| Name | Date started | Target end date |
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## GCE A LEVEL — ELECTROMAGNETIC INDUCTION QUESTION PACK

1325-01 (Legacy PH5)

REVISE
.wales

# PHYSICS — UNIT 4 TOPIC 5

## *Electromagnetic induction — flux, Faraday, Lenz, transformers & generators*

***Every EM-induction question from the legacy WJEC PH5 papers (June 2010 – June 2016)***

LEGACY 2008 SPECIFICATION · MAPS TO NEW UNIT 4 TOPIC 5

**Estimated time for entire question pack: ~1 hour 40 minutes**

*Derived from the legacy PH5 pace of* ***~1.3 min/mark*** *(80 marks in 1¾ hours).*

*You are advised to* ***not*** *attempt to complete all of this in one sitting.*

*For Examiner's use only*

| Q | Source | Max | Mark |
| --- | --- | --- | --- |
| 1 | Jun 10 Q5 | 10 | |
| 2 | Jun 12 Q6 | 10 | |
| 3 | Jun 13 Q5 | 11 | |
| 4 | Jun 14 Q6 | 10 | |
| 5 | Jun 15 Q2 | 12 | |
| 6 | Jun 11 Q3 | 10 | |
| 7 | Jun 16 Q4 | 11 | |
| **Total** | | **74** | |

## ABOUT THIS QUESTION PACK

This is a **comprehensive practice question pack**, not a single mock paper. It contains every electromagnetic-induction question (flux, flux linkage, Faraday's law, Lenz's law, generators) from the legacy WJEC PH5 papers between June 2010 and June 2016.

Questions are grouped by sub-topic, then ordered roughly by difficulty.

## INSTRUCTIONS

Use black ink or black ball-point pen. Answer all questions in the spaces provided.

*A calculator is required. The Data Booklet is allowed.*

# Unit 4 Topic 5 — Electromagnetic induction

WJEC GCE A Level Physics (from 2015) · Unit 4 Assessment Unit *Fields & Options*. The induction strand — flux, Faraday's law, Lenz's law and applications — maps directly onto the legacy PH5 specification (Section A "Capacitance and electromagnetic induction").

### Magnetic flux (A)

- $\Phi = BA\cos\theta$ for a flat area $A$ in a uniform field $B$, where $\theta$ is the angle between $B$ and the normal.
- Unit: weber (Wb), where 1 Wb = 1 T m$^2$.
- For $\theta = 0$ (B parallel to normal): $\Phi = BA$ (max). For $\theta = 90°$: $\Phi = 0$.

### Flux linkage (A)

- For a coil of $N$ turns: $N\Phi = NBA\cos\theta$.
- Also has units of Wb (or Wb-turns).
- This — not $\Phi$ — is what appears in Faraday's law for a multi-turn coil.

### Faraday's law (A)

- Induced EMF equals the negative rate of change of flux linkage: $\varepsilon = -N\frac{d\Phi}{dt}$.
- Magnitude: $|\varepsilon| = N\frac{d\Phi}{dt}$.
- For a rod moving at speed $v$ through B perpendicular to length $L$: $\varepsilon = BLv$.

### Lenz's law (C)

- The induced current flows in the direction that **opposes** the change of flux causing it.
- Provides the minus sign in Faraday's law — energy conservation.
- Used to determine the *direction* of induced currents and forces.

### AC generators (B)

- Coil rotating with angular speed $\omega$ in a uniform B-field.
- Flux linkage: $N\Phi = NBA\cos(\omega t)$.
- Induced EMF: $\varepsilon = NBA\omega\sin(\omega t)$, peak $\varepsilon_0 = NBA\omega$.

### Transformers & eddy currents (C)

- Turns ratio (ideal transformer): $\frac{V_s}{V_p} = \frac{N_s}{N_p}$.
- AC flux in primary → induces EMF in secondary via shared iron core.
- Eddy currents in the core cause heating; laminated cores reduce losses. Same mechanism produces magnetic braking.

## Section index for this question pack

# Electromagnetic induction in one page

Quick-reference notes — revisit before each section.

## Magnetic flux $\Phi$

Flux through a flat area $A$ in field $B$:

$$\Phi = BA\cos\theta$$

- $\theta$ = angle between $B$ and the area's *normal*.
- $B \parallel$ normal (coil face-on to field): $\Phi = BA$ (max).
- $B \perp$ normal (coil edge-on): $\Phi = 0$.
- Unit: weber (Wb) $=$ T m$^2$.

## Flux linkage $N\Phi$

For a coil of $N$ turns:

$$N\Phi = NBA\cos\theta$$

- Each turn experiences the same $\Phi$, so total flux linked is $N$ times.
- This is what appears in Faraday's law for a coil.
- Sometimes quoted in Wb-turns.

## Faraday's law

Induced EMF is the rate of change of flux linkage:

$$\varepsilon = -N\frac{d\Phi}{dt}$$

- Magnitude: $|\varepsilon| = N\frac{d\Phi}{dt}$.
- Flux can change because $B$, $A$, or $\theta$ changes.
- Larger $N$, larger $dB/dt$, larger $\frac{dA}{dt}$ → larger EMF.

## Lenz's law

The direction of the induced current is such that its effect opposes the change producing it.

- It is a statement of energy conservation.
- Gives the minus sign in Faraday's law.
- If flux is *increasing*, induced current makes B field that *opposes* the increase (and vice versa).

## Motional EMF: $\varepsilon = BLv$

A rod of length $L$ moving with speed $v$ perpendicular to $B$ has flux changing at $BLv$:

$$\varepsilon = BLv$$

- Rod, $B$ and $v$ all mutually perpendicular for the formula to apply.
- If the rails "widen" (effective $L$ increases), $\varepsilon$ grows even at constant $v$.

## Rotating coil (generator)

Coil of $N$ turns, area $A$, rotating at angular speed $\omega$ in uniform $B$:

- Flux linkage: $N\Phi = NBA\cos(\omega t)$.
- EMF: $\varepsilon = NBA\omega\sin(\omega t)$.
- Peak EMF: $\varepsilon_0 = NBA\omega$.
- $\varepsilon_{\text{rms}} = \frac{\varepsilon_0}{\sqrt{2}}$.

## Transformers

An AC EMF in the primary drives a changing flux through both coils via the iron core:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

- $N_s > N_p$: step-up. $N_s < N_p$: step-down.
- Ideal transformer: power conserved, $V_pI_p = V_sI_s$.

## Eddy currents & braking

A changing flux through a bulk conductor induces circulating currents ("eddies").

- By Lenz, these oppose the change — producing a **retarding force**.
- Power dissipated in resistance → heating.
- Used in magnetic brakes; minimised in transformer cores via lamination.

## Magnet near a coil

A bar magnet moving towards/through a coil induces an EMF:

- EMF $\propto$ speed of magnet (rate of flux change).
- EMF reverses sign when magnet passes through (flux is increasing then decreasing).
- If the coil is closed, an induced current flows — producing a force that opposes motion (damping).

## Mean vs peak EMF

- For a coil swinging through a small angle near $\theta = 0$ (face-on to $B$): $\cos\theta \approx 1$, so $\Phi$ is nearly constant — **mean EMF** $\approx 0$.
- Maximum $d\Phi/dt$ (and hence peak EMF) occurs when the coil is *edge-on* to $B$ ($\theta = 90°$).

## Useful identities

- $\Phi = BA$ when normal $\parallel B$.
- $\varepsilon_{\text{mean}} = -N\frac{\Delta\Phi}{\Delta t}$ for finite changes.
- $I = \frac{\varepsilon}{R}$ for the induced current in a closed loop of resistance $R$.
- $R = \frac{\rho L}{A_{\text{wire}}}$ for a wire of resistivity $\rho$.

## Strategy — 4 steps

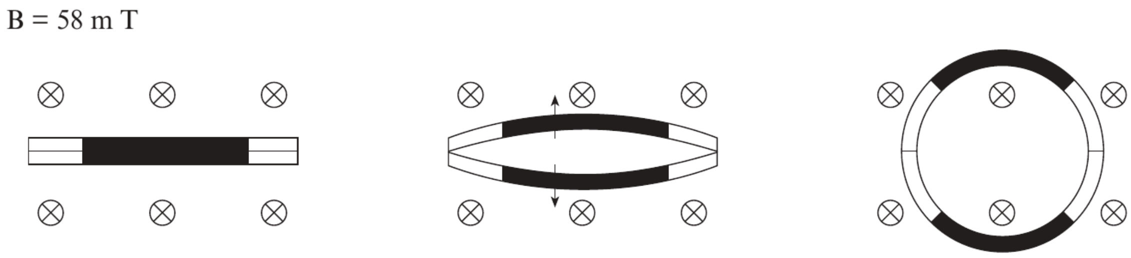
1. Identify what is changing: $B$, $A$, or $\theta$ (and whether it's a single loop or $N$ turns).
2. Compute $\Delta\Phi$ (or $\Phi(t)$) for the given geometry.
3. Apply $|\varepsilon| = N\frac{d\Phi}{dt}$ (mean or instantaneous).
4. Use Lenz's law for direction; current via $I = \varepsilon/R$.

# SECTION A

## *Faraday's law & induced EMF*

Questions 1 – 3 · 31 marks

**A5.** A magician's metallic wand can spring apart into the shape of a circular hoop (see below).




*(a)* The hoop is in a magnetic field. Explain why an emf is induced in the hoop as it expands. [3]

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*(b)* Explain why the current flows anticlockwise in the diagram. [2]

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*(c)* The hoop, of radius 31.0 cm, is in a region of uniform magnetic flux density (*B*) of 58 mT and expands from the wand shape to the hoop in a time of 63 ms. Calculate the average current flowing in the hoop as it expands if the resistance of the hoop is 0.44 Ω. [5]

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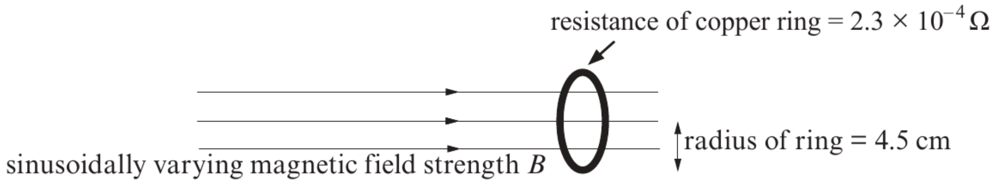
**6.** *(a)* State Faraday's law of electromagnetic induction. [2]

*(b)* A circular copper heating ring works by being placed in a sinusoidally varying magnetic field. A large sinusoidal current is then induced in the ring and the ring becomes hot (see below).




(i) The maximum rate at which the magnetic field strength changes is $72\ \text{T s}^{-1}$. Show that the maximum current flowing in the ring is approximately 2000 A. [4]

(ii) Calculate the rms value of the induced current. [2]

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(iii) Calculate the mean power dissipated in the heating ring. [2]

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Examiner only

**5.** *(a)* State the **two** laws of electromagnetic induction (Faraday's law and Lenz's law). [3]

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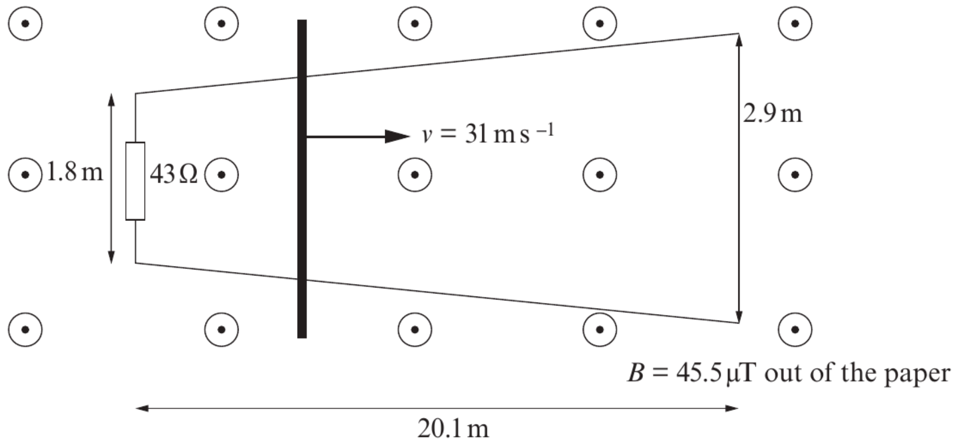
*(b)* A thick conducting bar is moved with constant speed over non-parallel conducting rails as shown below. The rails have negligible resistance and the $B$-field is uniform.




(i) Indicate the direction of the induced current on the diagram and explain how you arrived at your answer. [2]

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Examiner only

(ii) The conductor moves at a constant speed of $31\,\mathrm{m\,s^{-1}}$. Use Faraday's law to explain why the induced emf increases. [2]

(iii) The conductor starts moving from the end near the $43\,\Omega$ resistor. Calculate the mean current in the resistor when the conducting bar has travelled the full 20.1 m length of the track. [4]

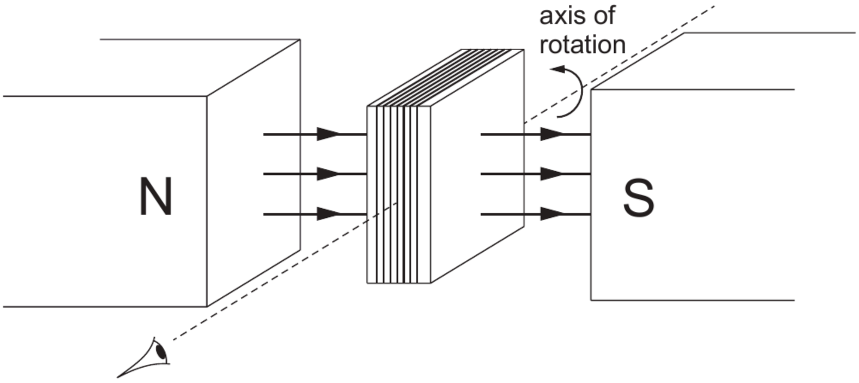
# SECTION B

## *AC generators & flux linkage*

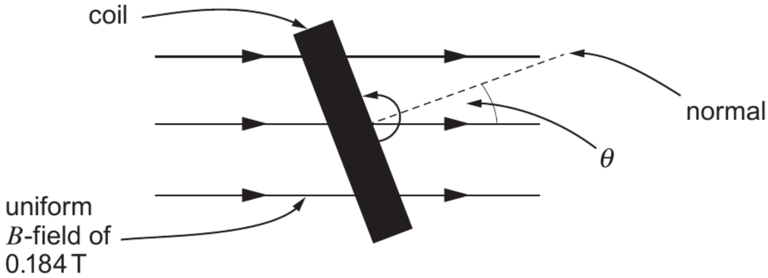
Questions 4 – 5 · 22 marks

Examiner only

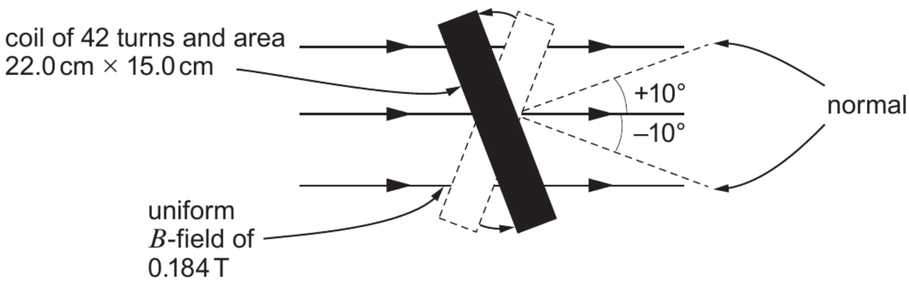
**6.** A rectangular coil rotates at a constant angular velocity within a uniform magnetic field. The coil has 42 turns and area 22.0 cm × 15.0 cm. The diagram below is a simplified 3D diagram of the coil when the magnetic field is perpendicular to the coil.




The second diagram is a 2D representation of the coil looking along the axis of rotation.




*(a)* (i) Calculate the flux **linkage** of the coil for the angles $\theta$ = –10° and $\theta$ = +10°. [2]

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Examiner only

(ii) Explain why the mean induced emf is zero as the coil moves between $\theta = -10°$ and $\theta = +10°$. [1]

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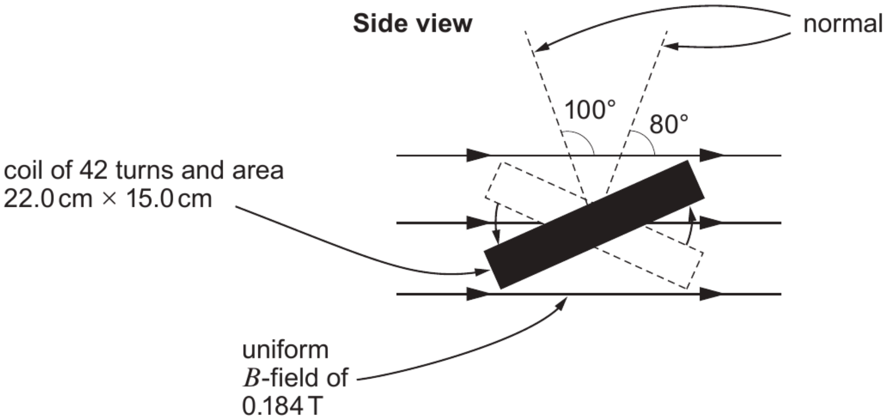
*(b)* Calculate the mean induced emf in the coil when the angle $\theta$ changes from 80° to 100° if the period of rotation of the coil is 0.100 s. [4]

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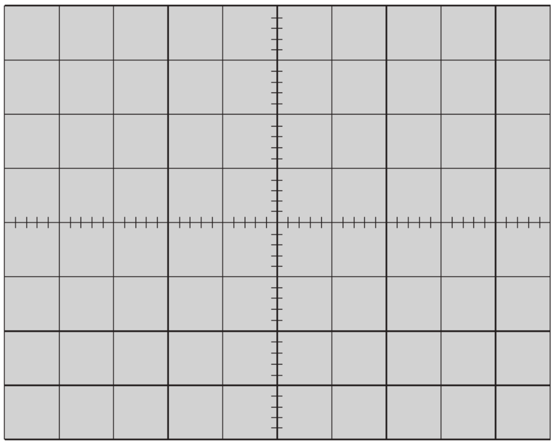
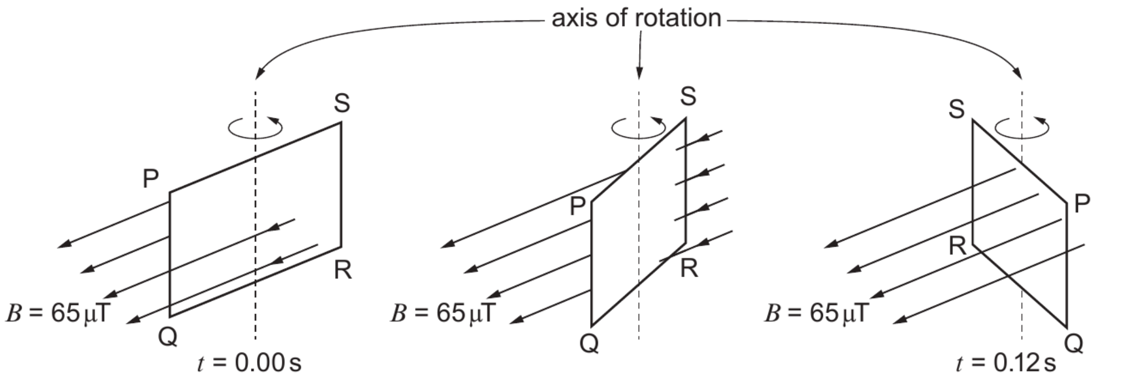
Examiner only

*(c)* An oscilloscope is used to display the sinusoidal emf in a different coil rotating at a frequency of 12.5 Hz and producing an **rms** pd of 12.0 V. The oscilloscope settings are 5 V per division (vertically) and 20 ms per division (horizontally). Sketch a trace that might be seen on the oscilloscope. (Space is provided for your workings.) [3]



**2.** A large square loop has sides of length 0.815 m and is rotated through 90° in a uniform magnetic field of 65 μT. The diagrams show the same square loop at different times.




*(a)* Determine the magnetic flux through the square loop: [3]

(i) when $t$ = 0.00 s (sides QR and SP are parallel to the $B$-field);

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(ii) and when $t$ = 0.12 s (PQ, QR, RS and SP are perpendicular to the $B$-field).

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*(b)* The square loop is made of copper. Explain why there is a current in the loop as it is rotated. [2]

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Examiner only

(c) Explain how Lenz's law will give the direction of the forces acting on the sides PQ and RS as the square loop is rotated. [2]

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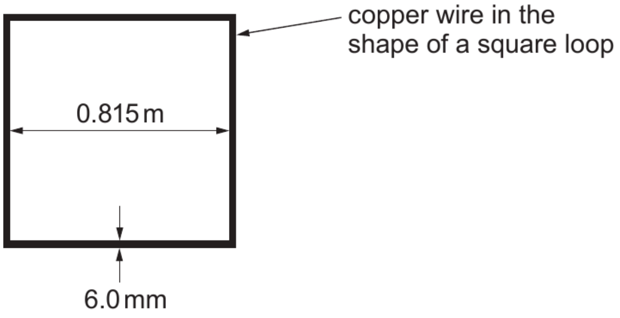
(d) The copper wire from which the square loop is made has a circular cross-section of diameter 6.0 mm. The resistivity of copper is $1.67 \times 10^{-8}\,\Omega\,m$. Calculate the **mean** current flowing through the square loop as it is rotated between $t = 0.00\,s$ and $t = 0.12\,s$. [5]

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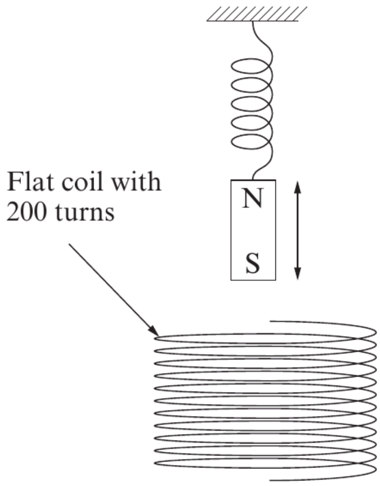
# SECTION C

## *Lenz's law & magnetic damping*

Questions 6 – 7 · 21 marks

**3**. A strong magnet is held on a spring and performs simple harmonic motion near a flat coil as shown.




*(a)* Explain briefly why an alternating emf is induced in the coil. [3]

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*(b)* (i) The induced emf varies in magnitude sinusoidally with a peak value of ±0.707 V. Calculate the rms value of the induced emf. [1]

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(ii) State the value of the rate of change of flux through each turn of the coil when the peak value of 0.707 V is obtained and explain how you obtained your answer. [3]

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Examiner only

*(c)* One end of the coil is connected with the other so that there is an induced current. Explain why the magnet's motion is now damped. [3]

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Examiner only

**4.** *(a)* State the laws of electromagnetic induction (Faraday's law and Lenz's law). [2]

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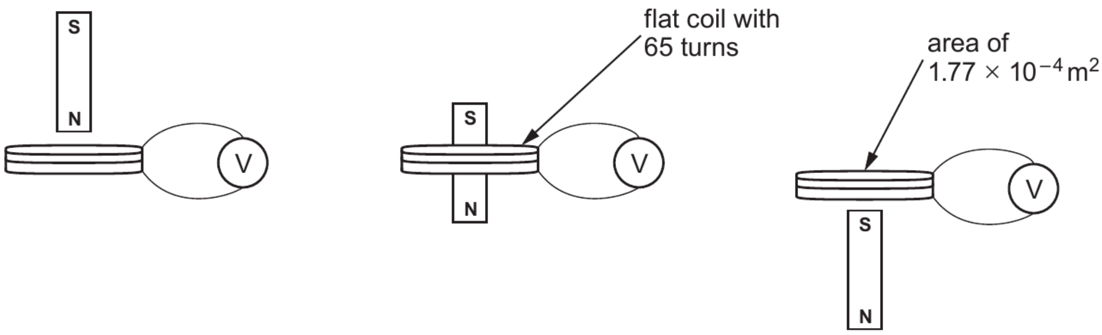
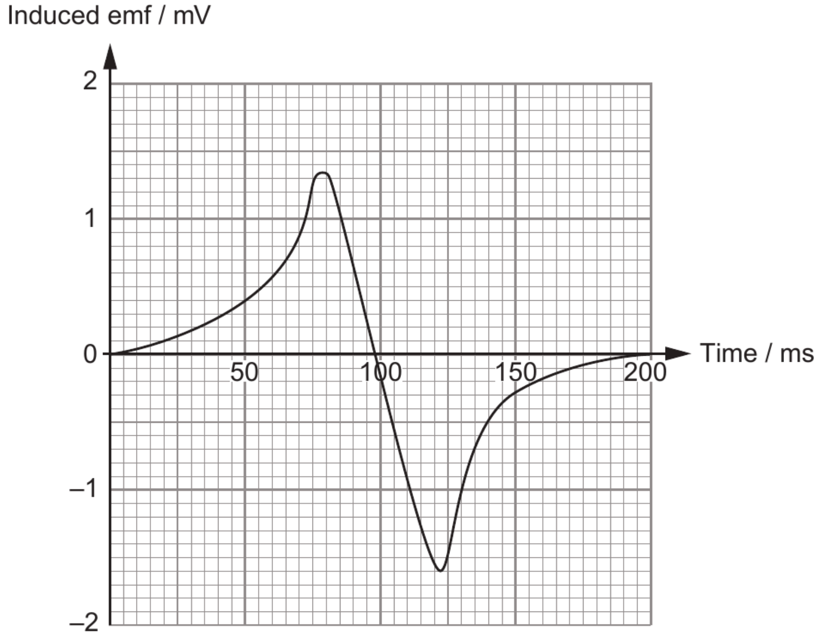
*(b)* A strong magnet drops vertically through a flat coil.




The emf induced in the coil is recorded using a voltmeter.



Examiner only

(i) Use the laws of Faraday and Lenz to explain why the measured emf varies as shown in the graph opposite. [3]

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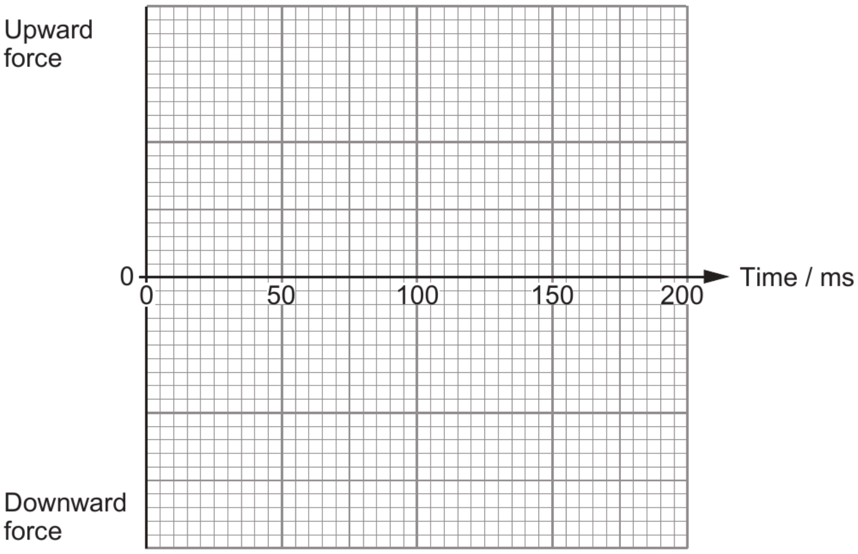
(ii) The voltmeter is now removed and the ends of the flat coil connected so that current can flow. Sketch a graph showing the variation of force exerted by the coil on the magnet against time (no calculations are required). [3]




(iii) Use the data in the diagrams of the dropping magnet on the opposite page to calculate the length of wire used to make the coil. [3]

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## END OF QUESTION PACK

*7 questions · 74 marks · ~1 h 40 min*

Mark schemes available from WJEC and Physics & Maths Tutor.