7.9 Electromagnetic Induction

XVIII

PHYSICS

AQA A Level Revision Notes

A Level Physics AQA

7.9 Electromagnetic Induction

CONTENTS

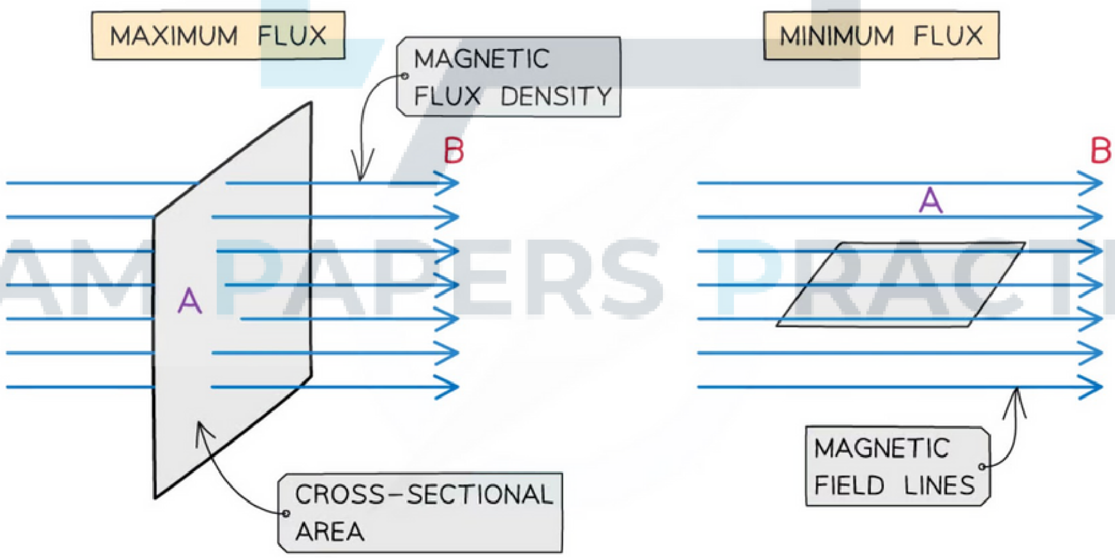
7.9.1 Magnetic Flux

Magnetic Flux

- Electromagnetic induction is when an **e.m.f** is induced in a closed circuit conductor due to it moving through a **magnetic field**
  - Examples are a flat coil or a solenoid
- This happens when a conductor **cuts** through magnetic field lines
- The amount of e.m.f induced is determined by the magnetic flux
- The amount of magnetic flux varies as the coil rotates within the field
  - The flux is the total magnetic field that passes through a given area
  - It is a maximum when the magnetic field lines are **perpendicular** to the plane of the area
  - It is 0 when the magnetic field lines are **parallel** to the plane of the area

- The **magnetic flux** is defined as:

  The product of the magnetic flux density and the cross-sectional area perpendicular to the direction of the magnetic flux density



The magnetic flux is maximum when the magnetic field lines and the area they are travelling through are perpendicular

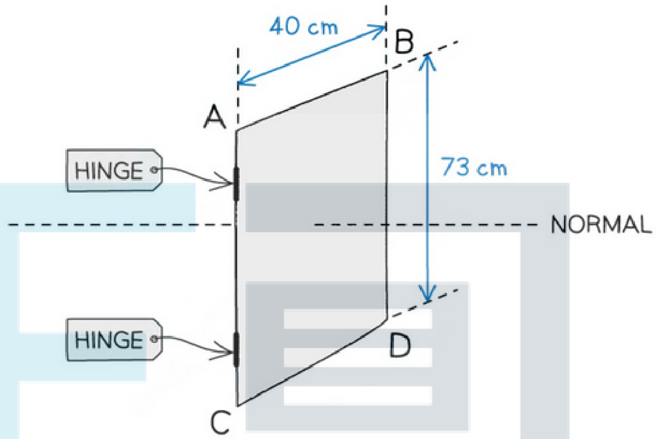
- In other words, magnetic flux is the **number of magnetic field lines through a given area**
- Magnetic flux is defined by the symbol Φ (greek letter 'phi')
  - It is measured in units of **Webers (Wb)**
- Magnetic flux can be calculated using the equation:

$$\Phi = BA$$

- Where:
  - Φ = magnetic flux (Wb)
  - B = magnetic flux density (T)
  - A = cross-sectional area (m^2)

Worked Example

An aluminium window frame has a width of 40 cm and length of 73 cm shown in the diagram below.



The frame is hinged along the vertical edge AC. When the window is closed, the frame is normal to the Earth's magnetic field with magnetic flux density 1.8×10^{-5} T.

a) Calculate the magnetic flux through the window when it is closed.

b) Sketch the graph of the magnetic flux against angle between the field lines and the normal when the window is opened and rotated by 180°

Part (a)

Step 1: Write out the known quantities

Cross-sectional area, $A = 40 \text{ cm} \times 73 \text{ cm} = (40 \times 10^{-2}) \times (73 \times 10^{-2}) = 0.292 \text{ m}^2$

Magnetic flux density, $B = 1.8 \times 10^{-5}$ T

Step 2: Write down the equation for magnetic flux

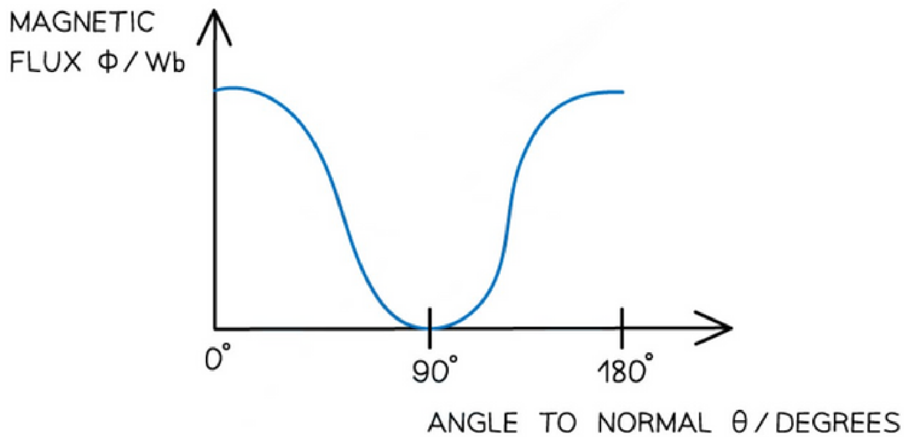
$$\Phi = BA$$

Step 3: Substitute in values

$$\Phi = (1.8 \times 10^{-5}) \times 0.292 = 5.256 \times 10^{-6} = 5.3 \times 10^{-6} \text{ Wb}$$

Part (b)

The magnetic flux will be at a minimum when the window is opened by 90° and a maximum when fully closed or opened to 180°



Exam Tip

Consider carefully the value of θ, it is the angle between the field lines and the line **normal** (perpendicular) to the plane of the area the field lines are passing through. If it helps, drawing the normal on the area provided will help visualise the correct angle.

7.9.2 Magnetic Flux Linkage

Magnetic Flux Linkage

- More coils in a wire mean a **larger** e.m.f is induced
- The **magnetic flux linkage** is a quantity commonly used for solenoids which are made of N turns of wire
- The flux linkage is defined as:

The product of the magnetic flux and the number of turns of the coil

- It is calculated using the equation:

Magnetic flux linkage = ΦN = BAN

- Where:
  - Φ = magnetic flux (Wb)
  - N = number of turns of the coil
  - B = magnetic flux density (T)
  - A = cross-sectional area (m^2)

- The flux linkage ΦN has the units of **Weber turns (Wb turns)**

Flux Linkage in a Rotating Rectangular Coil

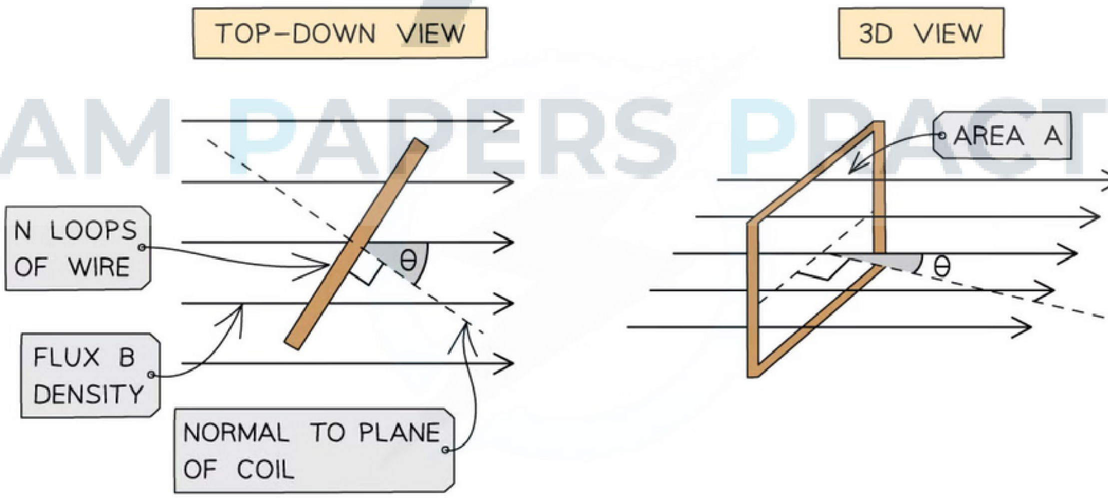
- When the magnet field lines are not completely perpendicular to the area *A*, then the component of magnetic flux density *B* is perpendicular to the area is taken
- The equation then becomes:

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

- Where:
  - Φ = magnetic flux (Wb)
  - B = magnetic flux density (T)
  - A = cross-sectional area (m^2)
  - θ = angle between magnetic field lines and the line perpendicular to the plane of the area (often called the normal line) (degrees)

- This means the magnetic flux is:
  - **Maximum** = BA when $\cos(\theta) = 1$ therefore **θ = 0°**. The magnetic field lines are perpendicular to the plane of the area
  - **Minimum** = 0 when $\cos(\theta) = 0$ therefore **θ = 90°**. The magnetic fields lines are parallel to the plane of the area

- An e.m.f is induced in a circuit when the magnetic flux linkage changes with respect to time
- This means an e.m.f is induced when there is:
  - A changing magnetic flux density B
  - A changing cross-sectional area A
  - A change in angle θ



The magnetic flux through a rectangular coil decreases as the angle between the field lines and plane decrease

- Magnetic field lines may not be completely perpendicular to the plane of the area that they pass through
- Therefore, the component of the flux density which is perpendicular is equal to:

$$\Phi N = BAN\cos(\theta)$$

- Where:
  - N = number of turns of the coil

Worked Example

A solenoid of circular cross-sectional radius 0.40 m and 300 turns is placed perpendicular to a magnetic field with a magnetic flux density of 5.1 mT. Determine the magnetic flux linkage for this solenoid.

Step 1: Write out the known quantities

- Cross-sectional area, $A = \pi r^2 = \pi(0.4)^2 = 0.503\ m^2$
- Magnetic flux density, B = 5.1 mT
- Number of turns of the coil, N = 300 turns

Step 2: Write down the equation for the magnetic flux linkage

$$\Phi N = BAN$$

Step 3: Substitute in values and calculate

$$\Phi N = (5.1 \times 10^{-3}) \times 0.503 \times 300 = 0.7691 = \mathbf{0.77\ Wb\ turns\ (2\ s.f)}$$

7.9.3 Principles of Electromagnetic Induction

Principles of Electromagnetic Induction

- Electromagnetic induction is a phenomenon which occurs when an e.m.f is induced when a conductor moves through a magnetic field
- When the conductor cuts through the magnetic field lines:
  - This causes a change in **magnetic flux (ΔΦ)**
  - Which causes **work to be done**
  - This work is then transformed into **electrical energy**

- Therefore, if attached to a complete circuit, a current will be induced
- This is known as **electromagnetic induction** and is defined as:

> **The process in which an e.m.f is induced in a closed circuit due to changes in magnetic flux**

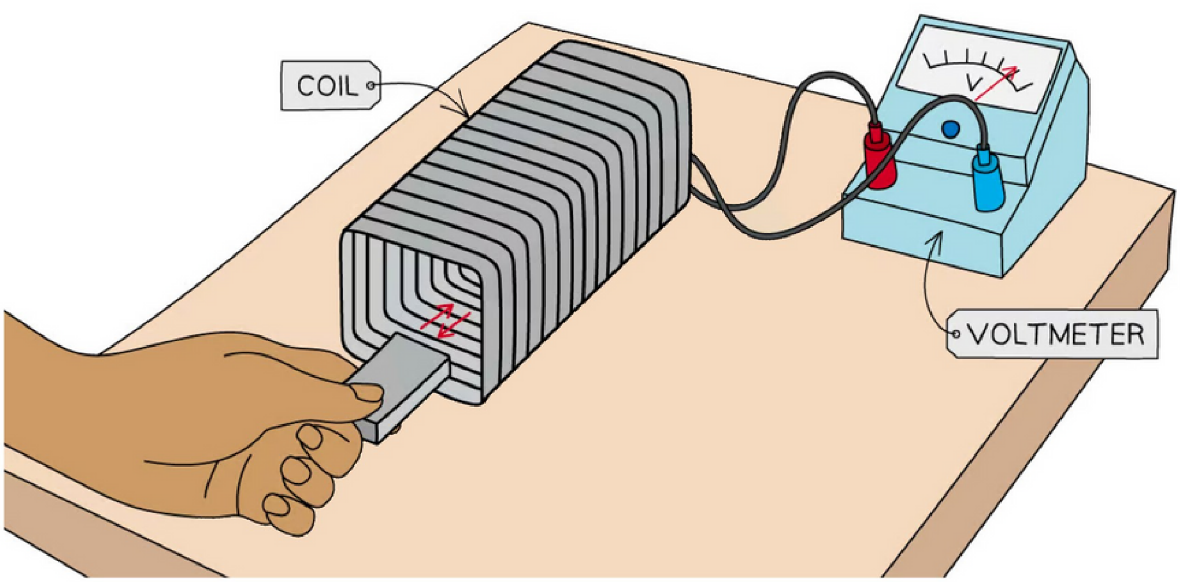
- This can occur either when:
  - A conductor cuts through a **magnetic field**
  - The direction of a magnetic field through a coil changes

- Electromagnetic induction is used in:
  - Electrical **generators** which convert mechanical energy to electrical energy
  - **Transformers** which are used in electrical power transmission

- This phenomenon can easily be demonstrated with a magnet and a coil, or a wire and two magnets

Experiment 1: Moving a magnet through a coil

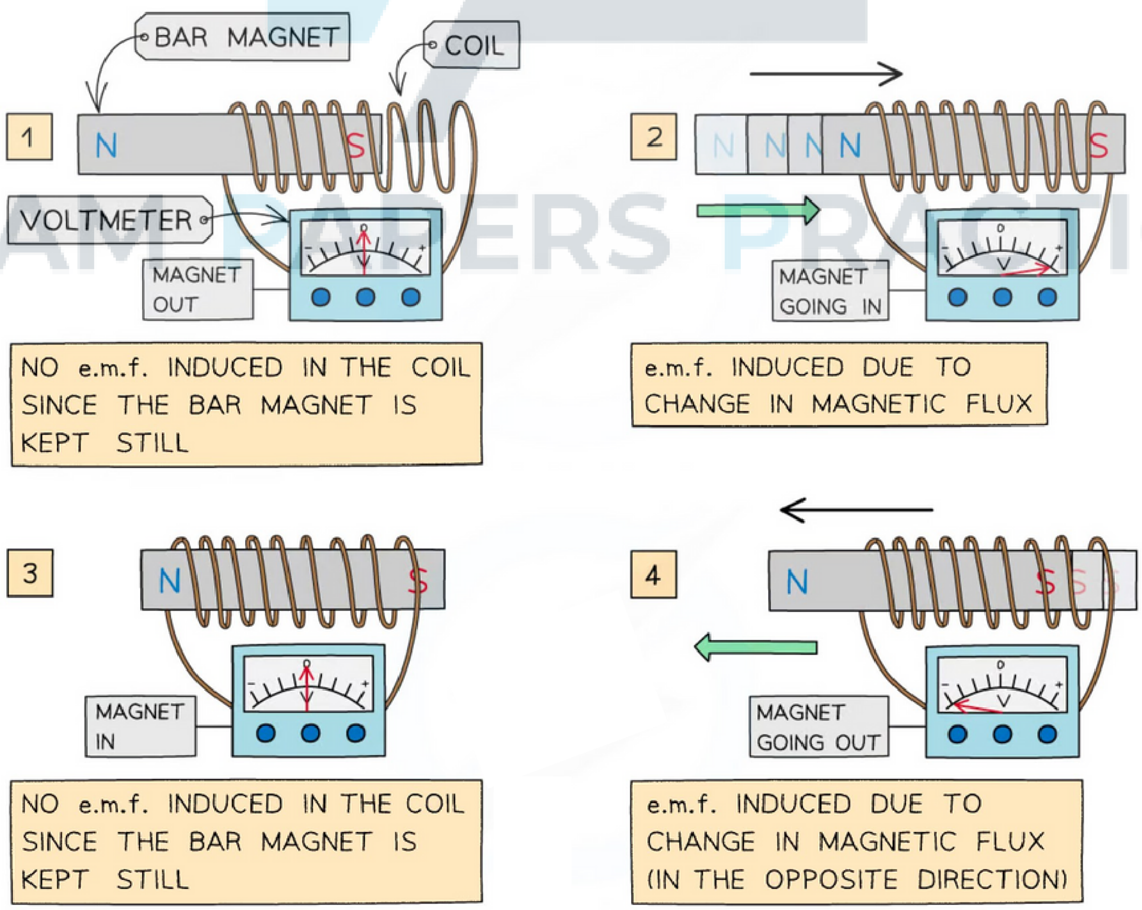
- When a coil is connected to a sensitive voltmeter, a bar magnet can be moved in and out of the coil to induce an e.m.f



A bar magnet is moved through a coil connected to a voltmeter to induce an e.m.f

The expected results are:

- When the bar magnet is **not moving**, the voltmeter shows a **zero reading**
  - When the bar magnet is held still inside, or outside, the coil, the rate of change of flux is zero, so, there is **no e.m.f induced**
- When the bar magnet begins to move inside the coil, there is a reading on the voltmeter
  - As the bar magnet moves, its magnetic field lines 'cut through' the coil, generating a **change in magnetic flux** ($\Delta\Phi$)
  - This induces an **e.m.f** within the coil, shown momentarily by the reading on the voltmeter
- When the bar magnet is taken back out of the coil, an e.m.f is induced in the **opposite direction**
  - As the magnet changes direction, the direction of the current changes
  - The voltmeter will momentarily show a reading with the opposite sign
- Increasing the **speed** of the magnet induces an e.m.f with a **higher magnitude**
  - As the speed of the magnet increases, the rate of change of flux increases
- The direction of the electric current, and e.m.f, induced in the conductor is such that it **opposes** the change that produces it

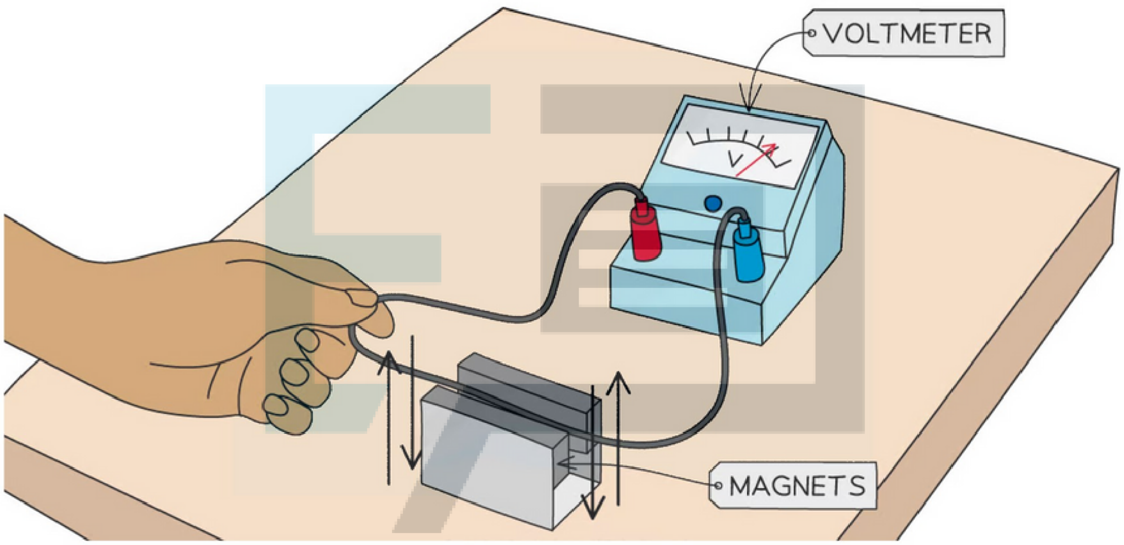


An e.m.f is induced only when the bar magnet is moving through the coil

- Factors that will increase the induced e.m.f are:
  - Moving the magnet **faster** through the coil
  - Adding more **turns** to the coil
  - Increasing the **strength** of the bar magnet

Experiment 2: Moving a wire through a magnetic field

- When a long wire is connected to a voltmeter and moved between two magnets, an e.m.f is induced
  - **Note:** there is no current flowing through the wire to start with



A wire is moved between two magnets connected to a voltmeter to induce an e.m.f

The expected results are:

- When the wire is **not moving**, the voltmeter shows a **zero reading**
  - When the wire is held still inside, or outside, the magnets the rate of change of flux is zero so there is **no e.m.f induced**

- As the wire is moved through between the magnets, an **e.m.f** is induced within the wire, shown momentarily by the reading on the voltmeter
  - As the wire moves, it 'cuts through' the magnetic field lines of the magnet, generating a **change in magnetic flux**

- When the wire is taken back out of the magnet, an e.m.f is induced in the **opposite direction**
  - As the wire changes direction, the direction of the current changes
  - The voltmeter will momentarily show a reading with the opposite sign

- As before, the direction of the electric current, and e.m.f, induced in the conductor is such that it **opposes** the change that produces it
- Factors that will increase the induced e.m.f are:

- Increasing the **length** of the wire
- Moving the wire between the magnets **faster**
- Increasing the **strength** of the magnets

7.9.4 Faraday's & Lenz's Laws

Faraday's & Lenz's Laws

- Faraday's Law links the rate of change of flux linkage with e.m.f
- It is defined as:

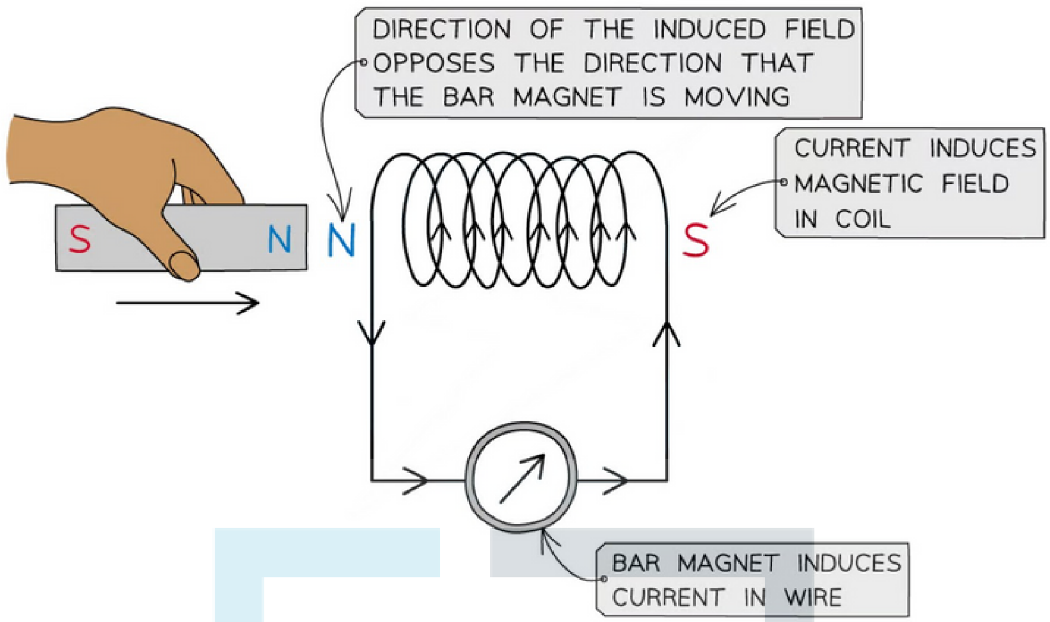
The magnitude of the induced e.m.f is directly proportional to the rate of change in magnetic flux linkage

- Lenz's Law gives the **direction** of the induced e.m.f as defined by Faraday's law:

The induced e.m.f acts in such a direction to produce effects that oppose the change causing it

Experimental Evidence for Lenz's Law

- To verify Lenz's law, the only apparatus needed is:
    - A bar magnet
    - A coil of wire
    - A sensitive ammeter
- **Note:** a cell is **not** required
- A known pole (either north or south) of the bar magnet is pushed into the coil, which induces a magnetic field in the coil
    - Using the right-hand grip rule, the curled fingers indicate the direction of the **current** and the thumb indicates the direction of the **induced magnetic field**
- The direction of the current is observed on the ammeter
    - Reversing the magnet direction would give an opposite deflection on the meter
- The induced field (in the coil) **repels** the bar magnet
- This is because of **Lenz's law**:
    - The direction of the induced field in the coil pushes against the change creating it, ie. the bar magnet



Lenz's law can be verified using a coil connected in series with a sensitive ammeter and a bar magnet

Calculating Induced EMF

- Faraday's Law as an equation is defined as:

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

- Where:
  - ε = induced e.m.f (V)
  - N = number of turns of coil
  - $\Delta\phi$ = change in magnetic flux (Wb)
  - Δt = time interval (s)

- This equation shows that the **gradient** of a magnetic flux against time graph is the e.m.f
- Lenz's law combined with Faraday's law is given by the equation:

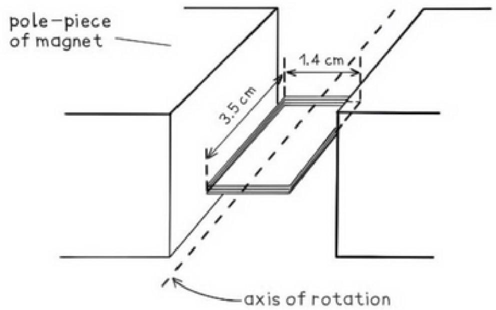
$$\varepsilon = -N \frac{\Delta\Phi}{\Delta t}$$

- This equation shows:
  - When a bar magnet goes through a coil, an e.m.f is induced within the coil due to a change in magnetic flux
  - A current is also induced which means the coil now has its own magnetic field
  - The coil's magnetic field acts in the **opposite direction** to the magnetic field of the bar magnet (shown by the minus sign)

- If a direct current (d.c) power supply is replaced with an alternating current (a.c) supply, the e.m.f induced will also be alternating with the same frequency as the supply

Worked Example

A small rectangular coil contains 350 turns of wire. The longer sides are 3.5 cm and the shorter sides are 1.4 cm.



The coil is held between the poles of a large magnet so that the coil can rotate about an axis through its centre.

The magnet produces a uniform magnetic field of flux density 80 mT between its poles.

The coil is positioned horizontally and then turned through an angle of 40° in a time of 0.18 s.

Calculate the magnitude of the average e.m.f. induced in the coil.

Step 1: Write down the known quantities

- Magnetic flux density, B = 80 mT = 80×10^{-3} T
- Area, $A = 3.5 \times 1.4 = (3.5 \times 10^{-2}) \times (1.4 \times 10^{-2}) = 4.9 \times 10^{-4}$ m^2
- Number of turns, N = 350
- Time interval, Δt = 0.18 s
- Angle between coil and field lines = 40°
  - Therefore θ, the angle between the normal to the area and the field lines = (90 – 40) = 50°

Step 2: Write out the equation for Faraday's law:

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

Step 3: Write out the equation for flux linkage:

$$\Phi N = BAN\cos(\theta)$$

Step 4: Substitute values into flux linkage equation:

$$\Phi N = (80 \times 10^{-3}) \times (4.9 \times 10^{-4}) \times 350 \times \cos(50) = 8.82 \times 10^{-3} \text{ Wb turns}$$

Step 5: Substitute flux linkage and time into Faraday's law equation:

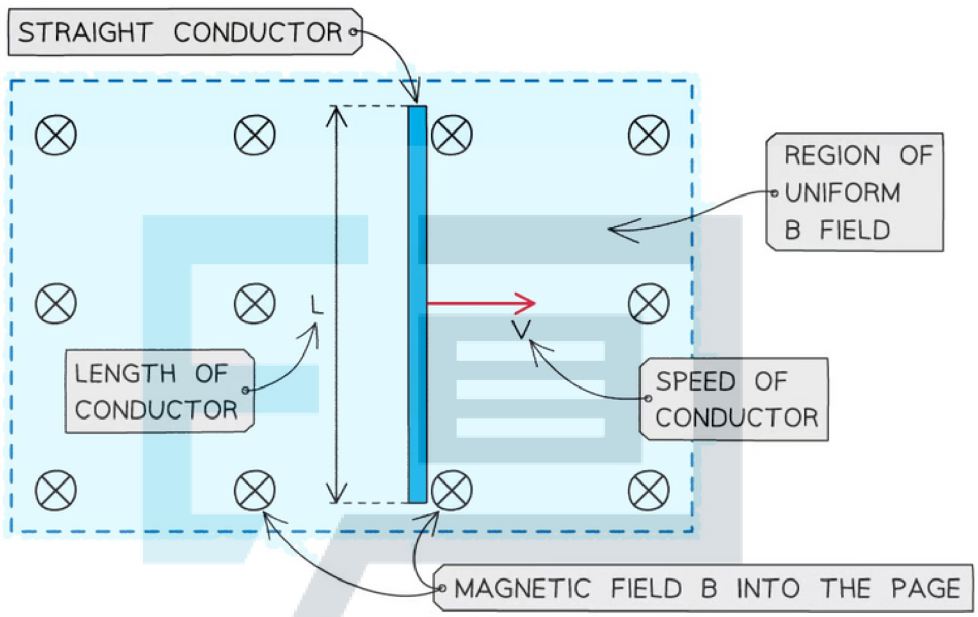
$$\varepsilon = \frac{8.82 \times 10^{-3}}{0.18} = 0.049 = 49\ \text{mV}$$

Exam Tip

The 'magnitude' of the e.m.f just means its size, rather than direction. This is often what is required in exam questions, so the minus sign in Lenz's law is not necessarily required in calculations.However, you may be expected to explain the significance of the minus sign in Lenz's law.

Moving Conductors in a Magnetic Field

- Similar to a coil or a solenoid, a straight conducting rod moving through a magnetic field will also have an e.m.f induced in it
- This is only when the conductor moves **perpendicular** to the magnetic field lines where it cuts through the magnetic flux lines



Conducting rod moving perpendicular to a magnetic field directed into the page

- The conducting rod has a length L and moves through a uniform magnetic field with flux density B at a constant velocity v
- The distance travelled by the conductor is:

$$s = v\Delta t$$

- Where:
  - s = distance travelled (m)
  - v = velocity (m s^{-1})
  - Δt = time interval (s)

- Therefore, the area A of the magnetic flux that it cuts through is:

$$A = Lv\Delta t$$

- The total flux the conductor cuts through is:

$$\Delta\Phi = BA = BLv\Delta t$$

- Faraday's law gives the e.m.f induced:

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

- Where for the conductor, $N = 1$
- Substituting the change in magnetic flux $\Delta\Phi$ into the e.m.f equation:

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

- Therefore, the induced e.m.f in the conductor as it moves through the magnetic field is:

$$\varepsilon = BLv$$

- This equation shows that the e.m.f induced increases if:
  - A **longer** conductor is in the field
  - The magnetic field **strength** is larger
  - The conductor cuts through the field lines **faster**

Worked Example

An aeroplane with a wingspan of 34.5 m flies at a speed 253 m s^{-1} perpendicular to the Earth's magnetic field. The Earth's magnetic field at the aeroplane's location has a strength of 0.06 mT.

Calculate the induced e.m.f between the wing tips.

Step 1: Write down the known quantities

- Length, $L = 34.5$ m
- Velocity, $v = 253$ m s^{-1}
- Magnetic field strength, $B = 0.06$ mT $= 0.06 \times 10^{-3}$ T

Step 2: Write down the e.m.f equation

$$\varepsilon = BLv$$

Step 3: Substitute in the values

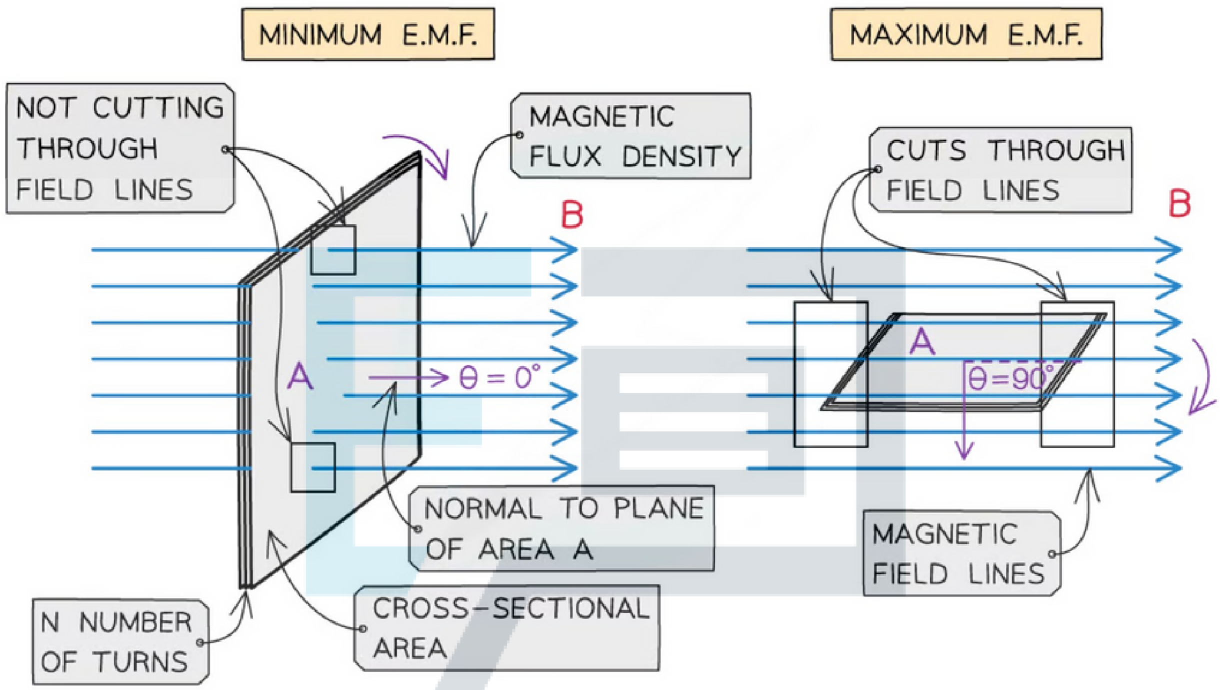
$$\varepsilon = (0.06 \times 10^{-3}) \times 34.5 \times 253 = 0.52371 = \mathbf{0.52\ V}$$

Exam Tip

Although calculations about a straight conductor moving through a magnetic field are common, the exam questions can be in other contexts.For example, the wing of an aeroplane moving through the Earth's magnetic field like in the worked example. If this is the case, treat the situation like the straight conductor and use the same equations

EMF Inducted in a Rotating Coil

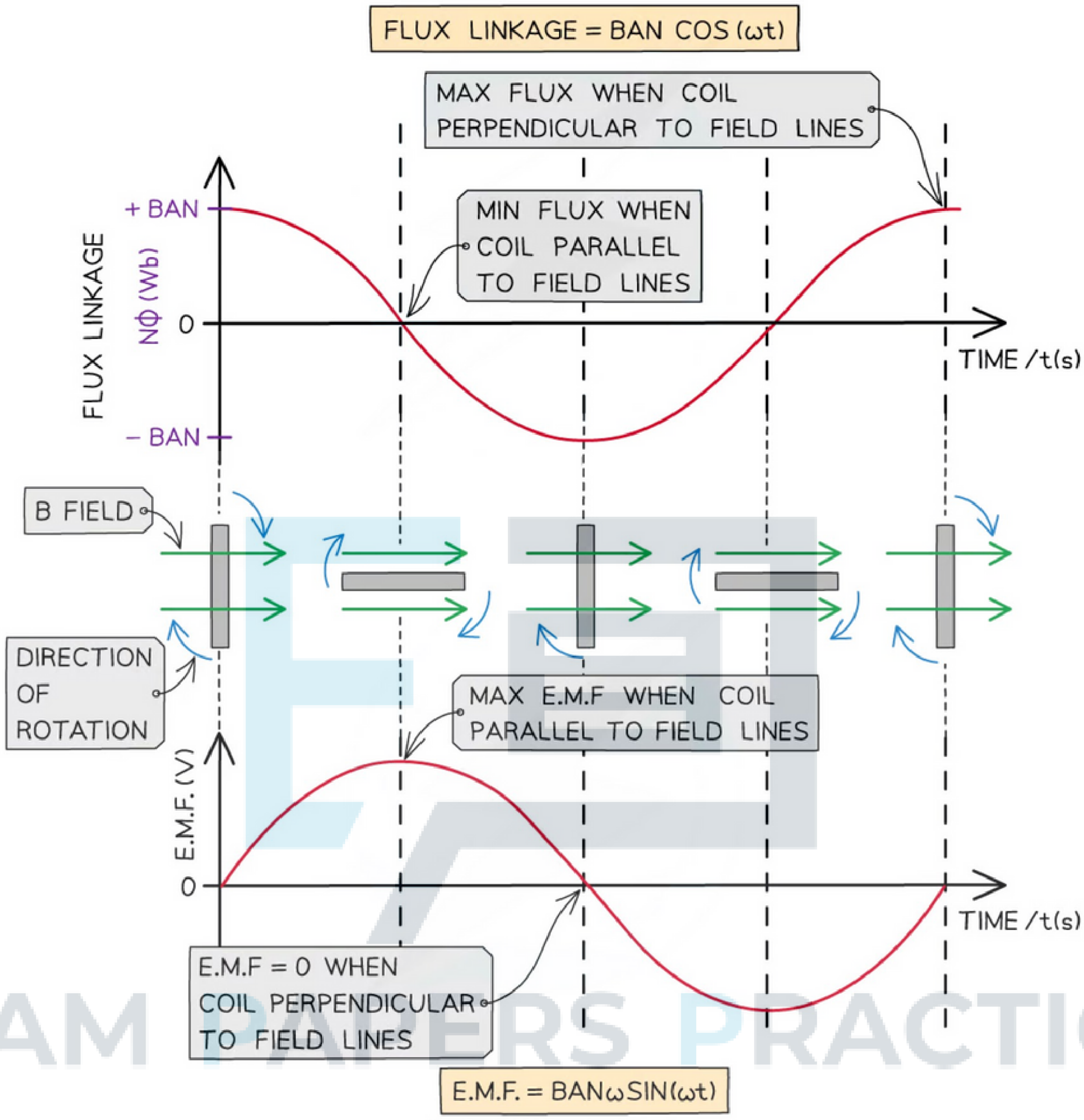
- When a coil rotates in a uniform magnetic field, the flux through the coil will vary as it rotates
- Since e.m.f is the rate of change of flux linkage, this means the e.m.f will also change as it rotates
  - The maximum e.m.f is when the coil **cuts through** the most field lines
  - The e.m.f induced is an **alternating** voltage



The maximum e.m.f is when the coil cuts through the field lines when they are parallel to the plane of the coil

- This means that the e.m.f is:
  - **Maximum** when **θ = 90°**. The magnetic field lines are parallel to the plane of the area (**or** the normal to the area is perpendicular to the field lines)
  - **0** when **θ = 0°**. The magnetic fields lines are perpendicular to the plane of the area (**or** the normal to the area is parallel to the field lines)

- Note that this is the **opposite** of the maximum and minimum flux through the coil



The e.m.f and flux linkage are 90° out of phase

- The flux linkage can also be written as:

$$N\Phi = BAN\cos(\omega t)$$

- Where the angle θ depends on the angular speed of the coil, ω:

$$\theta = \omega t$$

- The induced e.m.f, ε from Faraday's Law depends on the **rate of change** of flux linkage, which means it can also be written as:

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

- Where:
  - ε = e.m.f induced in the coil (V)

- B = magnetic flux density (T)
- A = cross-sectional area of the coil (m^2)
- ω = angular speed of the coil ($rad\ s^{-1}$)
- t = time (s)

- The equation shows that the e.m.f varies **sinusoidally** and it is 90° out of phase with the flux linkage

Worked Example

A rectangular coil was 40 turns, each with an area of 0.5 m^2 is rotated at 42 $rad\ s^{-1}$ in a uniform 3.15 mT magnetic field.

Calculate the maximum e.m.f induced in the coil.

Step 1: Write the known quantities

- Number of turns, $N = 40$
- Area, $A = 0.5\ m^2$
- Angular velocity, $\omega = 42\ rad\ s^{-1}$
- Magnetic flux density, $B = 3.15\ mT = 3.15 \times 10^{-3}\ T$

Step 2: Write down the e.m.f equation

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

Step 3: Determine when the maximum e.m.f will be

- The maximum e.m.f occurs when $\sin(\omega t) = \pm 1$, or when the coil is parallel to the magnetic field

Step 4: Substitute in the values

$$\varepsilon = (3.15 \times 10^{-3}) \times 0.5 \times 40 \times 42 \times \pm 1 = \mathbf{\pm 2.6\ V}$$

Exam Tip

Remember not to get mixed up with when the e.m.f or the flux linkage is at their maximum:

- When the plane of the coil is **perpendicular** to the field lines
  - The flux linkage is at its **maximum**
  - The e.m.f = **0**
- When the plane of the coil is **parallel** to the field lines
  - The flux linkage is **0**
  - the e.m.f is at its **maximum**

Since ω is in units of rads s^{-1}, make sure your calculator is in **radians** mode before doing entering any values into sin(ωt) or cos(ωt)

Required Practical: Investigating Flux Linkage on a Search Coil

Aims of the Experiment

- The overall aim of this experiment is to determine how the magnetic flux linkage varies with the angle of rotation of a search coil
- This is done by rotating a search coil through a uniform magnetic field created by a larger coil and recording the induced e.m.f within it
    - This is just one example of how this required practical might be carried out

Variables

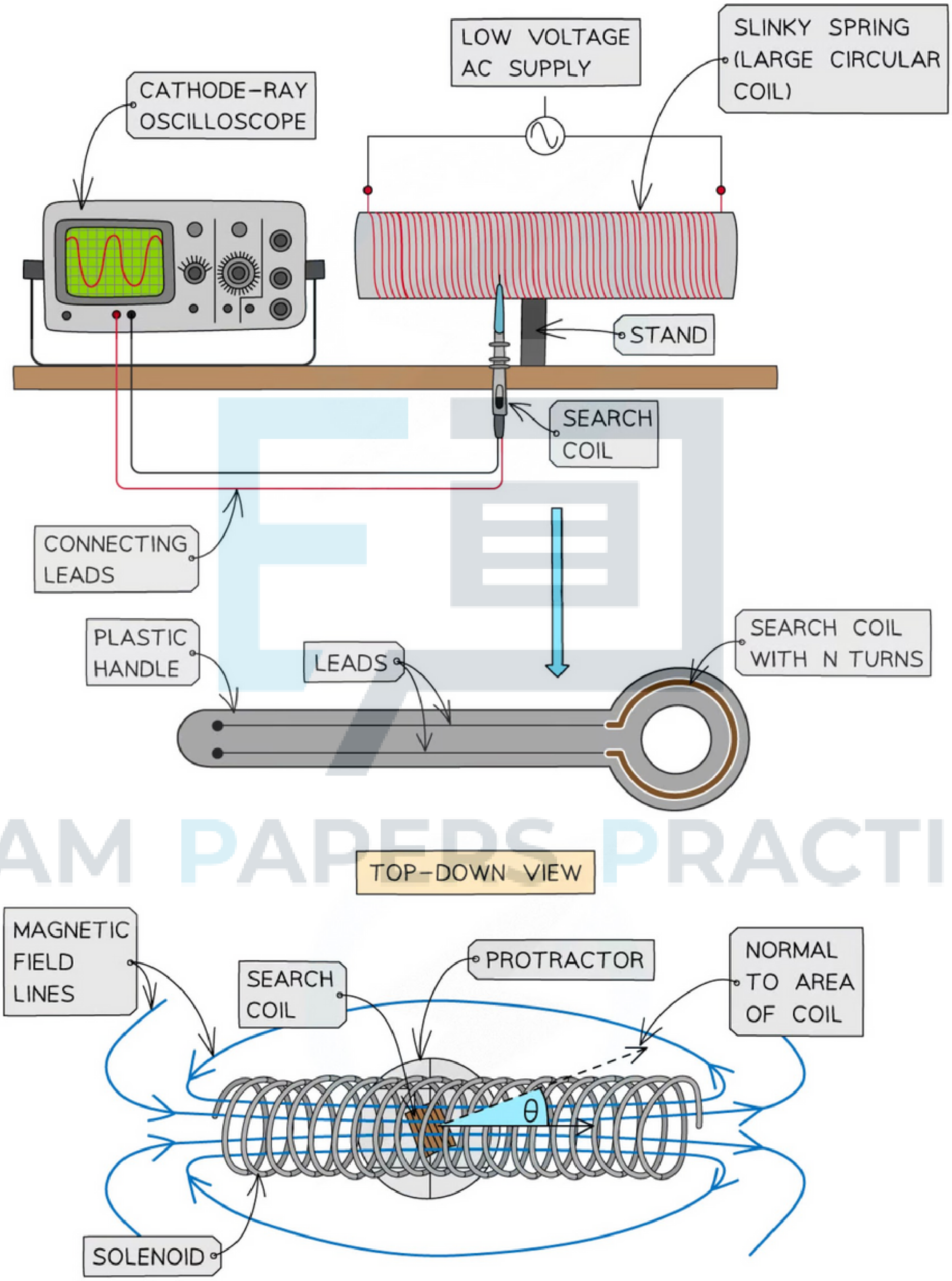
- Independent variable = Angle between the normal to the search coil and the magnetic field lines, θ
- Dependent variable= Induced e.m.f, ε
- Control variables:
    - Area of the search coil, *A*
    - Number of loops on both coils, *N*
    - Magnetic field strength, *B*
    - Frequency of the power supply, *f*

Equipment List

Apparatus	Purpose
Cathode–ray oscilloscope (CRO)	Used to measure the induced e.m.f. in the search coil
Large circular coil	The solenoid used to create the magnetic field for the search coil
Stand (or support) for circular coil	To support the large circular coil
Low voltage 50 Hz AC supply	To create a changing magnetic field through the search coil
Connecting leads	To connect the solenoid to the CRO
Protractor	To measure the angle of rotation of the search coil
Search coil with 500–2000 turns	To rotate within the magnetic field and measure the change in e.m.f. through
(optional) Clamp stand and boss	To support the search coil

- **Resolution** of measuring equipment:
    - Protractor = 1°
    - CRO = 2 mV / div

Method



1. Arrange the apparatus as shown in the diagram above. The slinky spring should be connected to the alternating power supply so the flux through the search coil placed within it will be constantly changing

2. Set up the CRO so its time-base is switched off, so it only shows the amplitude of the e.m.f. Adjust the voltage per division till the signal can be seen fully on the screen (eg. 10 mV / div)
3. Position the search coil so that it is halfway along the slinky spring
4. Orient the search coil so it is parallel to the slinky spring (and the plane of its area is perpendicular to the field)
5. Record the induced e.m.f in the search coil from the amplitude of the CRO trace. This should ideally be the peak-to-peak voltage (V_{pp}) which will then be halved for the peak e.m.f ε_0
6. Rotate the search coil by 10° (in either direction) using the protractor
7. Record the new V_{pp} and repeat the procedure until the search coil is at 90° to the slinky spring

- An example table might look like this:

ANGLE BETWEEN NORMAL TO AREA OF COIL AND B FIELD LINES

FROM CRO

$\frac{V_{pp}}{2}$

ANGLE θ / DEGREES	SIN (θ)	PEAK -TO- PEAK VOLTAGE V_{pp} / V	PEAK e.m.f. ε_0 / V
0			
10			
20			
30			
40			
50			
60			
70			
80			
90			

Analysing the Results

- The e.m.f in the coil varies with the equation:

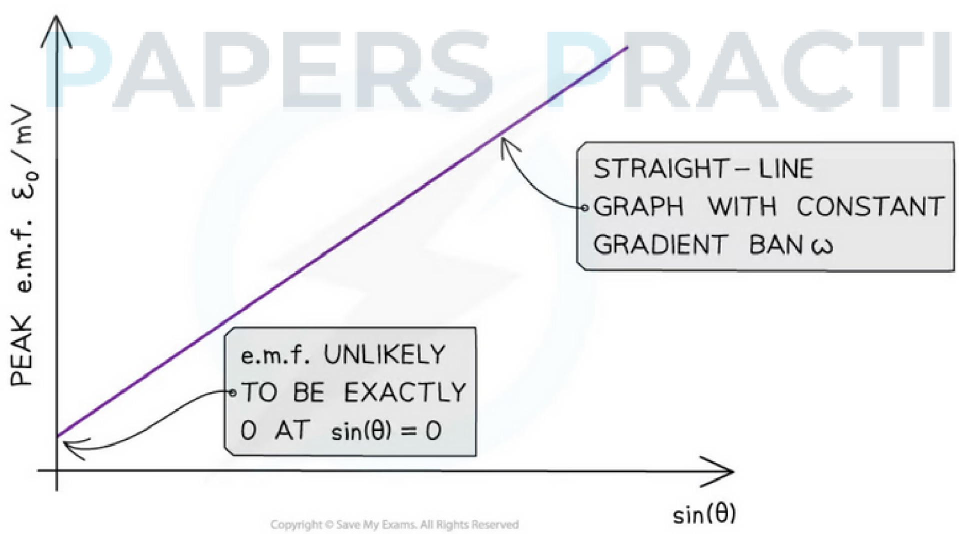
$$\varepsilon = BAN\omega \sin(\theta)$$

  - This comes from the equation for flux linkage at the normal to the plane of the coil at angle θ to the field lines
    - $N\Phi = BAN\cos\theta$
  - The search coil spins at a frequency f, where:
    - $\omega = 2\pi ft$

- The equation for flux linkage is differentiated to obtain an equation for the rate of change of flux linkage:
  - $\frac{N\Delta\varphi}{\Delta t} = \frac{BAN}{\Delta t} \times 2\pi f \times \sin(2\pi ft)$
- The equation for e.m.f. tell us that:
  - $\varepsilon = N\frac{\Delta\varphi}{\Delta t}$
  - Where: $N\Phi = BAN$
  - At maximum flux linkage, this gives a peak e.m.f. $\varepsilon_0 = \frac{BAN\omega}{\Delta t}$
- Hence, this equation can also be written as:
  - $\varepsilon = \varepsilon_0 \sin(2\pi ft)$

- Comparing this to the straight-line equation: y = mx + c
  - y = ε
  - x = sin(θ)
  - m = *BAN*ω
  - c = 0

- Plot a graph of peak e.m.f ε_0 against sin(θ) and draw a line of best fit
- This should be a straight-line graph
  - This shows that the induced e.m.f is proportional to the cosine of the angle between the search coil and the direction of the magnetic field lines



Evaluating the Experiment

Systematic Errors:

- Reduce systematic errors by calibrating the search coil using a known magnetic field and oscilloscope

- The field lines are unlikely to be perfectly parallel and perpendicular to the area of the coil
    - Therefore, the graph is likely to have a y-intercept for sin(θ) = 0
- Read the angle from the protractor far above and from the same point every time to reduce parallax error

Random Errors:

- The experiment could be made more reliable by repeating for a full turn (θ = 360°)
- An improvement could be to use a calibrated motor to rotate the search coil at a steady rate which will make the e.m.f values more accurate
- Use blu tack to make sure the protractor stays in the same place for each reading

Safety Considerations

- Keep water or any fluids away from the electrical equipment
- Make sure no wires or connections are damaged and contain appropriate fuses to avoid a short circuit or a fire
- Don't exceed the specified current rating for the coil in order not to damage it
- The larger coil will heat up whilst the current is through it, especially if it is very thin
    - Therefore, make sure not to leave the current on for longer than necessary

Worked Example

A student investigates how the flux linkage varies with the angle between a search coil and the direction of the magnetic field. They obtain the following results:

Angle θ / degrees	Peak-to-peak voltage V_{pp} / V
0	3.0
10	8.0
20	13.6
30	20.0
40	26.4
50	31.6
60	35.6
70	38.4
80	39.9
90	40.0

Determine whether the results show that the induced e.m.f is proportional to the sine of the angle between the search coil and the direction of the magnetic field lines

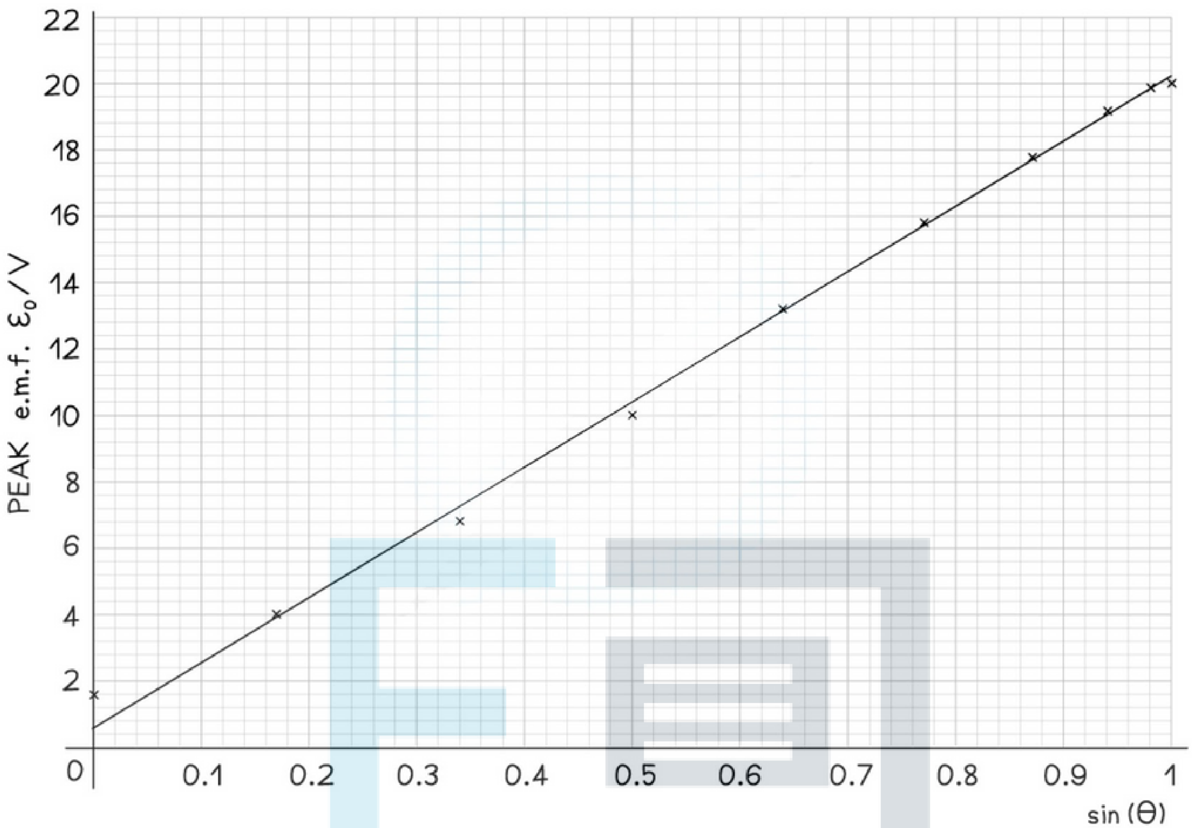
Step 1: Complete the table

- Add the extra columns sin(θ) and peak e.m.f and calculate these values

Angle θ / degrees	sin(θ)	Peak-to-peak voltage V_{pp} / V	Peak e.m.f. ε_0 / V
0	0.00	3.0	1.5
10	0.17	8.0	4.0
20	0.34	13.6	6.8
30	0.50	20.0	10.0
40	0.64	26.4	13.2
50	0.77	31.6	15.8
60	0.87	35.6	17.8
70	0.94	38.4	19.2
80	0.98	39.9	19.9
90	1.00	40.0	20.0

Step 2: Plot a graph of peak e.m.f against sin(θ)

- Make sure the axes are properly labelled and the line of best fit is drawn with a ruler



Step 3: Write a conclusion

- Since the graph of peak e.m.f against sin(θ) is a straight-line graph, this means that the e.m.f is proportional to the sine of the angle between the search coil and the direction of the magnetic field lines