Section
4.6

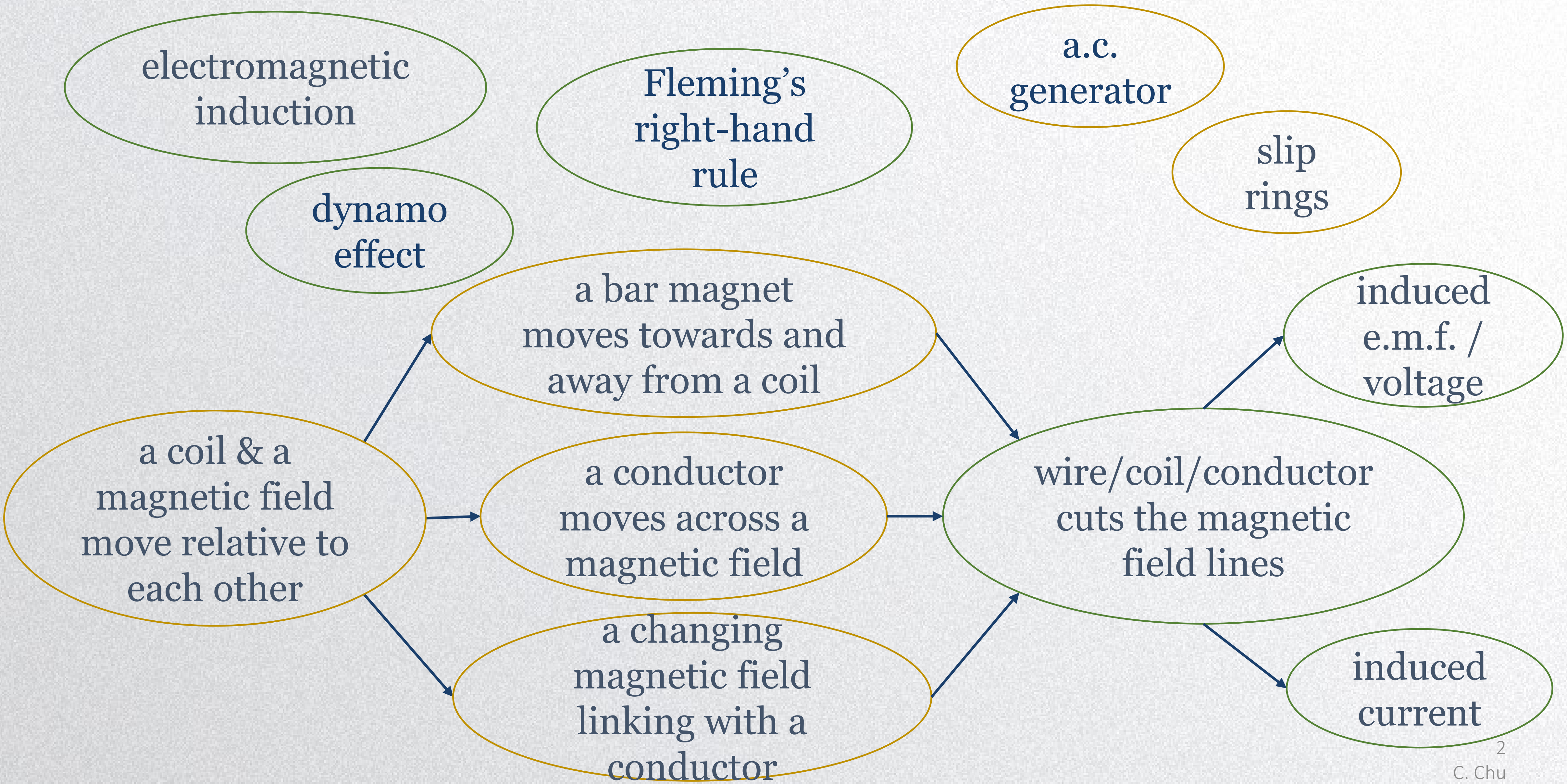
Electromagnetic induction

4.6.1 Generating electricity

4.6.2 Power lines and transformers

4.6.3 How transformers work

Generating electricity



Background

- A motor is a device for transforming electrical energy into mechanical (kinetic) energy. To generate electricity, we need a device that will do the opposite: it must **transform mechanical energy into electrical energy**.
- There are many different designs of generator, just as there are many different designs of electric motor. Some **generate direct current**, others generate **alternating current**. Some use **permanent magnets**, while others use **electromagnets**.
- The two types of current:
  - ✓ a.c.: alternating current, where the direction of current changes periodically
  - ✓ d.c.: direct current, which is unidirectional

Background

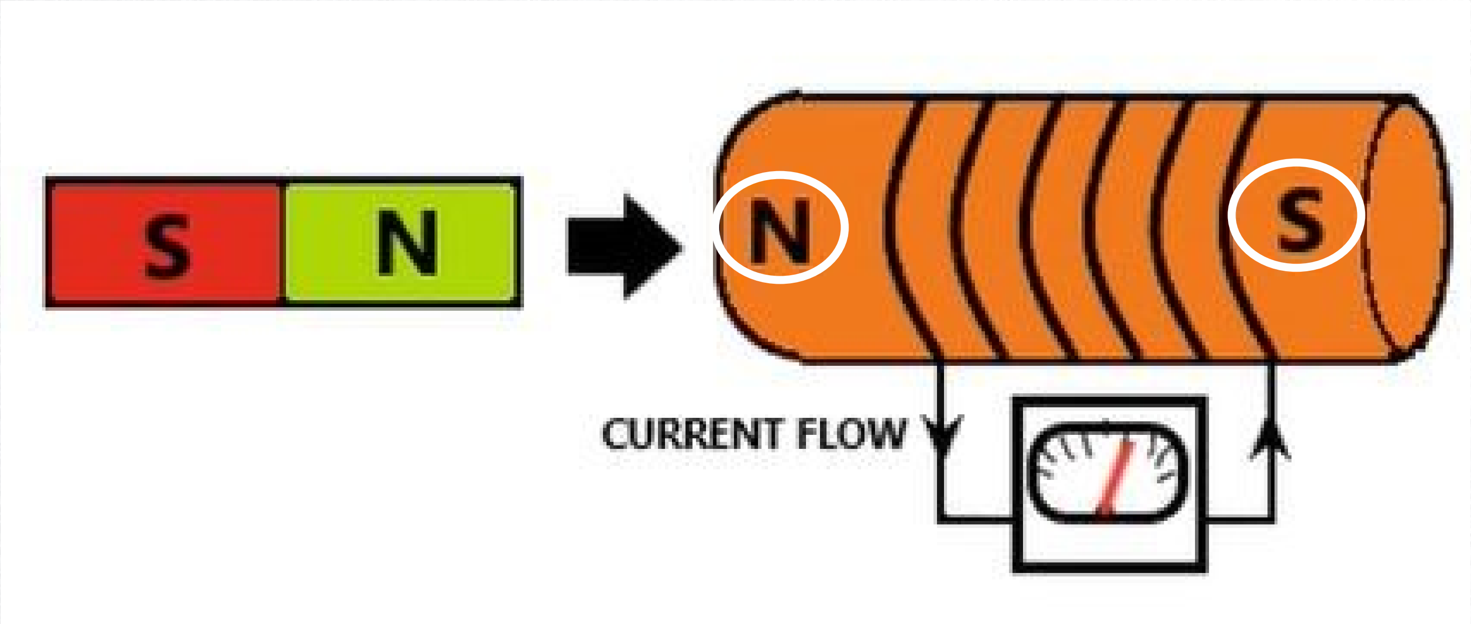
- All of these generators have 3 things in common:
  - ✓ **a magnetic field** (provided by magnets or electromagnets)
  - ✓ **a coil of wire** (fixed or moving)
  - ✓ **movement** (the coil and magnetic field move relative to one another).

- When the coil and the magnetic field move relative to each other, a current flows in the coil if it is part of *a* ***complete circuit***. This is known as an **induced current**.
- If the generator is *not connected up to a circuit (i.e.* ***incomplete circuit****)*, there will be an **induced e.m.f. (or induced voltage)** across its ends, **ready to make a current flow around a circuit**.

Electromagnetic Induction

- The process of **generating electricity from motion** is called **electromagnetic induction**.
- A conductor (such as a wire) moving across a magnetic field or a changing magnetic field linking with a conductor can induce an e.m.f. in the conductor.
  - ✓ Magnetic field lines of the magnet get "cut" from the coil.
- When a bar magnet is moved towards and away from a coil, it induced e.m.f. within the coil.
  - ✓ Magnetic field lines of the magnet get "cut" from the coil.

Bar magnet moving towards the coil

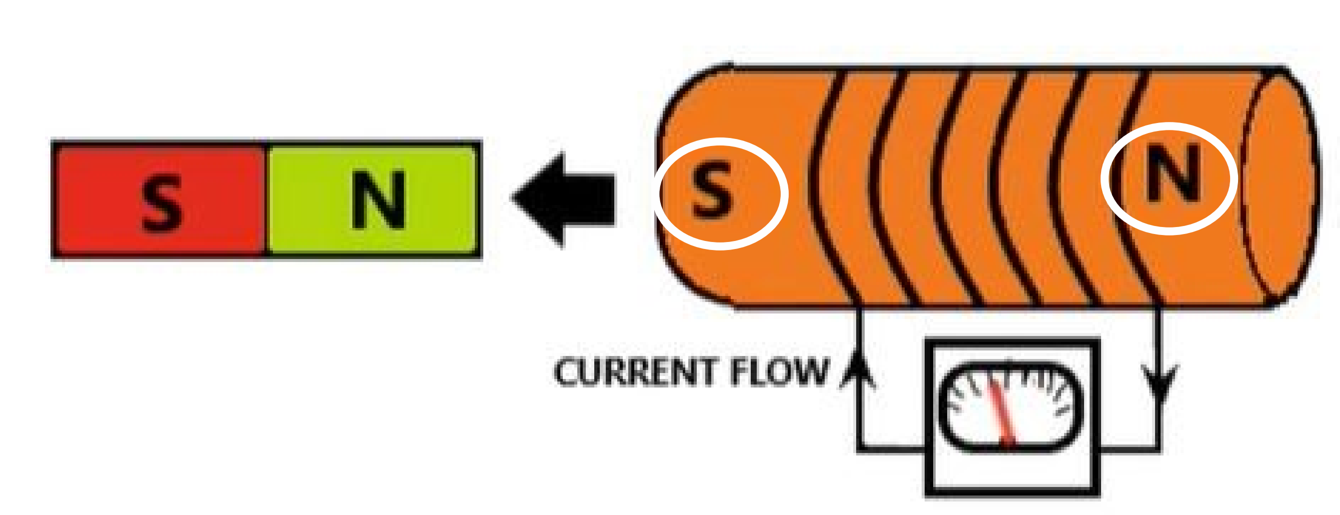


1. the coil and magnetic field move relative to one another
2. coil cuts the magnetic field lines of the bar magnet
3. induces an e.m.f. across the coil
4. induces current flowing through the coil
5. induced magnetic field

Bar magnet moving towards the coil

- When the north pole of the bar magnetic is moved towards the coil
  - ✓ Needle on the voltmeter briefly flick to the right, before returning to the centre.
  - ✓ Coil cuts the magnetic field lines of the bar magnet
  - ✓ This **induces an e.m.f.** across the coil which is measured by the voltmeter.
- **The e.m.f. across the coil causes a current to flow**
  - ✓ The current causes the coil to act like a bar magnet
  - ✓ The direction of e.m.f. induced (and therefore the north/south pole of the coil) will always **oppose** the movement of the bar magnet
  - ✓ If the north pole of the bar magnet **moves towards** one end of the coil, a north pole will be induced at that end

Bar magnet moving away from the coil



1. the coil and magnetic field move relative to one another
2. coil cuts the magnetic field lines of the bar magnet
3. induces an e.m.f. across the coil
4. induces current flowing through the coil
5. induced magnetic field

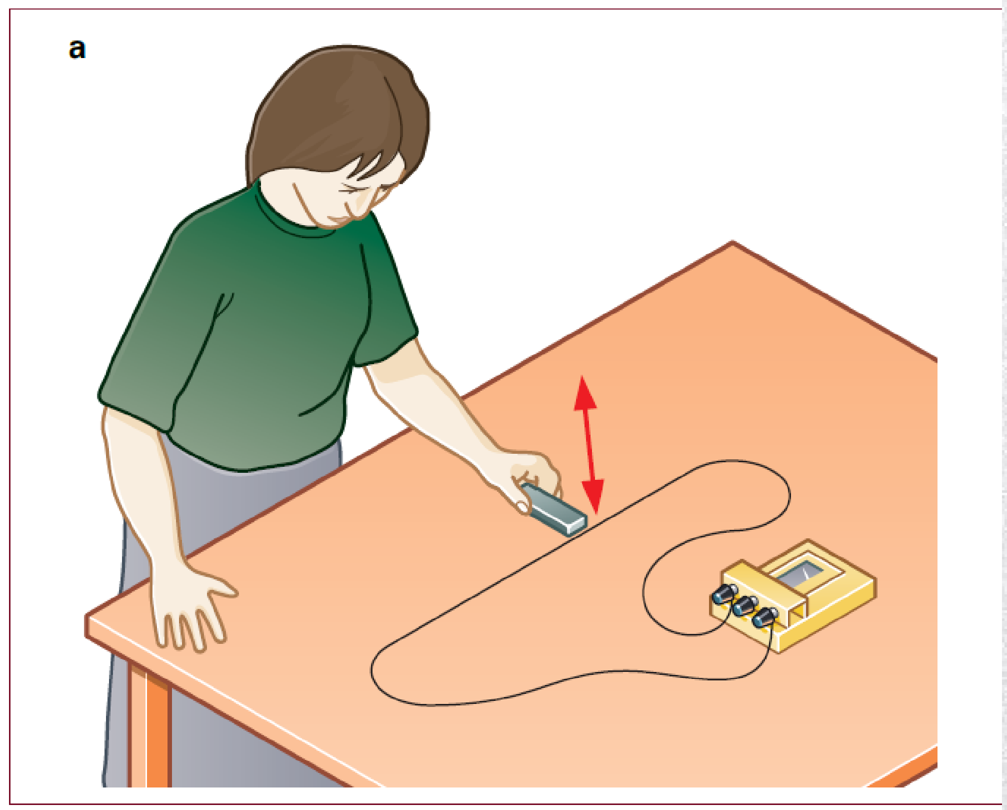
Bar magnet moving away from the coil

- When the north pole of the bar magnetic is moved away from the coil
  - ✓ Needle on the voltmeter briefly flick to the left, before returning to the centre.
  - ✓ Coil cuts the magnetic field lines in the opposite direction
  - ✓ The induces an e.m.f. will also be in the opposite direction
- **The e.m.f. across the coil causes a current to flow**
  - ✓ The current causes the coil to act like a bar magnet.
  - ✓ The direction of e.m.f. induced (and therefore the north/south pole of the coil) will always **oppose** the movement of the bar magnet
  - ✓ If the north pole of the bar magnet **away from** one end of the coil, a south pole will be induced at that end to oppose movement

The principles of electromagnetic induction

- The science of electromagnetism was largely developed by **Michael Faraday**. He invented the idea of the magnetic field, and drew field lines to represent it. He also invented the first electric motor, then he extended his studies to show *how the motor effect could work in reverse to generate electricity*.
- **A coil of wire and a magnet moving relative to each other** are needed to induce a voltage across the ends of a wire. This is called the **dynamo effect**. If the coil is part of a complete circuit, the **induced e.m.f.** will make an **induced current** flow around the circuit.

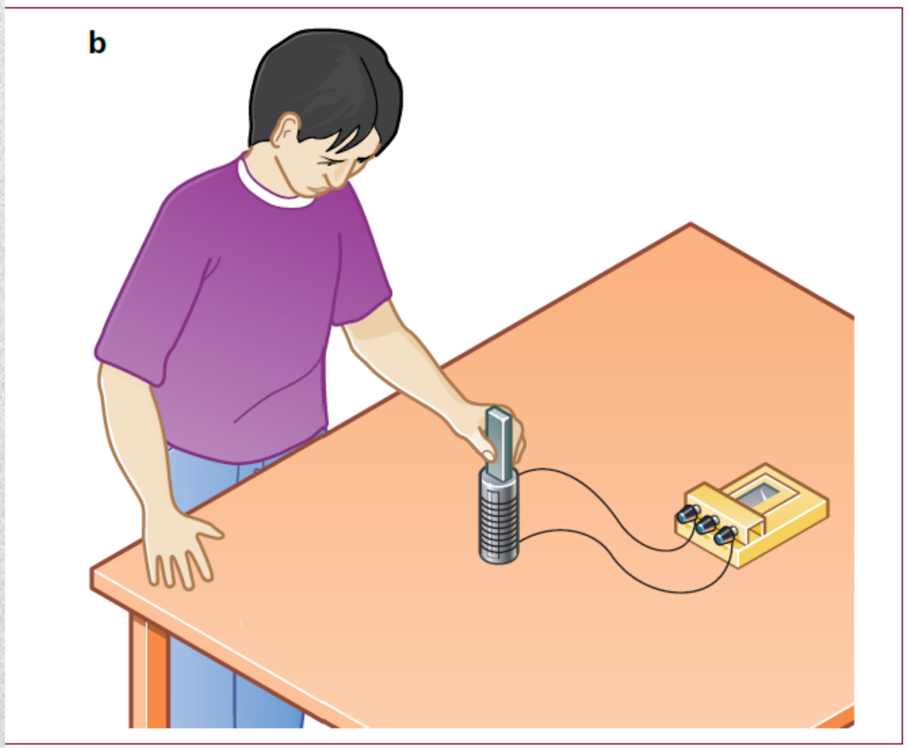
The principles of electromagnetic induction



A **single wire** is enough to induce an e.m.f.:

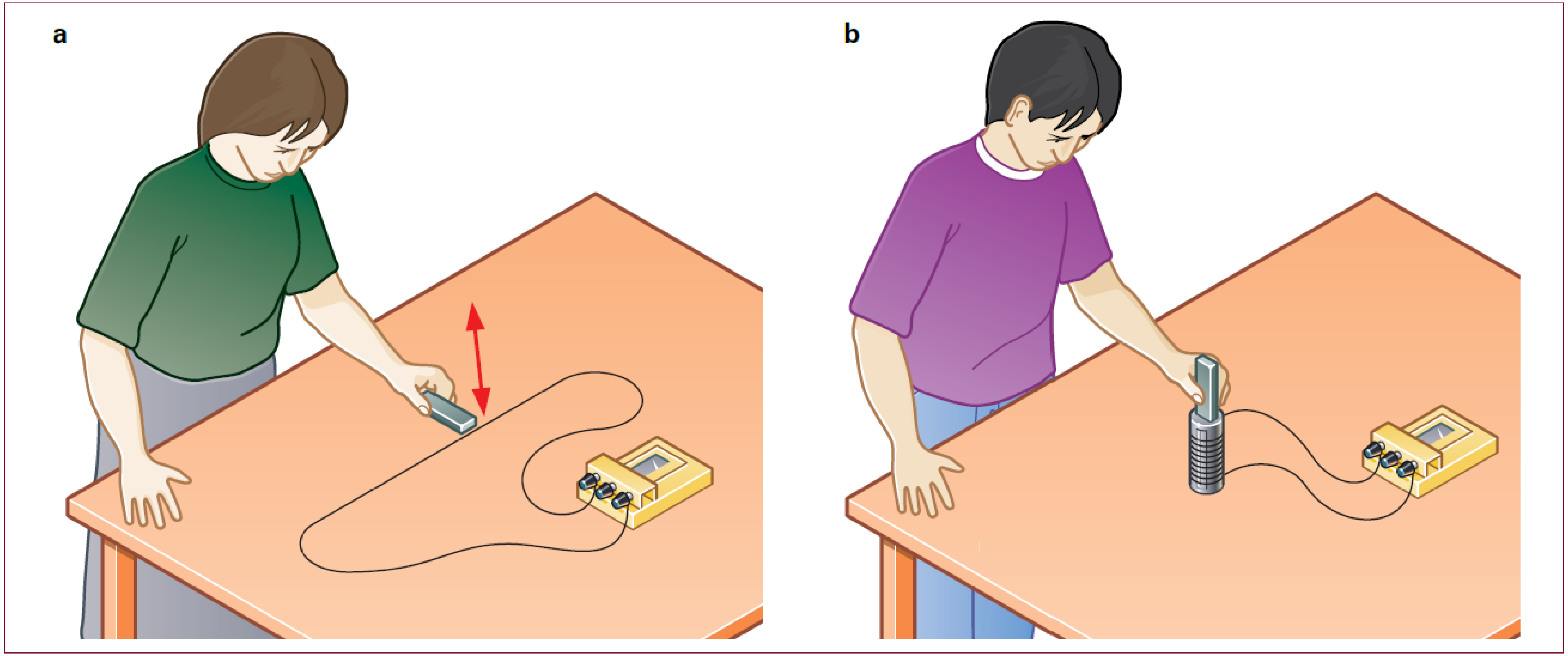
- Move one pole of the magnet downwards past the wire, and a current flows. Move the magnet back upwards, and a current flows in the opposite direction.
- Alternatively, the magnet can be stationary and the wire can be moved up and down next to it.

The principles of electromagnetic induction



- Similar effects can be seen by using **a magnet and a coil**. Pushing the magnet into and out of the coil induces a current, which flows back and forth in the coil.
- Here are two further observations:
  - ✓ Reverse the magnet to use the opposite pole, and the current flows in the opposite direction.
  - ✓ Hold the magnet stationary next to the coil, and no current flows. They must move relative to each other, or nothing will happen.
  - ✓ In these experiments it helps to use **a centre-zero meter**. Then, if the needle moves to the left , it shows that the current is flowing one way; if it moves to the right, the current is flowing the other way.

The principles of electromagnetic induction



a. Move a **magnet** up and down next to a stationary **wire** and an induced current will flow.
b. Similarly, move a **magnet** into and out of **a coil of wire** and an induced current will again flow.

Increasing the induced e.m.f.

- There are 3 ways to increase the e.m.f. induced in a coil or wire:
  - ✓ Use **a stronger** magnet.
  - ✓ Move the wire or coil **more quickly** relative to the magnet.
  - ✓ Use a coil with **more turns** of wire. (Each turn of wire will have an e.m.f. induced in it, and these all add together to give a bigger e.m.f.)

Induction and field lines

- Electromagnetic induction can be understood using Faraday's idea of magnetic field lines. Picture the field lines coming out of each pole of the magnets. As the magnet is moved, the field lines are cut by the wire, and it is this **cutting of field lines that induces the current**.

- This idea helps us to understand **the factors that affect the magnitude and direction of the induced e.m.f.**
  - ✓ If the magnet is *stationary*, there is *no cutting of field lines* and so *no e.m.f. is induced*.
  - ✓ If the magnet is *further from the wire*, the field lines are further apart and so fewer are cut, giving a smaller e.m.f.
  - ✓ If the magnet is *moved quickly*, the lines are cut more quickly and a bigger e.m.f. is induced.
  - ✓ *A coil gives a bigger effect than a single wire*, because each turn of wire cuts the magnetic field lines and each therefore contributes to the induced e.m.f.

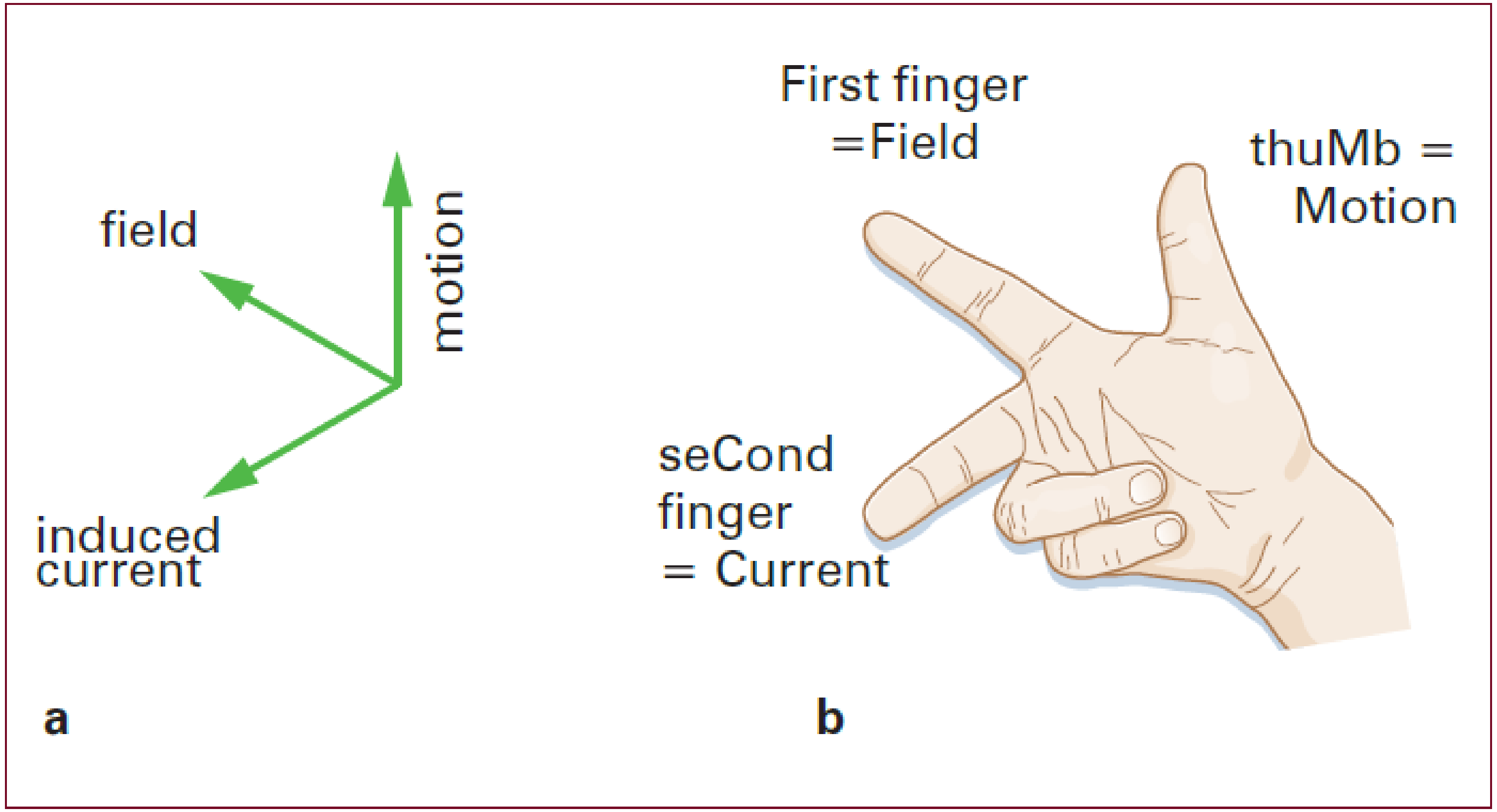
Direction of induced current

If a wire is moved so that it cuts across a magnetic field, a current will be induced in the wire. How can we work out **the direction of the current**?

- We have seen the **opposite effect** – when a current flows in a magnetic field, there is a force on it so that it moves. **The directions of force, field and current were given by Fleming's left-hand rule.**
- It is not surprising to find that, in the case of **electromagnetic induction**, the directions are given by **Fleming's right hand rule**. The thumb and first two fingers show the directions of the same quantities.

*Note: When using either of Fleming's rules, if you use the wrong hand, the direction you deduce will be opposite to the correct direction.

Fleming's right-hand rule

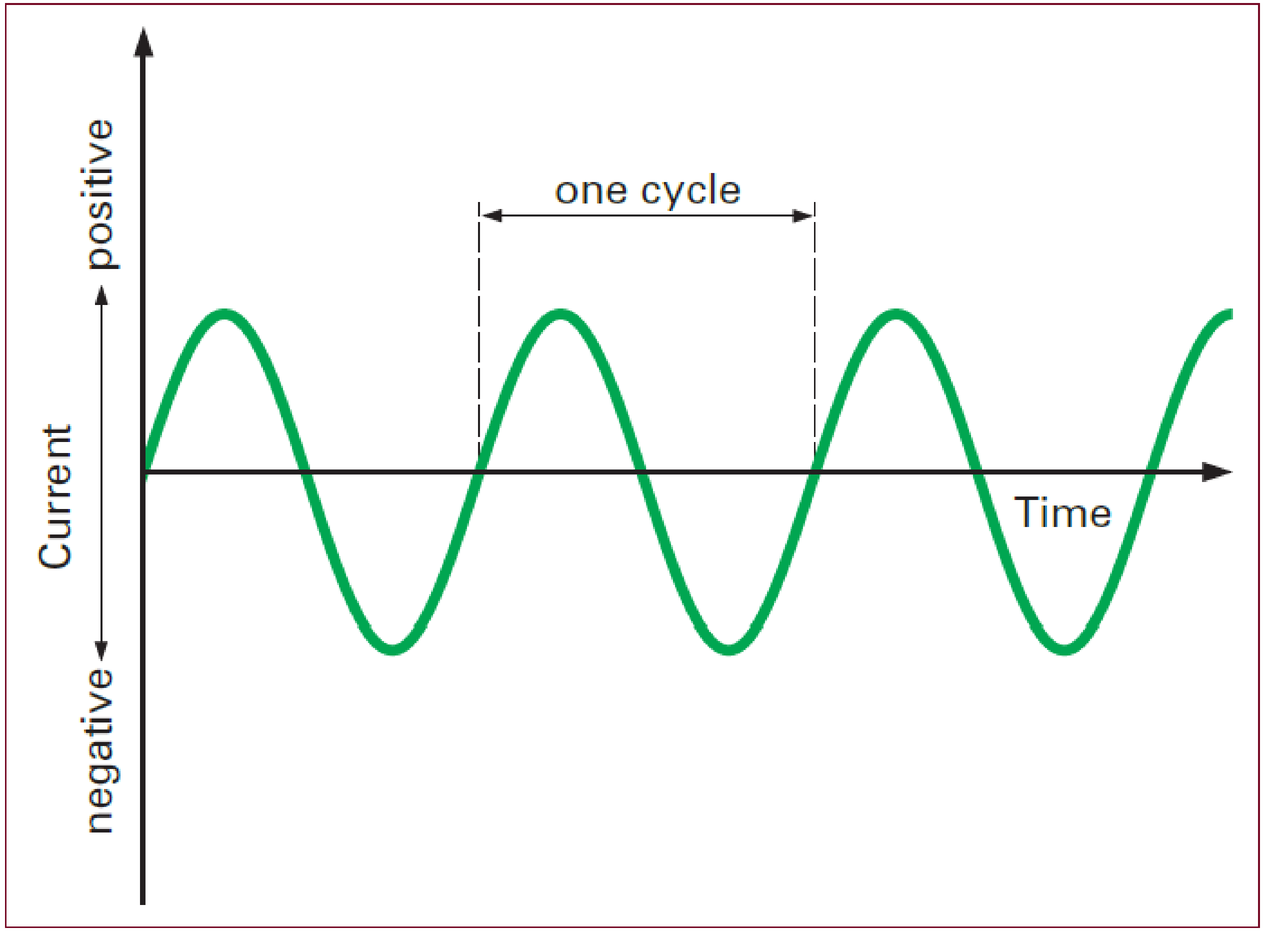


a. When a current is induced in a wire, motion, field and current are at right angles to each other.
b. Fleming's right-hand rule is used **to work out the direction of the induced current**.

Generating a.c.

- Faraday's discovery of electromagnetic induction led to the development of the electricity supply industry. In particular, it allowed engineers to design generators that could supply electricity. At first, this was only done on a small scale, but gradually generators got bigger and bigger, they were capable of supplying the electricity demands of thousands of homes.
- A generator of this type produces **alternating current (a.c.)**. This means that the current is not direct current (d.c.), which always flows in the same direction. Instead, **an alternating current flows back and forth**.
- In most countries, the electricity supply is a.c. with a frequency of 50 Hz or 60 Hz.

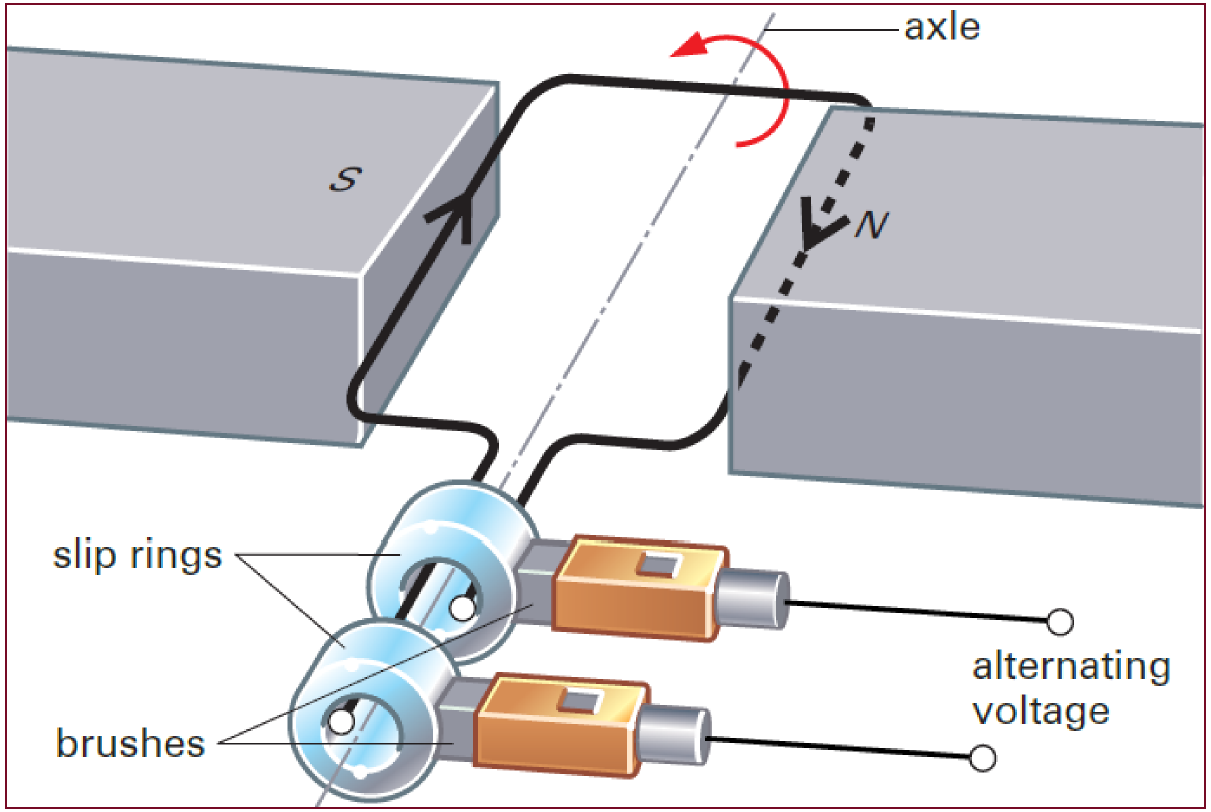
Generating a.c.



A graph to represent an alternating current.

For the first half of a cycle, the current flows one way. Then it goes into reverse.

An a.c. generator



A simple a.c. generator works like a motor in reverse. The **slip rings** and **brushes** are used to connect the alternating current to the external circuit.

An a.c. generator

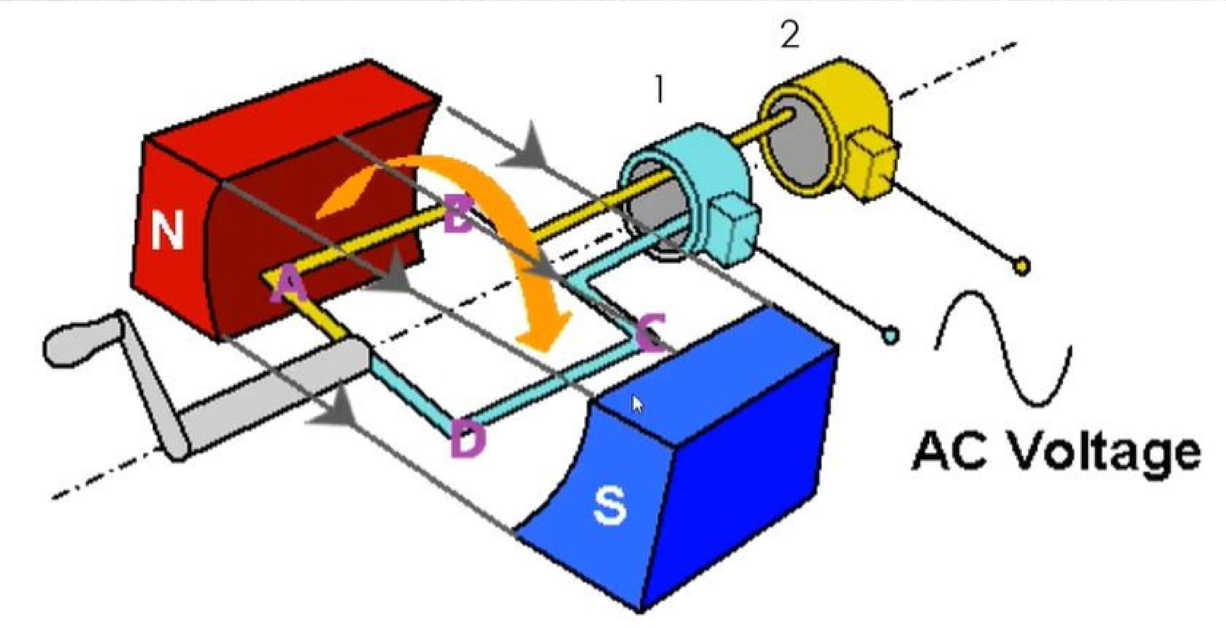
- A simple a.c. generator produces alternating current. In principle, this is like a d.c. motor, working in reverse. The axle is made to turn so that the coil spins around in the magnetic field, and a current is induced. The other difference is in the way the coil is connected to the circuit beyond. A d.c. motor uses a split-ring commutator, whereas **an a.c. generator uses <u>slip rings</u>.**

An a.c. generator

Why does this generator produce alternating current?

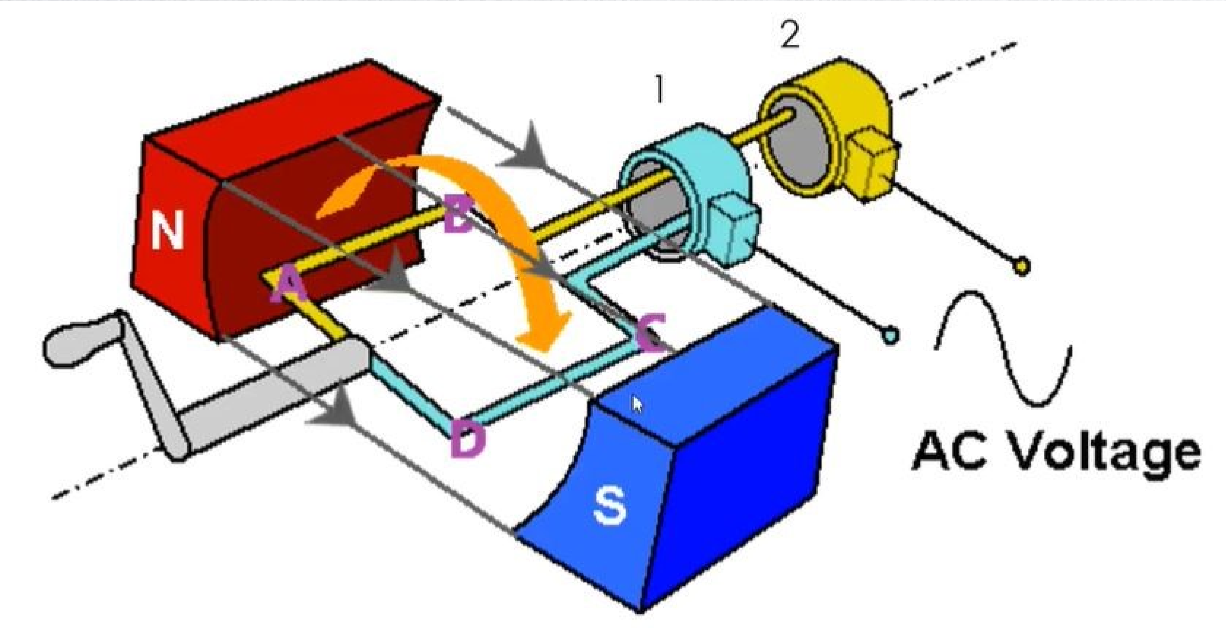
As the coil rotates, each side of the coil passes first the magnetic north pole and then the south pole. This means that the induced current flows first one way, and then the other. In other words, **the current in the coil is alternating**. The current flows out through the **slip rings**. Each ring is connected to one end of the coil, so the alternating current flows out through the **brushes**, which press against the rings.

An a.c. generator



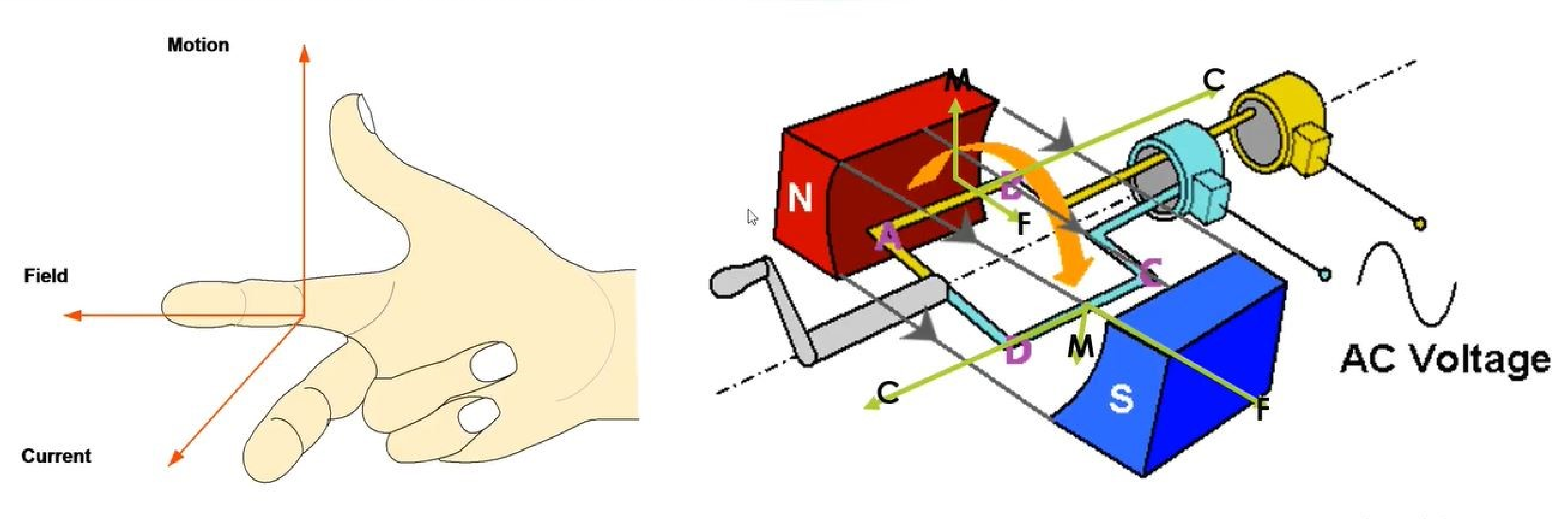
- Pay attention to:
  - ✓ The coil with corners A, B, C, and D
  - ✓ Two slip rings which are connected to an external circuit
  - ✓ AB connected to slip ring 2, DC connected to slip ring 1
  - ✓ Rotating coil

An a.c. generator



- Magnetic field lines go from north pole to south pole
- As the coil rotates, it cuts the magnetic field lines and induced e.m.f. and current
- In the diagram, side AB will cut the magnetic field upwards and side CD cuts the magnetic field downwards
- As the coil rotates, eventually AB will cut the field downwards and CD will cut it upwards
- Since the sides have now reversed, the direction of induced current will also become reversed when this happens

An a.c. generator - direction of induced current



An a.c. generator

If we think about how the coil cuts through magnetic field lines, we can understand why the a.c. graph varies between positive and negative values.

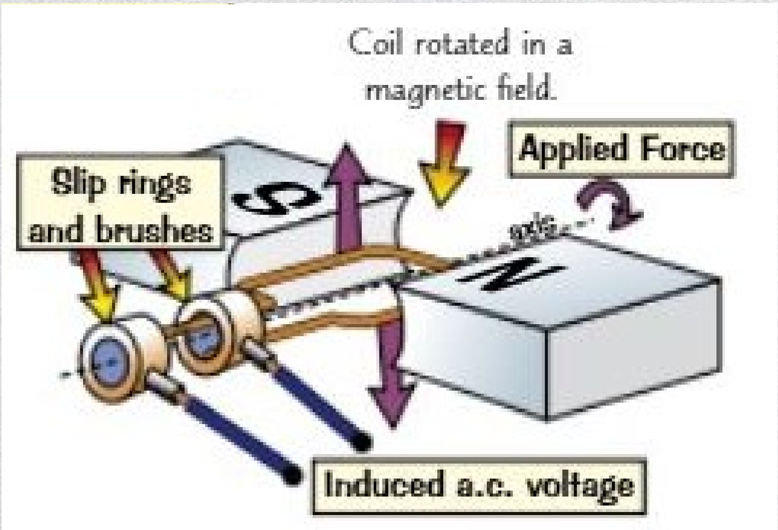
- With the coil in the **horizontal position**, its two long sides are **cutting rapidly through the magnetic field lines**. This gives a large induced e.m.f., corresponding to **a peak in the a.c. graph**.
- **When the coil is vertical, its long sides are moving along the field lines, so they are not cutting them.** This gives no induced e.m.f., a zero point on the a.c. graph.
- When the coil has turned through 180°, it will be cutting field lines quickly again, but **in the opposite direction**, so the induced e.m.f. will again be large, but this time it will be negative.

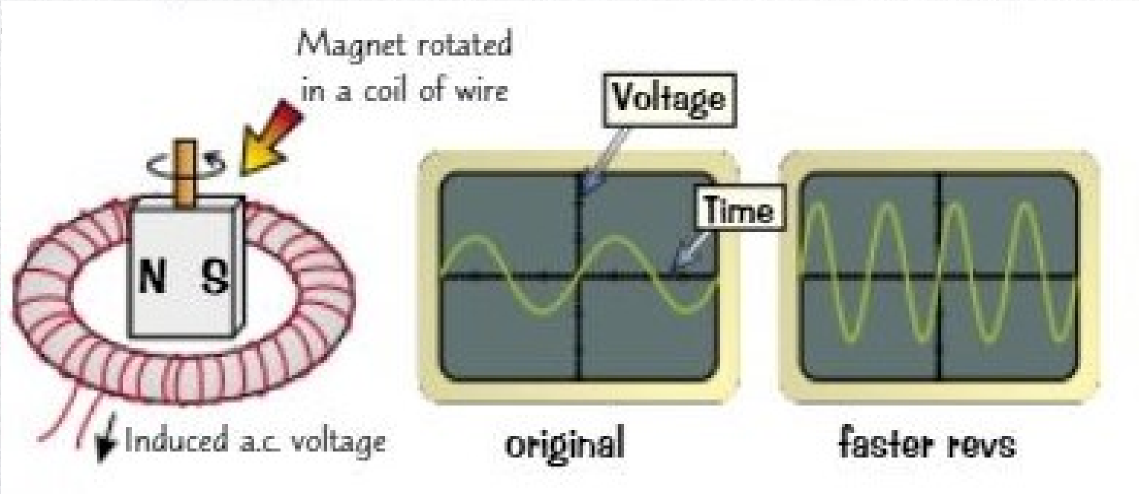
An a.c. generator

- There are 4 ways of **increasing the voltage generated by an a.c. generator**:
  - ✓ turn the coil more rapidly
  - ✓ use a coil with more turns of wire
  - ✓ use stronger magnets
- Each of these has **the effect of increasing the rate at which magnetic field lines are cut**, and so the induced e.m.f. is greater. **Each revolution of the coil generates one cycle of alternating current**. Spin the coil 50 times each second and the a.c. generated has a frequency of 50 Hz.

An a.c. generator - Summary

- Generators rotate a coil in a magnetic field, or a magnet in a coil.
- As the coil spins, a current is induced in the coil. This current changes direction every half turn.
- Instead of a split-ring commutator, a.c. generators have **slip rings and brushes** so the contacts don't swap every half turn, which makes a.c. voltage produced
- Faster revolutions produce not only more peaks but higher overall voltage, too.





Direction of the induced e.m.f.

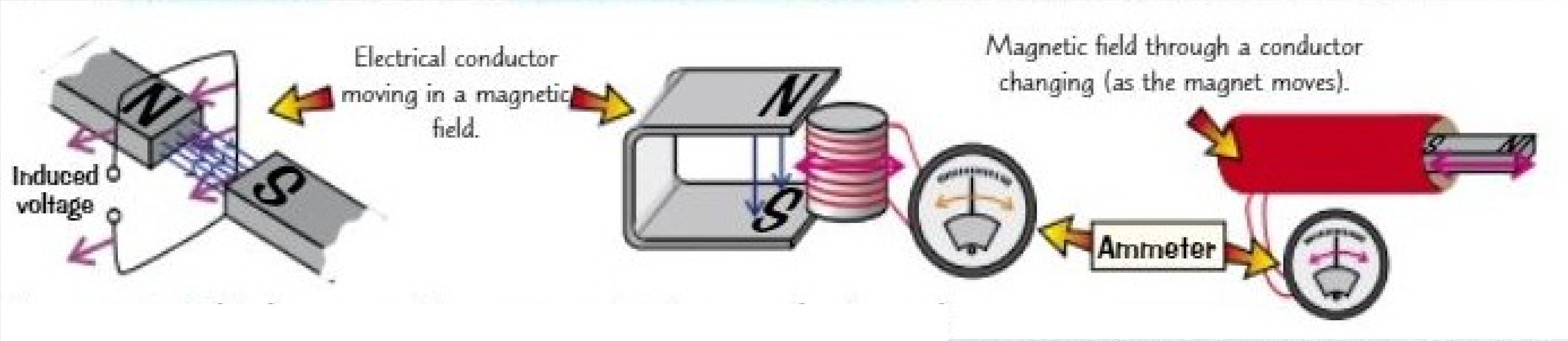
How does an induced current 'know' in which direction it must flow?

- The answer is that the current (like all currents) has a magnetic field around it. This field always pushes back against the field that is inducing the current. So, when the magnet's north pole is pushed towards the coil, the current flows so as to produce a north pole at the end of the coil nearest the magnet. These two north poles repel each other. Hence you have to push the magnet towards the coil, and thereby do work. The energy you use in pushing the magnet is transferred to the current. That is where the energy carried by a current comes from. It comes from the work done in making a conductor cut through magnetic field lines.

*Note: **An induced current always flows in such a way that its magnetic field opposes the change that causes it**.

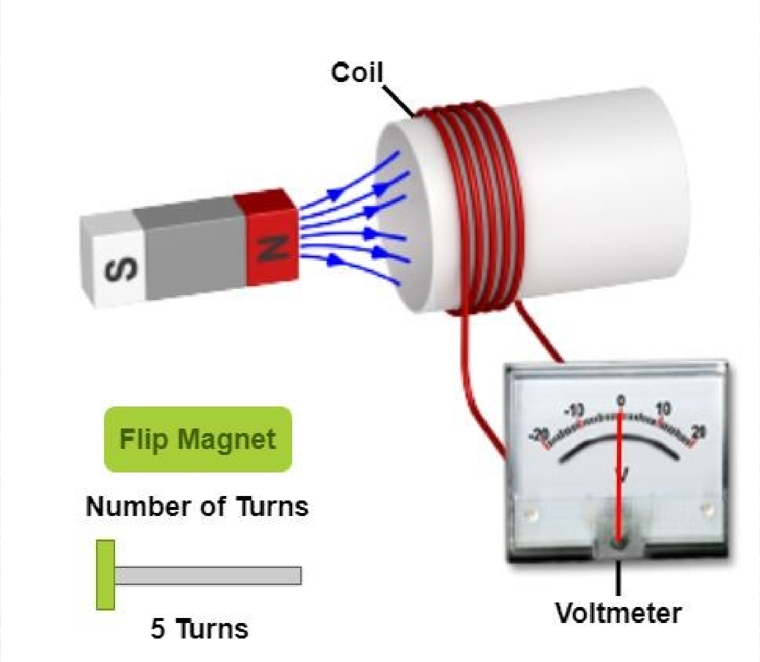
Electromagnetic Induction

- **The dynamo effect**: using electromagnetic induction to generate electricity using energy from kinetic energy stores (in a power station, this energy is provided by the turbine).
- Two ways that can get EM induction:
  1. An electrical conductor (a coil of wire) moves through a magnetic field
  2. The magnetic field through an electrical conductor changes (gets bigger or smaller or reverses)



Electromagnetic Induction

Simulation:



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Electromagnetic Induction

how does current generate a magnetic field

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As Ampere suggested, a **magnetic field** is produced whenever an electrical charge is in motion. The spinning and orbiting of the nucleus of an atom **produces a magnetic field** as **does** electrical **current** flowing through a wire. The direction of the spin and orbit determine the direction of the **magnetic field**.

Study question #1

What is electromagnetic induction?

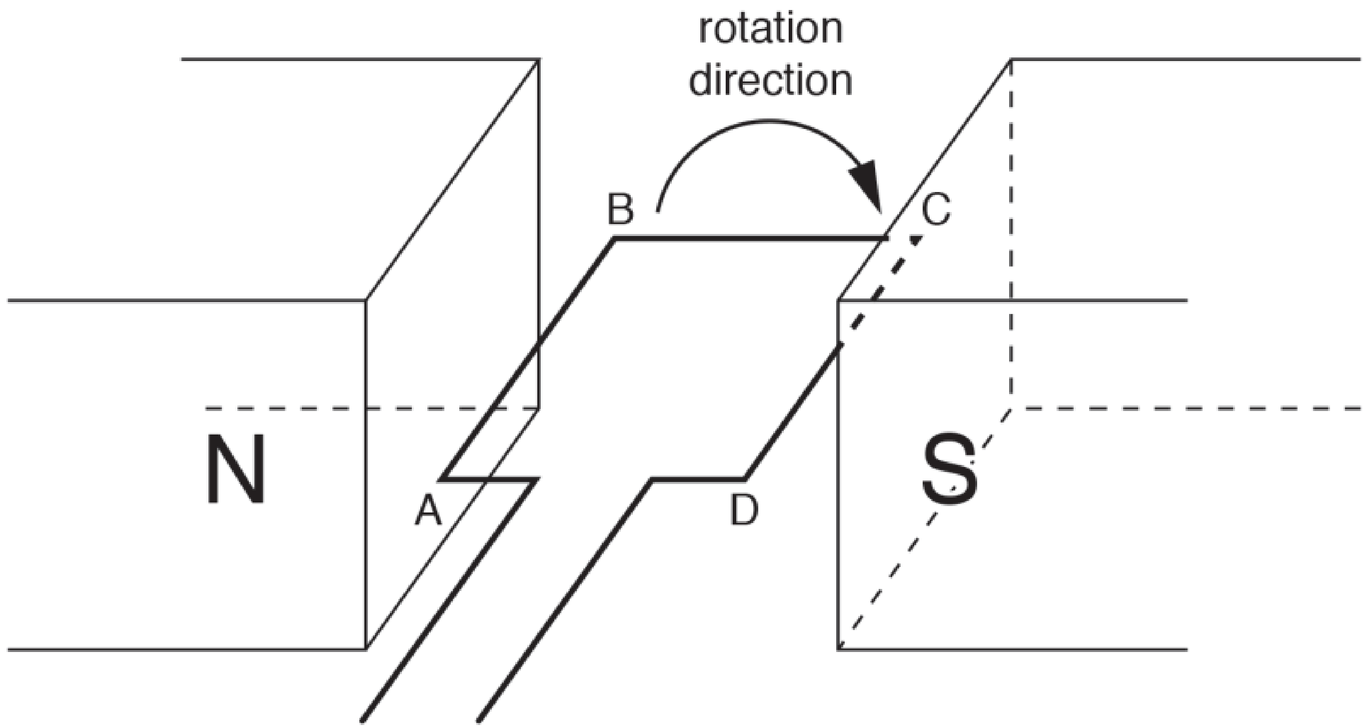
Study question #1

What is electromagnetic induction?

The creation of a voltage in a wire which is experiencing a change in magnetic field.

Study question #2

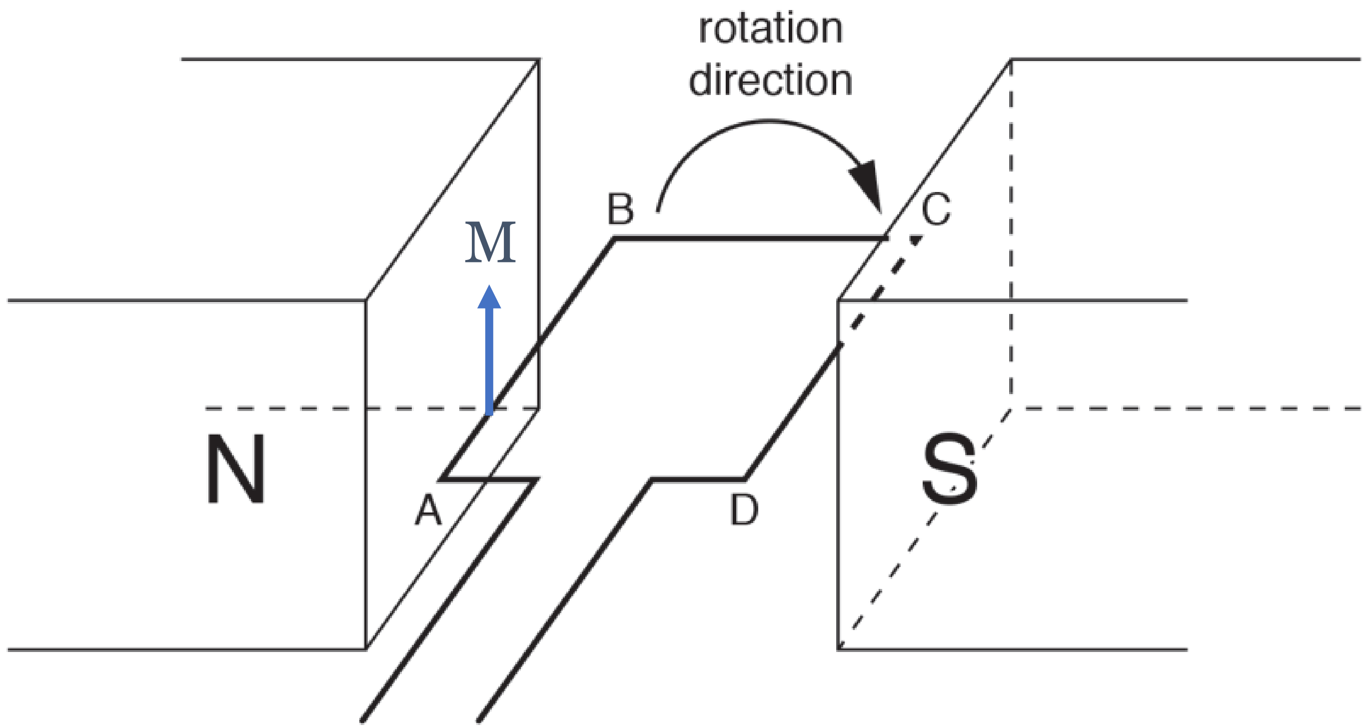
The diagram shows the coil ABCD of an a.c. generator between two magnetic poles.



(a) On the diagram, draw a straight arrow to indicate the direction in which side AB of the coil is moving. Label this arrow M. [1]

Study question #2

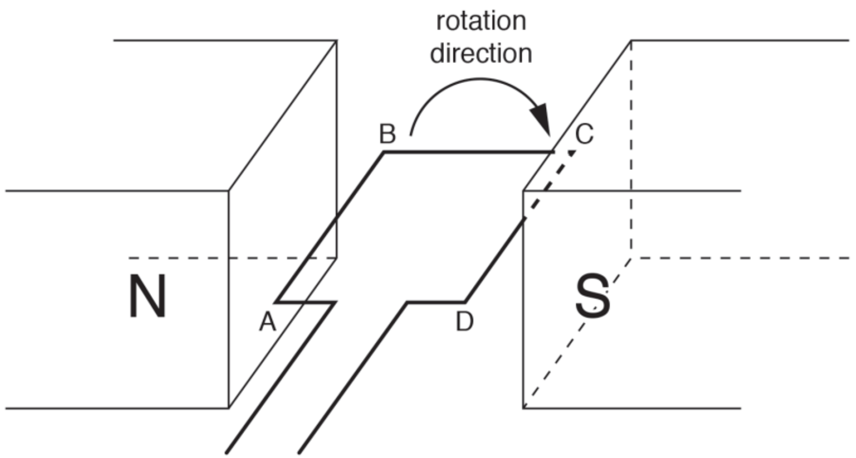
The diagram shows the coil ABCD of an a.c. generator between two magnetic poles.



(a) On the diagram, draw a straight arrow to indicate the direction in which side AB of the coil is moving. Label this arrow M. [1]

Study question #3

The diagram shows the coil ABCD of an a.c. generator between two magnetic poles.



(b) Deduce the direction of the current induced in side AB of the coil and explain your reasoning.

....

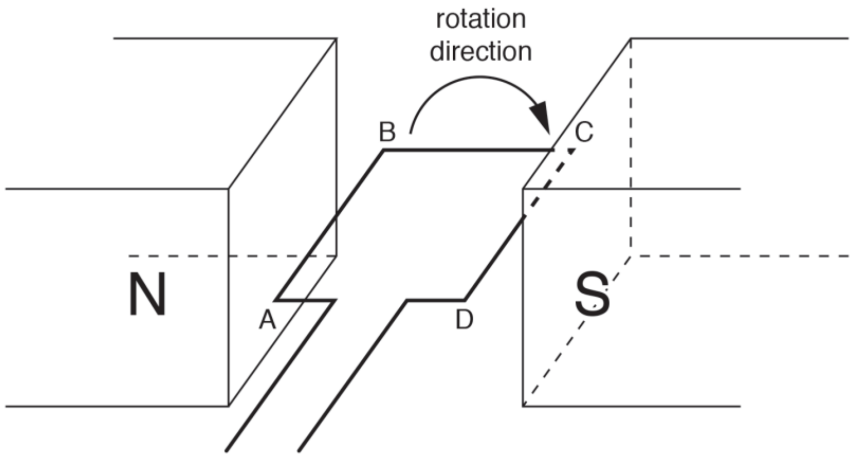
....

....

.... [2]

Study question #3

The diagram shows the coil ABCD of an a.c. generator between two magnetic poles.



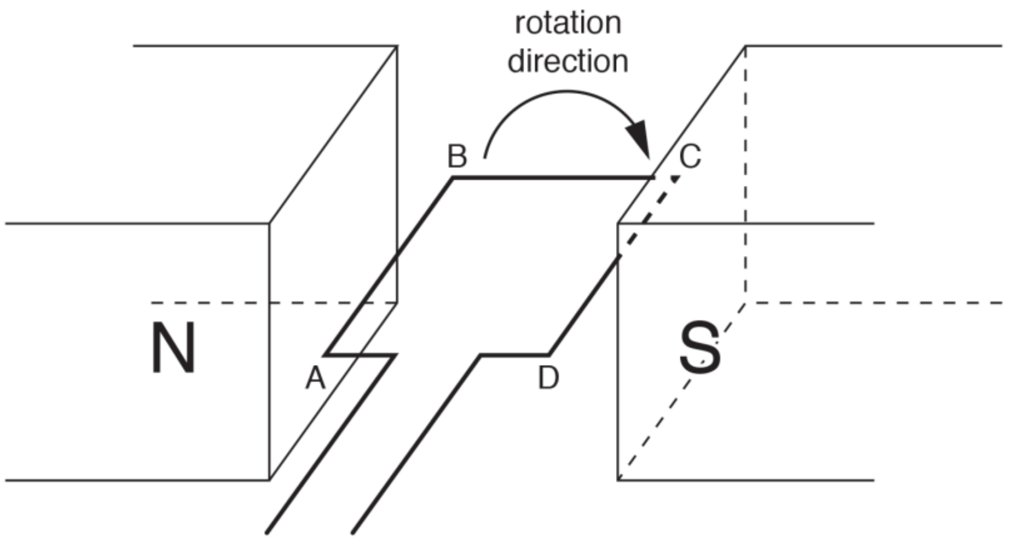
(b) Deduce the direction of the current induced in side AB of the coil and explain your reasoning.

The direction of the current induced in side AB of the coil is from A to B based on Fleming's right-hand rule [1]. The direction of first finger represents the direction of magnetic field from N to S, which is from left to right in this case. The thumb points to the direction of motion which is upwards. The direction of the second finger gives the direction of current. [1]

[2]

Study question #4

The diagram shows the coil ABCD of an a.c. generator between two magnetic poles.



The rate at which the coil of the a.c. generator rotates increases.

State **two** ways in which the alternating voltage changes.

1. ....

....

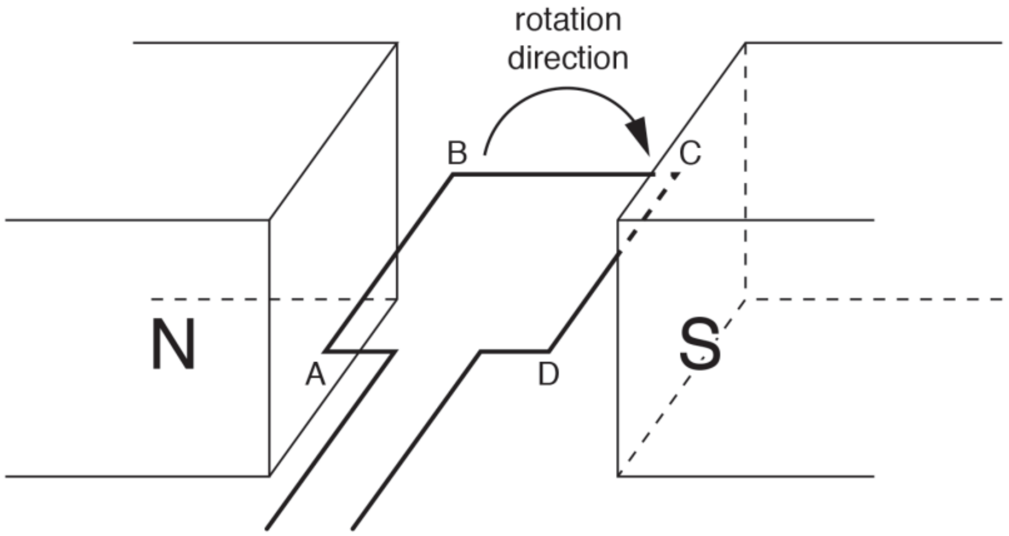
2. ....

.... [2]

[Total: 2]

Study question #4

The diagram shows the coil ABCD of an a.c. generator between two magnetic poles.



The rate at which the coil of the a.c. generator rotates increases.

State **two** ways in which the alternating voltage changes.

1. greater (maximum) voltage [1]

2. greater frequency OR smaller time period OR changes direction more often OR alternates faster [1]

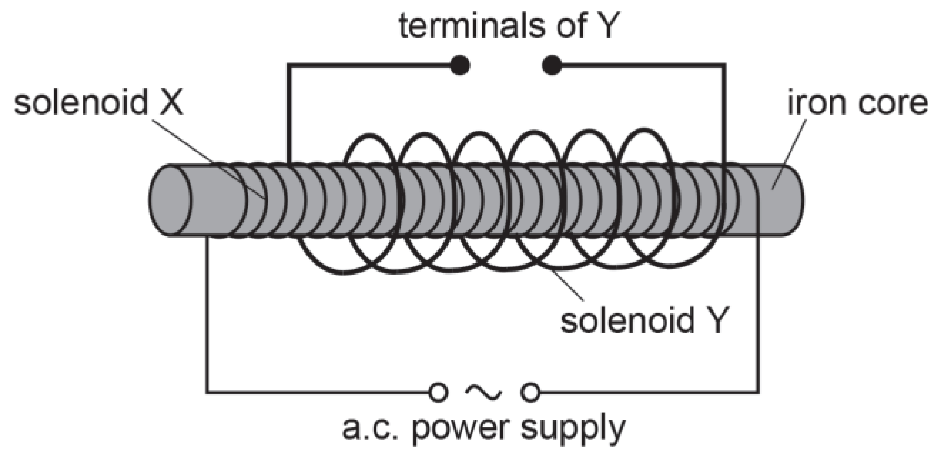
[2]

[Total: 2]

Study question #5

An electromagnet consists of a solenoid X that is made of copper wire. The solenoid contains an iron core.

The diagram shows the electromagnet inside a second solenoid Y.



Describe and explain what happens in solenoid Y when solenoid X is connected to an alternating current (a.c.) power supply.

....

....

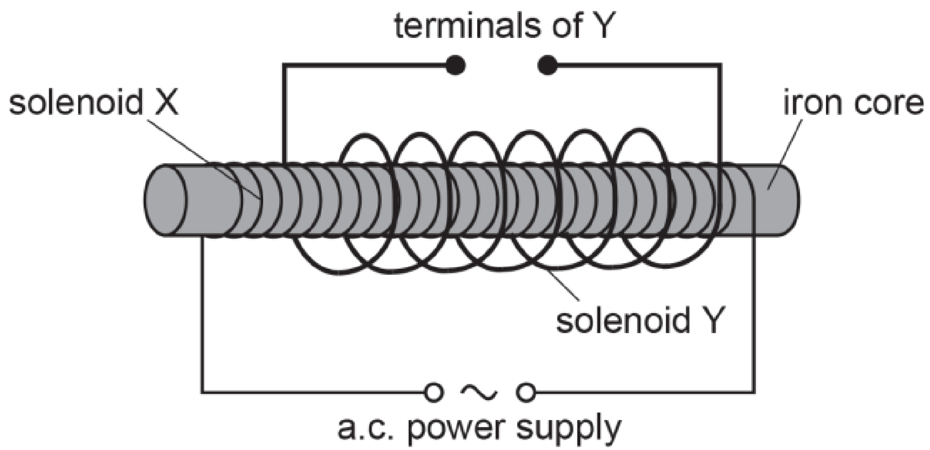
....

.... [3]

Study question #5

An electromagnet consists of a solenoid X that is made of copper wire. The solenoid contains an iron core.

The diagram shows the electromagnet inside a second solenoid Y.



Describe and explain what happens in solenoid Y when solenoid X is connected to an alternating current (a.c.) power supply.

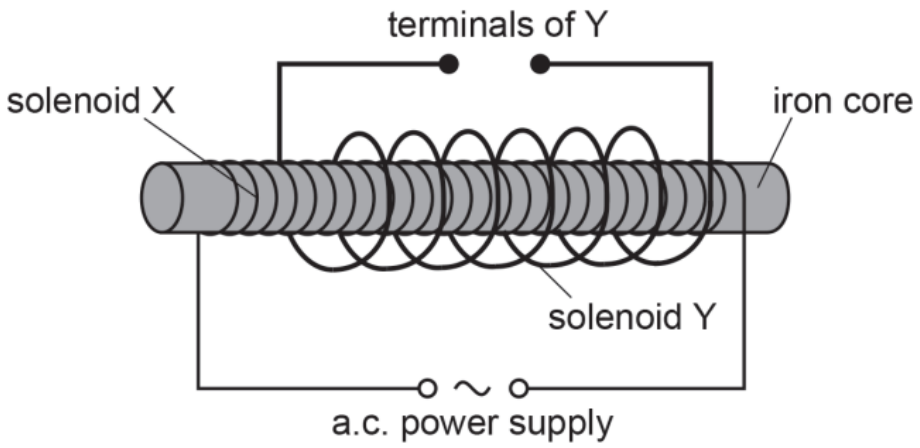
alternating / changing / varying magnetic field produced by X [1] electromagnetic induction in Y [1] alternating electro-motive force (e.m.f.) between terminals of Y [1]

[3]

Study question #6

An electromagnet consists of a solenoid X that is made of copper wire. The solenoid contains an iron core.

The diagram shows the electromagnet inside a second solenoid Y.



A switch and a lamp are connected in series with the terminals of solenoid Y. When the switch is closed, the lamp lights up at normal brightness.

Describe and explain what happens to the current in solenoid X when the switch is closed.

....

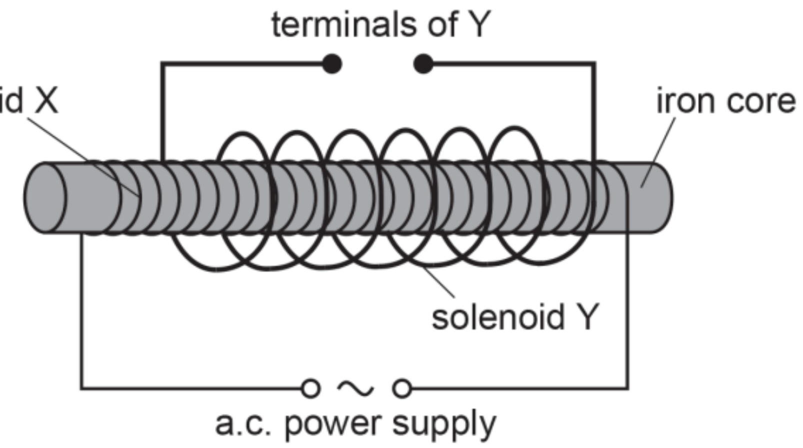
....

.... [2]

Study question #6

An electromagnet consists of a solenoid X that is made of copper wire. The solenoid contains an iron core.

The diagram shows the electromagnet inside a second solenoid Y.



A switch and a lamp are connected in series with the terminals of solenoid Y. When the switch is closed, the lamp lights up at normal brightness.

Describe and explain what happens to the current in solenoid X when the switch is closed.

current in X increases [1]

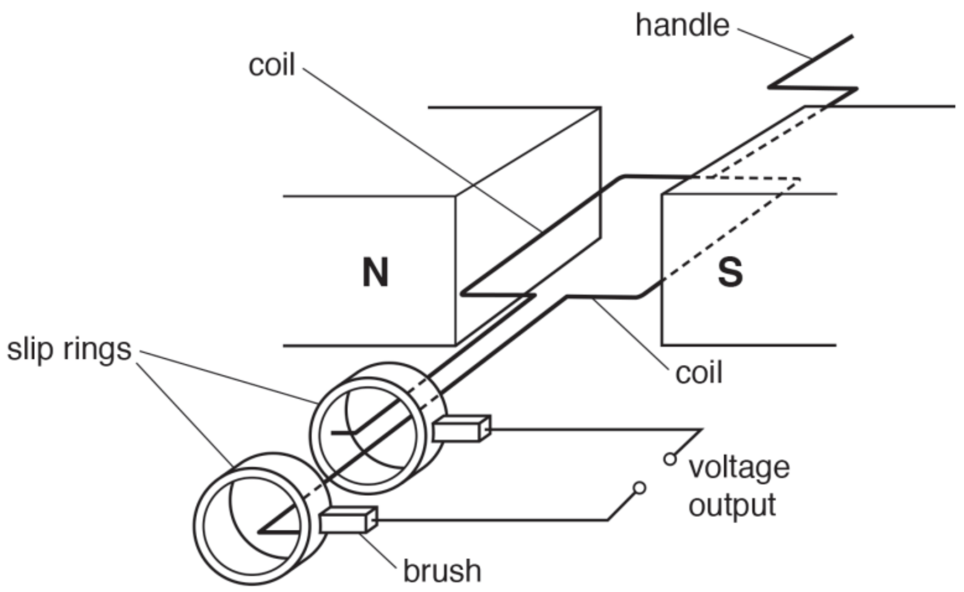
to supply the power used in Y / the lamp [1]

[2]

Study question #7

A student turns the handle of an alternating current (a.c.) generator and the coil rotates.

The diagram represents the structure of the a.c. generator.



There is an alternating voltage output between the two terminals.

State the position of the rotating coil when the alternating output voltage is at a maximum value and explain why the maximum output occurs at this position.

....

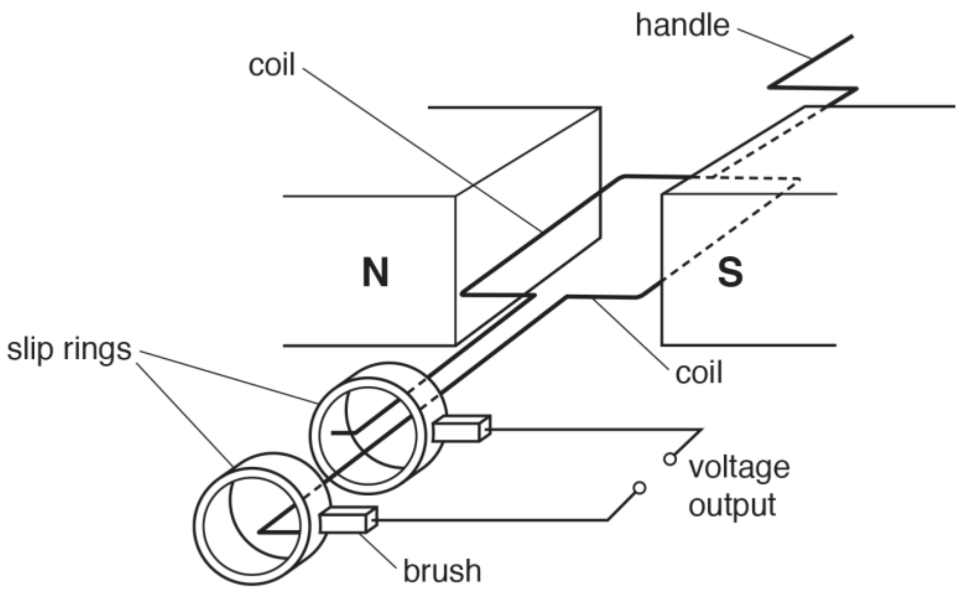
....

.... [2]

Study question #7

A student turns the handle of an alternating current (a.c.) generator and the coil rotates.

The diagram represents the structure of the a.c. generator.



There is an alternating voltage output between the two terminals.

State the position of the rotating coil when the alternating output voltage is at a maximum value and explain why the maximum output occurs at this position.

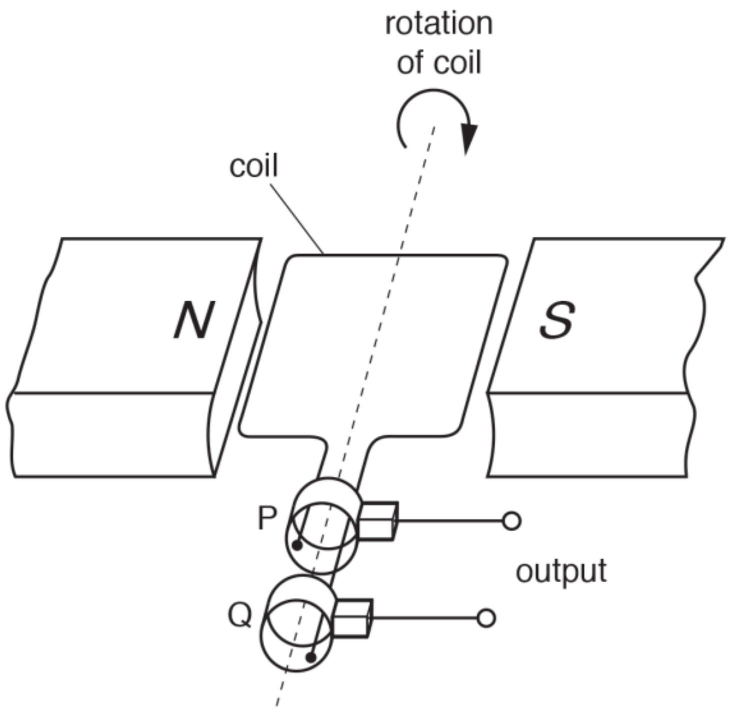
(plane of coil) horizontal OR in position shown in ....

diagram [1] coil cutting magnetic field the fastest [1] ....

.... [2]

Study question #8

The diagram shows a simple alternating current generator.



State the name of the components labelled P and Q and state their purpose.

Name: ....

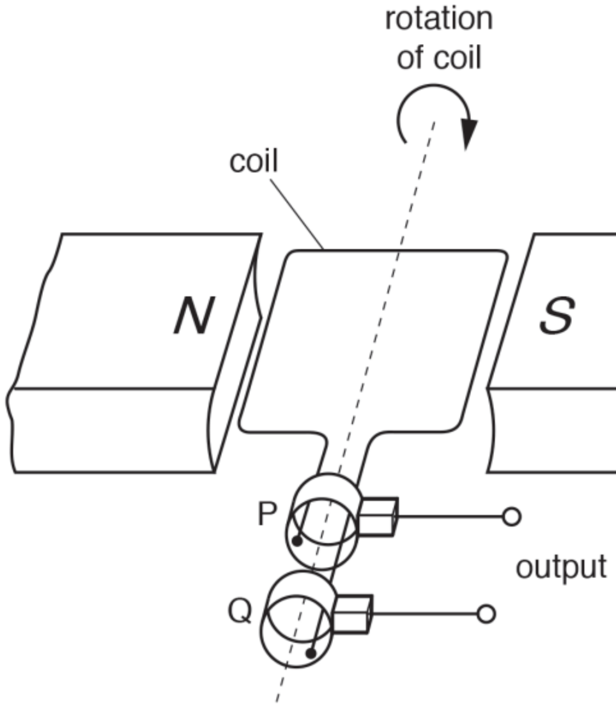
Purpose: ....

.... [2]

[Total: 2]

Study question #8

The diagram shows a simple alternating current generator.



State the name of the components labelled P and Q and state their purpose.

Name: slip rings [1]

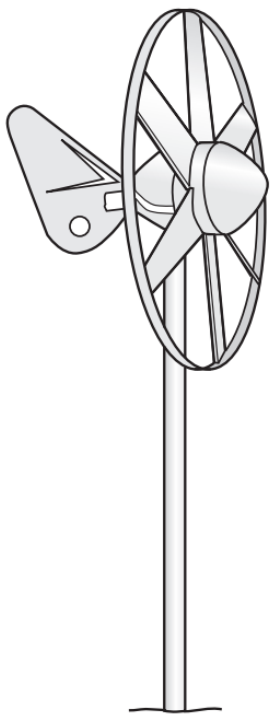
Purpose: provide continuous connection while coil rotating [1]

[2]

[Total: 2]

Study question #9

The figure shows a small wind-turbine used to generate electricity.



The wind-turbine drives an electric generator.

Describe the essential action within the generator that produces electricity.

....

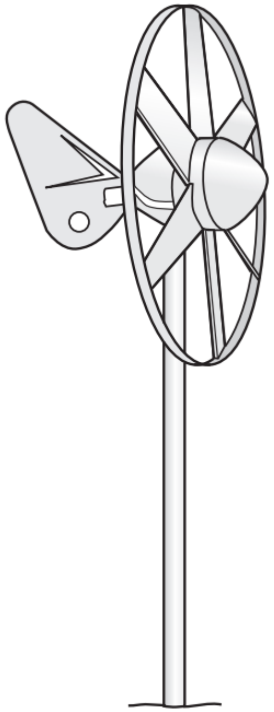
....

.... [2]

[Total: 2]

Study question #9

The figure shows a small wind-turbine used to generate electricity.



The wind-turbine drives an electric generator.

Describe the essential action within the generator that produces electricity.

....

....

.... [2]

[Total: 2]

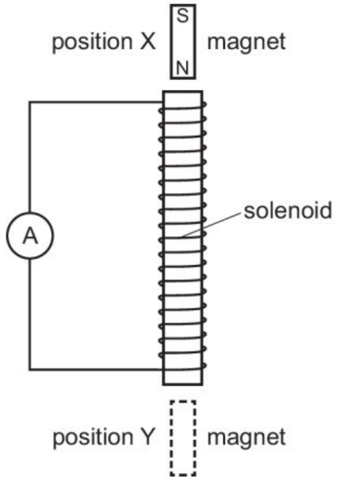
rotation/movement of wire/coil in magnetic field / between magnetic poles / cutting magnetic field

OR rotation/movement of magnet in coil / near wire

Study question #10

A solenoid is held in a vertical position. The solenoid is connected to a sensitive, centre-zero ammeter.

A vertical bar magnet is held stationary at position X just above the upper end of the solenoid as shown in the figure.



The magnet is released and it falls through the solenoid. During the initial stage of the fall, the sensitive ammeter shows a small deflection to the left.

The magnet passes the middle point of the solenoid and continues to fall. It reaches position Y.

Describe and explain what is observed on the ammeter as the magnet falls from the middle point of the solenoid to position Y.

....

....

....

....

....

.... [4]

[Total: 4]

Study question #10

A solenoid is held in a vertical position. The solenoid is connected to a sensitive, centre-zero ammeter.

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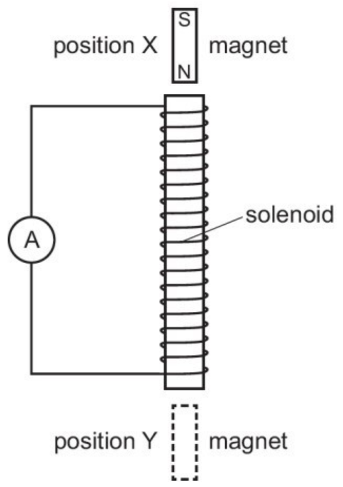

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The magnet passes the middle point of the solenoid and continues to fall. It reaches position Y.

Describe and explain what is observed on the ammeter as the magnet falls from the middle point of the solenoid to position Y.

....

....

....

....

....

.... [4]

[Total: 4]

meter deflects in opposite direction [1]

deflection is greater OR for shorter time [1]

magnet moving faster [1]

more field lines cut per second OR opposite pole and direction and end of solenoid [1]

THANK YOU

Section
4.6

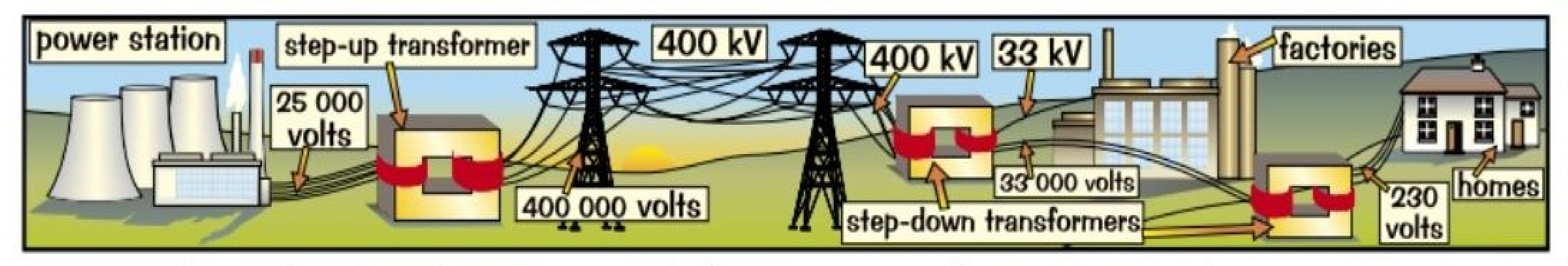
Electromagnetic induction

4.6.1 Generating electricity

4.6.2 Power lines and transformers

4.6.3 How transformers work

Power lines & Transformers



national grid

power station

power lines

transformers

Power stations

- Power stations may be 100 km or more from the places where the electricity they generate is used. This electricity must be distributed around the country.
- High voltage electricity leaves the power station. Its voltage may be as much as one million volts. To avoid danger to people, it is usually carried in cables called **power lines** slung high above the ground between tall pylons.
- Lines of pylons stride across the countryside, heading for the urban and industrial areas that need the power. This is a country's **national grid**.

Power lines

- When the power lines approach the area where the power is to be used, they enter a local distribution centre. Here the voltage is reduced to a less hazardous level, and the power is sent through more cables (overhead or underground) to local substations.
- In the substation, transformers reduce the voltage to the local supply voltage, typically 230 V. Wherever you live, there is likely to be a substation in the neighbourhood. It may be in a securely locked building, or the electrical equipment may be surrounded by fencing, which carries notices warning of the hazard.
- From the substation, electricity is distributed around the neighbouring houses.

Power lines

- In some countries, the power is carried in cables buried underground.
- Other countries use tall ‘poles’, which hold the cables above the level of traffic in the street to distribute the power.
- Overhead power lines and cables can be an eyesore, but the cost of burying cables underground can be ten or a hundred times as great as using poles.

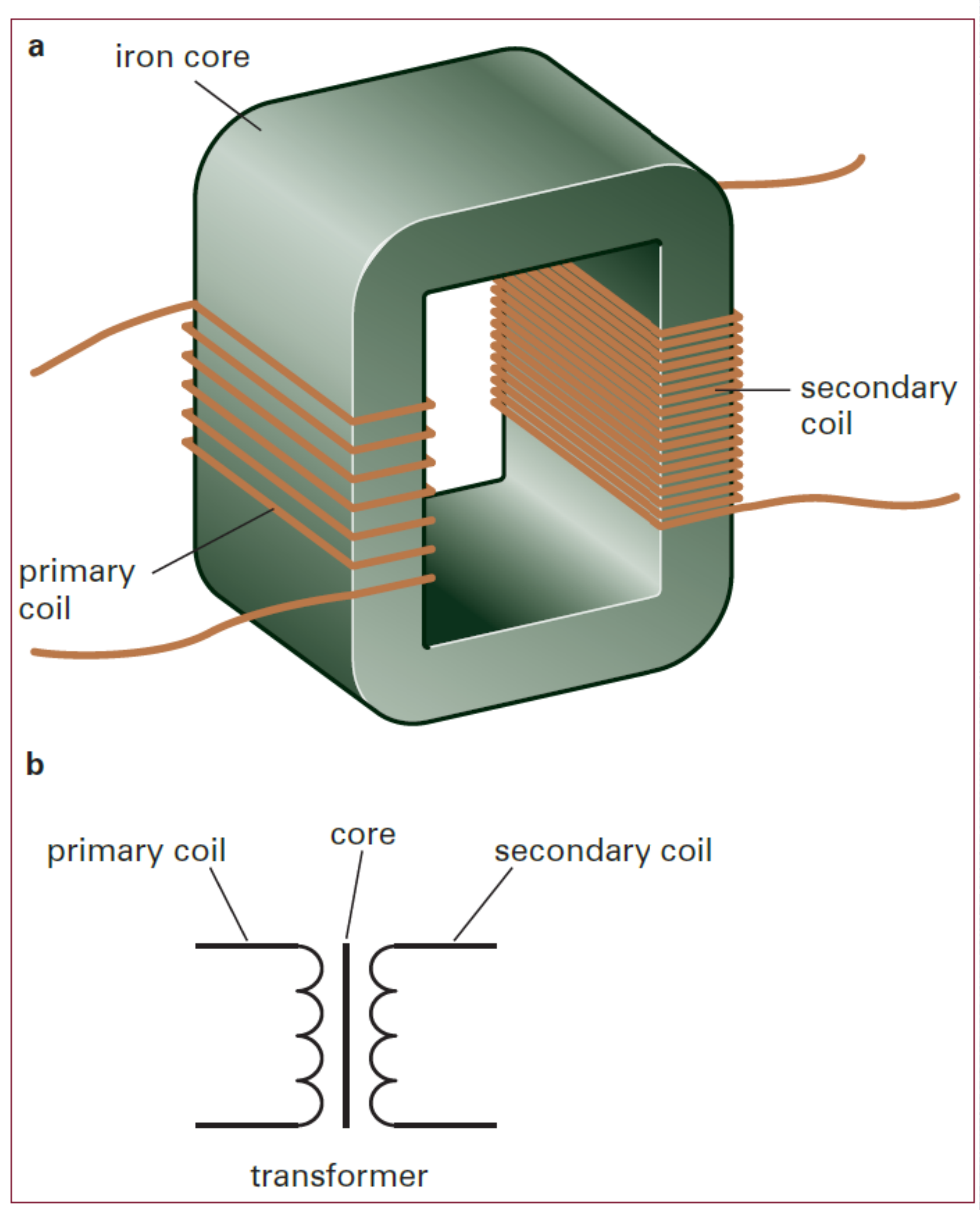
Why use high voltages?

- The high voltages used to transmit electrical power around a country are dangerous. That is why the cables that carry the power are supported high above people, traffic and buildings on tall pylons. Sometimes the cables are buried underground, but this is much more expensive, and the cables must be safely insulated.
- There is a good reason for using high voltages. It means that the current flowing in the cables is relatively low, and this wastes less energy.
- When a current flows in a wire or cable, some of the energy it is carrying is lost because of the cable's resistance – the cables get warm. A small current wastes less energy than a high current.

Why use high voltages?

- Electrical engineers do everything they can to reduce the energy losses in the cables. If they can reduce the current to half its value (by doubling the voltage), the losses will be one-quarter of their previous value.
- This is because energy losses in cables are proportional to the square of the current flowing in the cables:
  - ✓ double the current gives four times the losses
  - ✓ three times the current gives nine times the losses.

Transformer



Primary coil

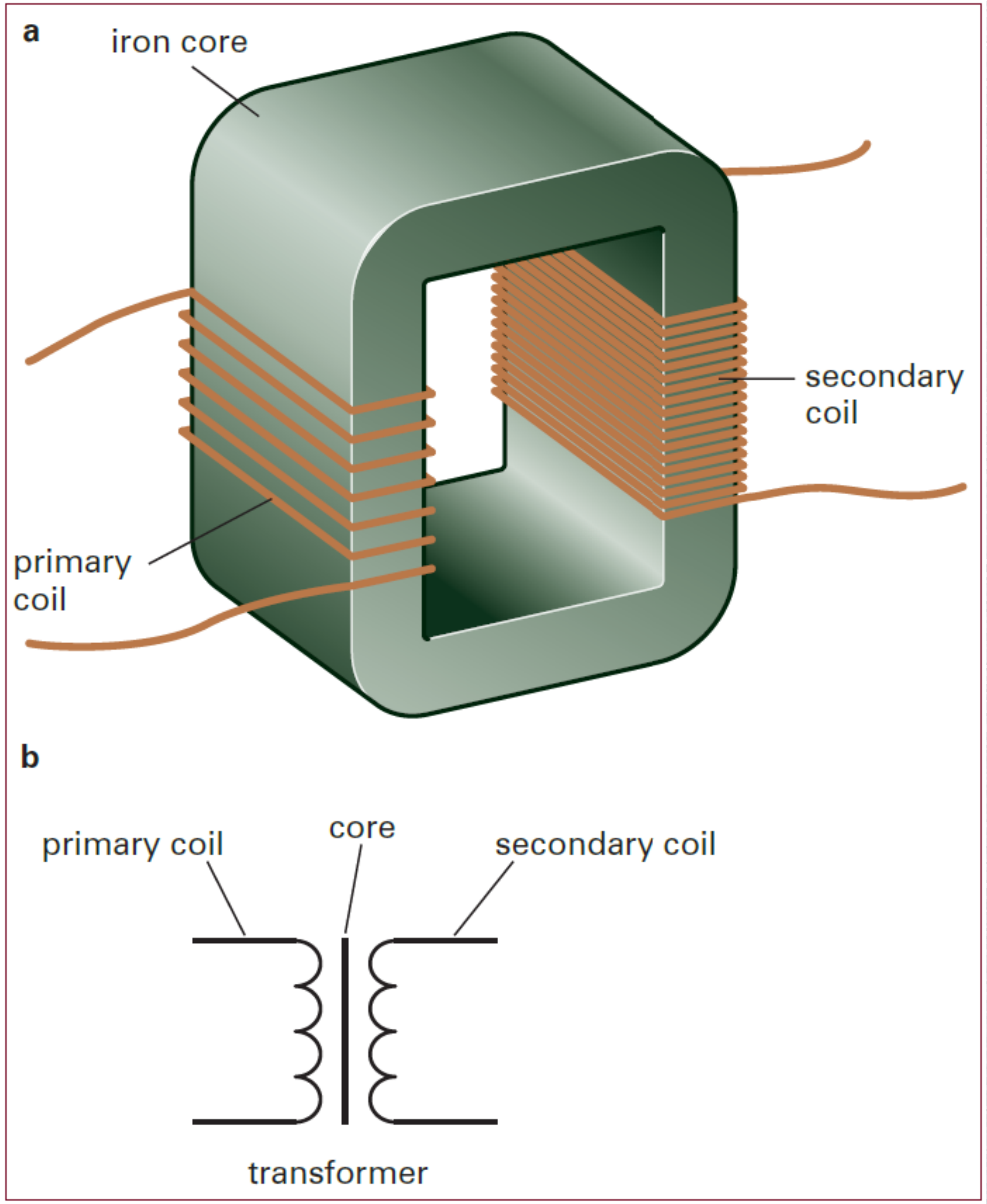
Secondary coil

Iron core

step-up transformer

step-down transformer

Transformer



a. The structure of a transformer. This is a **step-up transformer** because there are more turns on the **secondary coil** than on the **primary**. If the connections to it were reversed, it would be a **step-down transformer**.

b. The circuit symbol for a transformer shows the two coils with the core between them.

Transformer

- A transformer is a device used to increase or decrease the voltage of an electricity supply. They are designed to be as efficient as possible (up to 99.9% efficient).
- This is because the electricity we use may have passed through as many as 10 transformers before it reaches us from the power station. A loss of 1% of energy in each transformer would represent a total waste of 10% of the energy leaving the power station.
- Power stations typically generate electricity at 25 kV. This has to be converted to the grid voltage – say 400 kV – using transformers. For these voltages, we say that the voltage is stepped up by a factor of 16.

Transformer

- Every transformer has 3 parts:
  - ✓ **a primary coil** – the incoming voltage Vp is connected across this coil
  - ✓ **a secondary coil** – this provides the voltage Vs to the external circuit
  - ✓ **an iron core** – this links the two coils.
- Notice that there is no electrical connection between the two coils. **They are linked together only by the iron core.**

Transformer

- Notice also that the voltages are both **alternating voltages** – a transformer does not change a.c. to d.c. or anything of the sort. It changes the size of an alternating voltage. To step up the input voltage by a factor of 16, there must be 16 times as many turns on the secondary coil as on the primary coil. Comparing the numbers of turns on the two coils.
- A **step-up transformer <u>increases</u> the voltage**, so there are **more turns** on the **secondary** than on the primary.
- A **step-down transformer <u>reduces</u> the voltage**, so there are **fewer turns** on the secondary than on the primary. (Note that, if the voltage is stepped up, the current must be stepped down, and vice versa.)

Transformer

- Transformers change the size of the voltage of an alternating current.
- They all have two coils, the **primary** and the **secondary**, joined with an **iron core**.
- When an alternating voltage is applied across the primary coil, the magnetically soft (iron) core **magnetizes and demagnetizes** quickly. This **induces an alternating voltage in the secondary coil**.
- The **ratio between the primary and secondary voltages** is the same as the ratio between **the number of turns** on the primary and secondary coils.

*Note: **transformers only work with a.c.**

Transformer

- The ratio of the numbers of turns tells us the factor by which the voltage will be changed. Hence we can write an equation, known as the transformer equation, relating the two voltages, *Vp* and *Vs*, to the numbers of turns on each coil, *Np* and *Ns*.

$$\frac{\text{Input (primary) voltage}}{\text{Output (secondary) voltage}} = \frac{\text{Number of turns on prinmary}}{\text{Number of turns on secondary}}$$

$$\frac{V_P}{V_S} = \frac{\mathrm{N_P}}{\mathrm{N_S}} \quad or \quad \frac{V_S}{V_P} = \frac{\mathrm{N_S}}{\mathrm{N_P}}$$

- The number of turns on the secondary coil divided by the number of turns on the primary coil is called the **turns ratio**.

Transformer

- Transformers are nearly 100% efficient so “Power in = Power out”

$$\boldsymbol{Power}\ \mathbf{in} = \boldsymbol{Power\ out}$$

$$\boldsymbol{V_P I_P = V_S I_S}$$

$$\rightarrow \quad \frac{I_s}{I_p} = \frac{\mathrm{N_P}}{\mathrm{N_S}}$$

Study question #1

A transformer with 320 turns on its primary coil and 770 turns on its secondary coil has a primary voltage of 65 V. Calculate the secondary voltage.

Study question #1

A transformer with 320 turns on its primary coil and 770 turns on its secondary coil has a primary voltage of 65 V. Calculate the secondary voltage.

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

$$V_s = \frac{N_s}{N_p} V_p = \frac{770}{320} \times 65 = 156.4 = 160\,V\ (to\ 2\ s.f.)$$

THANK YOU

Section 4.6

Electromagnetic induction

4.6.1 Generating electricity

4.6.2 Power lines and transformers

4.6.3 How transformers work

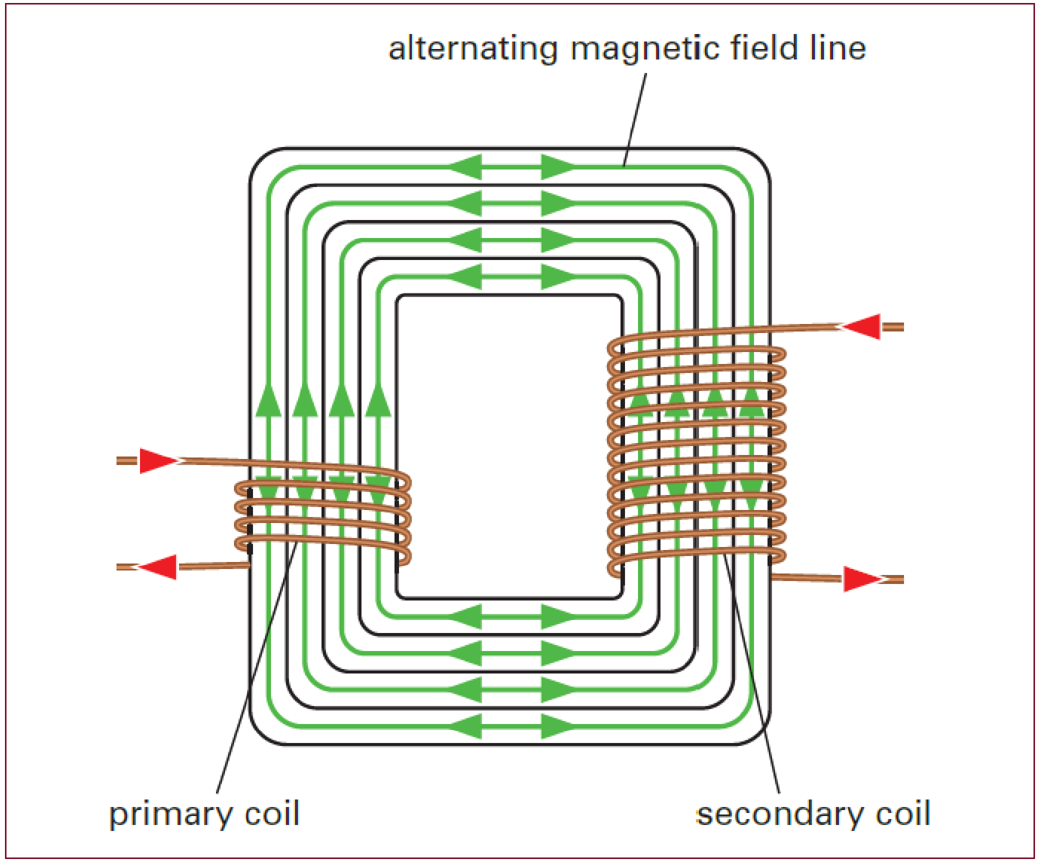
Transformer

- **Transformers only work with alternating current (a.c.)**. It makes use of **electromagnetic induction**.
- The **primary coil** has alternating current flowing through it. It is thus an **electromagnet**, and produces an alternating magnetic field.
- The core transports this alternating field around to the secondary coil. Now the secondary coil is a conductor in a changing magnetic field. A current is induced in the coil.
- If the secondary coil has only a few turns, the e.m.f. induced across it is small. If it has a lot of turns, the e.m.f. will be large.

Transformer

- **If direct current is connected to a transformer, there is no output voltage**. This is because the magnetic field produced by the primary coil is unchanging. With an unchanging field passing through the secondary coil, no voltage is induced in it.
- **The magnetic field links the primary and secondary coils**. The energy being brought by the current in the primary coil is transferred to the secondary by the magnetic field. **This means that the core must be very good at transferring magnetic energy**. A **soft magnetic material** must be used – usually an alloy of iron with a small amount of silicon. Even in a well-designed transformer, **some energy is lost because of the resistance of the wires**, and because the core 'resists the flow' of the changing magnetic field.

Transformer



The a.c. in the primary coil produces a varying magnetic field in the core. This induces a varying current in the secondary coil.

Calculating current

- To transmit a certain power *P*, we can use a small current *I* if we transmit the power at high voltage *V*.
- This follows from the equation for electrical power:

$$\text{electrical power } \boldsymbol{P = I \times V}$$

Calculating energy saving

- **The higher the voltage, the smaller the current in the cables, and so the smaller the energy losses**.
- Increasing the voltage by a factor of 20 reduces the current by a factor of 20. This means that the power lost in the cables is greatly reduced (in fact, it is reduced by a factor of 20^2, which is 400), and so thinner cables can safely be used.
- The current flowing in the cables is a flow of coulombs of charge. At high voltage, we have fewer coulombs flowing, but each coulomb carries more energy with it.

Thinking about power

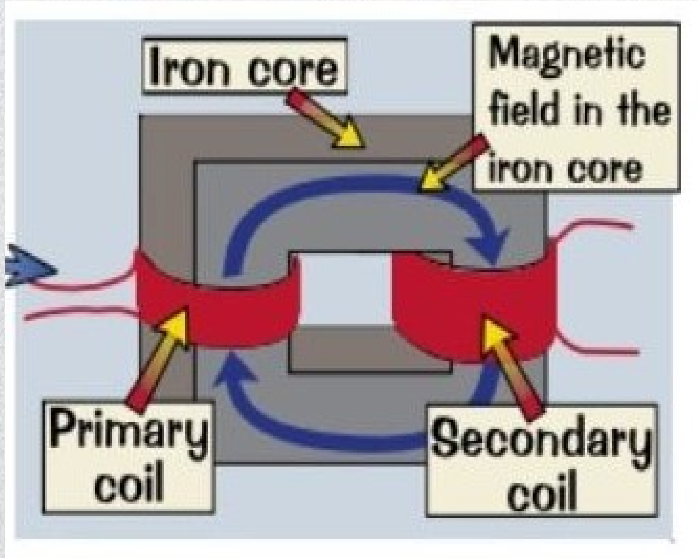
- If a transformer is 100% efficient, no power is lost in its coils or core. This is a reasonable approximation, because well-designed transformers waste only about 0.1% of the power transferred through them.
- This allows us to write an equation relating the primary and secondary voltages, V_p and V_s, to the primary and secondary currents, I_p and I_s, flowing in the primary and secondary coils, using $P = IV$
- **Power in to primary coil = power out of secondary coil**

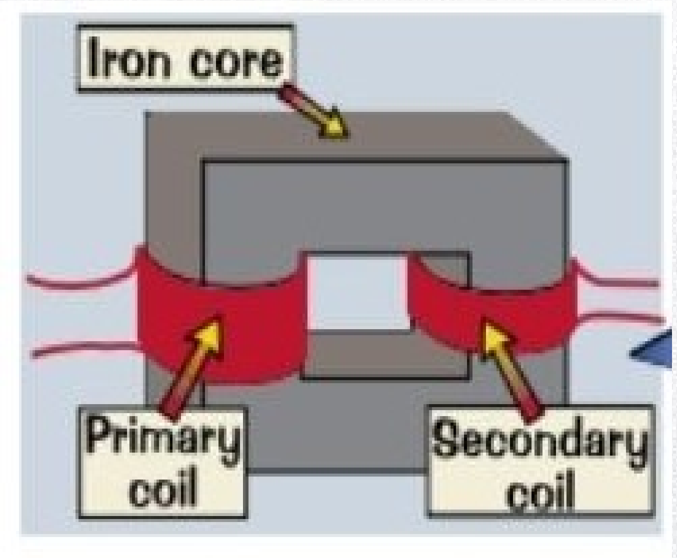
$$I_p \times V_p = I_s \times V_s$$

*Note: this equation assumes that **no power is lost in the transformer**.

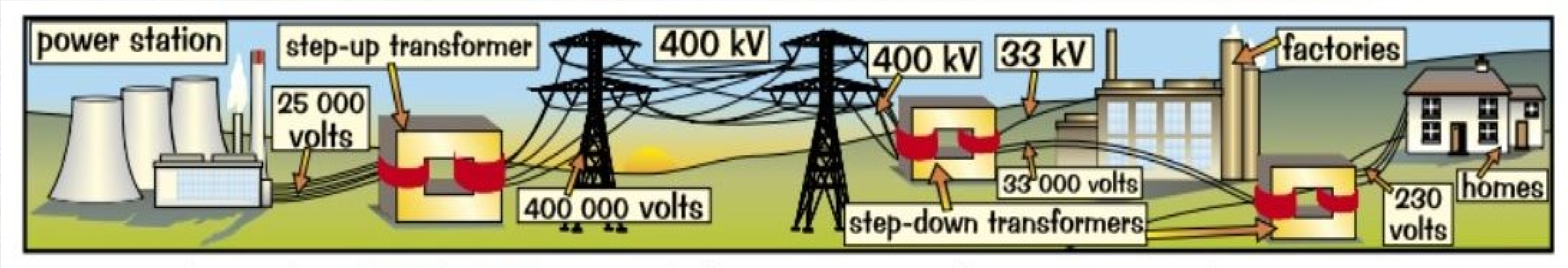
Transformer

- **Step-up** transformers: increase the voltage. They have more turns on the secondary coil than the primary coil.
- **Step-down** transformers: decrease the voltage. They have more turns on the primary coil than the secondary.





Transformers make transmitting mains electricity more efficient



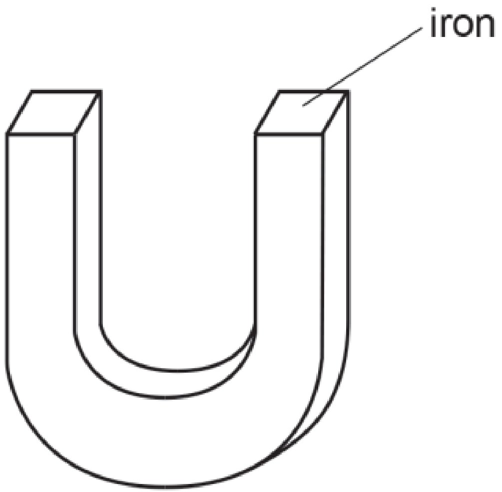
Step-up and **step-down** transformers are used when transmitting electricity across the country:

1. The voltage produced by power stations is too low to be transmitted efficiently. *Power = VI*, so the lower the voltage the higher the current for a given amount of power, and current causes wires to heat up.
2. A step-up transformer is used to boost the voltage before it is transmitted.
3. A step-up transformers are used at the end of the journey to reduce the voltage so it's more useful and safer to use.

Study question #1

A student makes a transformer .

The student is provided with two lengths of insulated wire and the U-shaped piece of iron shown in the diagram.



Explain the function of the piece of iron in the transformer.

....

....

.... [2]

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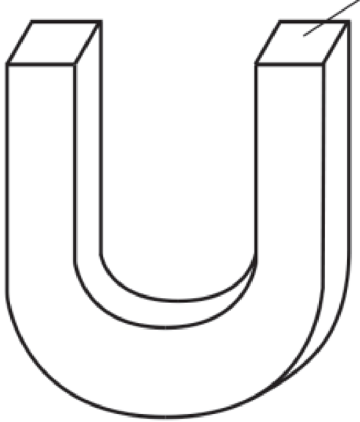


Explain the function of the piece of iron in the transformer.

links magnetic fields of coils, i.e. primary and secondary ;

stronger magnetic field in secondary; better induction;

[2]

Study question #2

Explain why the voltage of the supply to the primary coil of a transformer must be alternating.

....

....

....

.... [2]

[Total: 2]

Study question #2

Explain why the voltage of the supply to the primary coil of a transformer must be alternating.

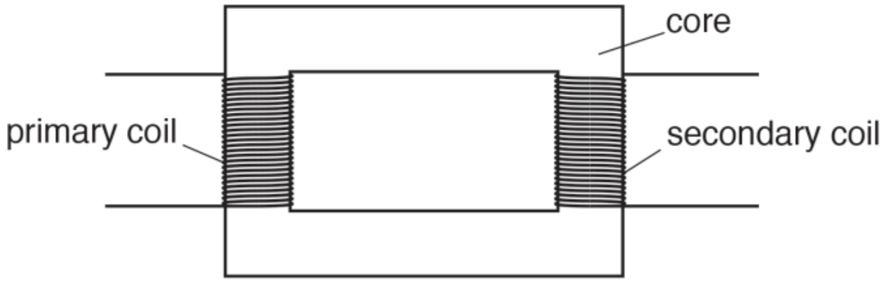
to produce an alternating/changing magnetic field (1) so that current/voltage
is induced (continuously) in the secondary coil OR secondary circuit (1)

[2]

[Total: 2]

Study question #3

A transformer consists of two coils of wire wound on a metal core. The diagram represents the transformer.



The primary coil of the transformer is connected to the output voltage of an a.c. generator which supplies an alternating current.

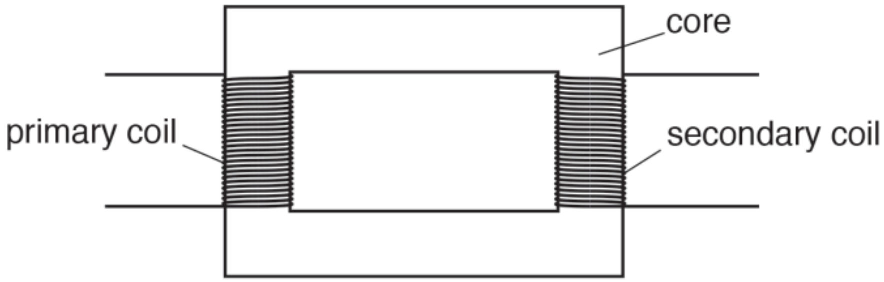
There are 560 turns on the primary coil and 910 turns on the secondary coil of the transformer. The voltage between the two terminals of the secondary coil is 78 V.

Calculate the voltage supplied by the a.c. generator.

generator voltage = ... [2]

Study question #3

A transformer consists of two coils of wire wound on a metal core. The diagram represents the transformer.



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There are 560 turns on the primary coil and 910 turns on the secondary coil of the transformer.
The voltage between the two terminals of the secondary coil is 78 V.

Calculate the voltage supplied by the a.c. generator.

$$n_p = 560$$
$$n_s = 910$$
$$\frac{n_p}{n_s} = \frac{V_p}{V_s}$$

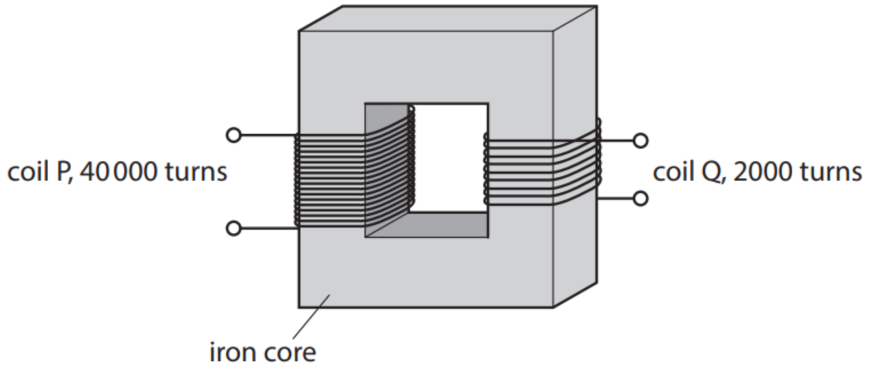
$$V_p = \frac{n_p}{n_s} V_s$$
$$= \frac{560}{910} * 78 = 48V$$

generator voltage = ... $48V$ .... [2]

Study question #4

A battery charger includes a transformer and a rectifier.

The figure represents the transformer, consisting of an iron core with two coils P and Q wound on to the core.



P consists of 40 000 turns and Q consists of 2000 turns.

When P is connected to a 230 V a.c. supply, there is an e.m.f. across the terminals of Q.

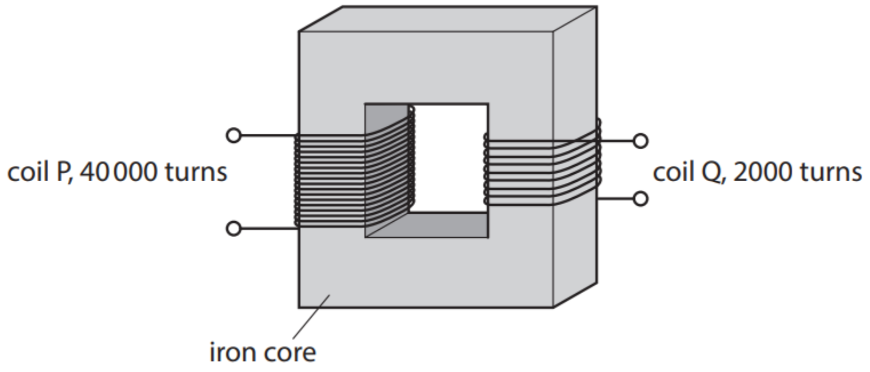
Calculate the size of this e.m.f.

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

Study question #4

A battery charger includes a transformer and a rectifier.

The figure represents the transformer, consisting of an iron core with two coils P and Q wound on to the core.



P consists of 40 000 turns and Q consists of 2000 turns.

When P is connected to a 230 V a.c. supply, there is an e.m.f. across the terminals of Q.

Calculate the size of this e.m.f.

$$V_s = \frac{n_s}{n_p} V_p$$
$$= \frac{2000}{4000} * 230$$
$$= 115V$$

e.m.f = ... $115V$ .... [2]

THANK YOU