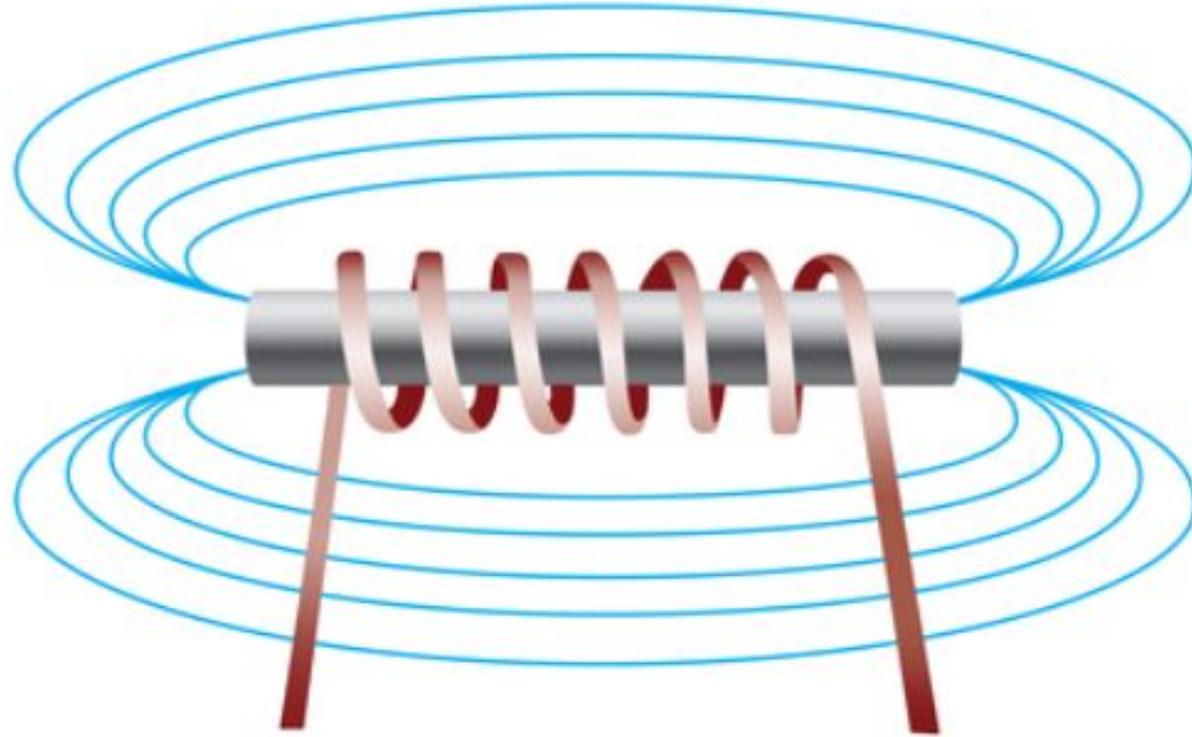


# Magnetic Fields and Electromagnetism



# Material Covered

## Magnetic Fields

1. Magnetic Field Patterns.
2. Force on a Wire.
3. Moving Charges in Magnetic Fields.

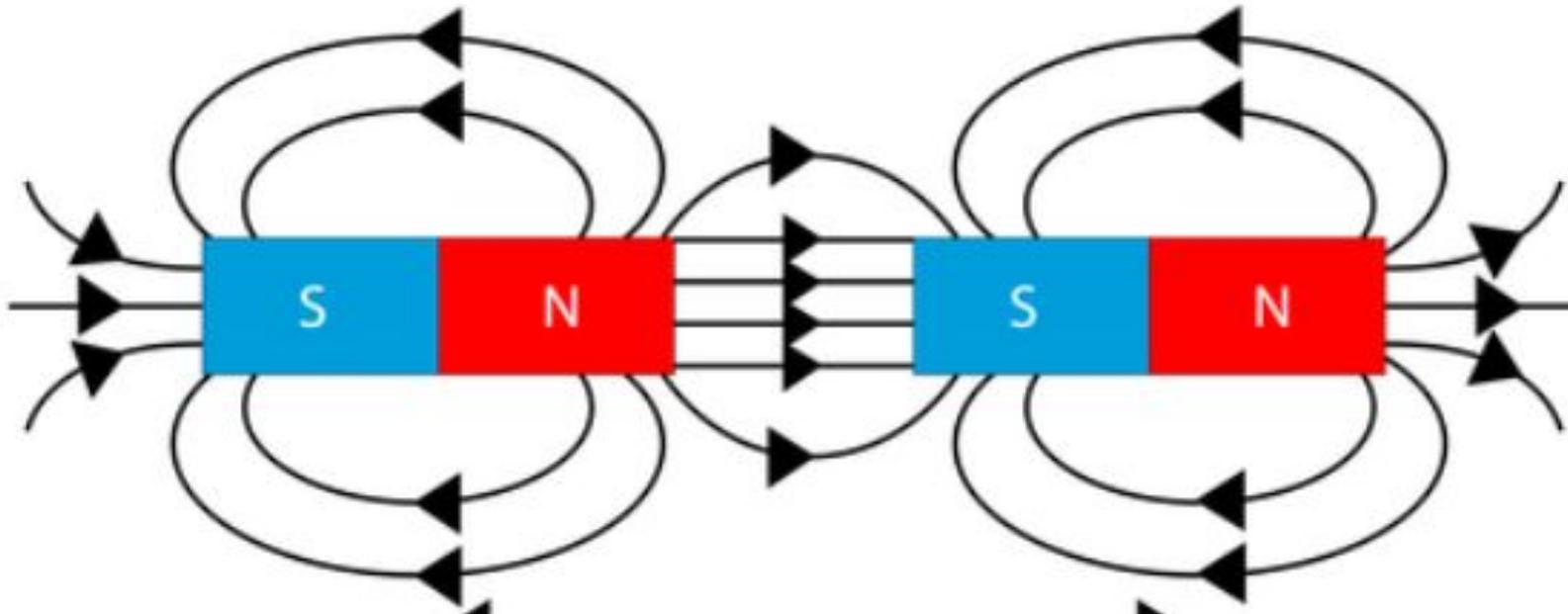
## Electromagnetic Induction

1. Magnetic Flux Linkage.
2. Lenz's Law and Faraday's Law.

## Generating Electricity

1. A.C Generator.
2. Transformers.

# Magnetic Fields



# Specification Points - AQA

## 3.7.5.1 Magnetic flux density (A-level only)

Content	Opportunities for skills development
<p>Force on a current-carrying wire in a magnetic field: <math>F = BIl</math> when field is perpendicular to current.</p> <p>Fleming's left hand rule.</p> <p>Magnetic flux density <math>B</math> and definition of the tesla.</p>	
<p><b>Required practical 10:</b> Investigate how the force on a wire varies with flux density, current and length of wire using a top pan balance.</p>	

## 3.7.5.2 Moving charges in a magnetic field (A-level only)

Content	Opportunities for skills development
<p>Force on charged particles moving in a magnetic field, <math>F = BQv</math> when the field is perpendicular to velocity.</p> <p>Direction of force on positive and negative charged particles.</p> <p>Circular path of particles; application in devices such as the cyclotron.</p>	<p><b>MS 4.3</b></p> <p>Convert between 2D representations and 3D situations.</p>

# Specification Points – OCR A

## 6.3.1 Magnetic fields

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### Learning outcomes

---

*Learners should be able to demonstrate and apply their knowledge and understanding of:*

- (a) magnetic fields are due to moving charges or permanent magnets
- (b) magnetic field lines to map magnetic fields
- (c) magnetic field patterns for a long straight current-carrying conductor, a flat coil and a long solenoid
- (d) Fleming's left-hand rule
- (e)
  - (i) force on a current-carrying conductor;  
 $F = BIL \sin \theta$
  - (ii) techniques and procedures used to determine the uniform magnetic flux density between the poles of a magnet using a current-carrying wire and digital balance
- (f) magnetic flux density; the unit tesla.

## 6.3.2 Motion of charged particles

---

### Learning outcomes

---

*Learners should be able to demonstrate and apply their knowledge and understanding of:*

- (a) force on a charged particle travelling at right angles to a uniform magnetic field;  $F = BQv$
- (b) charged particles moving in a uniform magnetic field; circular orbits of charged particles in a uniform magnetic field
- (c) charged particles moving in a region occupied by both electric and magnetic fields; velocity selector.

# Specification Points – OCR B

## 6.1.1 Electromagnetism

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### Learning outcomes

---

- (a) *Describe and explain:*
- (iii) electromagnetic forces; qualitatively as arising from tendency of flux lines to contract or interaction of induced poles; quantitative calculation limited to force on a straight current-carrying wire in a uniform field
- (b) *Make appropriate use of:*
- (i) the terms: **B**-field, magnetic field, flux, flux linkage, induced e.m.f, eddy currents
  - (iii) diagrams of lines of flux in magnetic circuits; continuity of lines of flux.
- (c) *Make calculations and estimates involving:*
- (ii)  $F = ILB$
- (d) *Demonstrate and apply knowledge and understanding of the following practical activities (HSW4):*
- (ii) determining the uniform magnetic flux density between the poles of a magnet using a rigid current carrier and digital balance.

# Specification Points - Edexcel

121. understand and use the terms *magnetic flux density*  $B$ , *flux*  $\phi$  and *flux linkage*  $N\phi$

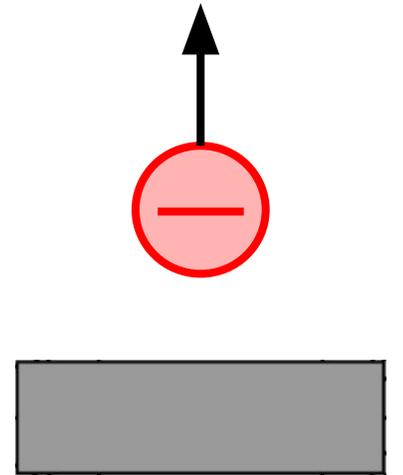
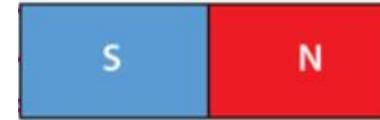
122. be able to use the equation  $F = Bqv \sin\theta$  and apply Fleming's left-hand rule to charged particles moving in a magnetic field

123. be able to use the equation  $F = BIl \sin\theta$  and apply Fleming's left-hand rule to current carrying conductors in a magnetic field

# Magnetic Field Patterns

A magnetic field is a **force field** which **exerts** an **electromagnetic force** on magnetic materials (like iron) or moving charges (like electrons).

- **Magnetic fields** are produced by permanent magnets or moving charges.



The **strength** of a magnetic field is measured by the **magnetic flux density  $B$**  which has **units** of **Teslas (T)**.

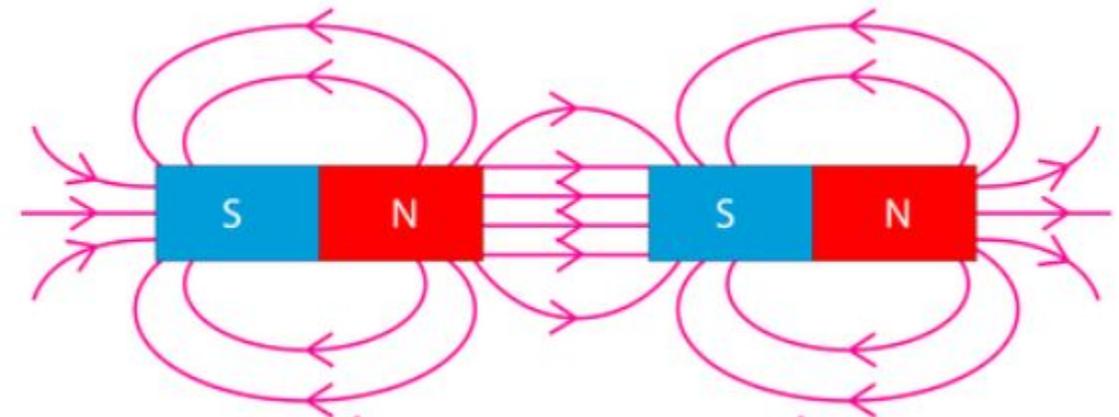
The **magnetic flux density** is defined as the **force per unit length per unit current** on a **current-carrying conductor** at **right angles** to the **magnetic field**.

# Magnetic Field Patterns

**Magnetic fields are represented by magnetic field lines (also called magnetic flux lines).**

- The **denser** the field lines, the **stronger** the magnetic flux density  $B$ .
- The field lines point in the **direction** of the magnetic force on a north pole of a magnet.
- **Magnetic field lines** must always be **closed** and never **cross**.

Equally spaced magnetic field lines indicate a **uniform field**.



## Exemplar Plot/Sketch Exam Question

**Context: Interacting magnetic fields**

**Key information.** How does this translate to **field lines**?

- 1) Consider the three magnets  $X$ ,  $Y$  and  $Z$  arranged as shown in the diagram. All magnets have equal magnetic flux density. Draw the magnetic field lines from each magnet on the diagram.

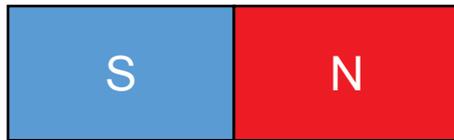
**[3 marks]**

**Identify key components** of field lines and **draw diagram**

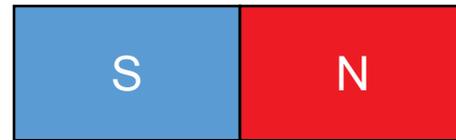
**3 key components** that need to be **shown on our drawing**



## Exemplar Plot/Sketch Exam Question



*X*



*Y*



*Z*

## Exemplar Plot/Sketch Question Answer

### Determine key aspects of sketch

All magnets have same flux density, so should have equal number of force lines.

**[1 Mark]**

Force lines move from a north pole to a south pole and are closed

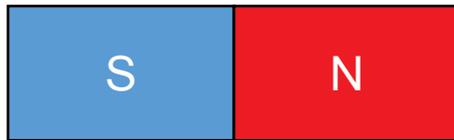
**[1 Mark]**

X and Y attract, so there will be a uniform field between them

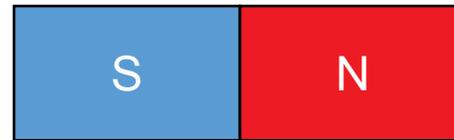
Y and Z repel, so force lines will diverge away from each other

**[1 Mark]**

## Exemplar Plot/Sketch Question Answer



*X*



*Y*

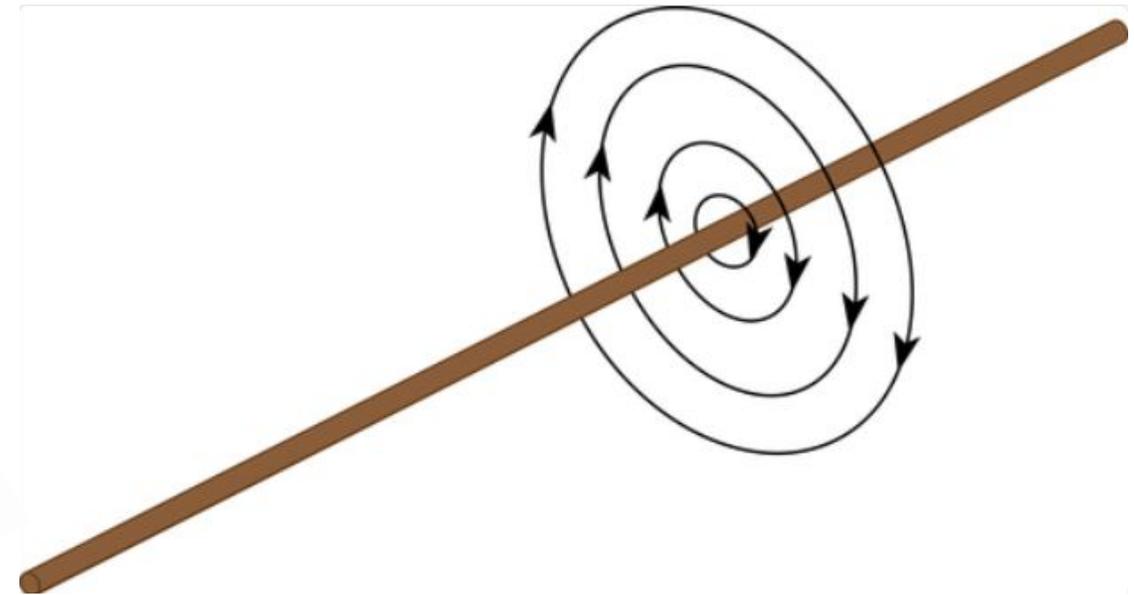


*Z*

# Magnetic Force on a Wire

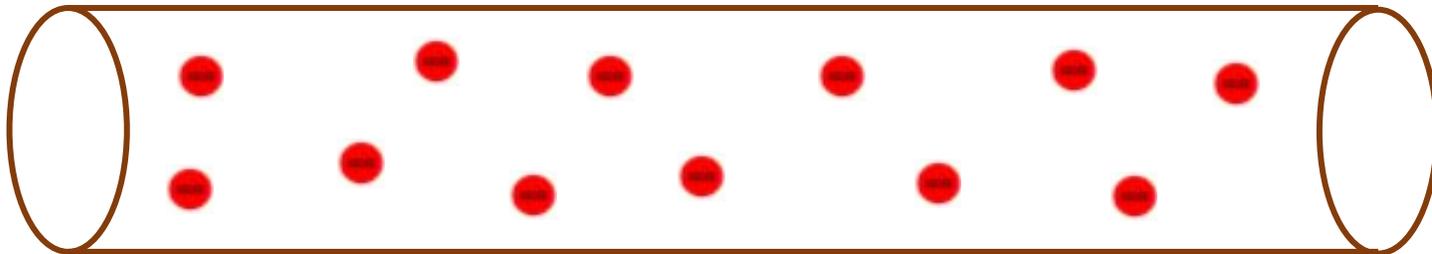
The magnetic field pattern of a current-carrying wire is produced by the moving electrons in the wire.

- The magnetic field lines form a circle in a plane perpendicular to the length of the wire.
- The direction of the field lines is dictated by the right-hand grip rule.



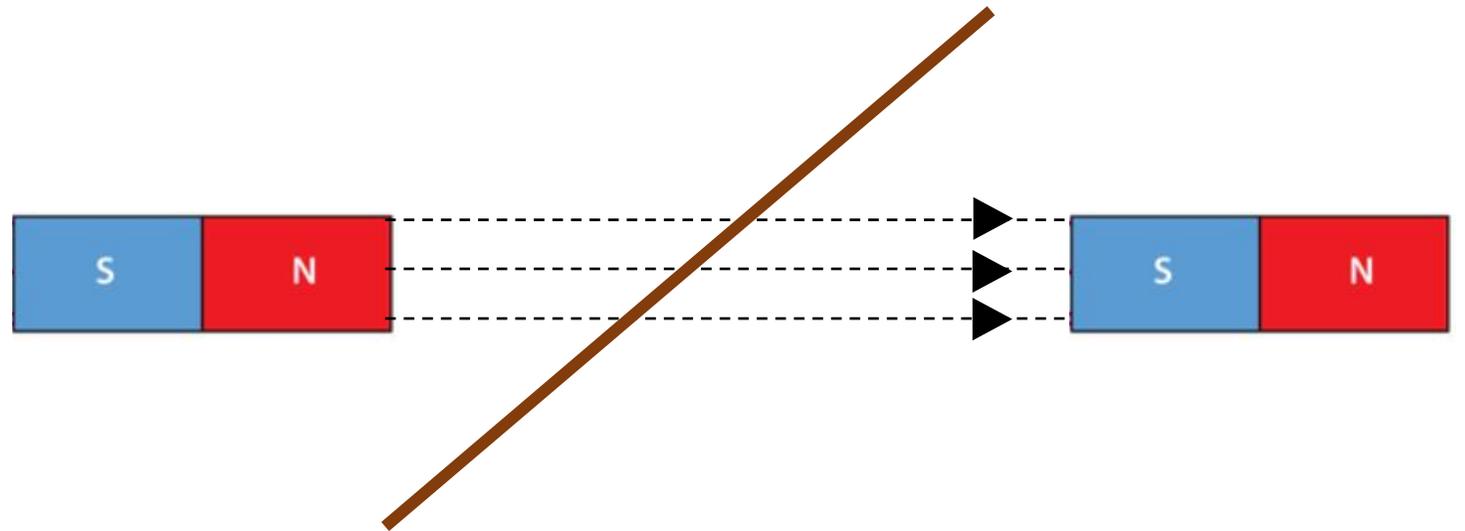
A **current-carrying wire** in a **magnetic field** causes a **magnetic force** to **act** on the **moving electrons** in the **wire**.

- This **force  $F$**  points **mutually perpendicular** to the **direction** of the **current ( $I$ )** and the **magnetic field ( $B$ )**.
- This is shown by **Fleming's left hand rule**.



The **strength** of the **magnetic force** ( $F$ ) on a **wire** in a **magnetic field** depends on:

- The **magnetic flux density**,  $B$  (in Teslas).
- The **current** in the **wire**,  $I$  (in Amps).
- The **length** of the **wire** in the **field**,  $L$  (in metres).
- The **angle** that the **wire** makes with the **field**,  $\theta$ .



$$F = BIL \sin \theta$$

**Context:** Wire with current in a magnetic field.

## Exemplar Calculation Exam Question

**Acceleration**, how does this apply to our **formula**?

- 1) Consider a straight wire of mass  $6.5 \text{ g}$  passing through a magnetic field with magnetic flux density  $7.5 \times 10^{-2} \text{ T}$ .  $14 \text{ cm}$  of the wire is in the field and perpendicular to it. The diagram shows the setup of the wire and the magnetic field. As an electric current passes through the wire, it moves with a constant acceleration of  $2 \text{ ms}^{-2}$  into the page (in regard to the diagram). Calculate the strength of the current flowing through the wire and state its direction.

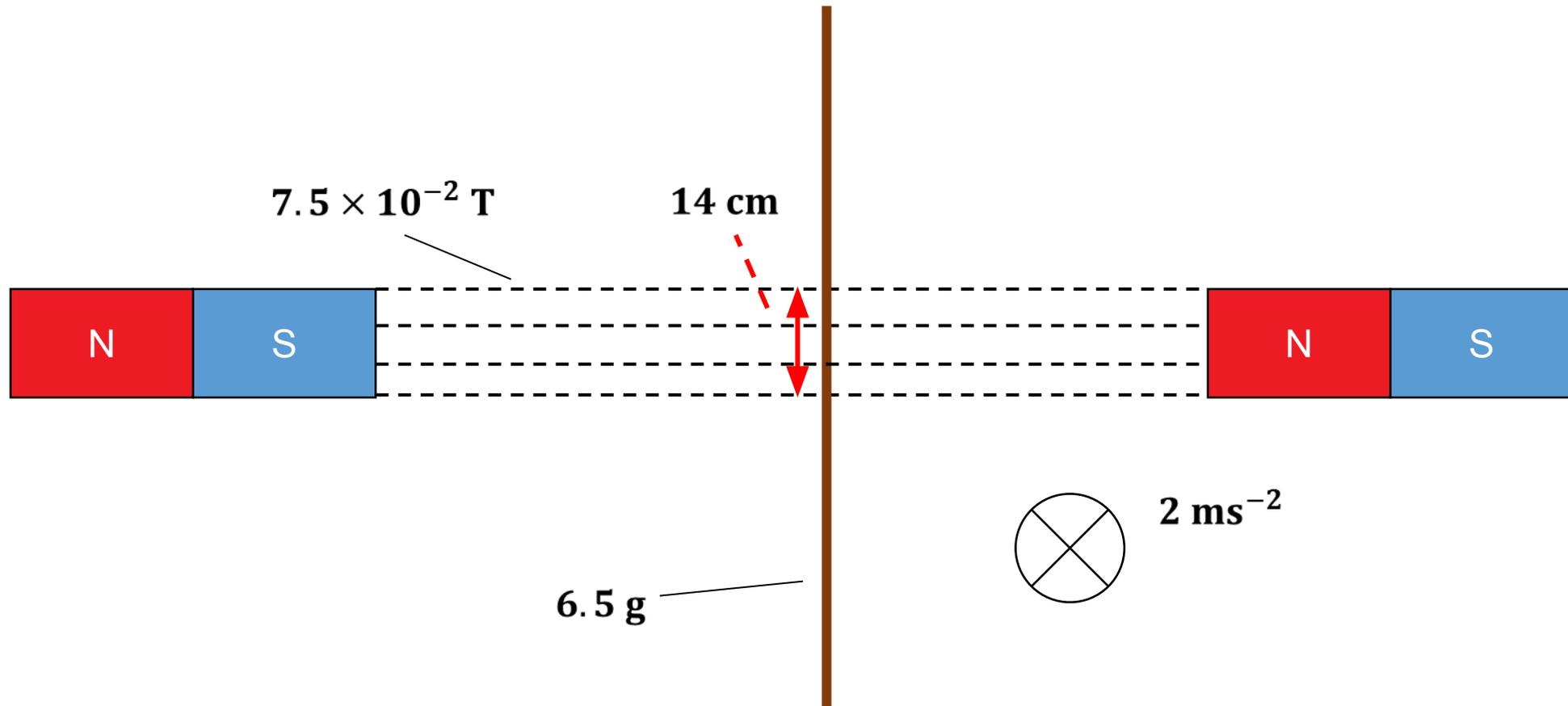
**[5 marks]**

**Calculation question**, determine what **formula** to use. Do we need to **determine** any other **variables**?

**State direction** of current - **separate method** to calculation.

**Indicates** that there will be about **4 steps** to our **calculation** as well as determining **direction of current**.

## Exemplar Calculation Exam Question



## Exemplar Calculation Question Answer

**Determine** force acting on wire

Wire moves with constant acceleration, so force acting on it is given by  $F = ma$

$$F = 6.5 \times 10^{-3} \text{ kg} \times 2 \text{ ms}^{-1}$$

$$F = 0.013 \text{ N}$$

**[1 Mark]**

## Exemplar Calculation Question Answer

**Determine** current in wire

Magnetic flux density acting on wire in magnetic field given by

$$F = BIL \sin \theta = BIL \sin 90 = BIL$$

Rearrange to find strength of current

$$I = \frac{F}{BL}$$

$$I = \frac{0.013 \text{ N}}{7.5 \times 10^{-2} \text{ T} \times 0.14 \text{ m}}$$

$$I = 1.24 \text{ A}$$

[1 Mark]

[1 Mark]

## Exemplar Calculation Question Answer

### Determine direction of current

Given that acceleration and hence force goes **into the page**

Magnetic field goes from North to South pole of magnets

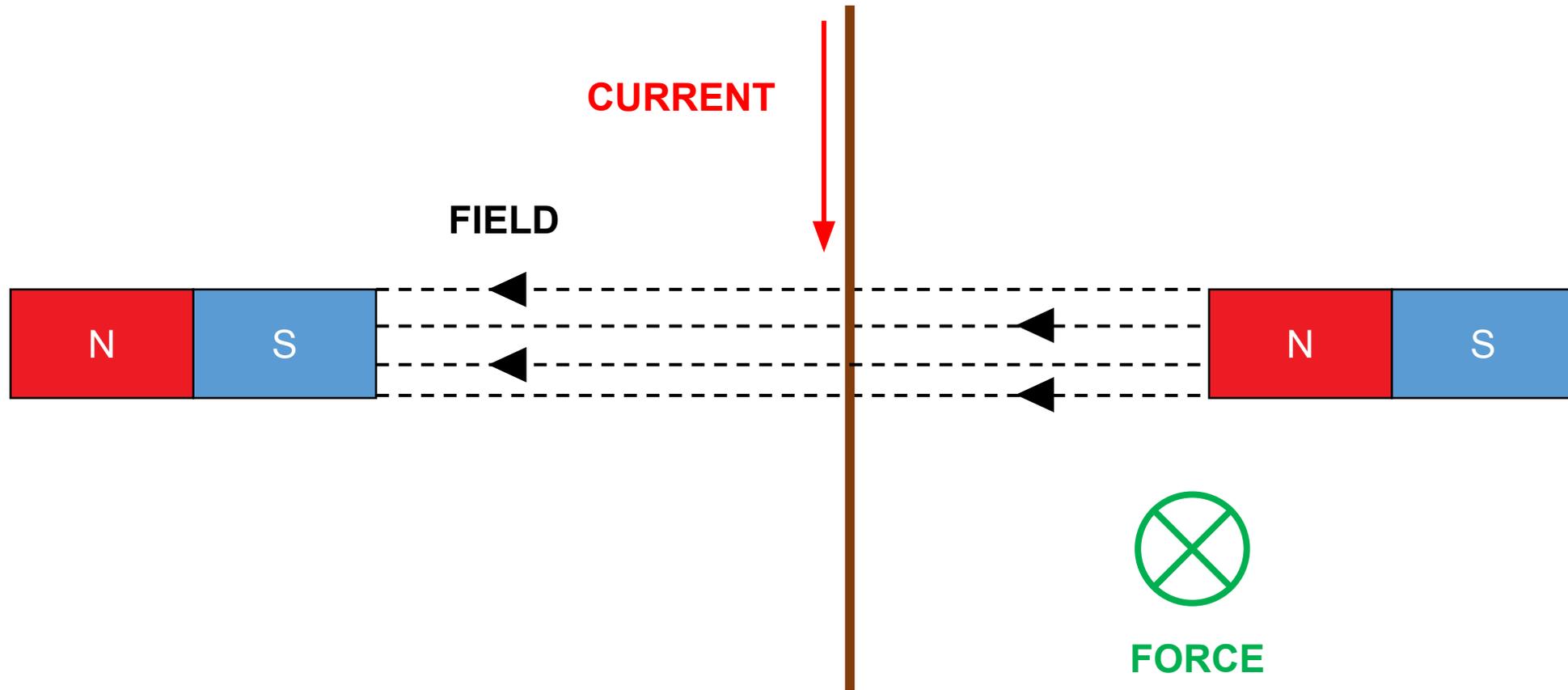
So magnetic field is going to the **left** on the page

[1 Mark]

Hence by Fleming's Left Hand Rule, current must be going **down** on the page

[1 Mark]

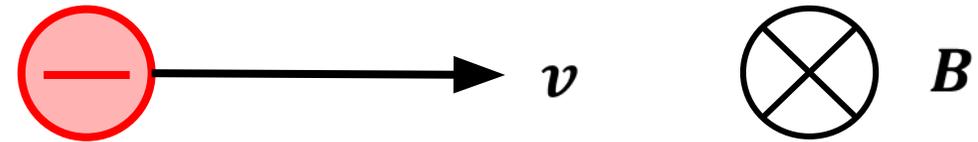
## Exemplar Calculation Exam Question



# Moving Charges in Magnetic Fields

We can **derive** an **expression** for the **force** on a free **charged particle** with **charge**  $q$  moving at **velocity**  $v$ .

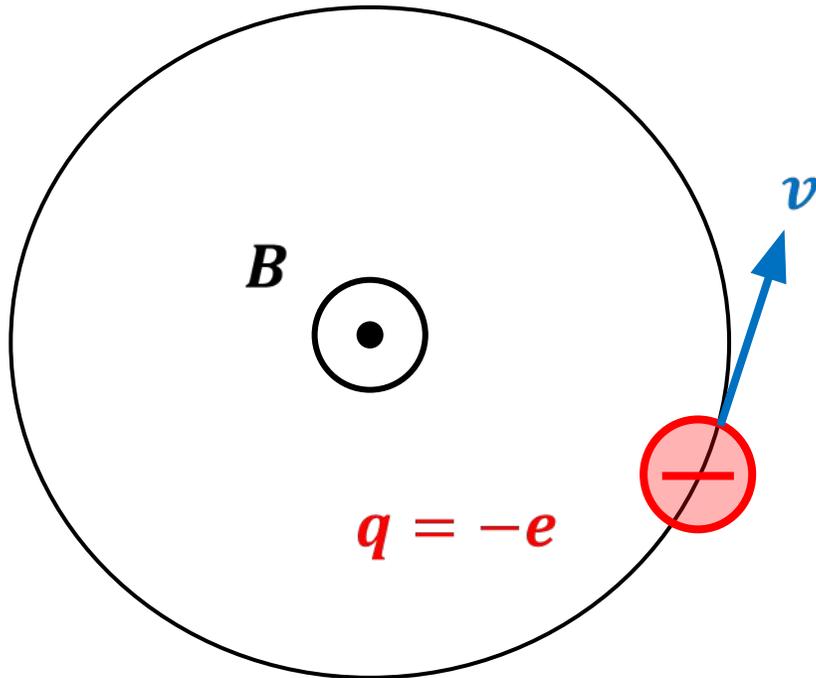
$$F = BIL$$



$$F = Bqv$$

**Fleming's Left Hand Rule** applies but be aware that  $v$  **points** in the **opposite direction** to  $I$  for **negative charges**.

As the magnetic force  $F$  always acts **perpendicularly** to the **instantaneous velocity**  $v$ , it can cause **charged particles** to undergo **circular motion** in **magnetic fields**.



$$F = Bqv$$

$$F_c = \frac{mv^2}{r}$$

No **work** is **done** on the **charged particle** as its **speed** and **kinetic energy** do not change.

## Exemplar Explanation Exam Question

Explanation of a method, work through steps in detail

**Context: Charged particles and circular motion**

- 1) Explain, with reference to circular motion, how the mass of a particle with known charge can be calculated by firing it into a controlled magnetic field at a certain speed and tracking its path of motion.

**[6 marks]**

What is **known**, what **needs to be measured**, what **needs to be calculated**?

**6 marks so 6 key points to make**

- 
- Fire particle with known velocity  $v$  perpendicularly to magnetic field with known magnetic flux density  $B$ .
- 

**[1 Mark]**

- 
- By Fleming's Left Hand rule, particle will experience a force  $F$ , perpendicular to both its motion and the direction of the field.
- 

**[1 Mark]**

- 
- Force will cause particle's motion to change, but direction of force will change as well. Force will always be perpendicular to motion, resulting in circular motion.
- 

**[1 Mark]**

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[1 Mark]

- So mass of particle can be found from formula

$$mv^2/r = Bqv$$

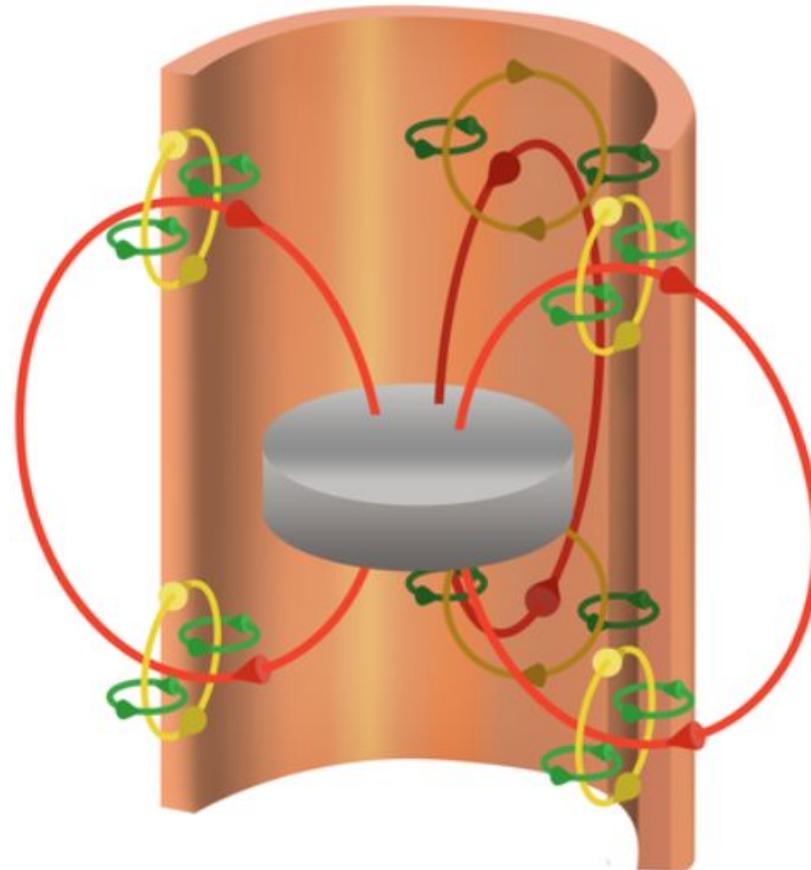
$$m = Bqr/v$$

[1 Mark]

- All terms in formula predetermined except  $r$ , which is found by analysing the circular path of the particle.

[1 Mark]

# Electromagnetic Induction



# Specification Points - AQA

## 3.7.5.3 Magnetic flux and flux linkage (A-level only)

### Content

Magnetic flux defined by  $\Phi = BA$  where  $B$  is normal to  $A$ .

Flux linkage as  $N\Phi$  where  $N$  is the number of turns cutting the flux.

Flux and flux linkage passing through a rectangular coil rotated in a magnetic field:

$$\text{flux linkage } N\Phi = BAN\cos\theta$$

## 3.7.5.4 Electromagnetic induction (A-level only)

### Content

Simple experimental phenomena.

Faraday's and Lenz's laws.

Magnitude of induced emf = rate of change of flux linkage

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

Applications such as a straight conductor moving in a magnetic field.

# Specification Points – OCR A

## 6.3.3 Electromagnetism

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### Learning outcomes

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*Learners should be able to demonstrate and apply their knowledge and understanding of:*

- (a) magnetic flux  $\phi$ ; the unit weber;  $\phi = BA\cos\theta$
- (b) magnetic flux linkage
- (c) Faraday's law of electromagnetic induction and Lenz's law
- (d) (i) e.m.f. = – rate of change of magnetic flux linkage;  $\mathcal{E} = -\frac{\Delta(N\phi)}{\Delta t}$   
(ii) techniques and procedures used to investigate magnetic flux using search coils

# Specification Points – OCR B

## 6.1.1 Electromagnetism

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### Learning outcomes

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- (a) *Describe and explain:*
- (ii) the action of a dynamo: change of flux linked produced by relative motion of flux and conductor
  - (iv) simple linked electric and magnetic circuits: flux produced by current turns, need for large conductance and permeance and the effect of increasing the dimensions of an electromagnetic machine; qualitative effect of iron and air gap.
- (b) *Make appropriate use of:*
- (i) the terms: **B**-field, magnetic field, flux, flux linkage, induced e.m.f, eddy currents
- (c) *Make calculations and estimates involving:*
- (i)  $\phi = BA, \mathcal{E} = -\frac{d(\phi N)}{dt}$
- (d) *Demonstrate and apply knowledge and understanding of the following practical activities (HSW4):*
- (i) observing induced e.m.fs produced under varying conditions such as dropping a magnet through a coil attached to a data logger or oscilloscope

# Specification Points - Edexcel

121. understand and use the terms *magnetic flux density*  $B$ , *flux*  $\phi$  and *flux linkage*  $N\phi$

124. understand the factors affecting the e.m.f. induced in a coil when there is relative motion between the coil and a permanent magnet

125. understand the factors affecting the e.m.f. induced in a coil when there is a change of current in another coil linked with this coil

126. understand how to use Lenz's law to predict the direction of an induced e.m.f., and how the prediction relates to energy conservation

127. understand how to use Faraday's law to determine the magnitude of an induced e.m.f. and be able to use the equation that combines Faraday's and Lenz's laws

$$\mathcal{E} = \frac{-d(N\phi)}{dt}$$

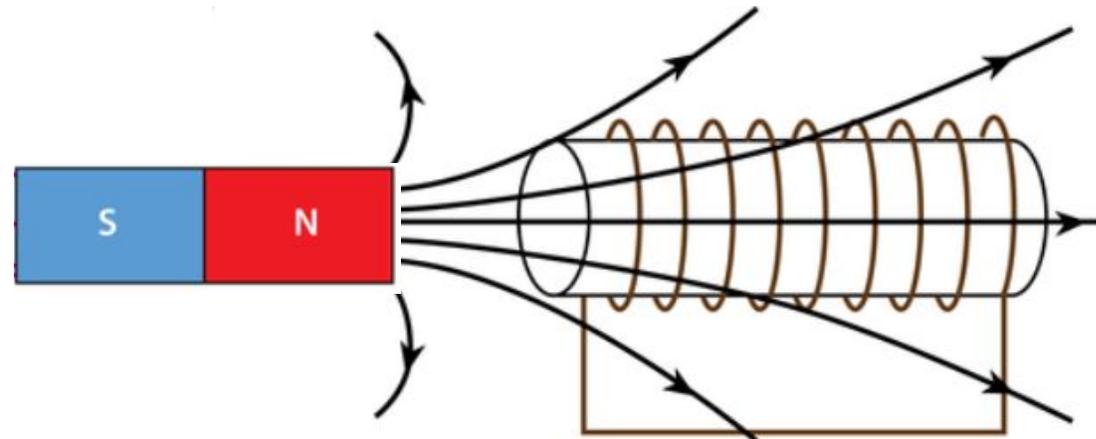
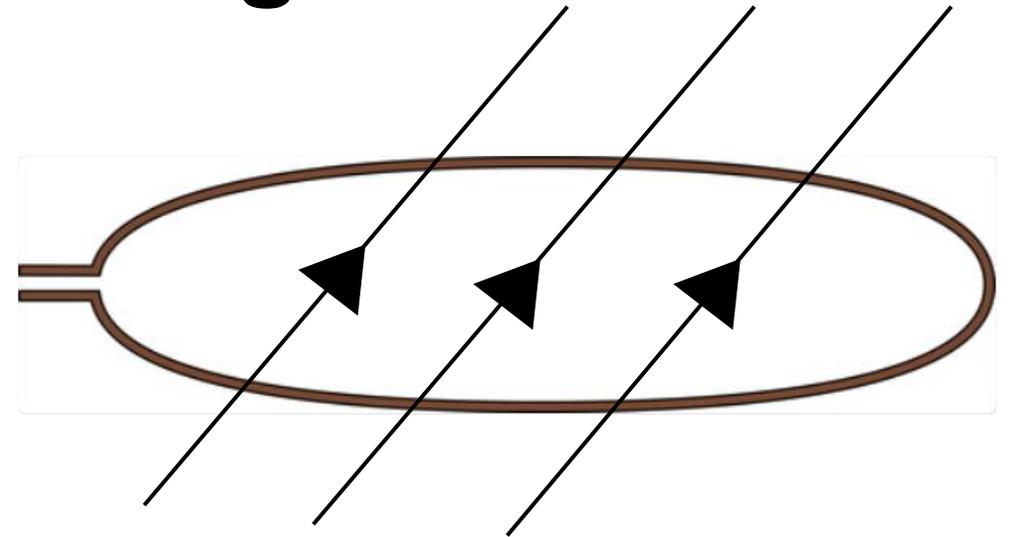
# Magnetic Flux Linkage

The **magnetic flux**  $\phi$  through an **area** is given by the **magnetic flux density multiplied by the area normal to the field**.

$$\phi = BA \cos \theta$$

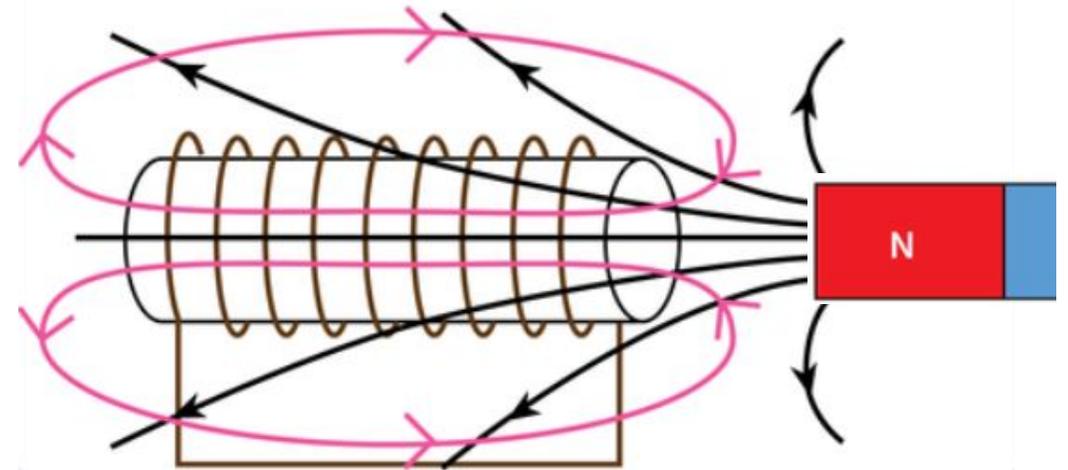
For a **coil of wire** consisting of  $N$  **turns**, the **magnetic flux linkage**  $\Phi$  through the **coil** is given by:

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



An **e.m.f** ( $\varepsilon$ ) is **induced** in a **coil** when there is a **change** in **magnetic flux** or **magnetic flux linkage** caused by the **relative motion** of **conductors** and **fluxes** (or the **cutting** of **magnetic field lines**).

- The **induced e.m.f** causes a **current** to **flow** through the **conductor**.
- This **current** can **produce** an **induced magnetic field**, causing the **coil** and **iron core** to act like a **magnet** with **magnetic poles**.
- This **phenomenon** is known as **electromagnetic induction**.



## Exemplar Explanation Exam Question

Consider **orientations**  
and **angles**.

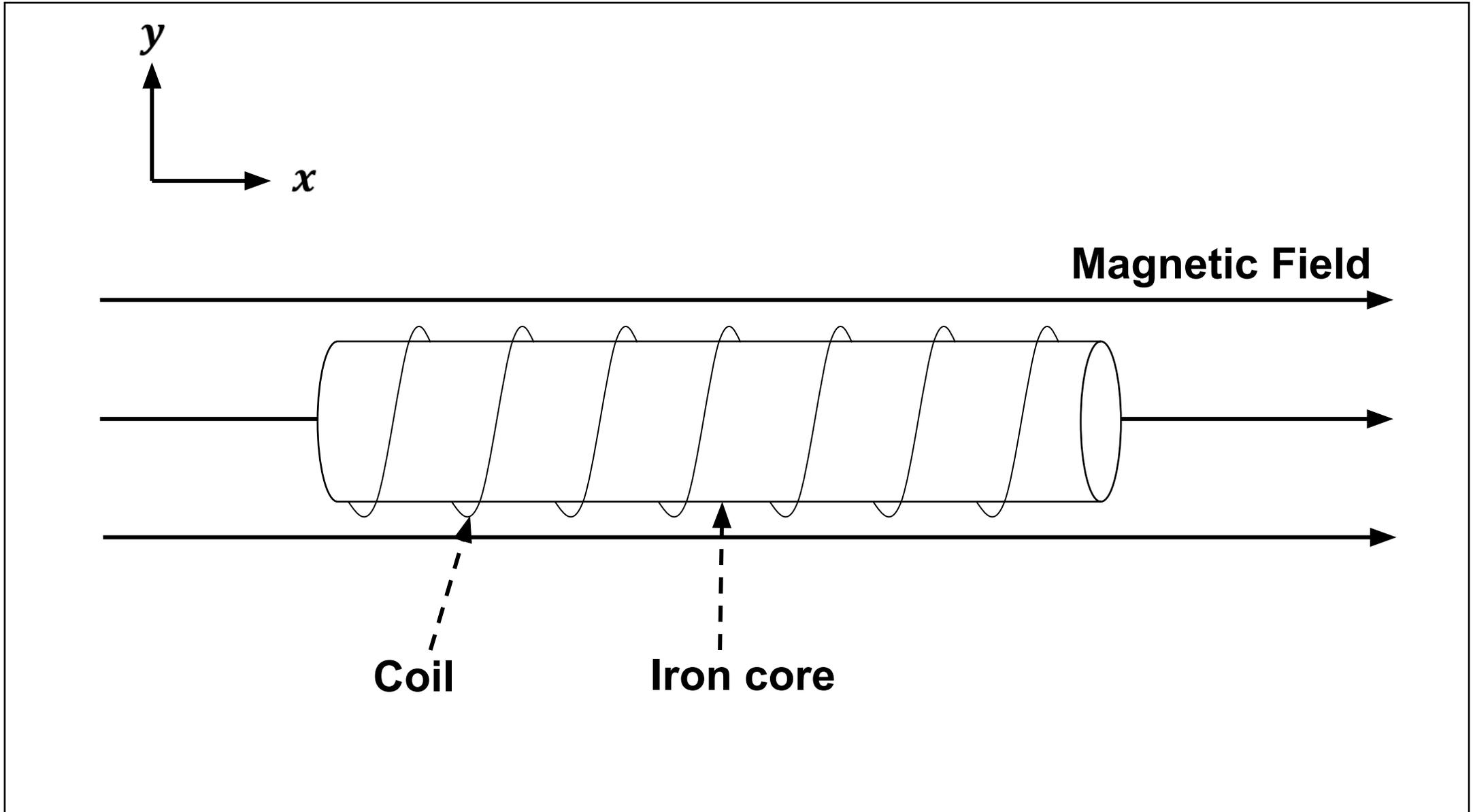
**Context: emf induced** in a **coil**  
**rotating** in a **magnetic field**.

- 1) The following diagram shows a coil of wire wrapped around a cylindrical iron core in a magnetic field. The core and magnetic field are both initially pointing in the  $x$ -direction. Explain why rotating the core around its  $x$ -axis will *not* induce an emf in the coil whereas rotating around its  $y$ -axis will.

**[5 marks]**

**Explanation**, work through  
**theory** and **explain outcome** of  
rotations.

**5 marks** so **5 key points** to make.



- 
- Emf is induced when there is a change to the magnetic flux linkage.
- 

[1 Mark]

- 
- Magnetic flux is given by magnetic flux density multiplied by the area of the iron core normal to the field  $\Phi = NBA \cos \theta$ .
- 

[1 Mark]

- 
- $N$ ,  $B$  and  $A$  are constant, so change in  $\Phi$  only comes from change in angle between core and field.
- 

[1 Mark]

---

- Rotating core along the  $x$ -axis **will not** change its angle with the field, so an emf **will not** be induced

[1 Mark]

- Rotating core along the  $y$ -axis **will** change its angle with the field, so an emf **will** be induced

[1 Mark]

# Faraday's Law and Lenz's Law

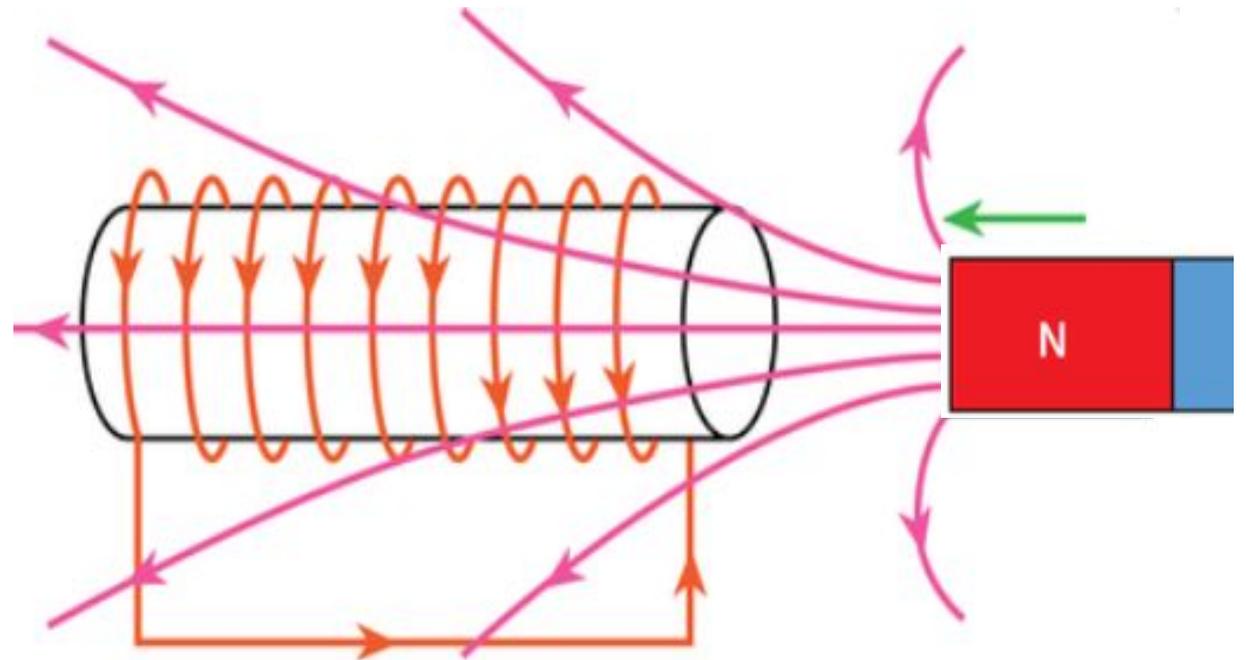
**Faraday's Law** states that the **magnitude** of the **induced e.m.f** is **directly proportional** to the **rate of change** of **magnetic flux linkage**.

**Lenz's Law** states that the **direction** of the **induced field** is such as to **oppose** the **change producing** it.

- **Lenz's Law** is a **consequence** of **energy conservation**.

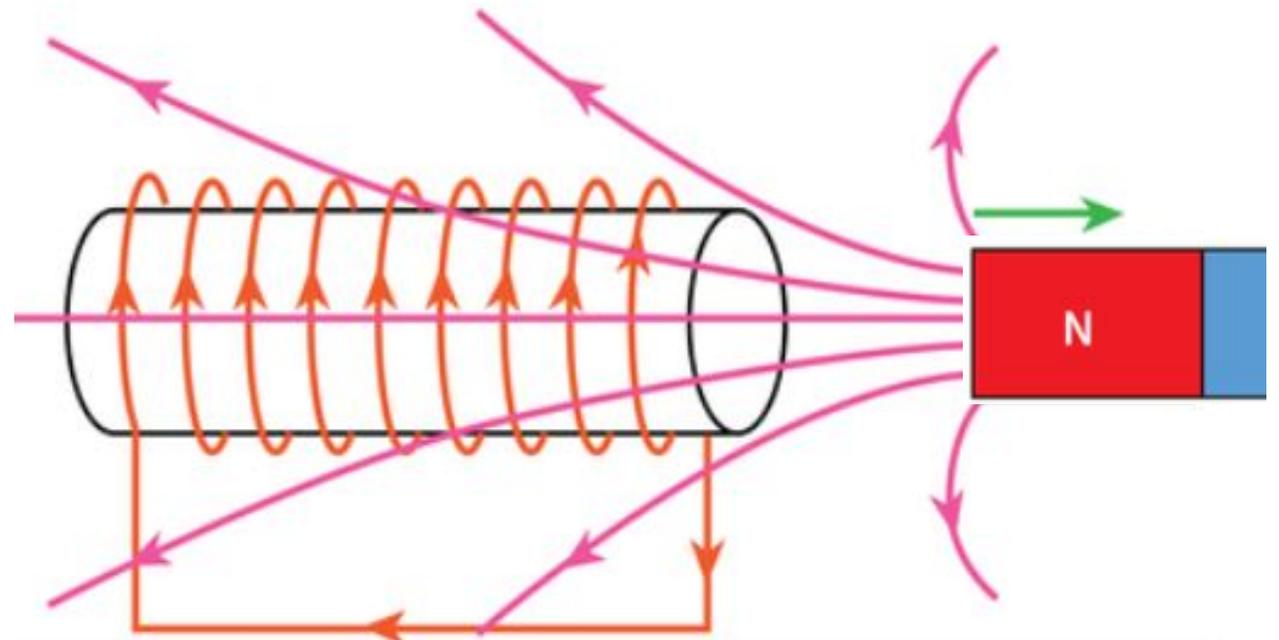
Moving the **north pole** of a **magnet** towards a **coil** produces a **current** which **induces** a **north polarity** at the **closest end** of the **coil**.

- This **induced field** **repels** the **movement** of the **permanent magnet**.
- This **acts** to **oppose** the **change** producing the **field** according to **Lenz's Law**.



Moving the **north pole** of a **magnet** away from a **coil** induces a **south polarity** at the **closest end** of the **coil**.

- This **induced field** attracts the **permanent magnet**.
- The **current** always **flows anticlockwise** around the **north pole**.



How does this fit into known **equations**?

## Exemplar Statement Exam Question

**Context: Inducing emf using magnets**

1) (i) A wire coiled around a iron core is held in a magnetic field, whose magnetic flux density is increasing at a constant rate  $k$ . State, with a reason, the relationship between  $k$  and the emf  $\varepsilon$  induced in the coil.

(ii) A second coil is moved away from the north pole of a magnet. State the direction of the current induced in the coil and why it is in this direction.

Need to give **reasoning** for **answers**

**4 marks total, 2 statements** for each part.

**[4 marks]**

## Exemplar Statement Question Answer

**(i) State relation between  $k$  and  $\varepsilon$**

$\varepsilon$  is proportional to  $k$

**[1 Mark]**

**State reason for relation**

By Lenz's Law,  $\varepsilon = -\frac{d\Phi}{dt}$ , and the rate of increase for  $\Phi$  is  $k$

**[1 Mark]**

## Exemplar Statement Question Answer

### (ii) State direction of current

Current will move clockwise as viewed from furthest (north) pole.

**[1 Mark]**

### State reason for direction

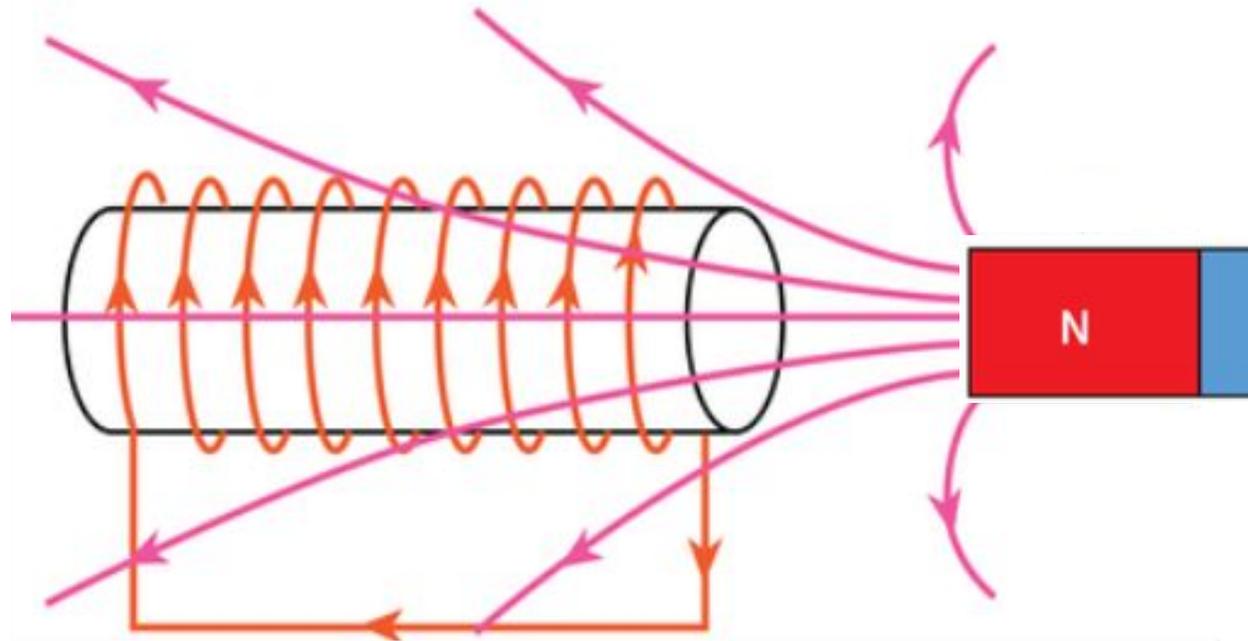
This is because the magnetic field induced by the current will oppose the change causing it, as stated by Lenz's Law.

In this case, the induced field will attract the magnet to oppose the motion of the magnet moving away from it.

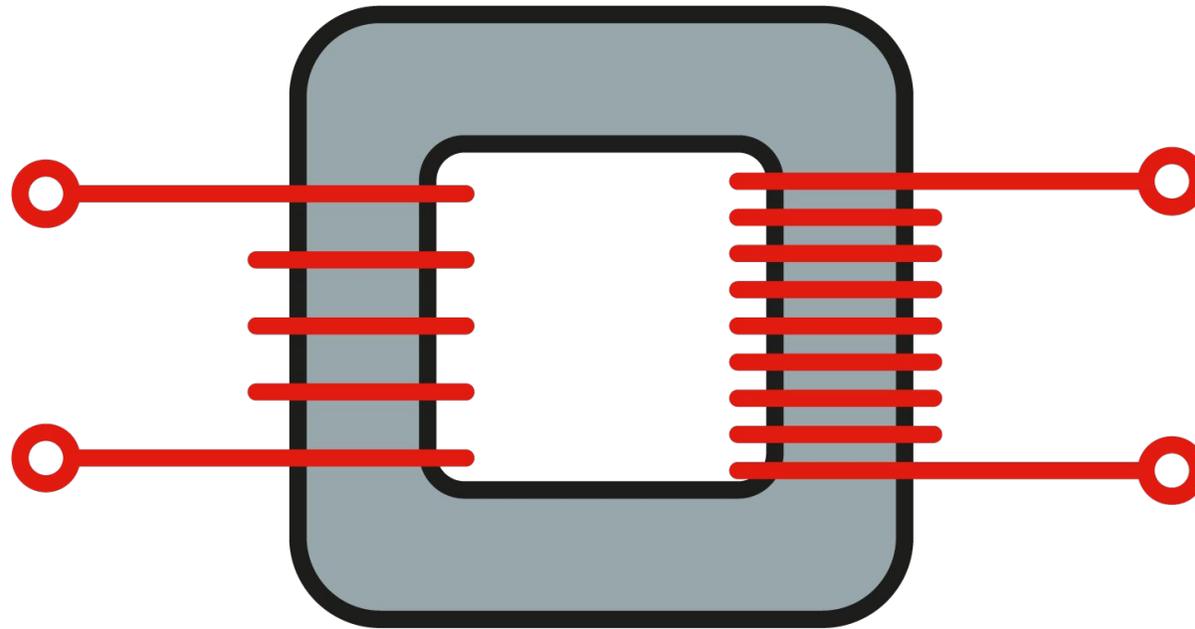
**[1 Mark]**



## Exemplar Statement Question Answer



# Generating Electricity



# Specification Points - AQA

emf induced in a coil rotating uniformly in a magnetic field:

$$\varepsilon = BAN\omega \sin \omega t$$

## 3.7.5.6 The operation of a transformer (A-level only)

Content	Opportunities for skills development
<p>The transformer equation: <math>\frac{N_s}{N_p} = \frac{V_s}{V_p}</math></p> <p>Transformer efficiency = <math>\frac{I_s V_s}{I_p V_p}</math></p> <p>Production of eddy currents.</p> <p>Causes of inefficiencies in a transformer.</p> <p>Transmission of electrical power at high voltage including calculations of power loss in transmission lines.</p>	<p><b>MS 0.3 / AT b, h</b></p> <p>Investigate relationships between currents, voltages and numbers of coils in transformers.</p>

# Specification Points – OCR A

- (e) simple a.c. generator
- (f) (i) simple laminated iron-cored transformer;  
$$\frac{n_s}{n_p} = \frac{V_s}{V_p} = \frac{I_p}{I_s}$$
 for an ideal transformer
- (ii) techniques and procedures used to investigate transformers.

# Specification Points – OCR B

## 6.1.1 Electromagnetism

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### Learning outcomes

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**(a)** Describe and explain:

- (i)** the action of a transformer: magnetic flux from a coil; induced e.m.f = rate of change of flux linkage

**(b)** Make appropriate use of:

- (i)** the terms: **B**-field, magnetic field, flux, flux linkage, induced e.m.f, eddy currents

by sketching and interpreting:

- (ii)** graphs of variations of currents, flux and induced e.m.f

**(c)** Make calculations and estimates involving:

**(i)**  $\phi = BA, \mathcal{E} = -\frac{d(\phi N)}{dt}$

**(iii)**  $\frac{V_1}{V_2} = \frac{N_1}{N_2}$  for an ideal transformer

**(iv)**  $\frac{I_2}{I_1} = \frac{N_1}{N_2}$  for an ideal transformer

**(d)** Demonstrate and apply knowledge and understanding of the following practical activities (HSW4):

- (iii)** investigate transformers.

# Specification Points - Edexcel

126. understand how to use Lenz's law to predict the direction of an induced e.m.f., and how the prediction relates to energy conservation

127. understand how to use Faraday's law to determine the magnitude of an induced e.m.f. and be able to use the equation that combines Faraday's and Lenz's laws

$$\mathcal{E} = \frac{-d(N\phi)}{dt}$$

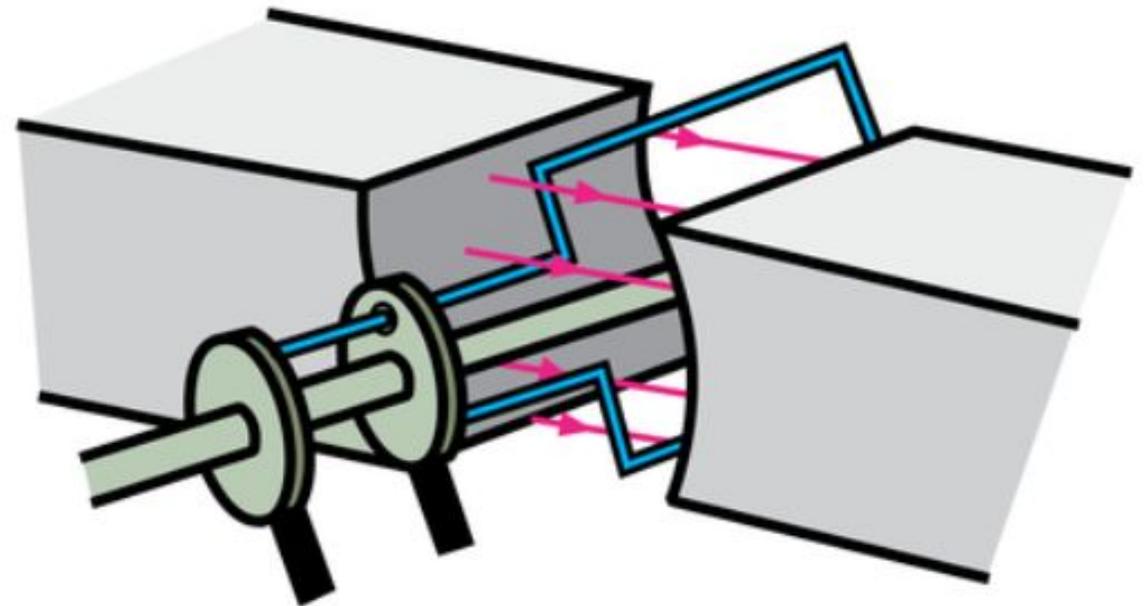
128. understand what is meant by the terms *frequency*, *period*, *peak value* and *root-mean-square value* when applied to alternating currents and potential differences

129. be able to use the equations  $V_{rms} = \frac{V_0}{\sqrt{2}}$  and  $I_{rms} = \frac{I_0}{\sqrt{2}}$

# A.C Generator

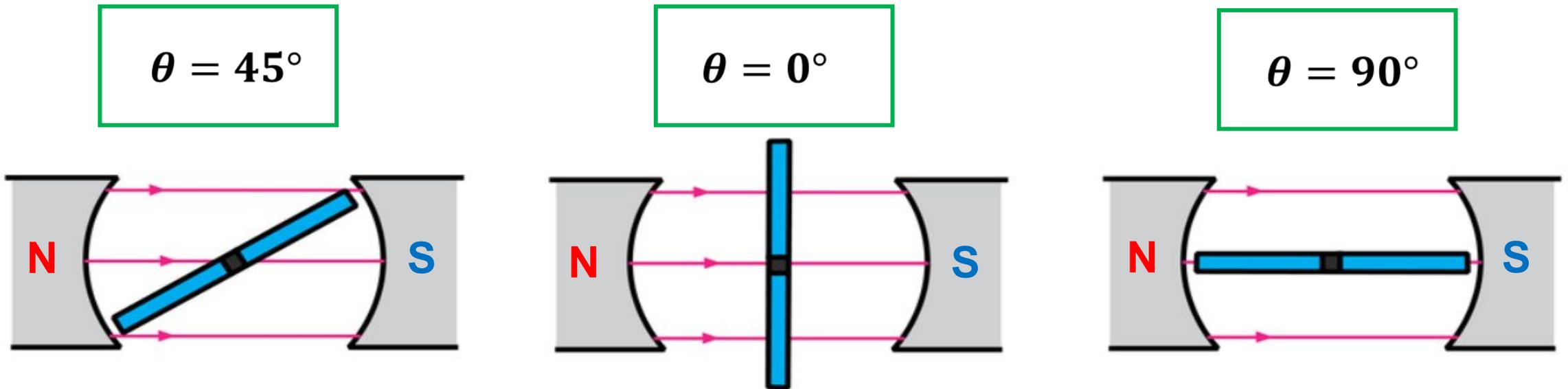
**Electromagnetic induction is used to generate electricity as an alternating current.**

- A **generator** consists of a **rectangular coil turning** in a **uniform magnetic field**.
- As the **coil spins**, it **cuts the field lines** at a **rate proportional** to its **turning frequency**.
- This **induces** an **e.m.f** across the **coil** and causes a **current to flow**.
- The **direction** of this **current** can be found by **applying Lenz's Law**.



The **magnitude** and **direction** of the **induced e.m.f** at any **instant in time** depends on the **orientation** of the **coil**.

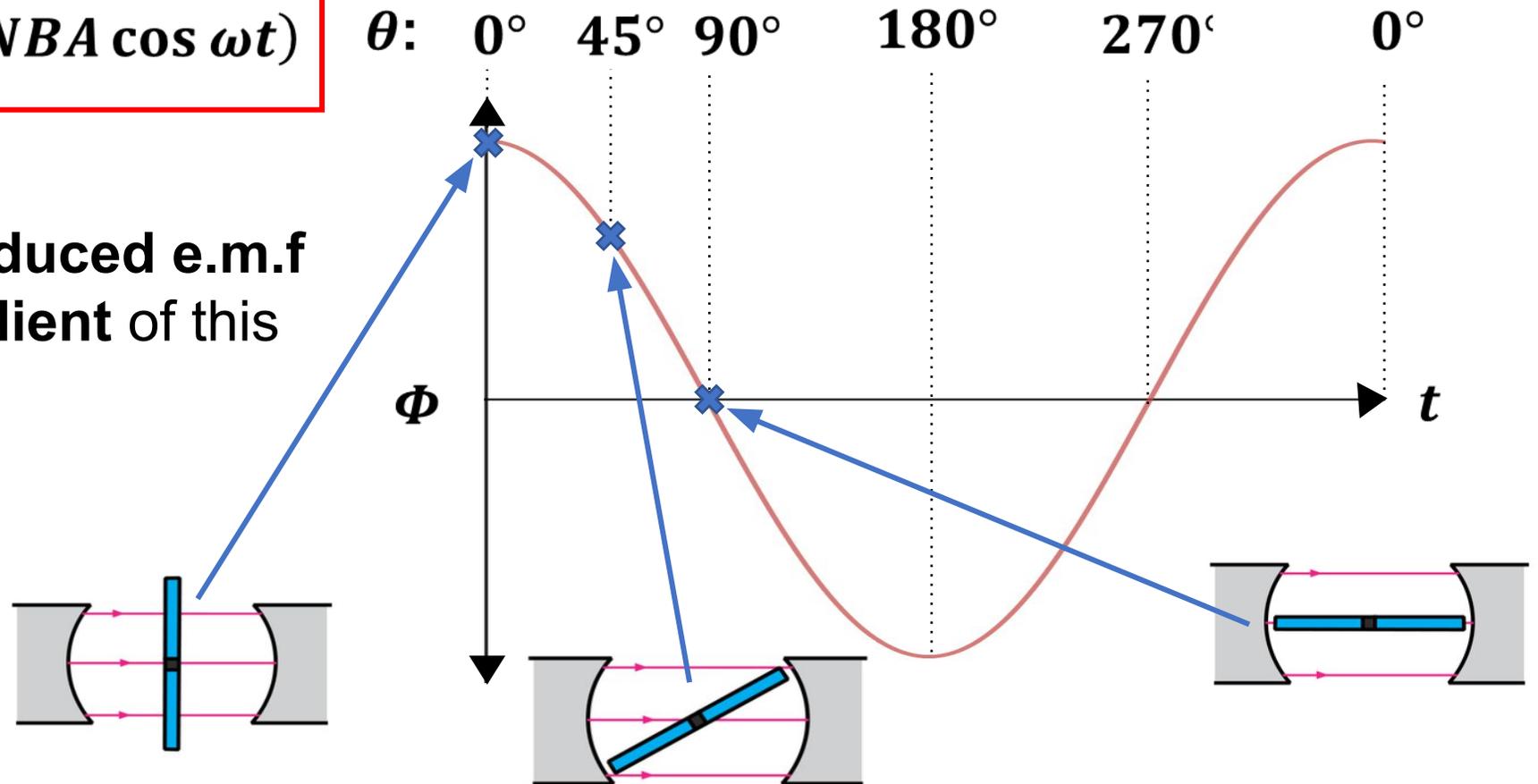
- This is measured by the **angle ( $\theta$ )** that the **normal** to the **coil** makes to the **magnetic field lines**.



The **variation of flux linkage over time** as the **coil turns** is given by a **cosine graph**.

$$\Phi = NBA \cos \theta (= NBA \cos \omega t)$$

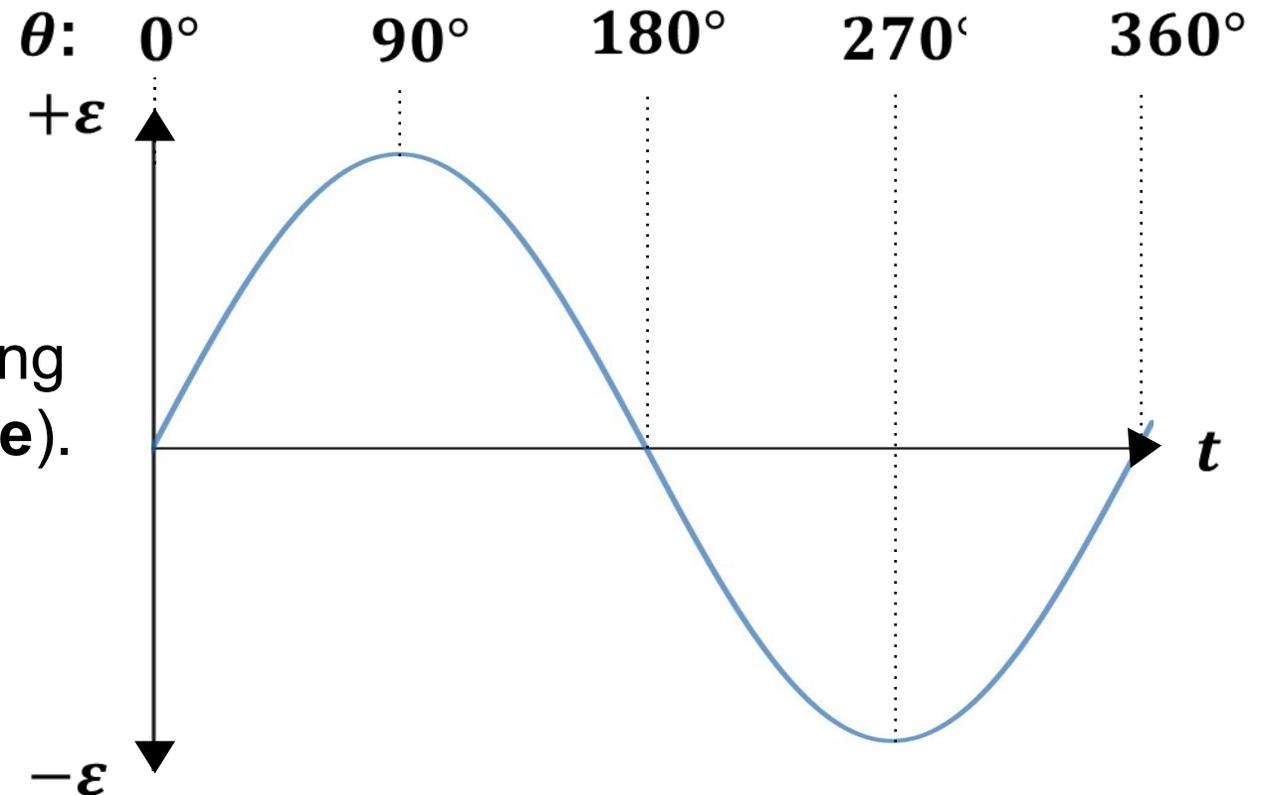
- The **variation of induced e.m.f** is given by the **gradient** of this **graph**.



The **variation of e.m.f over time** as the **coil turns** is given by a **sine graph**.

$$\varepsilon = \frac{d\Phi}{dt} = NBA\omega \sin(\omega t)$$

- The **induced e.m.f is maximum** when the most **field lines** are being **cut per second** (max **flux change**).
- The **direction** (and **sign**) of the **e.m.f** flips every **half turn** of the **coil**, producing an **alternating current**.



**Context: Power generation.** Graph shows an **AC current**.

## Exemplar Calculation Exam Question

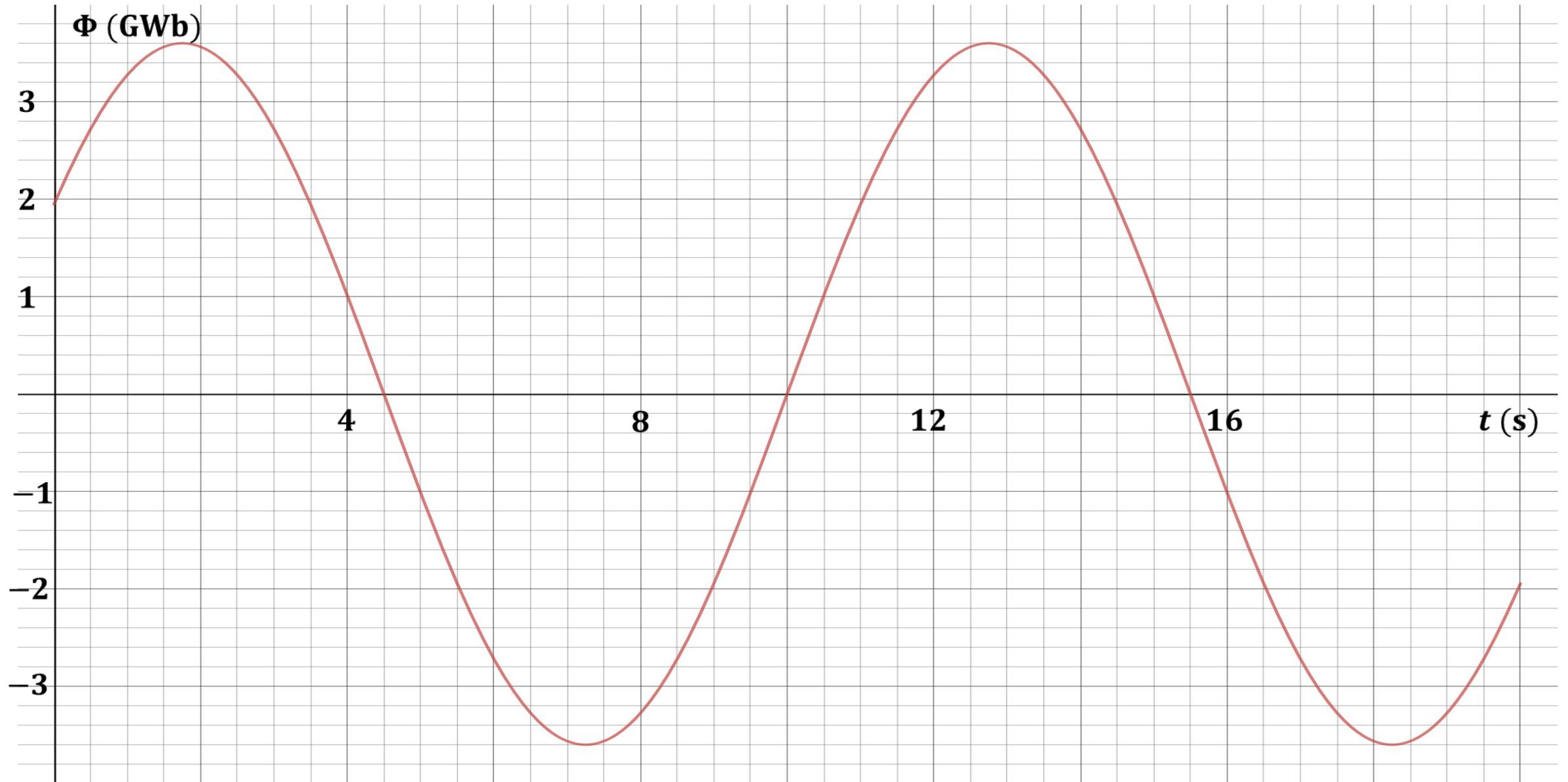
- 1) A power company takes a sample from the energy produced by a wind turbine. As the turbine rotates, it spins a large rectangular wire inside a magnetic field. The company produces the following graph of the flux linkage in the coil over a **20 s** period.
  - (i) Assuming the speed of rotation for the turbine remains constant, estimate the number of revolutions the coil will undergo in an hour.
  - (ii) Given the magnetic field has magnetic flux density  $3 \times 10^4 \text{ T}$  and the coil has dimensions  $3 \text{ m} \times 5 \text{ m}$ , calculate the number of coils in the wire.

Remember to **convert units**.

**Calculation** questions, remember **formulae** and **identify important values**.

**[4 marks]**

**4 marks total, 2 short calculations**



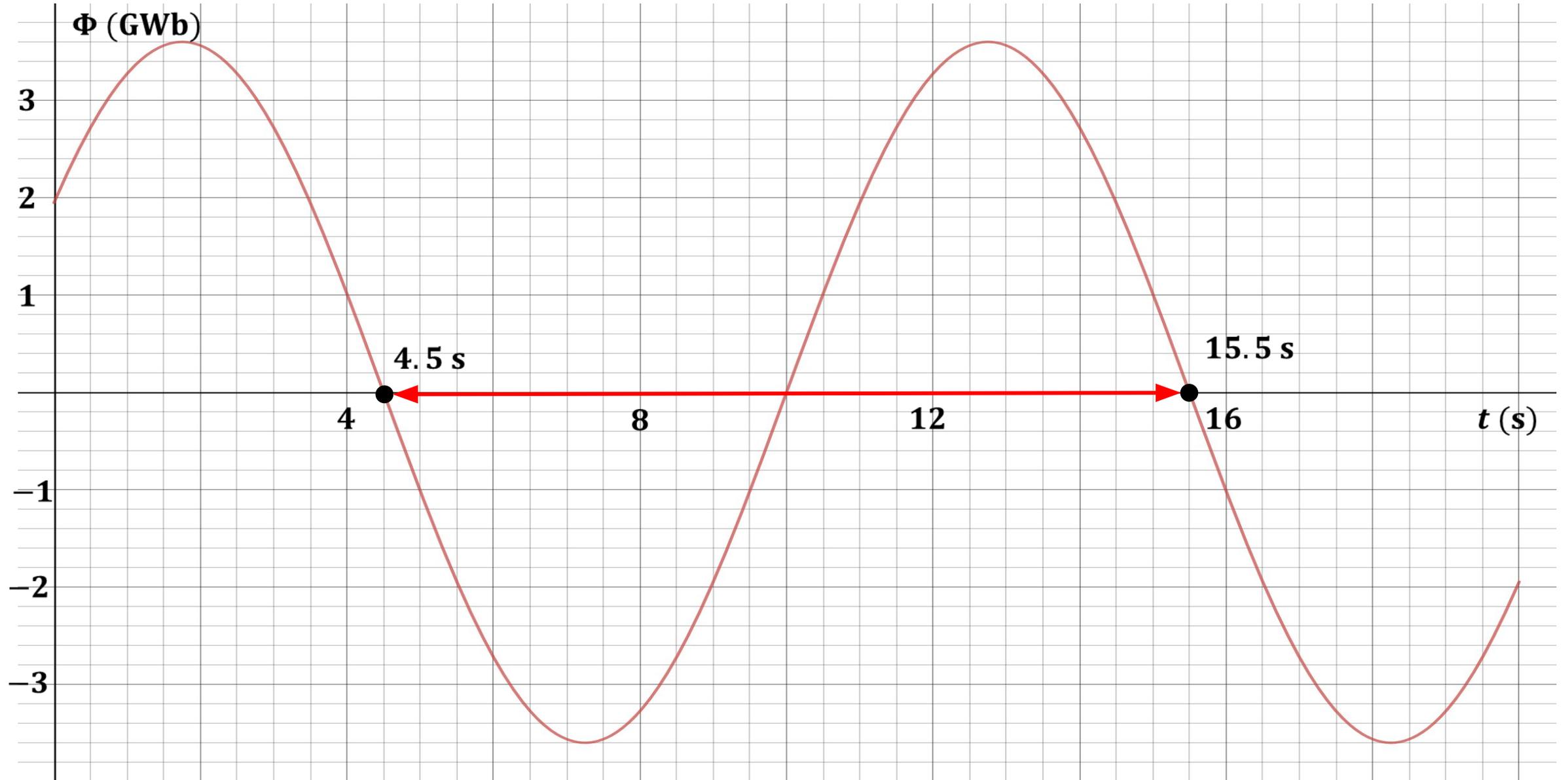
## Exemplar Calculation Question Answer

### (i) Determine period of oscillation

One full rotation of the coil will be same as it rotating through  $0^\circ$  to  $360^\circ$ .

i.e. the time it takes for a full rotation is a period on the given sine graph

**[1 Mark]**



## Exemplar Calculation Question Answer

So period of rotation is  $15.5 - 4.5 = 11 \text{ s}$

**Determine number of rotations in an hour**

One hour is  $60 \times 60 = 3600 \text{ s}$

Hence number of rotations is

$$\frac{3600}{11} = 327 \text{ rotations}$$

**[1 Mark]**

## Exemplar Calculation Question Answer

### (ii) Determine peak flux linkage

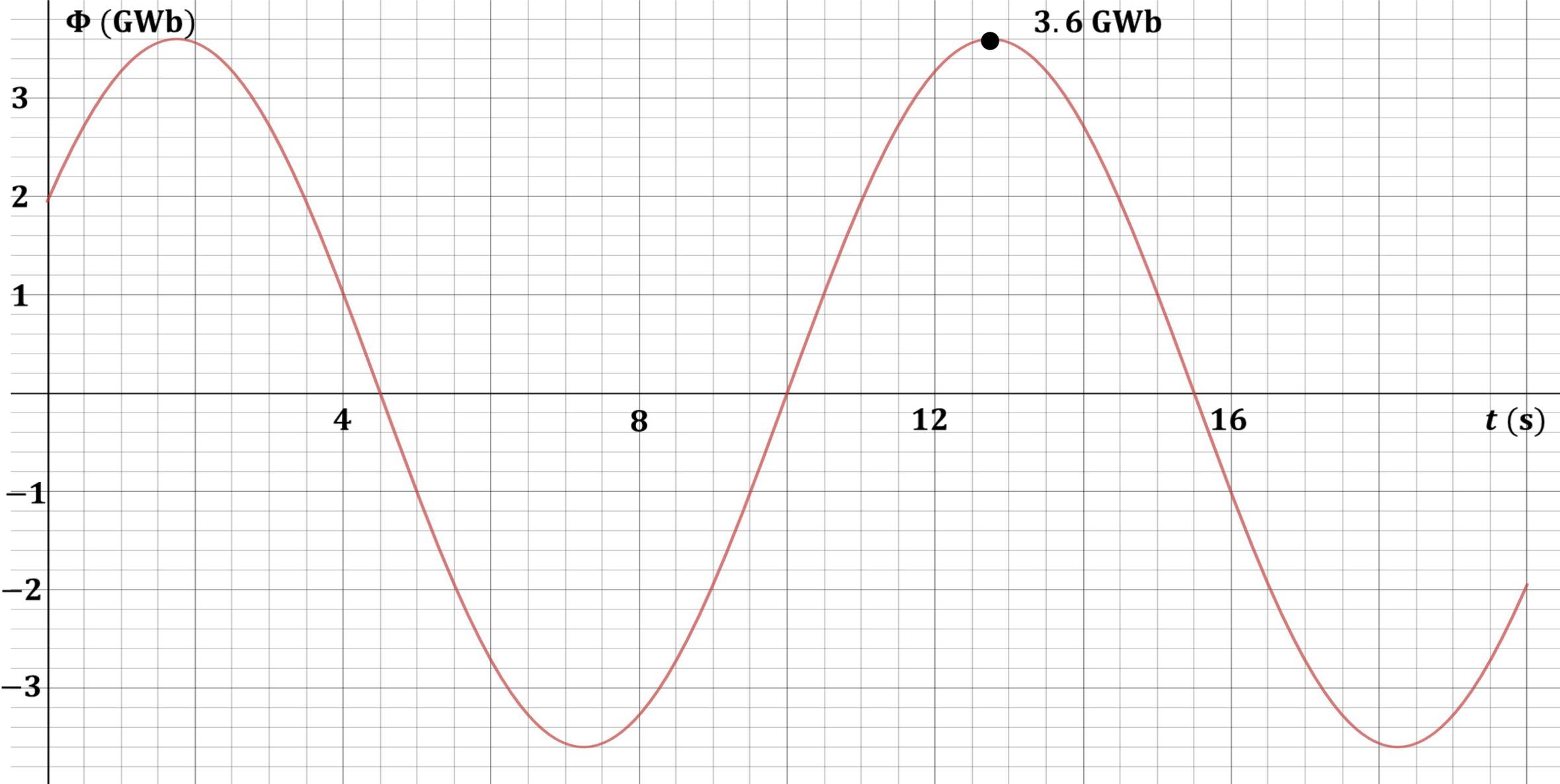
Peak value of flux linkage can be read from max value of the graph.

This is when coil is parallel to field, with  $\sin(\theta) = 1$

Hence  $\Phi_{peak} = NBA$

$$N = \frac{\Phi_{peak}}{BA}$$

[1 Mark]



## Exemplar Calculation Question Answer

### Calculate variables

$$3.6 \text{ GWb} = 3.6 \times 10^9 \text{ Wb}$$

$$A = 5 \times 3 = 15 \text{ m}^2$$

[1 Mark]

### Substitute values

$$N = \frac{\Phi_{peak}}{BA}$$

$$N = \frac{3.6 \times 10^9}{3 \times 10^4 \times 15} = 8000 \text{ coils}$$

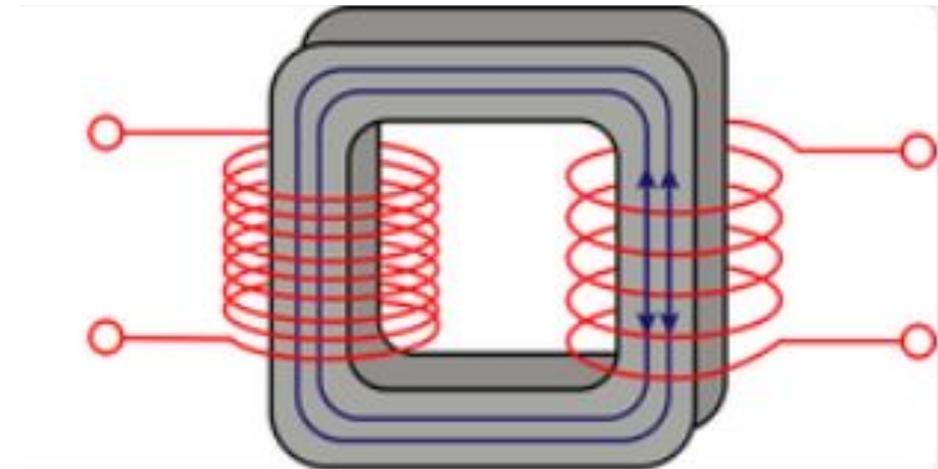
[1 Mark]

# Transformers

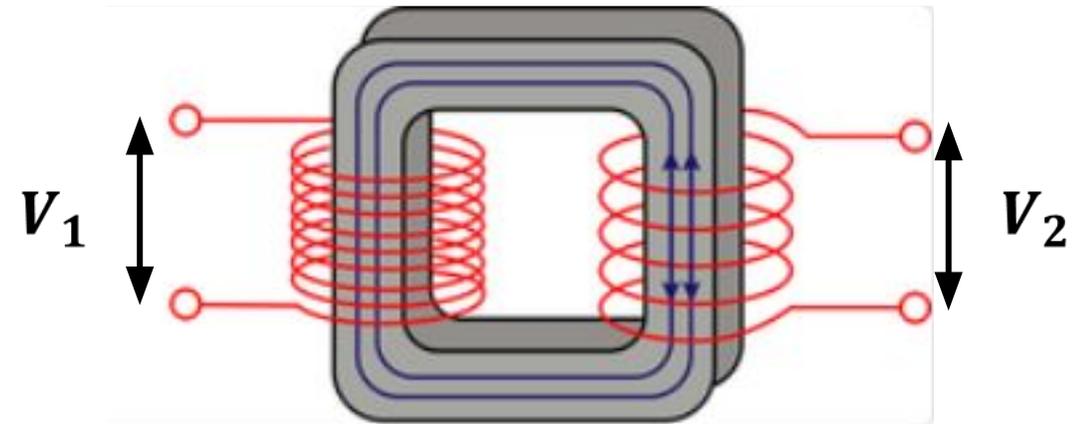
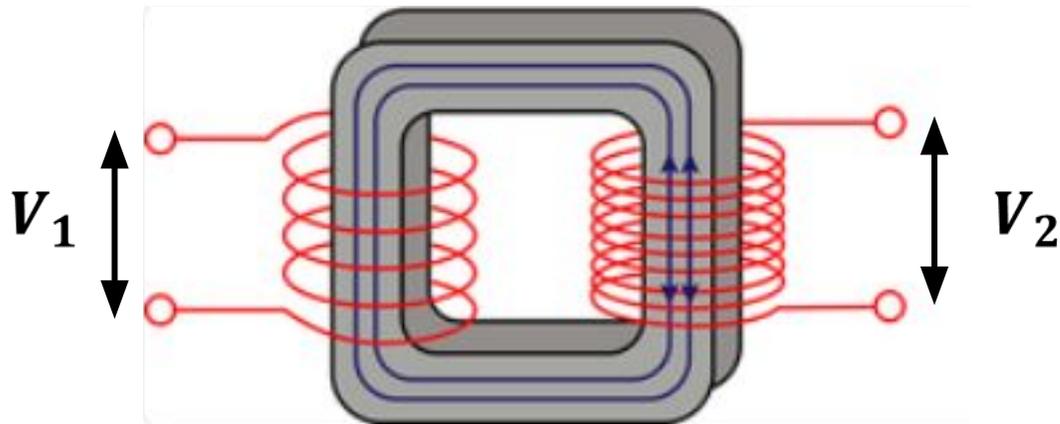
A **transformer** is a **device** used to **change** the **peak voltage** of an **alternating current**.

- A **transformer** consists of **2 wires** wrapped around **each side** of an **iron core**.
- The **change** in **peak voltage** ( $V$ ) is given by the **turn ratio** of the **number of coils** ( $N$ ) on **each side** of the **transformer**.

$$\frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}$$



- The **alternating current** in the **first coil** induces a rapidly changing **magnetic flux** ( $\phi$ ) in the **iron core**.
- This **alternating magnetic flux** ( $\phi$ ) induces an **alternating current** in the **second coil**.

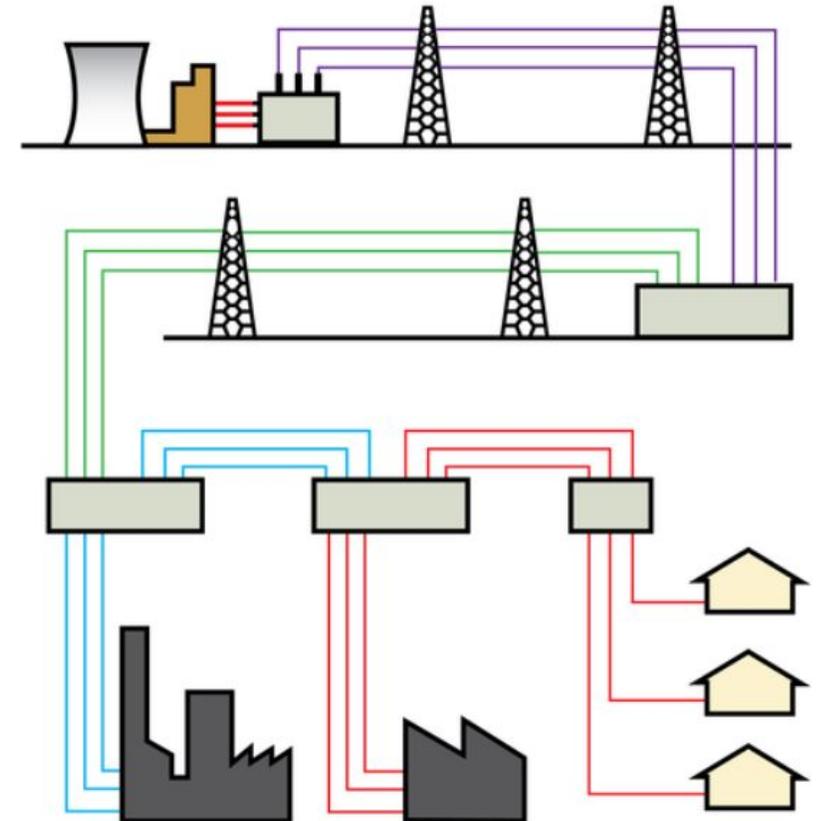


**Transformers** are almost **100% efficient** as **power losses** are **reduced** by using:

- **Low resistance** windings.
- A **laminated iron core** preventing **eddy currents**.
- Easily magnetisable **soft iron core**.

**Transformers** are used in **electrical power transmission** throughout the **National Grid**.

- **Step-up transformers** are used to **transmit electricity at high voltage** to avoid **resistive losses** in **power lines**.



## Exemplar Experimental Analysis Exam Question

Basic **diagram** given, how could this be **adapted** to **improve** our **results**?

**Devising experiment**, what kind of **measurements** are we taking?

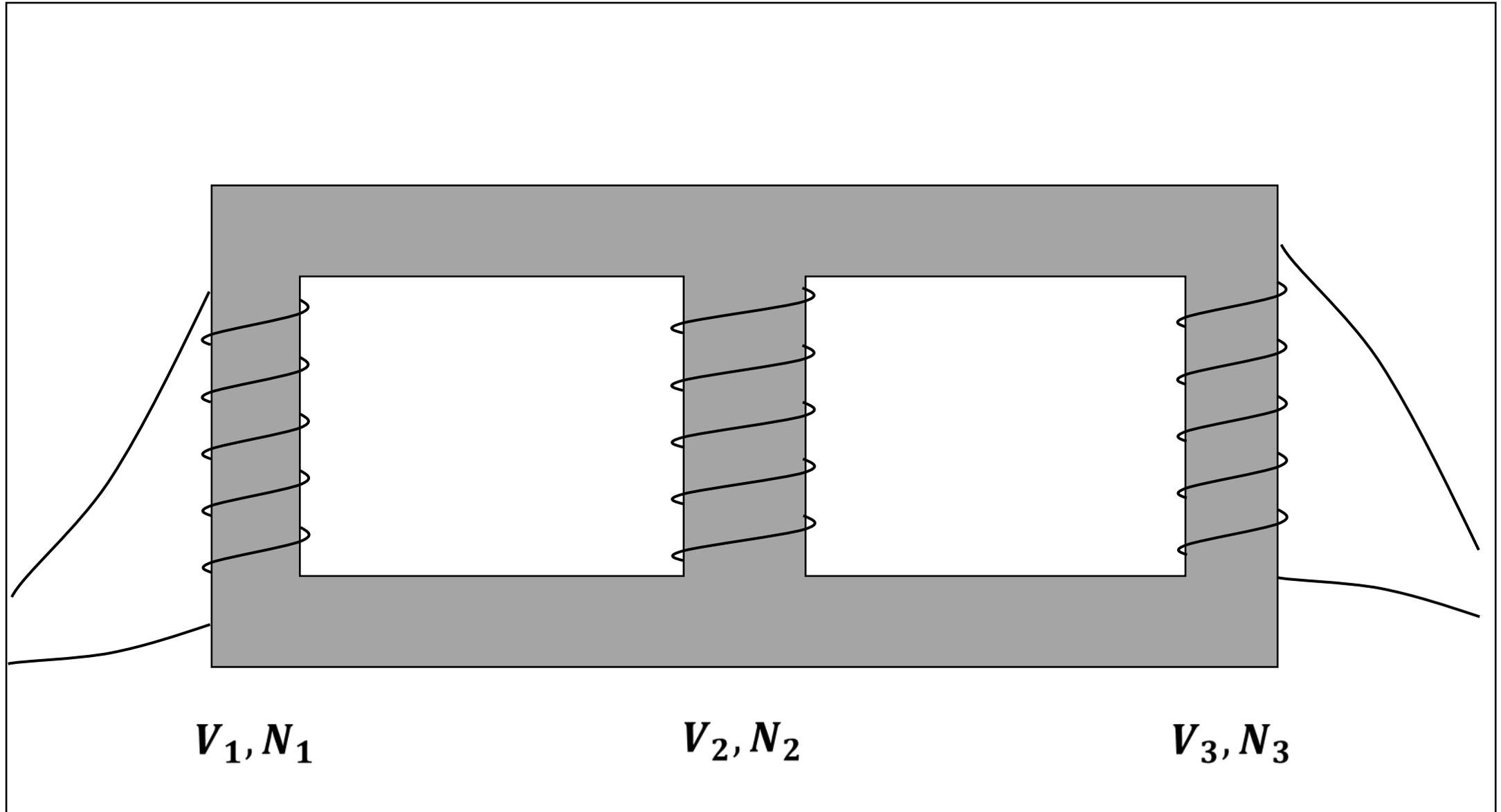
**Context: Transformers** and **transformer rule**.

- 1) Devise an experiment to test if the transformer rule still applies for a three-coiled transformer (similar to a basic example shown in the diagram). You should state and explain your initial hypothesis.

**[5 marks]**

**State** initial **hypothesis** and give a **reason**, what is the **expected result**?

**5 marks total, 5 key points** from **theory/hypothesis** and **method**.



## THEORY

- Set up coils as shown in diagram, only Coil 1 is connected to an alternating power source. [1 Mark]
- Alternating current in Coil 1 will induce alternating magnetic field, which will induce emf and current in Coil 2 with ratio  $V_1/N_1 = V_2/N_2$ . [1 Mark]
- Alternating current will induce second magnetic field in Coil 2, which will induce another current in Coil 3 . [1 Mark]
- Ratio of second and third coils is  $V_2/N_2 = V_3/N_3$ , which also means that  $V_1/N_1 = V_3/N_3$ . Will test this. [1 Mark]

## METHOD

- Set up coils with voltmeter connected to each and alternating emf on Coil 1. [1 Mark]
- Separate Coils 1 and 3 so magnetic field induced by Coil 1 doesn't interact with Coil 3. [1 Mark]
- Measure with voltmeter connected across coil for varying combinations of number of coils. [1 Mark]
- Check that ratio  $V/N$  is consistent across all 3 Coils / across Coils 1 and 3. [1 Mark]

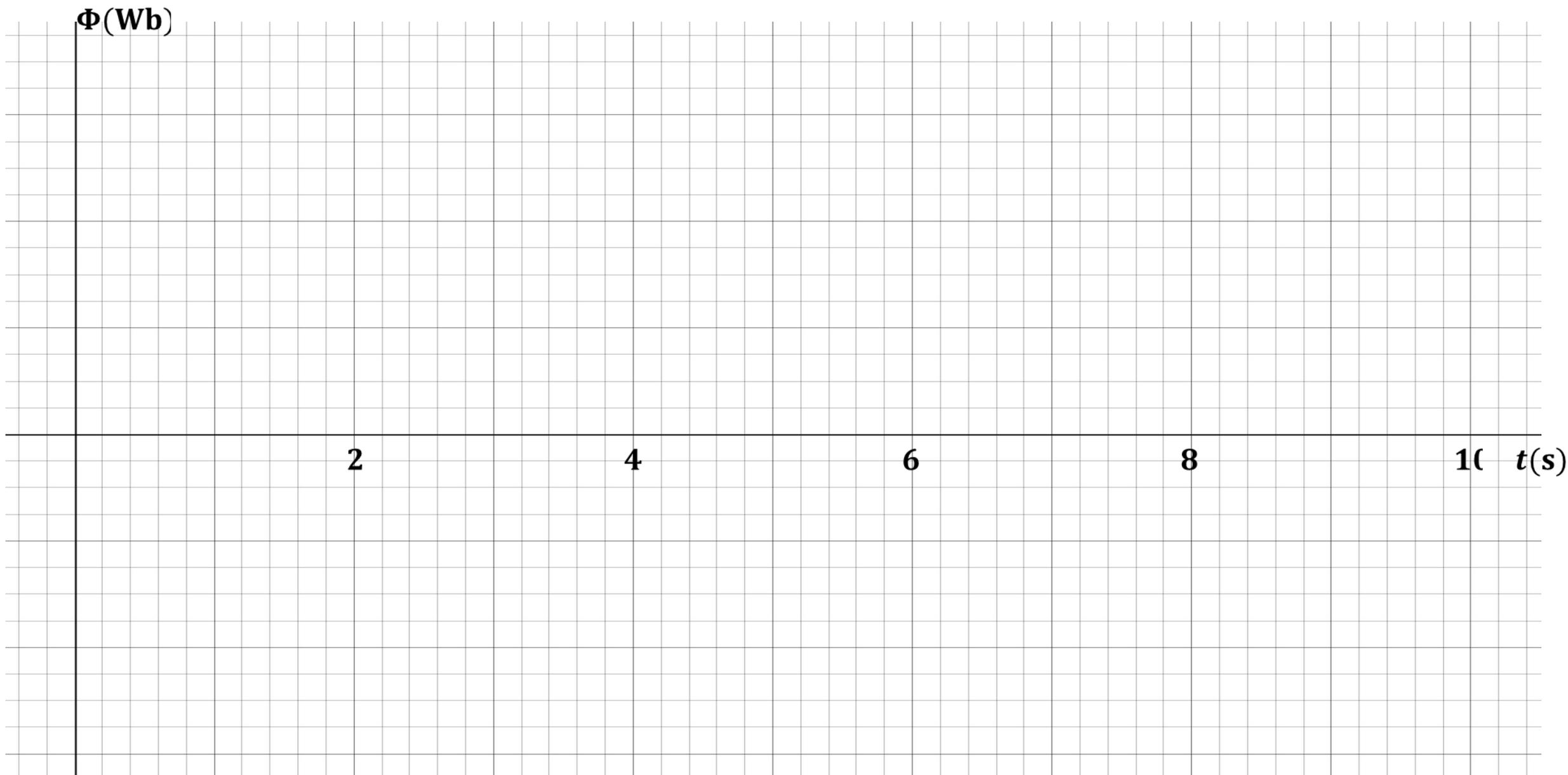
**[Maximum 5 Marks]**

# MINI MOCK PAPER



1. On the axes provided, draw the graph of the magnetic flux  $\Phi$  induced at time  $t$  by a rectangular coil with **25** coils and area **8 m<sup>2</sup>** spinning in a magnetic field with magnetic flux density **3 T**. The coil completes **20** revolutions a minute and initially makes an angle of **60°** with the magnetic field, with the initial emf being positive.  
You should provide a suitable scale for your  $y$ -axis values.

**[4 marks]**



## Exam Question Answer

### Determine details for graph

Graph is of  $\Phi = NBA \cos \theta$

So plot a cosine graph with peak value of  $NBA = 25 \times 3 \times 8 = 600 \text{ Wb}$

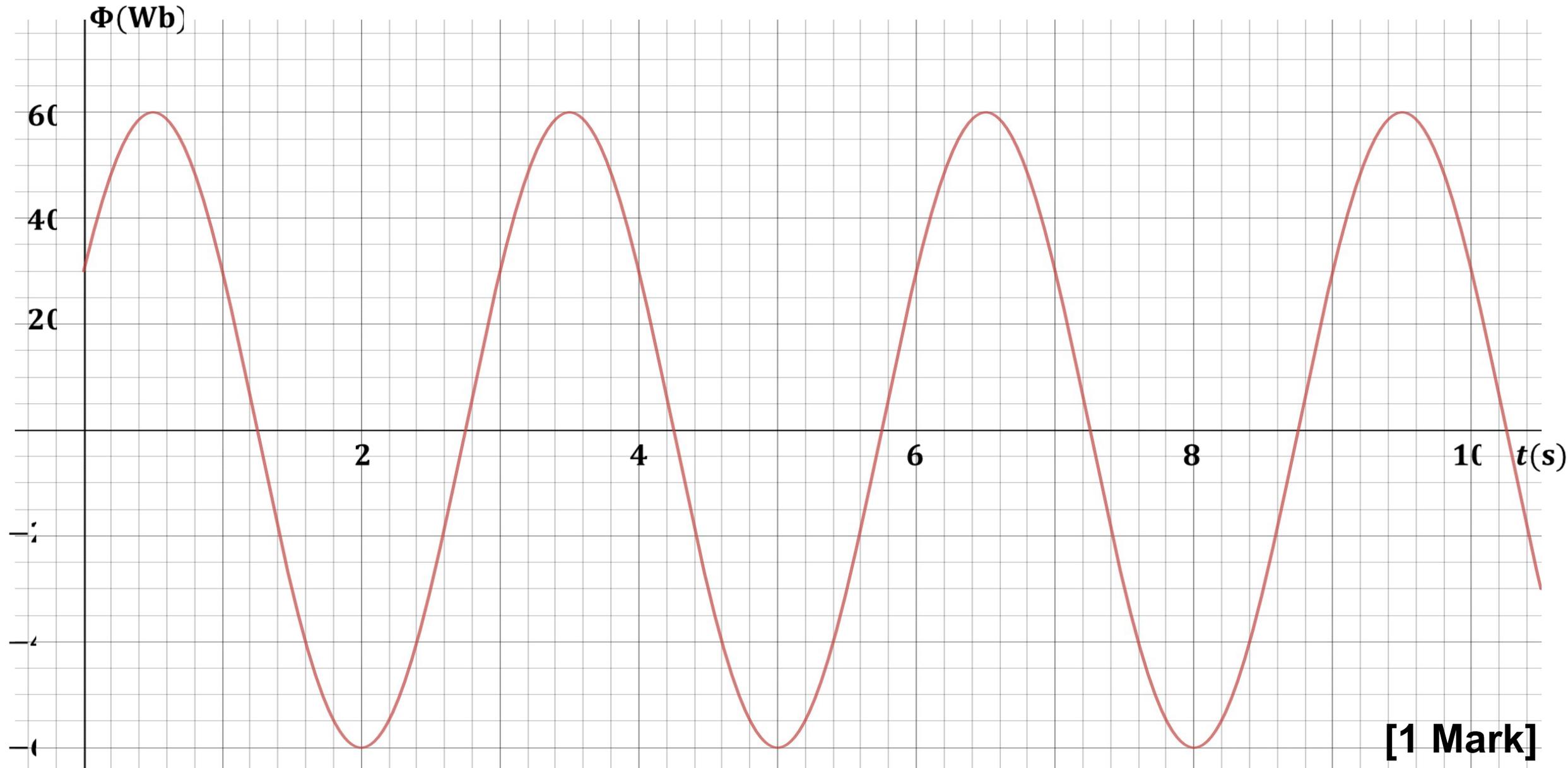
[1 Mark]

20 rotations per minute  $\Rightarrow$  period =  $\frac{60}{20} = 3 \text{ s}$

[1 Mark]

Initial angle is  $60^\circ$ , so start graph at  $600 \cos 60 = 300 \text{ Wb}$

[1 Mark]



[1 Mark]

1.

2. A power plant uses a transformer to decrease the current in power lines and reduce energy lost through heat. It estimates that the company loses £1 a day for every ampere above **800 A** in its power lines. The plant generates power at **50 kW** which is sent into an ideal step-up transformer with **45** and **300** turns on its primary and secondary coils respectively. The input p.d is **8 V**. Estimate how much money would be lost in a day with this setup.

**[3 marks]**

## Exam Question Answer

Rearrange transformer equations in terms of known quantities

$$\frac{I_P}{I_S} = \frac{N_S}{N_P}$$

$$I_S = \frac{I_P N_P}{N_S}$$

$$I_P = \frac{P_{input}}{V_P} = \frac{P_{output}}{V_P}$$

$$I_S = \frac{P_{output} N_P}{V_P N_S}$$

[1 Mark]

## Exam Question Answer

Substitute in given variables to determine output power

$$I_S = \frac{P_{output} N_P}{V_P N_S} = \frac{50 \times 10^3 \times 45}{8 \times 300} = 937.5 \text{ A}$$

[1 Mark]

Calculate money lost

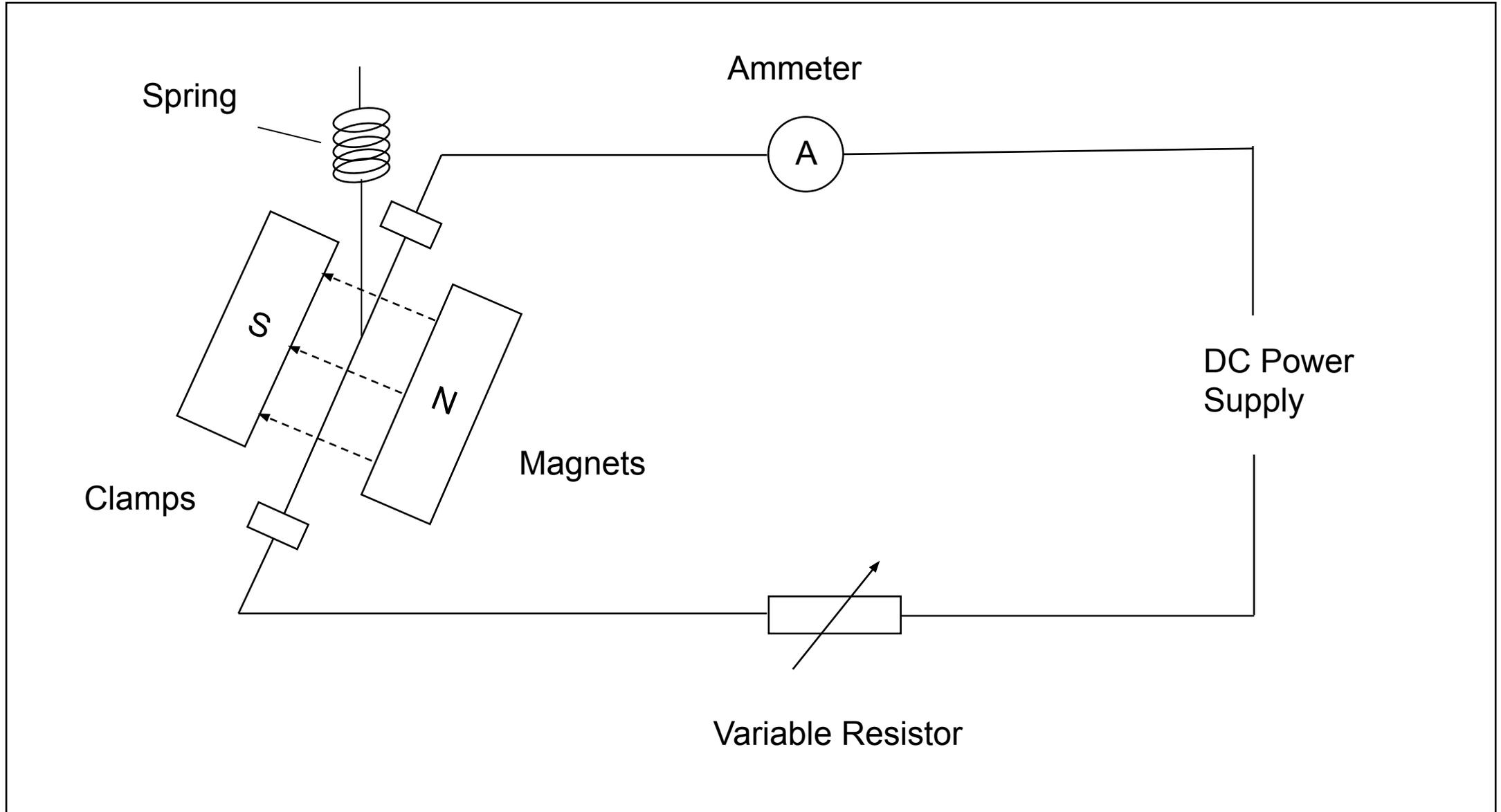
$$\text{Money lost} = \text{£}1 \times (937.5 \text{ A} - 800 \text{ A}) = \text{£}137.50$$

[1 Mark]

3. Akane sets up an experiment to calculate the magnetic field density between two magnets. She sets up a circuit with a DC power supply, variable resistor and ammeter. She then loosely holds a section of the wire between the two magnets and hooks it to a spring with known spring constant. Her setup is shown in the diagram.

Describe a potential method she could use with this setup to calculate the magnetic flux density of the field. Specify how she could make her results as accurate as possible

**[6 marks]**



## Method

- Direct current anticlockwise around circuit
- Clamped wire will experience a downward magnetic force.
- Force causes string to be extended, extension can be measured.
- Hooke's Law can be used to determine magnitude of force from extension,  $F = kx$

## Method

- Use the variable resistor to measure force,  $F$  for varying currents,  $I$
- Plotting  $F$  against  $I$  will give a straight line graph. As  $F = BIL \sin \theta$ , the magnetic flux density  $B$  can be determined from the gradient of the graph.

[Max 4 points]

## Accuracy

- Use a protractor to accurately measure the angle between the wire and the field. Alternatively, use a set square to ensure wire and field are perpendicular
- Use a micrometre to measure the spring extensions and the length of wire in the field.
- Record readings for at least 8 different currents to find most accurate line of best fit

## Accuracy

- Hooking spring to the wire at two points restricts turning effect of magnetic force.
- Avoid using large currents/forces to stop spring reaching elastic limit

[Max 4 points]