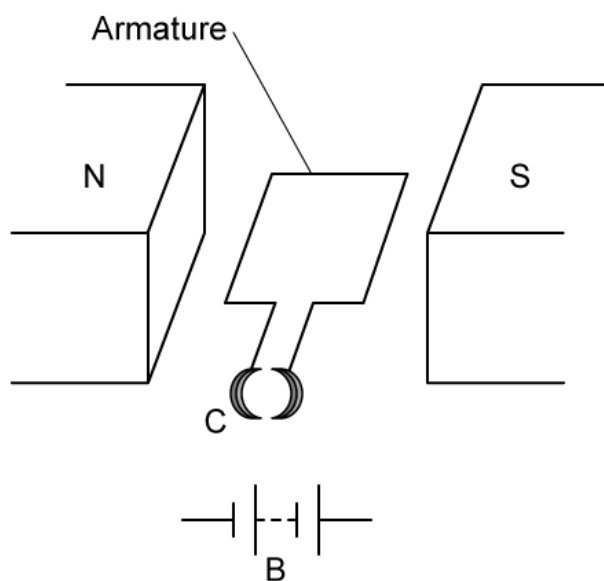
Determine the times on the graph at points A, B, C and D.

(2 marks)

Hard Questions

- 1 (a) The diagram below is a representation of a simple dc electric motor. The armature consists of a single rectangular coil and rotates between the poles of a permanent magnet.

The connections between the coil and battery B are not shown. The split ring is labelled C.



For this circuit

- (i) Complete the circuit by drawing the missing components onto the diagram. [1]
- (ii) State the direction of the motion of the coil. [1]
- (iii) Describe how the connections from battery B to the split ring enable the coil to rotate continuously in one direction. [3]

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(5 marks)

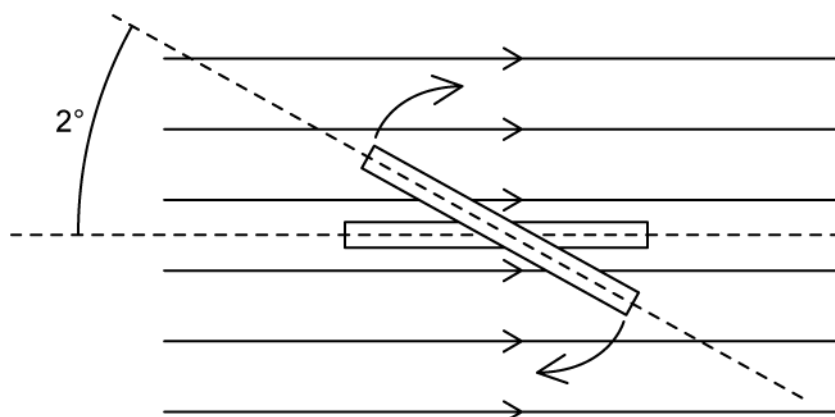
- (b) An A.C. generator consists of a coil between two magnets. The coil starts in the vertical position and rotates.

State and explain the shape of the graph of e.m.f. generated by this configuration over time.

(3 marks)

- (c) A different coil of length 4050 mm and 3700 mm width is now used in the same generator in a magnetic flux density of 0.98 T. The coil has 62 turns and rotates at the same frequency as the previous coil, 25 Hz.

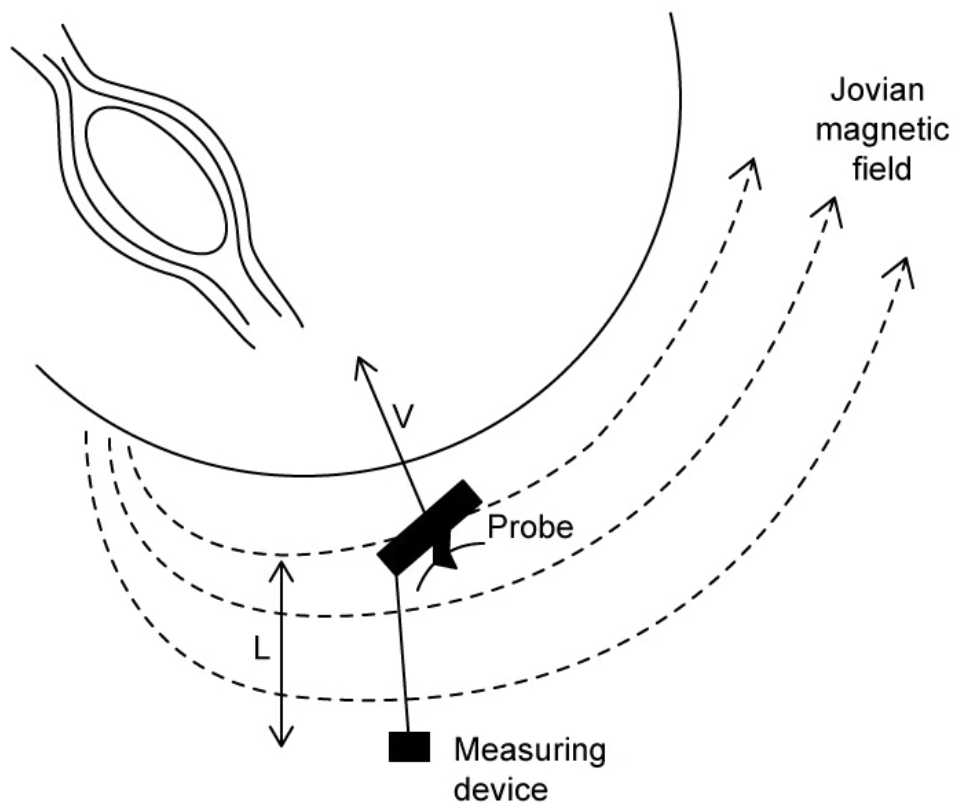
Calculate the magnitude of the e.m.f. generated by the coil when it moves through an angle of 2.0° from an initially horizontal position.



(3 marks)

- 2 (a)** An unmanned probe is in orbit around Jupiter at right angles to the planet's magnetic field. The probe launches a remote measuring device which remains connected to it by a conducting cable.

When the probe and the device are at a distance L the cable is held in a straight line which is also perpendicular to Jupiter's magnetic field.



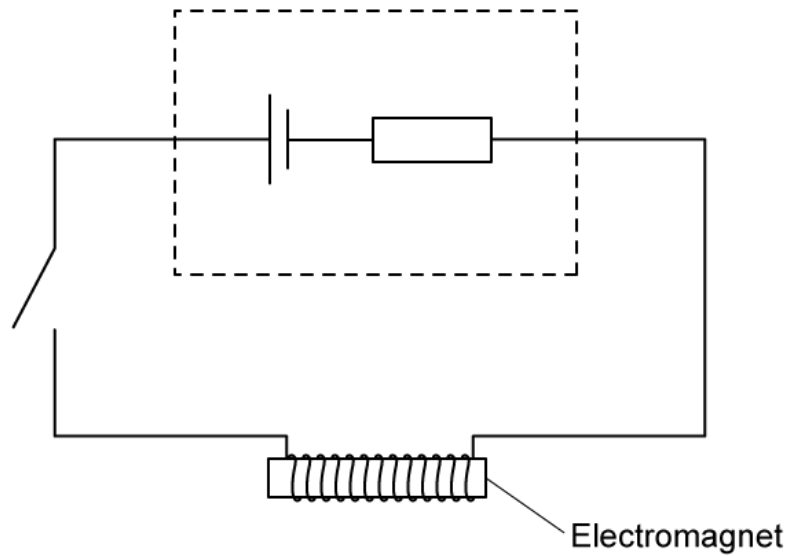
For the motion of the cable in the magnetic field

- (i) Sketch a labelled diagram to show the cable, field lines and direction of the force on the electrons within the cable. [2]
- (ii) The magnetic field vector B is at an angle θ to the field lines. Deduce an expression for the motional e.m.f. which is induced in the conducting wire. [3]

(5 marks)

(b) This question is about the motional e.m.f. which can be induced in different situations.

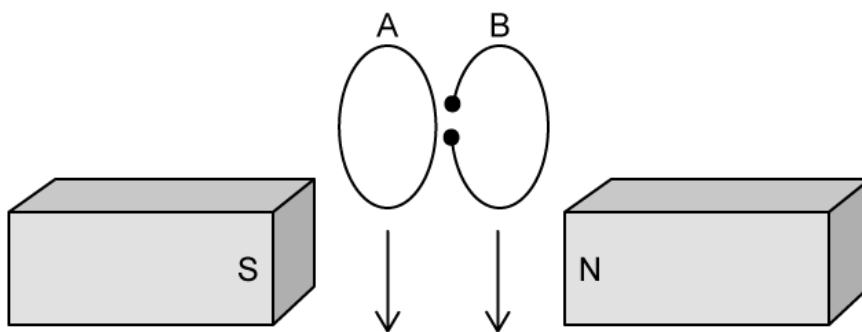
A circuit is set up as shown and then the switch is closed so that current can flow. Observations are made for the first 100 ms.



Explain the effects on the electromagnet of the switch being closed. The analysis should make reference to the expected changes in current, e.m.f. and energy.

(6 marks)

- 3 (a) In an experiment two metal rings A and B are dropped from the same height between two magnets. The rings are identical, apart from a small slit cut in B.



Describe and explain the motion of A and B as they fall between the magnets. The use of sketches to illustrate is encouraged.

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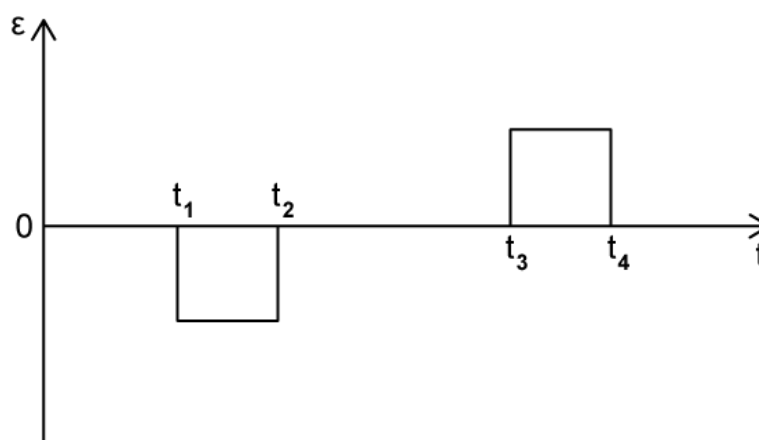
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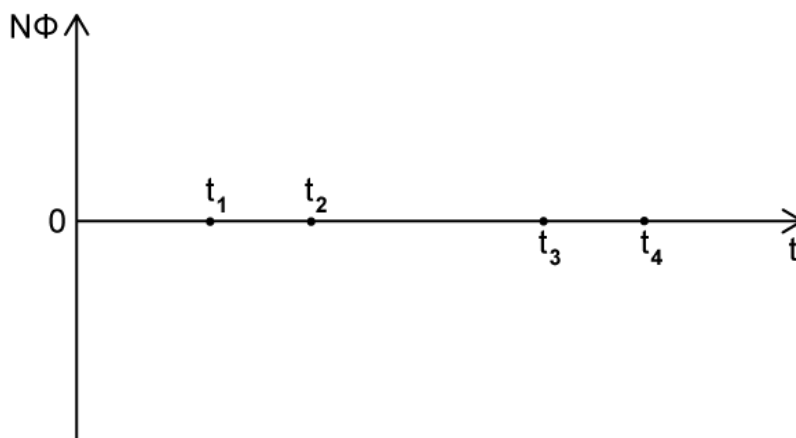
(5 marks)

- (b) In a thought experiment the variation of induced e.m.f. ϵ in a coil with time is considered.



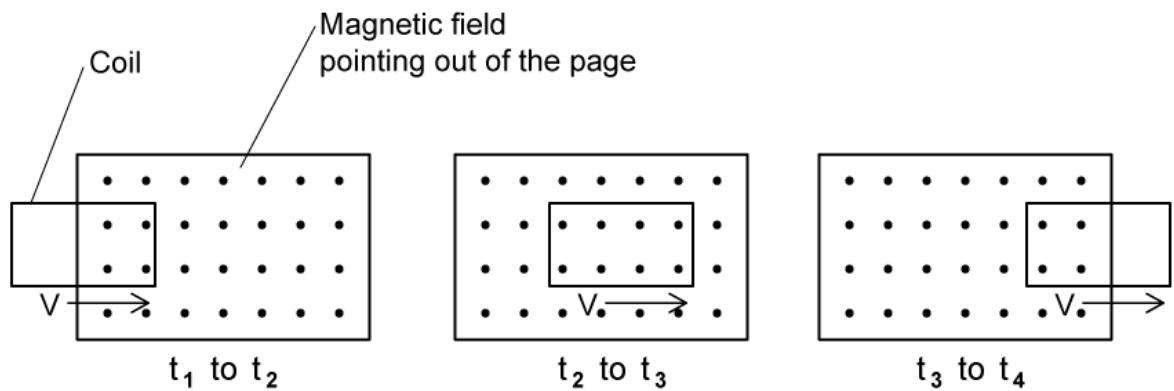
Students are asked to discuss the properties of the graph shown above to determine how it might be reproduced.

Use the axes provided to sketch a graph of the magnetic flux linkage $N\Phi$ through the conductor between $t = 0$ to $t = t_4$.



(5 marks)

- (c) The graph in part (b) was produced using a coil moving at constant speed into and then out of a uniform magnetic field. The motion is represented in the diagram.



By analysing the stages of the motion explain why no induced e.m.f. is seen for the section t_2 to t_3 although the coil can be described as 'cutting magnetic field lines' at that time.

(2 marks)

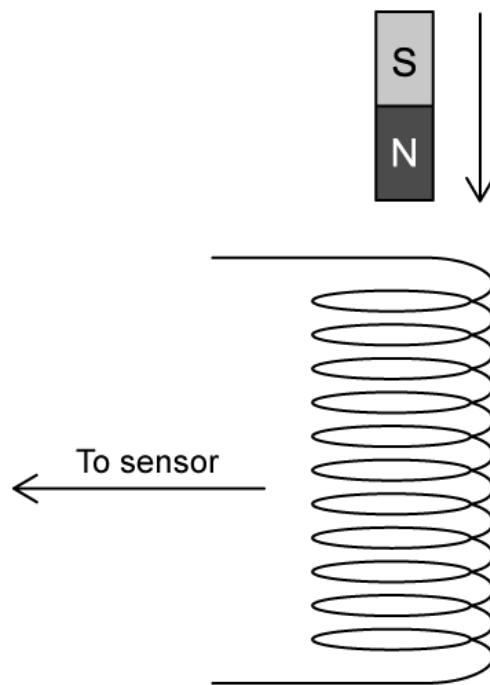
- (d) An experiment is designed to model an aeroplane flying parallel to the Earth's surface at a constant speed v .

The wingspan of the plane is modelled by a thin metallic rod of length $L = 75.0$ cm which is connected to a voltmeter. The Earth's magnetic field is at 70° to the vertical and has a flux density of 1.8×10^{-4} T.

Determine the speed at which the metal rod would need to be propelled to generate an emf of 0.15 mV across the ends.

(2 marks)

4 (a) A magnet is dropped through a vertical solenoid.



On the axes provided sketch a graph of the expected e.m.f. as time progresses.



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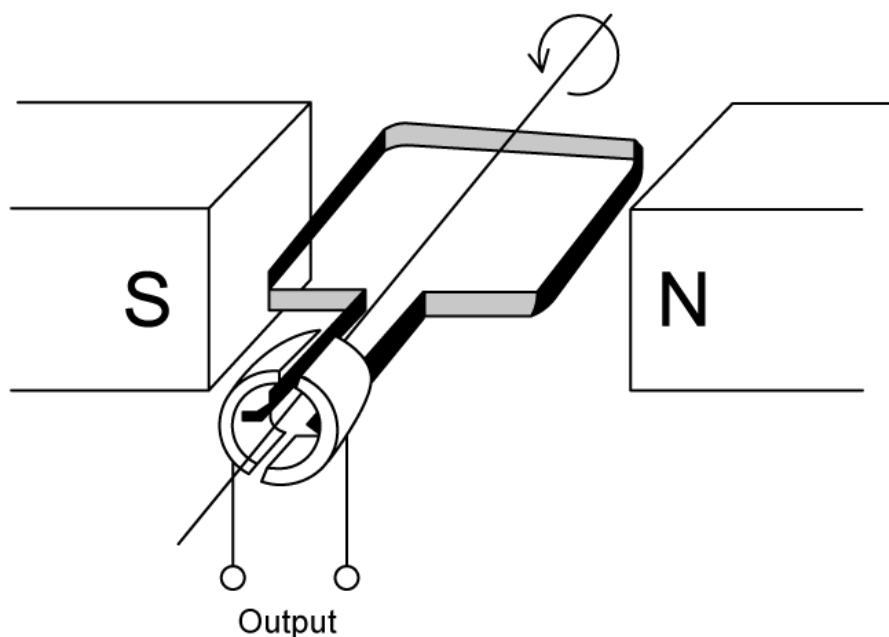
(3 marks)

(b) Explain the shape of the graph from part (a).

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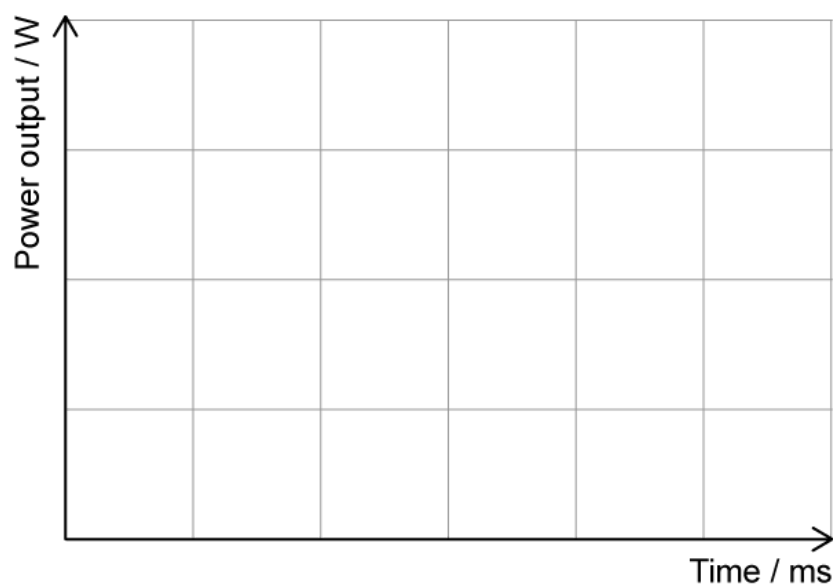
(3 marks)

- 5 (a) A generator in a hydroelectric plant features a coil rotating in a magnetic field with a constant angular velocity.



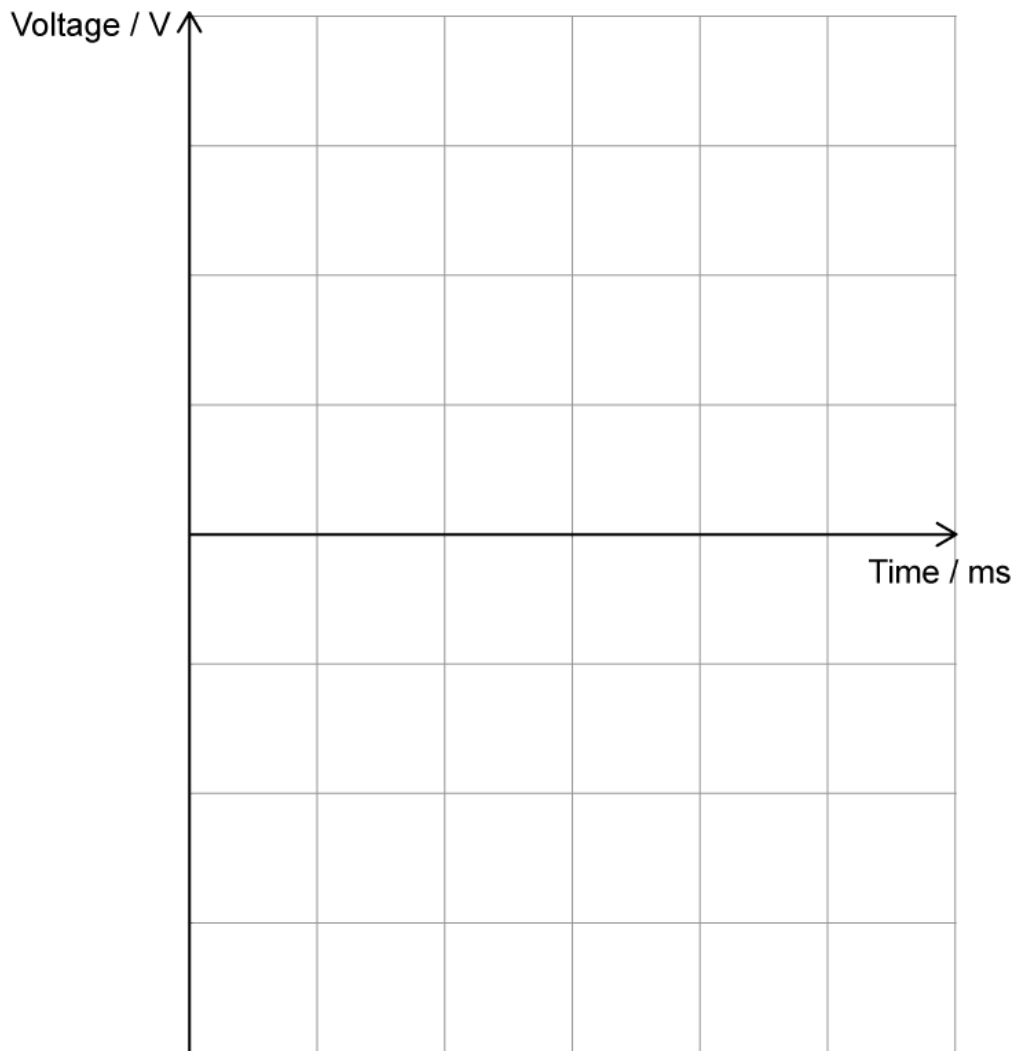
The power output varies over time for a generator rotating with a maximum power output of P_0 and a frequency of 20 Hz.

- (i) Sketch the variation of power output with time for a single complete revolution of the coil. Indicate any key values on your axes.



[2]

- (ii) Sketch the variation of voltage with time for a single complete revolution of the coil. Indicate any key values on your axes.



[2]

(4 marks)

(b) Using Faraday's Law, show that the new power output is $16P_0$ if the frequency of the rotation of the coil increases to 80 Hz.

You may use the following equation

(4 marks)

- (c) A graph showing the variation in power over time for a different hydroelectric generator is shown below.

In this generator, when the rate of flow of water from the dam doubles, the frequency of revolution of the coil also doubles.

On the diagram above, sketch a curve showing the new variation in power over time when the flow rate halves.

(2 marks)