Section

4.5

Electromagnetic forces

4.5.1 Magnetic effect of a current

4.5.2 How electric motors are constructed

4.5.3 Force on a current-carrying conductor

Background

Static electricity vs. Magnetism

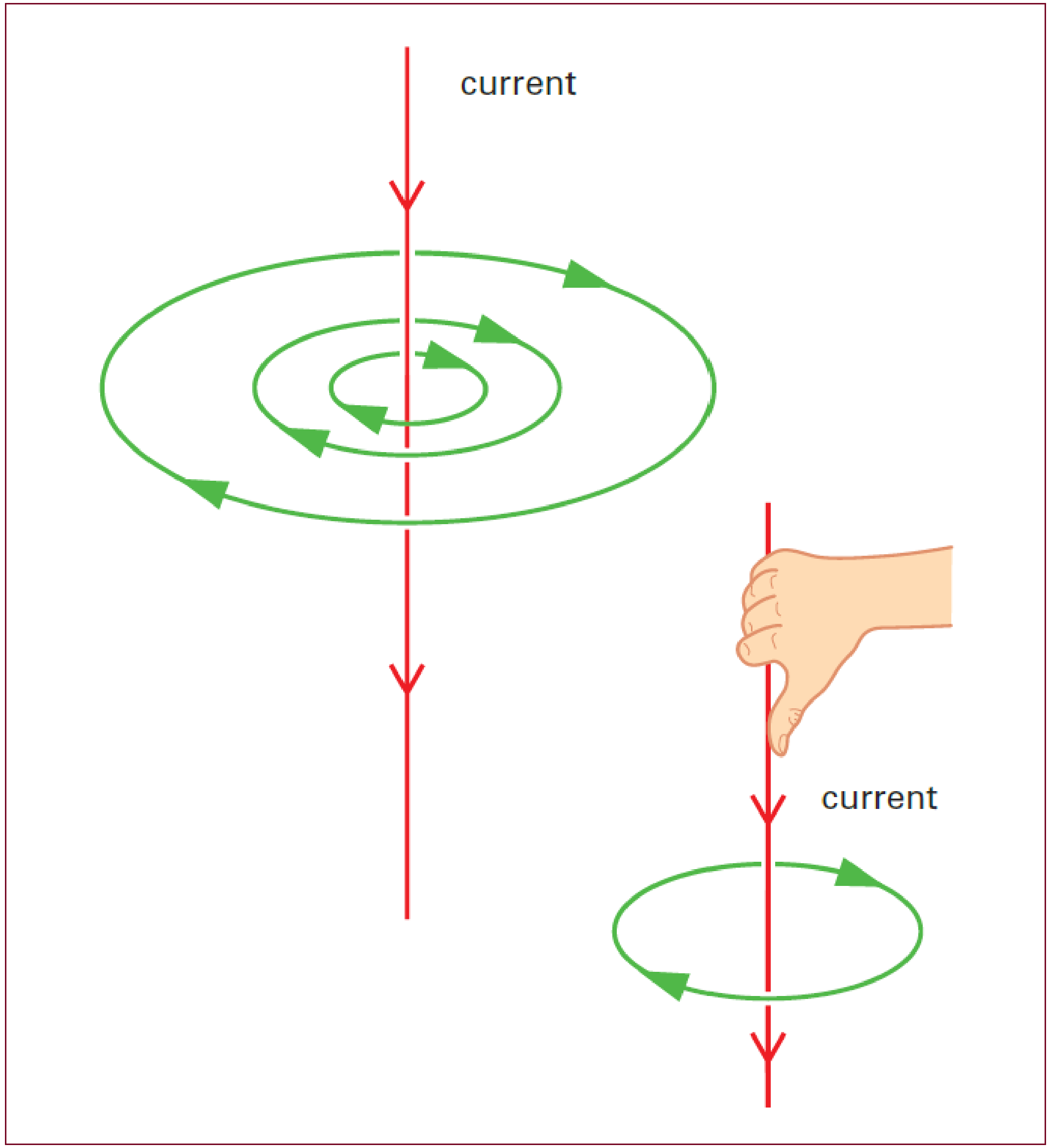
similar patterns

- 2 types of charge or pole
- attractive & repulsive forces
- a force that gets weaker at a distance

Background

- There are two ways to produce a magnetic field – using a permanent magnet or an electromagnet (a coil of wire through which a current flows).
- The second of these shows there is a close connection between **electricity and magnetism**.
- This was discovered by Hans Christian Oersted, a Danish scientist, early in the 19th century. He noticed that **both static electricity and magnetism showed similar patterns**. He also proved that the current in the wire was producing a magnetic effect, which was acting on the compass needle near by.

The magnetic effect of a current



The magnetic field around a current in a straight wire. The field lines are circles around the wire. **The further away from the wire, the weaker is the field.**

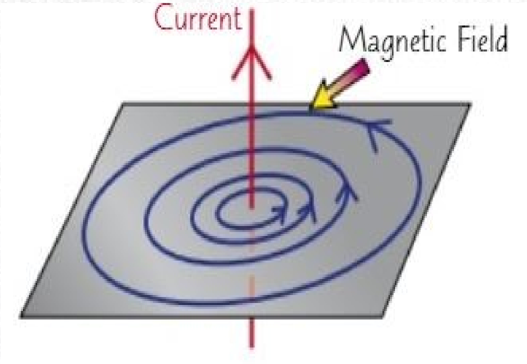
The magnetic effect of a current

- An **electromagnet** can be made by passing a current through a coil of wire (a solenoid). The flow of current results in a magnetic field around the solenoid. The field is similar to the field around a bar magnet.
- If you uncoil a solenoid, you will have a straight wire. With a current flowing through it, it will have a magnetic field around it. The field lines are circles around the current.
- Every electric current is surrounded by the magnetic field that it creates. An electromagnet is simply a clever way of making use of this, because winding the wire into a coil is **a way of concentrating the magnetic field**.
- The **right-hand grip rule** tells you the direction of the field lines.

Electromagnetism – Summary

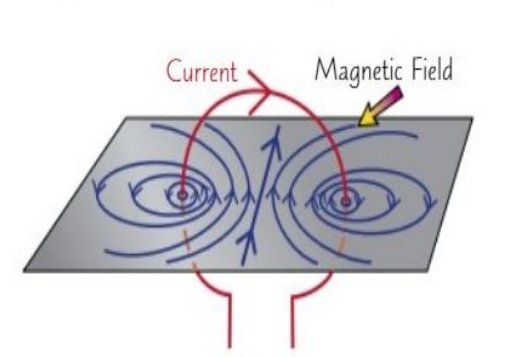
The magnetic field around a **straight wire**:

- The magnetic field around a straight wire is made up of concentric circles with the wire in the centre.



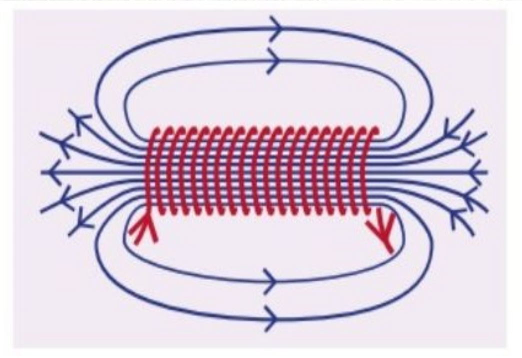
The magnetic field around a **flat circular coil**:

- The magnetic field in the centre of a flat circular coil of wire is similar to that of a bar magnet.
- There are concentric ellipses (stretched circles) of magnetic field lines around the coil.



The magnetic field around a **solenoid**:

- The magnetic field inside a current-carrying solenoid is strong and uniform.
- Outside the coil, the field is just like the one around a bar magnet.
- The ends of a solenoid act like the north and south poles of a bar magnet.
- This type of magnet is called an electromagnet.



Study question #1

The diagram is a simplified top view of a flat coil. There is an alternating current (a.c.) in the coil.

Describe the magnetic effect of this alternating current.

....

....

.... [2]

Study question #1

The diagram is a simplified top view of a flat coil. There is an alternating current (a.c.) in the coil.

Describe the magnetic effect of this alternating current.

magnetic field produced (1)

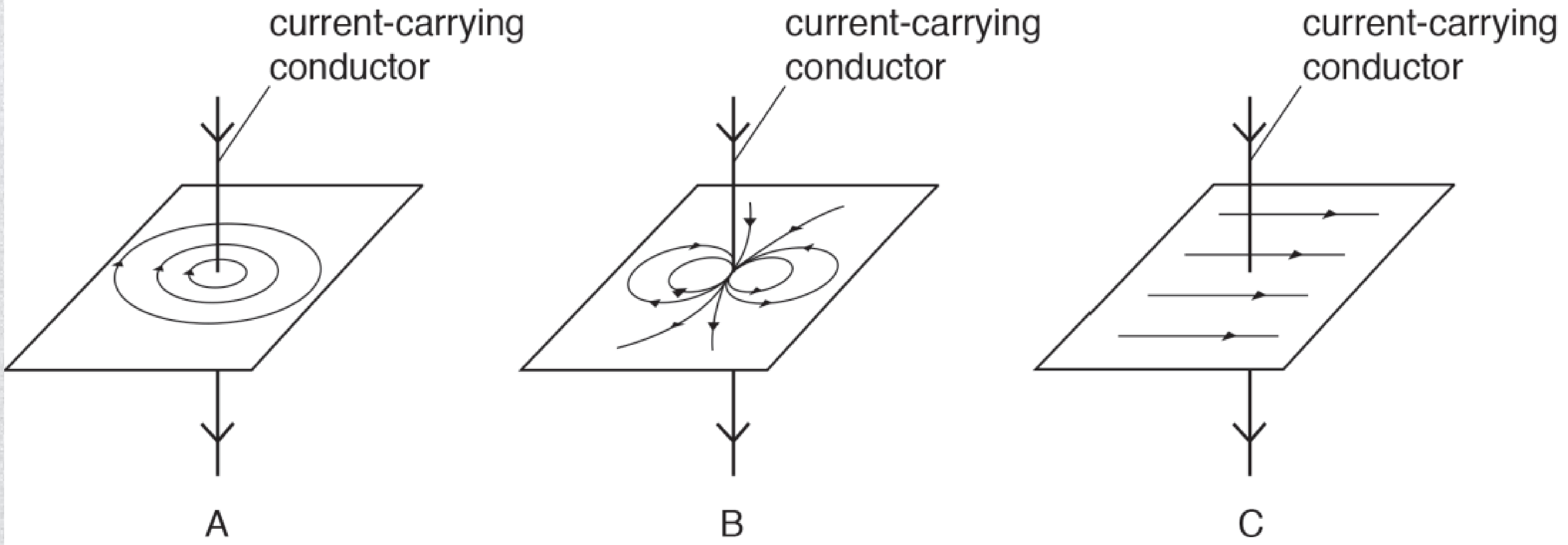
magnetic field / magnetic flux /magnetic effect / magnetism alternates

/ changes direction / reverses (1)

[2]

Study question #2

Each of the three diagrams shows a current-carrying conductor and a magnetic field pattern.

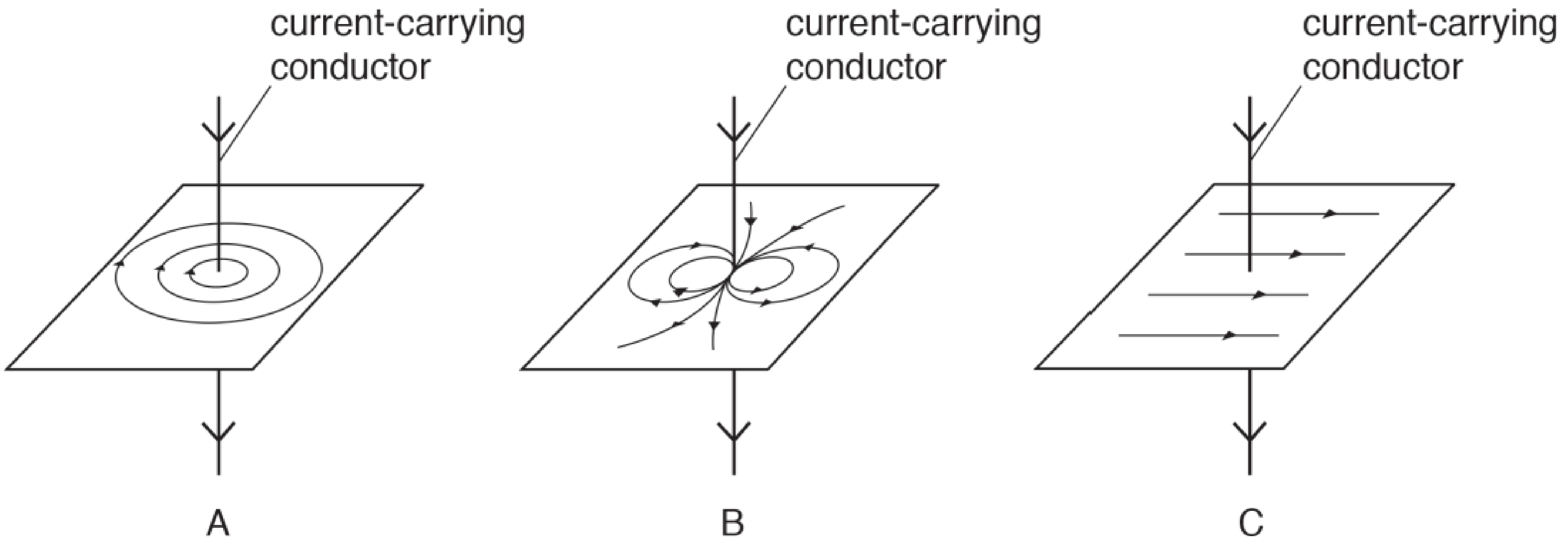


State the diagram which correctly shows the magnetic field around a current-carrying conductor.

.... [1]

Study question #2

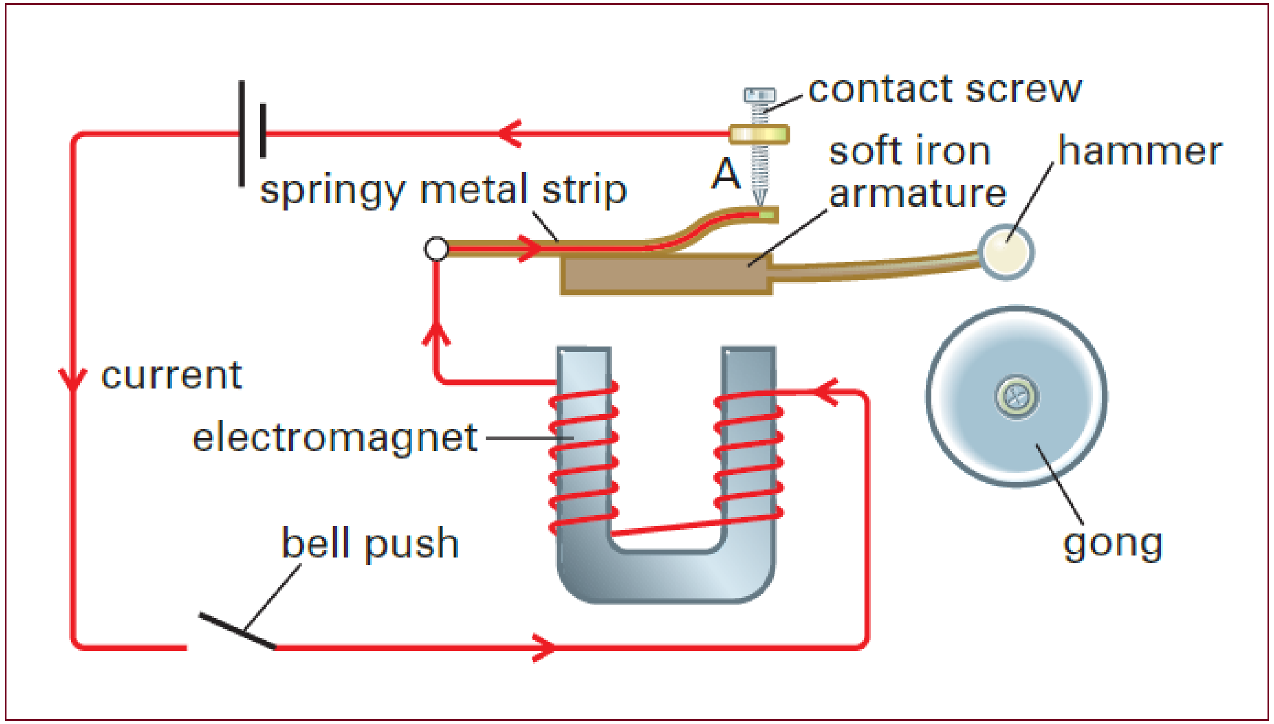
Each of the three diagrams shows a current-carrying conductor and a magnetic field pattern.



State the diagram which correctly shows the magnetic field around a current-carrying conductor.

Diagram A correctly shows the magnetic field around a current-carrying conductor. [1]

Electric bells



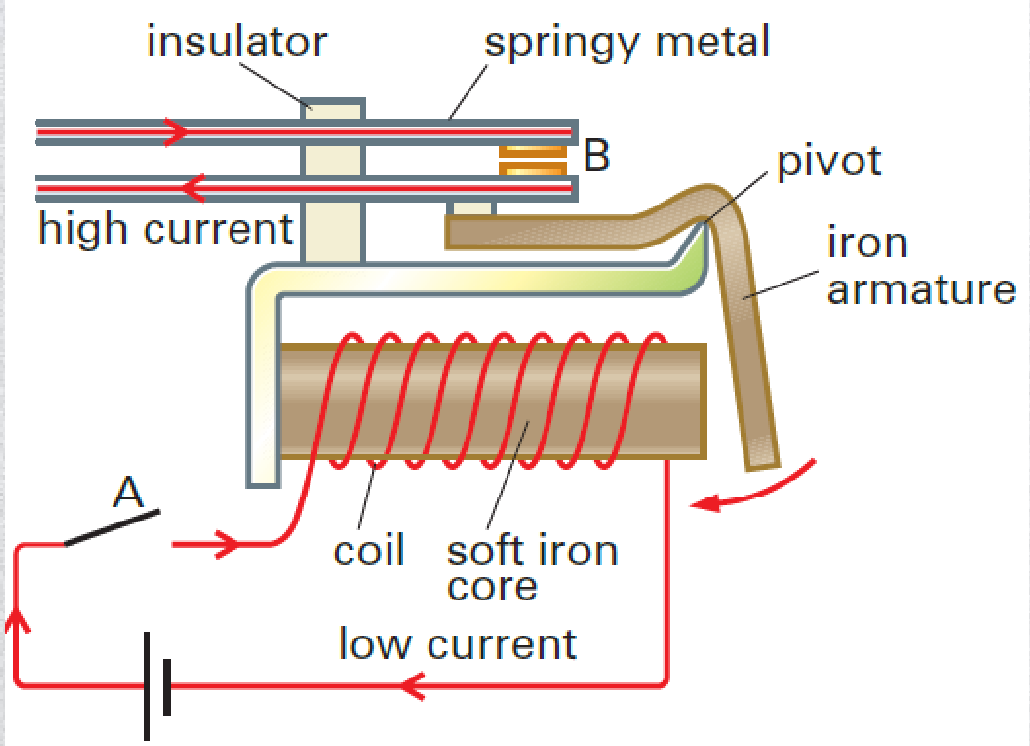
For as long as the bell push is depressed, the hammer springs back and forth, striking the gong. The contact screw at A can be adjusted to ensure that the circuit breaks each time the hammer is attracted by the electromagnet.

Electric bells

An electric bell is a surprisingly clever device. It works using **direct current** from a battery, but it makes a hammer move repeatedly back and forth to strike the gong and produce the sound, which tells us, for example, that someone is at the door. Notice that the hammer is attached to a springy metal strip, and is normally not in contact with the gong.

- When someone presses on the bell push, the circuit is completed. Current flows from the battery round through the electromagnet coil and the springy strip, and back to the battery via the contact point A.
- **The coil is now magnetised and attracts the springy strip**. Two things now happen: *the hammer strikes the gong* and *the circuit breaks at point A*.
- **The current stops, the coil is no longer magnetised, and the strip springs back to its original position**.
- Now the circuit is complete again and a current flows once more. The coil is magnetised and attracts the iron again, the hammer strikes the gong, and so on.
- This process repeats itself for as long as the bell push is depressed.

Relays



A relay is a switch operated by an **electromagnet**.

- When switch A is closed, a small current flows around a circuit through the coil of the electromagnet.
- The electromagnet attracts the iron armature. As the armature tips, it pushes the two contacts at B together, **completing the second circuit**.

Relays

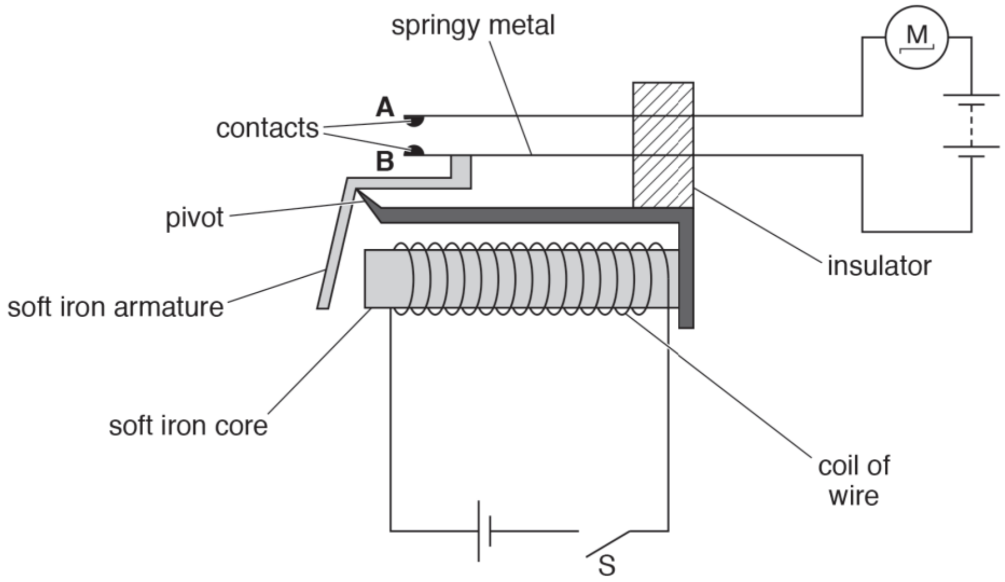
A relay is used **to make a small current switch a larger current on and off**.

For example, when a driver turns the ignition key to start a car, a small current flows to a relay in the engine compartment.

This closes a switch to complete the circuit, which brings a high current to the starter motor from the battery.

Study question #4

The diagram shows a relay operated by switch S.



Using the diagram, describe how closing the switch, S, causes the electric motor to operate.

....

....

....

....

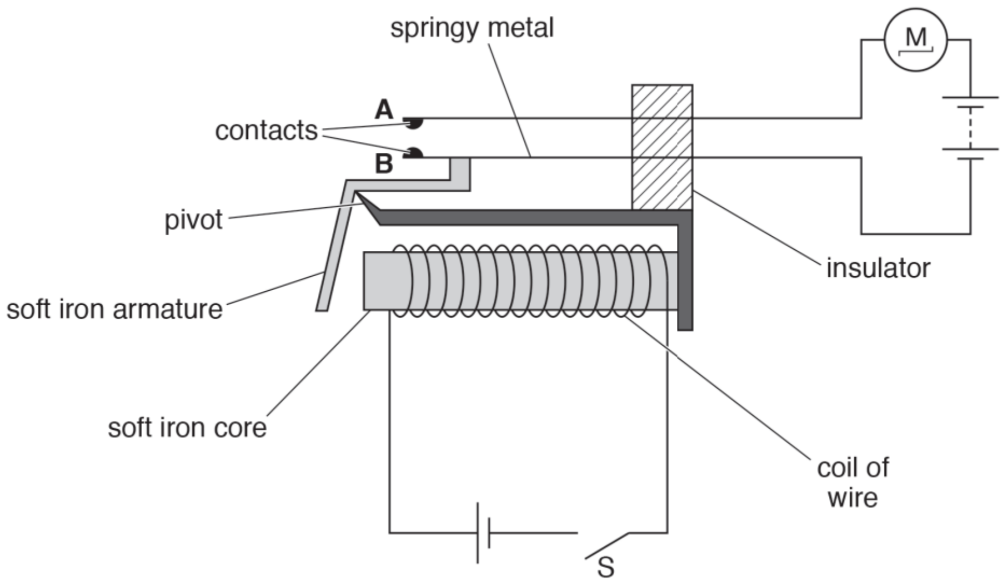
....

....

.... [4]

Study question #4

The diagram shows a relay operated by switch S.



Using the diagram, describe how closing the switch, S, causes the electric motor to operate.

....

....

....

....

....

....

.... [4]

when switch S is closed there is a current in the coil of wire [1] soft iron core becomes magnetized /magnetic field created [1] soft iron armature attracted to core [1] contacts A and B close which makes motor circuit completed/current in motor circuit [1]

Comparing magnetic fields - Summary

We represent magnetic fields by drawing field lines. The arrows on the lines show the direction of the field at any point. This is the direction of the force on a north magnetic pole placed in the field.

- **Current in a wire**: The field lines are circles around the wire. Further from the wire they are further apart, showing that the field is weaker. If the current is greater, the field will be stronger and so the lines will be closer together. *Reversing the current reverses the direction of the field.*
- **Current in a solenoid**: The field lines are close together at the poles of the electromagnet. Further from the coil, the lines are further apart (weaker field). *Inside the coil the field lines run parallel to each other showing that the field is uniform (its strength is constant).* Again, *increasing the current gives a stronger field. Reversing the current reverses the field.*

Electromagnetism - Summary

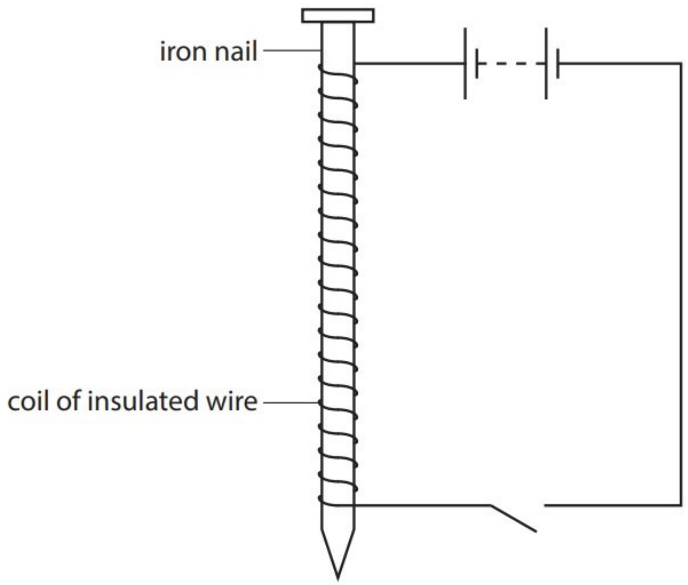
- **Electric currents** produce their own **magnetic field**.
  - ✓ An electric current in a conductor produces a magnetic field around it.

- The **larger** the electric current, the **stronger** the magnetic field.

- The **direction of the magnetic field** depends on the **direction of the current**.

Study question #5

A way of making a magnet is shown in the figure.



(a) State the name given to this type of magnet.

.... [1]

(b) Suggest an advantage of this type of magnet.

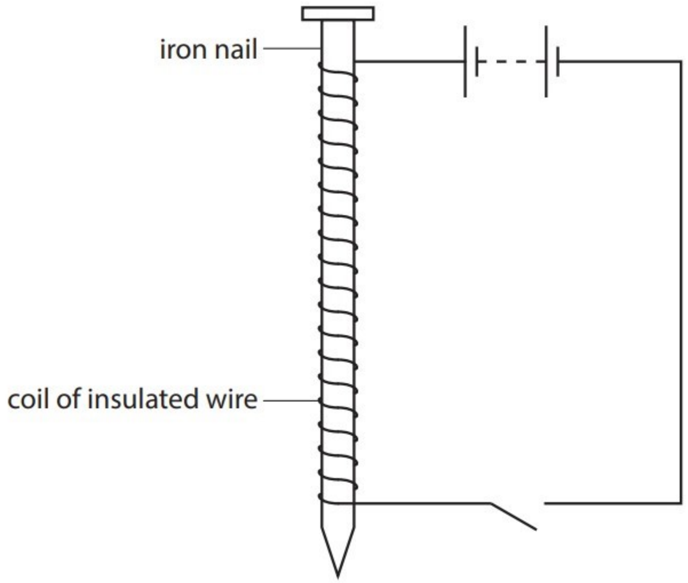
....

.... [1]

[Total: 2]

Study question #5

A way of making a magnet is shown in the figure.



(a) State the name given to this type of magnet.

electromagnet [1]

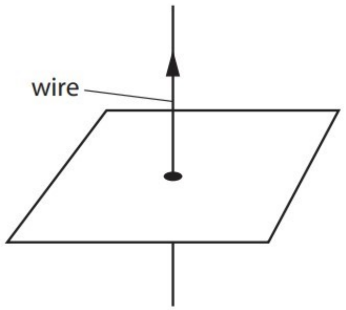
(b) Suggest an advantage of this type of magnet.

(magnetic field/magnetism) can be controlled / can be switched off [1]

[Total: 2]

Study question #6

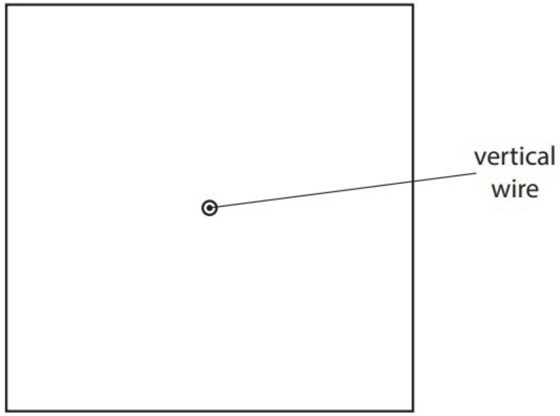
The figure shows a vertical wire passing through a horizontal piece of card.



There is a direct current (d.c.) in the wire. The current produces a magnetic field around the wire.

The figure below shows the wire and the card viewed from above.

On the figure below, carefully draw **two** complete field lines produced by the current-carrying wire.



[1]

[Total: 1]

Study question #6

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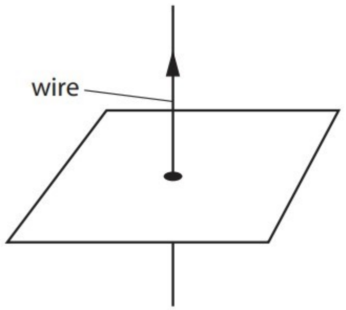

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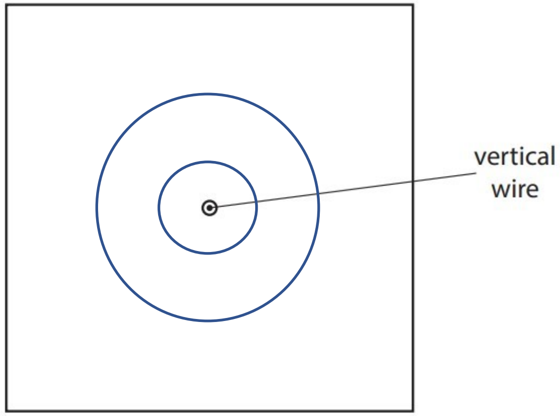
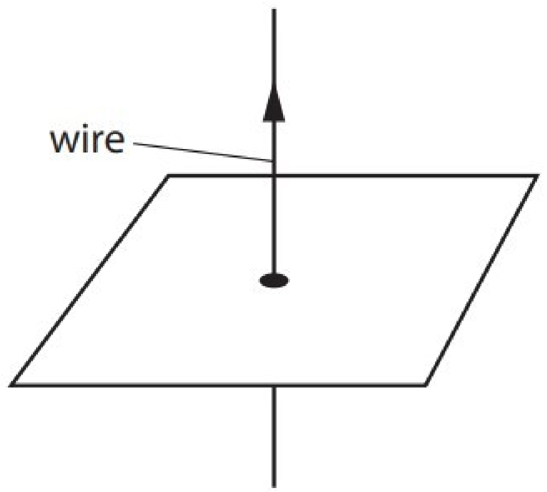


[1]

[Total: 1]

Study question #7

The figure shows a vertical wire passing through a horizontal piece of card.



There is a direct current (d.c.) in the wire. The current produces a magnetic field around the wire.

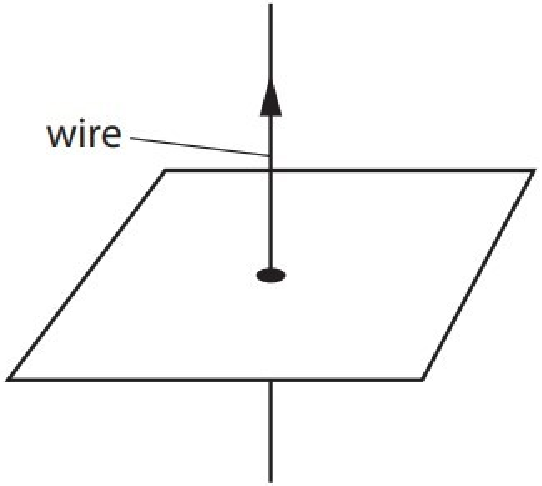
Name a piece of equipment that can be used to investigate the magnetic field produced by the current-carrying wire.

.... [1]

[Total: 1]

Study question #7

The figure shows a vertical wire passing through a horizontal piece of card.



There is a direct current (d.c.) in the wire. The current produces a magnetic field around the wire.

Name a piece of equipment that can be used to investigate the magnetic field produced by the current-carrying wire.

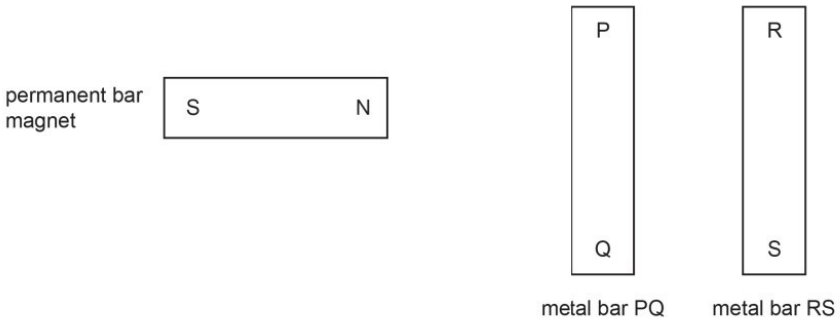
iron filings OR (plotting) compass

.... [1]

[Total: 1]

Study question #8

A student has a permanent bar magnet and two metal bars, as shown in the diagram.



The student tests bar PQ and bar RS separately. He holds the N pole of the permanent bar magnet close to each end of each metal bar. The table shows the results of the tests.

end of metal bar	result of test with N pole
P	attracted
Q	repelled
R	attracted
S	attracted

Deduce whether each metal bar is a magnet, an unmagnetised magnetic material or a non-magnetic material.

Give a reason for each of your answers.

1. metal bar PQ..

....

....

2. metal bar RS..

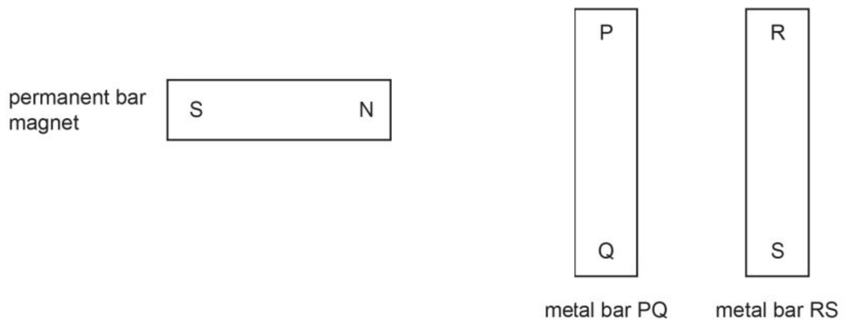
....

.... [4]

[Total: 4]

Study question #8

A student has a permanent bar magnet and two metal bars, as shown in the diagram.



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end of metal bar	result of test with N pole
P	attracted
Q	repelled
R	attracted
S	attracted

Deduce whether each metal bar is a magnet, an unmagnetised magnetic material or a non-magnetic material.

Give a reason for each of your answers.

1. metal bar PQ..

....

....

2. metal bar RS..

....

.... [4]

[Total: 4]

1. metal bar PQ is a (permanent) magnet [1] (because magnet) repels end Q [1]

2. metal bar RS is an unmagnetised magnetic material [1] (because magnet) attracts both ends (of RS) [1]

Study question #9

Some students plot the magnetic field lines around a bar magnet. They have the apparatus shown in the diagram and a large sheet of paper.

Describe how the students use the apparatus in the diagram to show the pattern of the magnetic field lines around the bar magnet.

You may draw a diagram to assist with your description.

....

....

....

....

....

.... [3]

[Total: 3]

Study question #9

Some students plot the magnetic field lines around a bar magnet. They have the apparatus shown in the diagram and a large sheet of paper.

Describe how the students use the apparatus in the diagram to show the pattern of the magnetic field lines around the bar magnet.

You may draw a diagram to assist with your description.

any three from:

Place plotting compass next to magnet

mark a dot of compass needle

move compass other side of the dot

align needle with the dot, mark another dot

other side of needle and repeat

start again from another position next to magnet

[3]

[Total: 3]

Study question #10

Explain the difference between ‘soft’ and ‘hard’ magnetic materials.

Study question #10

Explain the difference between ‘soft’ and ‘hard’ magnetic materials.

Soft magnetic materials lose their induced magnetism quickly [1 mark], and hard magnetic materials keep their induced magnetism permanently [1 mark].

Study question #11

How to strengthen the magnetic field around a solenoid?

Study question #11

How to strengthen the magnetic field around a solenoid:

- *increasing the current in the coil;*
- *increasing the number of turns in the solenoid;*
- *using a soft iron core within the solenoid.*

THANK YOU

Section

4.5

Electromagnetic forces

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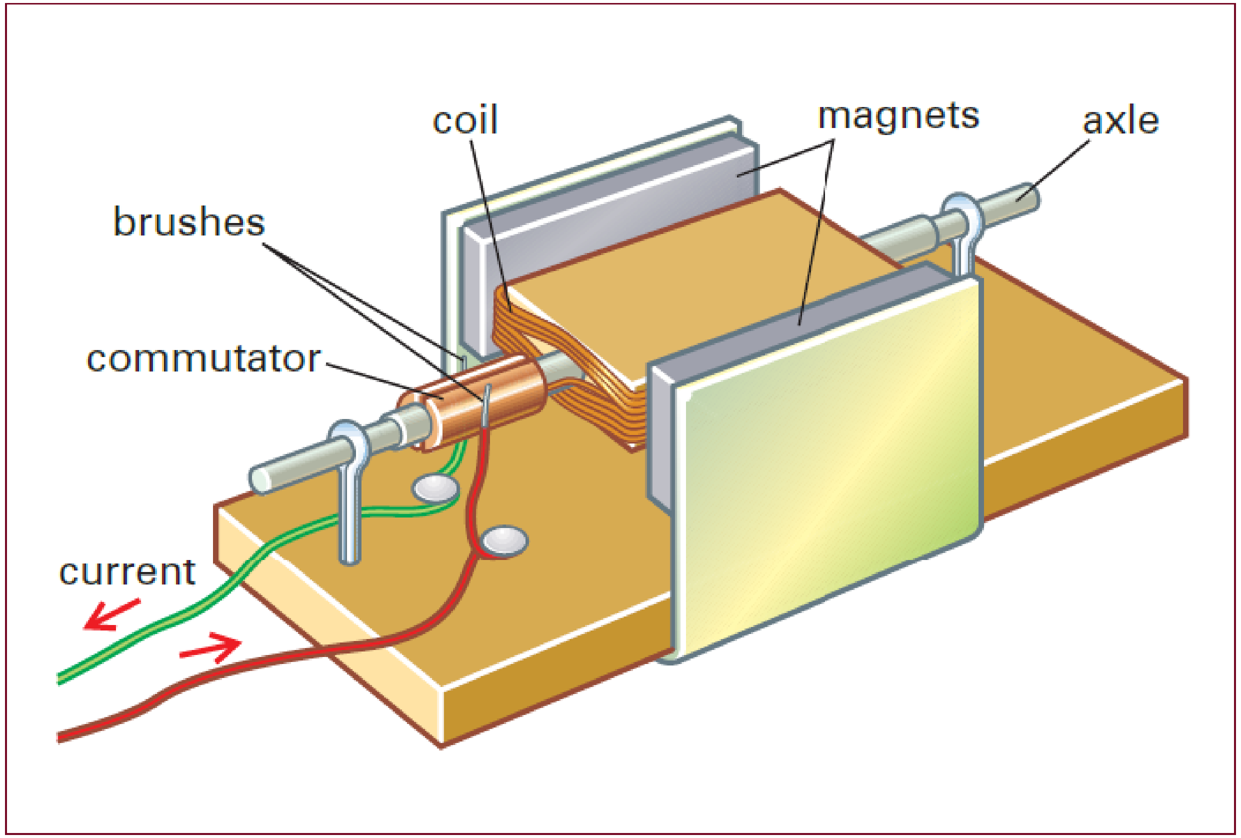
4.5.2 How electric motors are constructed

4.5.3 Force on a current-carrying conductor

Electric Motor



Electric motors are cleverly designed **to produce movement** that continues as long as the **current flows**.

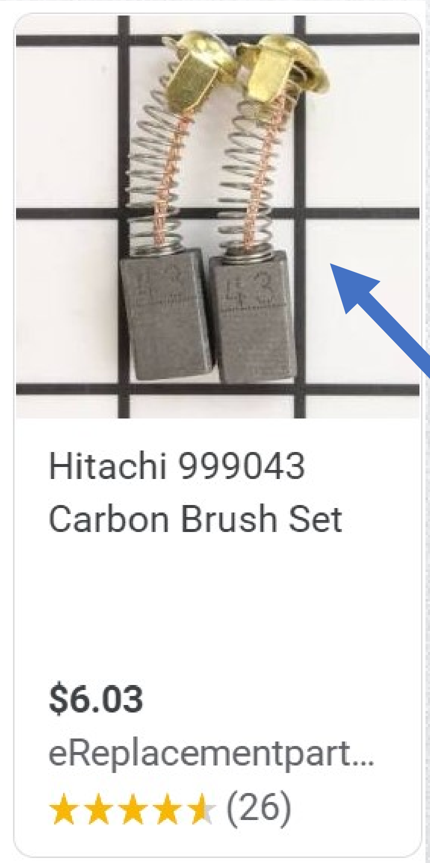
- Key components
- Functions of each component
- Working principle of d.c. motor

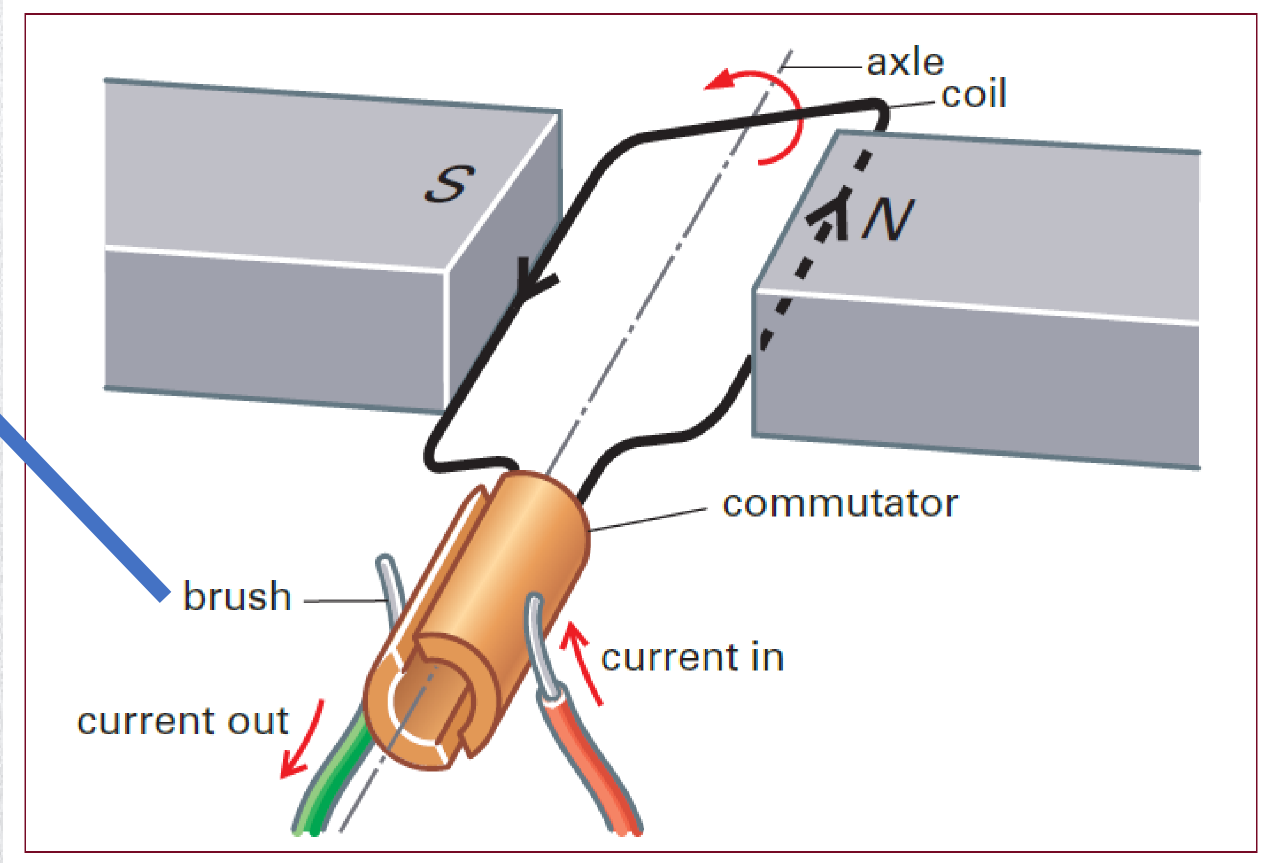
Electric Motor

Key components and functions of each :

- a **coil of wire**, which acts as **an electromagnet** when a direct current flows through it
- **two magnets**, to provide a steady magnetic field passing through the coil; this magnetic field can be attracted or repelled by another magnetic field to produce movement.
- **a split-ring commutator**, through which current reaches the coil
- **two brushes**, which are springy wires that press against the two metal sections of the commutator

Electric Motor





A spinning electric motor. The coil is an electromagnet, which is attracted round by the permanent magnets. **Every half turn**, the **commutator** reverses the current flowing through the coil, so that it **keeps turning in the same direction**.

Electric Motor

Working principle of d.c. motor:

- A current flows in through the right-hand brush, around the coil, and out through the other brush.
- When the current is flowing, the coil becomes an **electromagnet**. At the instant shown (on the previous slide), *the uppermost side of the coil is its north pole and the lowermost side is its south pole*. The north pole of the coil is attracted to the south pole of the permanent magnet on the left, and so the coil starts to turn to the left (anticlockwise).
- This is where the commutator comes in. The coil is attracted round by the two permanent magnets. *Its momentum carries it past the vertical position*. Now, the brush connections to the two halves of the commutator are reversed. **The current flows the opposite way around the coil.**

Electric Motor

How an electric motor works:

- We again have a north pole on the uppermost side of the coil, so it turns another 180° anticlockwise.
- Without the commutator, the coil would simply turn until it was vertical. The **commutator cleverly reverses the current through the coil every half turn**, so that the coil keeps on turning.
- For a **d.c. motor** like this to be of any use, its axle must be connected to something that is to be turned – a wheel, a pulley or a pump, for example. The turning effect can be increased by increasing the number of turns of wire on the coil.

Electric Motor

Why does electromagnet (i.e. coil of wire) in the d.c. motor spins round?

Electric Motor

Why does electromagnet (i.e. coil of wire) in the d.c. motor spins round?

The electromagnet spins round because its magnetic field interacts with the field of the permanent magnets.

Electric Motor

How to make a motor more powerful (i.e. rotate faster)?

Making motors more powerful

An electric motor makes use of a coil of wire with a current flowing through it – in other words, an electromagnet. **The electromagnet spins round because its magnetic field interacts with the field of the permanent magnets.** This means that a motor can be made more powerful in three ways:

- **by increasing the current** in the electromagnet
- **by having more turns of wire** on the coil
- **by making the permanent magnets stronger**.

*Note there are **two magnetic fields** in an electric motor: the field of the permanent magnets and the field of the current-carrying coil.

Electric Motor

How to reverse the direction of the motor?

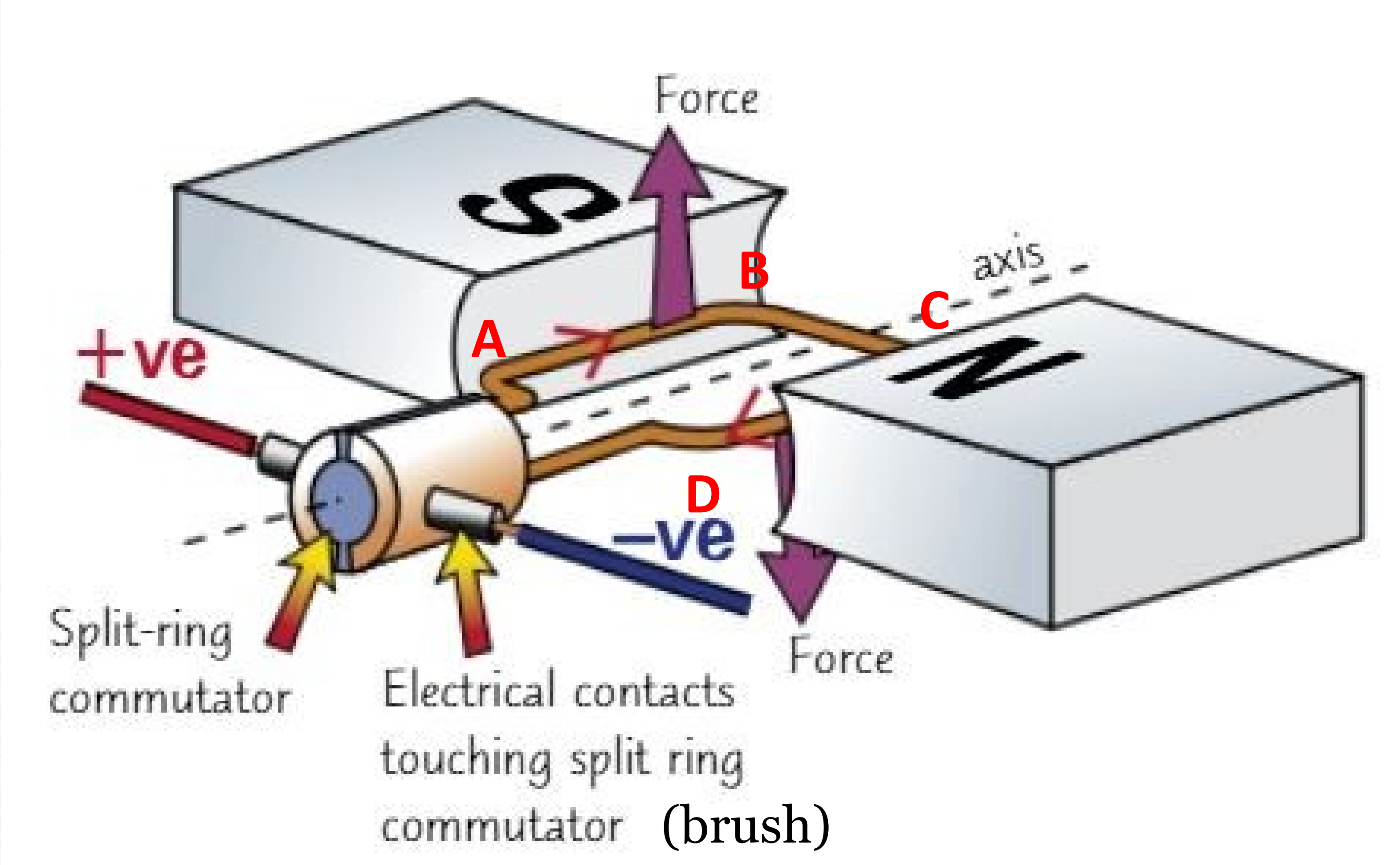
Electric Motor

How to reverse the direction of the motor?

The direction of the motor can be reversed by:

1) swap the polarity of the d.c. supply; 2) swap the magnetic poles over

Electric Motor - Summary



Electric Motor - Summary

- 4 factors which **speed it up**:
  - More current
  - More turns on the coil
  - Stronger magnetic field
  - Add a soft iron core in the coil
- The **forces** acting on the two side arms of the coil, which are just the usual forces that act on any current in a magnetic field.
- Because the coil is on a spindle and the forces act one up and one down, it rotates.
- Fleming's **left-hand rule** to work out which way coil will turn.
- The **split-ring commutator** is a way of swapping the contacts **every half turn** to **keep the motor rotating in the same direction**.
- The **direction of the motor** can be reversed by: 1) swap the **polarity of the d.c. supply**; 2) swap the **magnetic poles** over.

Study question #1

State two ways to reverse the direction of rotation of a simple d.c. electric motor.

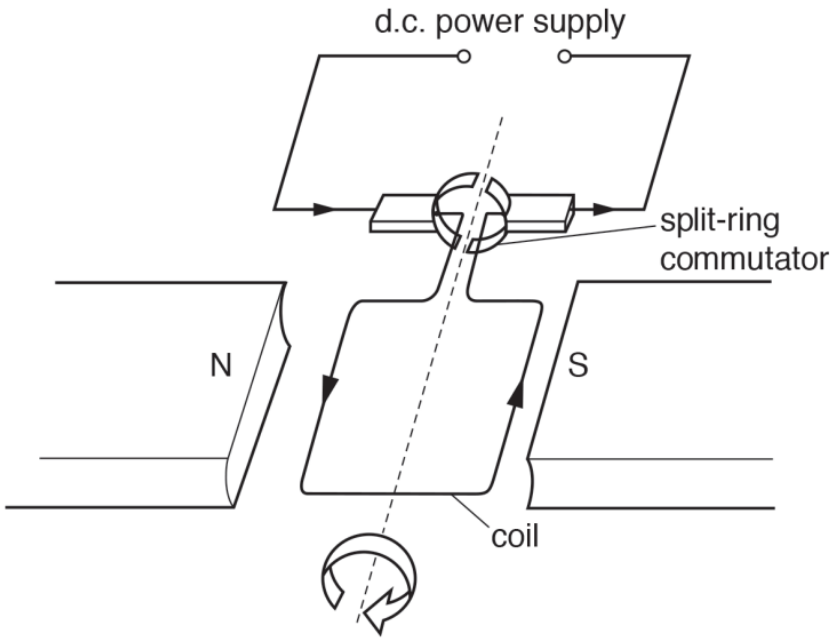
Study question #1

State two ways to reverse the direction of rotation of a simple d.c. electric motor.

By either swapping the polarity of the d.c. supply (change the direction of the current) or by swapping the magnetic poles over.

Study question #2

The diagram shows a simple direct current (d.c.) motor.



Explain the purpose of the split-ring commutator.

....

....

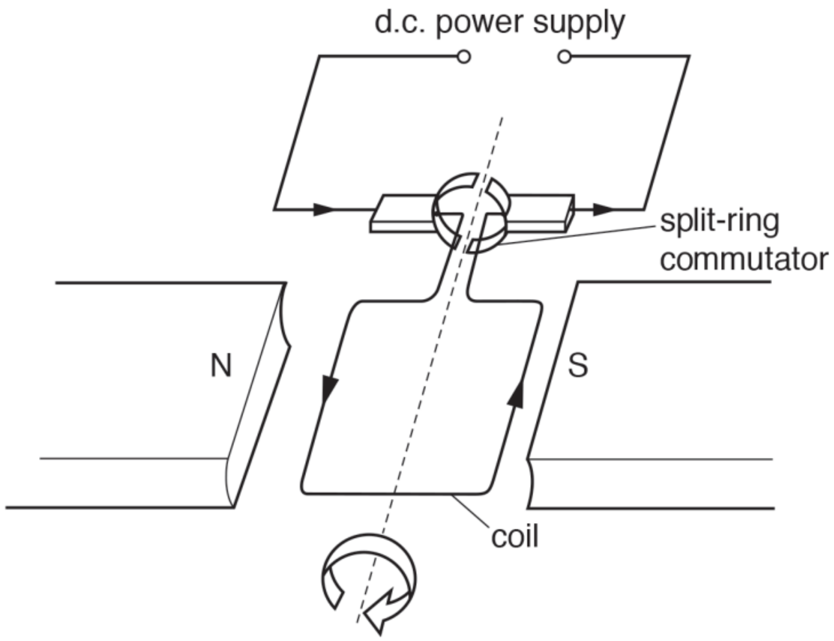
....

.... [3]

[Total: 3]

Study question #2

The diagram shows a simple direct current (d.c.) motor.



Explain the purpose of the split-ring commutator.

keeps coil rotating in the same direction (1)

by changing direction of current (in the coil) (1)

every half cycle / 180 degrees (1)

[3]

[Total: 3]

THANK YOU

Section

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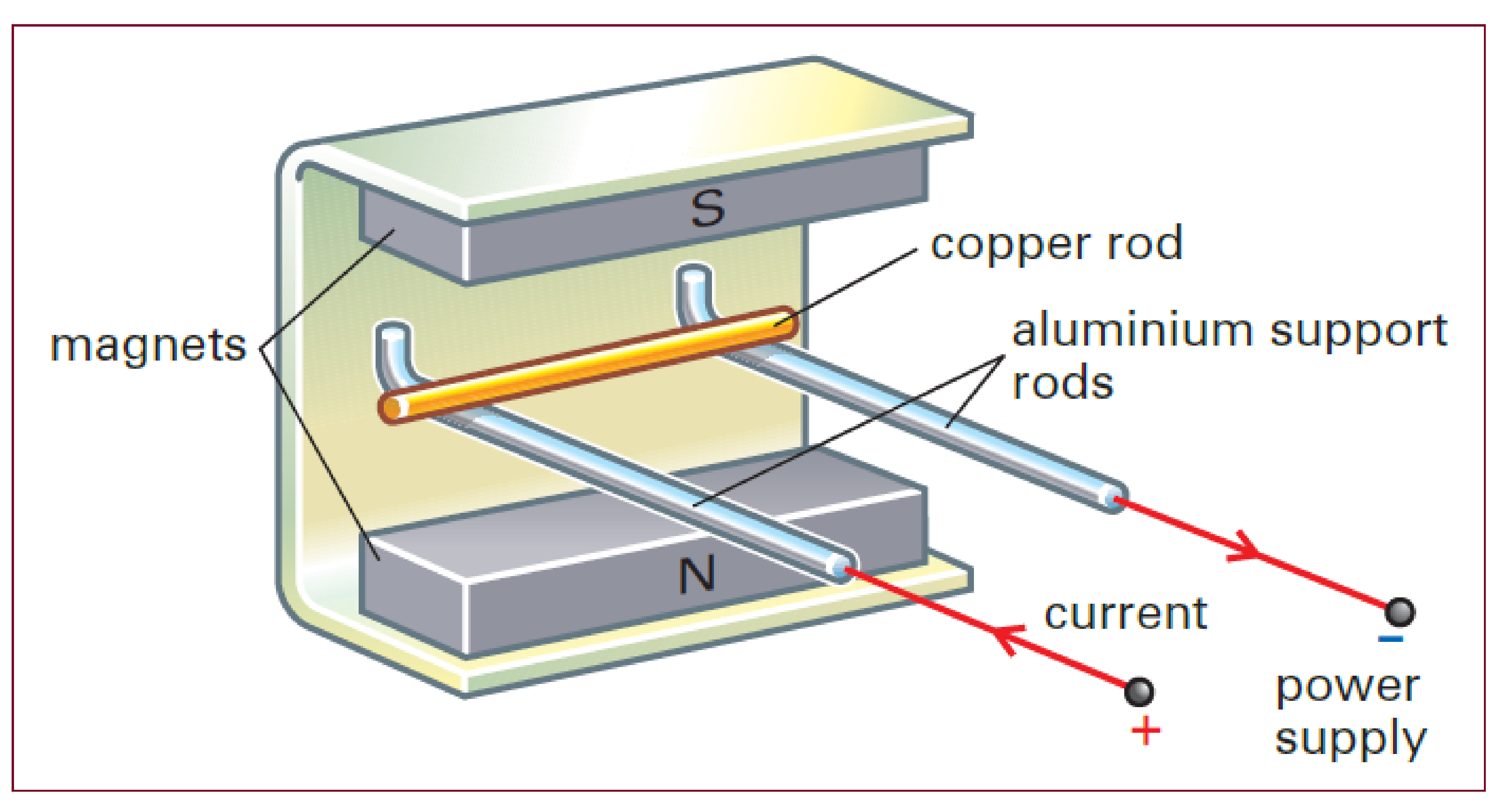
Forces on a current-carrying conductor



1. What are the forces exerting on the copper rod, before the power supply is turned on?
2. What is the motion of the copper rod when the current starts to flow? And why is that?
3. What will happen if we change the copper rod into a plastic rod ? Or an iron rod?

Forces on a current-carrying conductor

The current from the power supply flows along one support rod, through the copper rod, and out through the other support rod. The two magnets provide a vertical magnetic field.

What happens when the current starts to flow?

The copper rod is free to roll along the two aluminum support rods. It is pushed by a horizontal force. ***The force comes about because the magnetic field around the current is repelled by the magnetic field of the permanent magnets.***

Forces on a current-carrying conductor

How to increase the force exerting onto the rod?

Forces on a current-carrying conductor

The force can be increased in two ways:

- by increasing the current and
- by using magnets with a stronger magnetic field.

This force, which every electric motor makes use of, is known as the ***motor effect***.

Forces on a current-carrying conductor

How to make the rod rolls in the opposite direction?

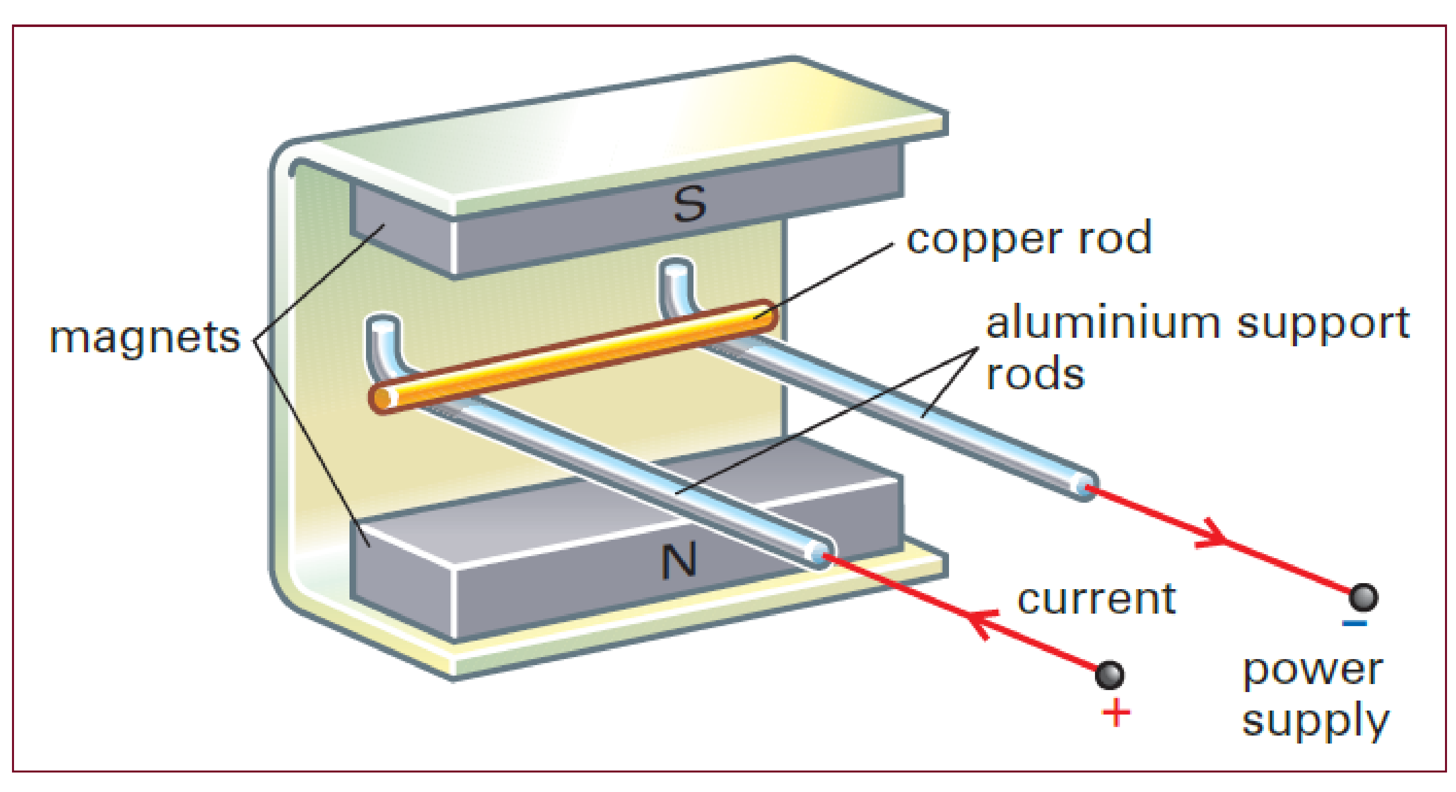
Forces on a current-carrying conductor

By swapping the connections to the power supply, you can reverse the direction of the current in the copper rod. The rod rolls in the opposite direction, showing that the force on it has been reversed. Similarly, if the magnets are reversed so that the magnetic field is in the opposite direction, the force on the copper rod is reversed.

So, **the force caused by the motor effect is reversed if:**

- the **direction of the current** is reversed
- the **direction of the magnetic field** is reversed.

Forces on a current-carrying conductor - Summary

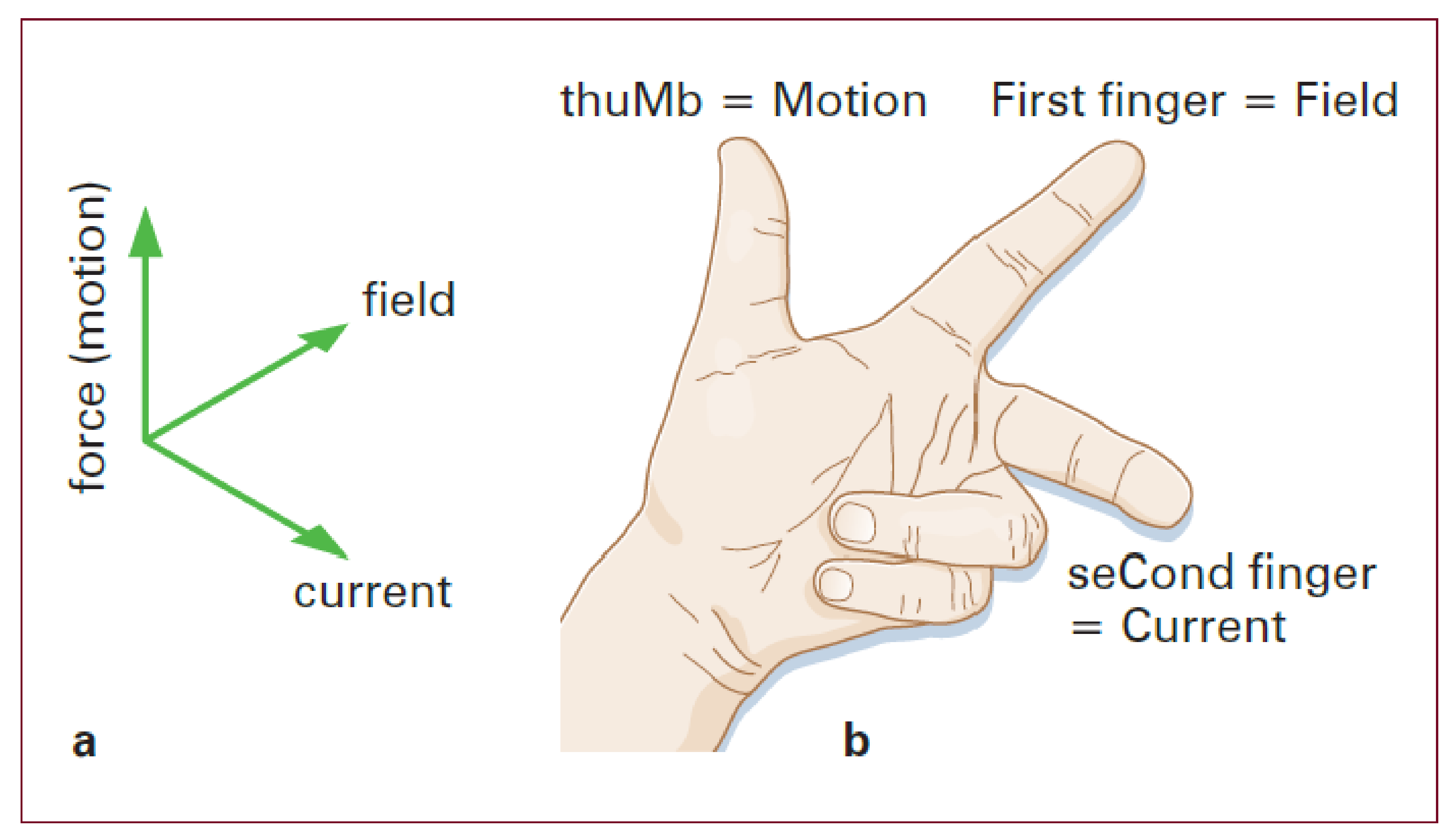


Demonstrating the motor effect.

There is a magnetic field around the current in the copper rod. This interacts with the field of the magnets, and the result is a horizontal **force** on the rod.

A **copper rod** is used because it is a **non-magnetic material** (A steel rod would be attracted to the magnets).

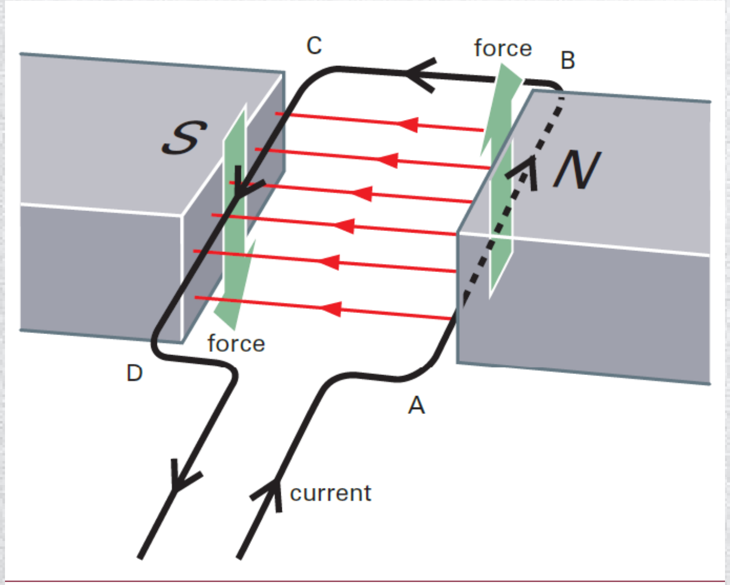
Fleming’s left-hand rule



a. Force, field and current are at right angles to each other.

b. Fleming’s left-hand rule: keeping thumb and first two fingers at 90° to each other

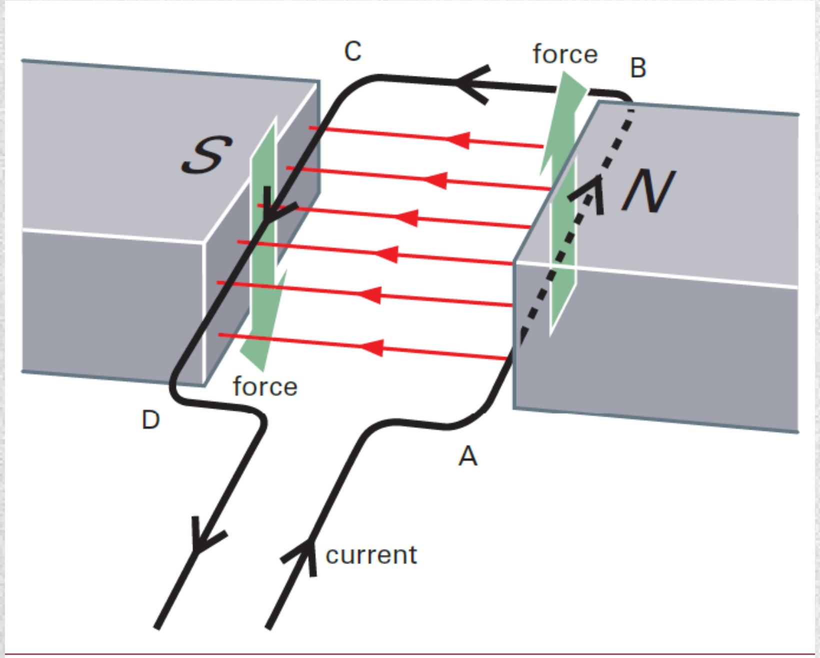
Electric motor



We can apply Fleming's left-hand rule to an electric motor.

- Side AB: The current flows from A to B, across the magnetic field. Fleming's left-hand rule shows that a force acts on it, vertically upwards.
- Side CD: The current is flowing in the opposite direction to the current in AB, so the force on CD is in the opposite direction, downwards.
- Sides BC & DA: *The current here is parallel to the field. Since it does not cross the field, there is no force on these sides.*

Electric motor



Vertical position (@90°)

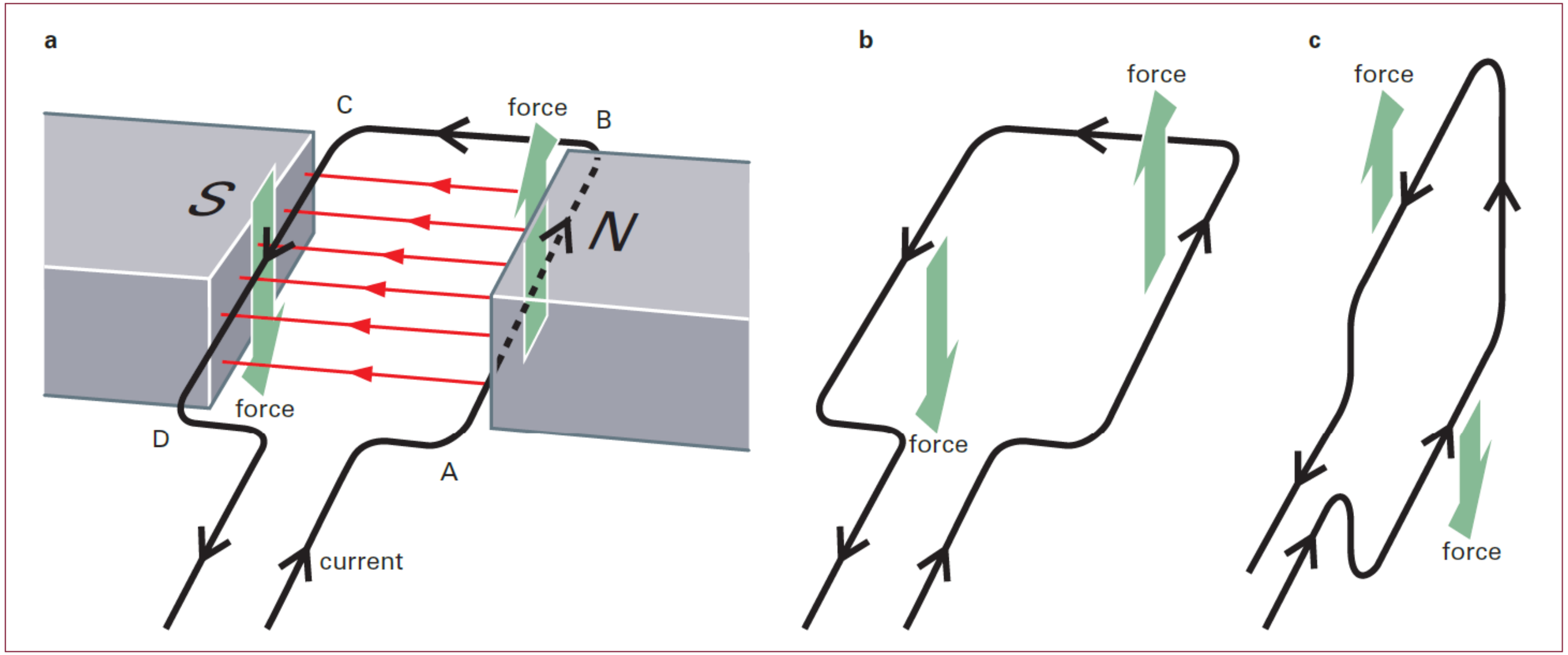
Current: Yes

Force: Yes

Moment: No

The forces will not turn the coil when it is vertical. This is where we have to rely on the coil's momentum to carry it further round.

Fleming's left-hand rule

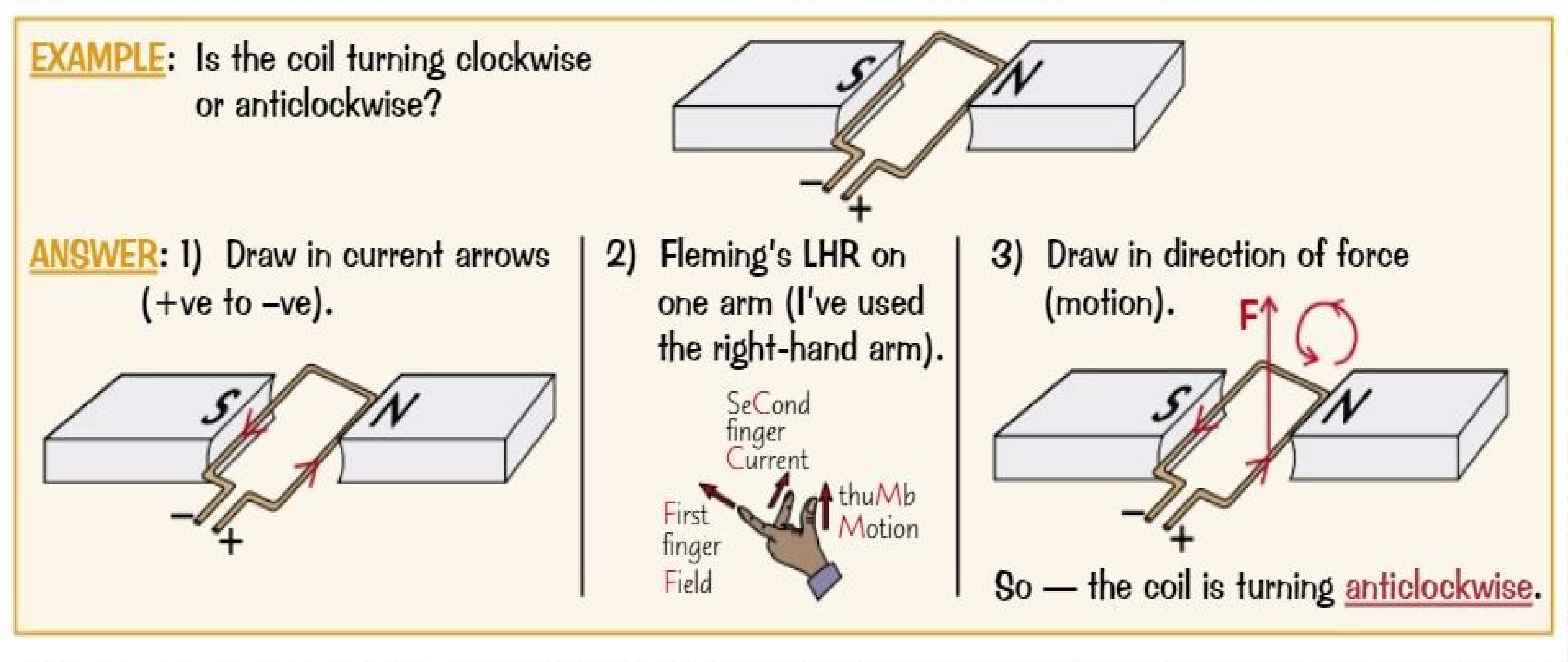


a. A simple electric motor. Only the two longer sides experience a force, since their **currents cut across the magnetic field**.

b. The two forces provide the **turning effect** needed to make the coil rotate.

c. When the coil is **in the vertical position**, the forces have **no turning effect.**

Electric motor



The motor effect - Summary

- The **motor effect**: A ***current*-carrying** wire in the presence of a ***magnetic field*** will experience a ***force***.
- The **direction of the force** can be figured out by ***Left Hand Rule***.
  - Thu**m**b: **m**otion
  - **F**irst finger : magnetic **f**ield
  - Se**c**ond finger: **c**urrent
- A current-carrying coil in a magnetic field may experience a turning effect and that **the turning effect is increased by increasing**:

  (a) the **number of turns** on the coil

  (b) the **current**

  (c) the **strength of the magnetic field**

The motor effect - Summary

- When a current-carrying wire is put between magnetic poles, the two magnetic fields affect one another. The result is a force on the wire. This can cause the wire to move, which is called the **motor effect**.
- This is because charged particles (e.g. electrons in a current) moving through a magnetic field will experience a force, as long as they're not moving parallel to the field lines.

Study question #1

State what the three fingers in Fleming's left-hand rule represent.

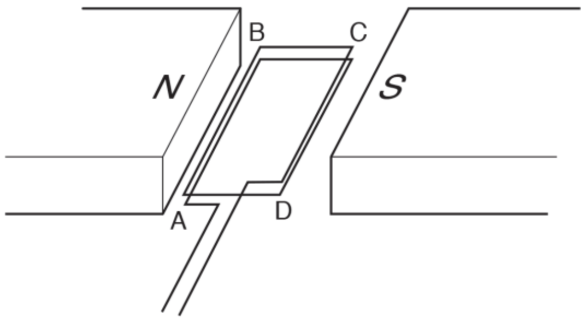
Study question #1

State what the three fingers in Fleming's left-hand rule represent.

The first finger is the magnetic field, the second finger is the current and the thumb is the force/motion [1 mark].

Study question #2

4 The diagram shows a coil ABCD with two turns. The coil is in a magnetic field.



When there is a current in the coil, the coil experiences a turning effect.

The value of the current is 3 A. Place **one** tick in each column of the table to indicate how the turning effect changes with the change described.

turning effect	number of turns on coil increased to six	current increased to 9 A	strength of magnetic field decreased by a factor of 2
decreased by factor of 4			
decreased by factor of 3			
decreased by factor of 2			
no change			
increased by factor of 2			
increased by factor of 3			
increased by factor of 4			

[3]

[Total: 3]

Study question #2

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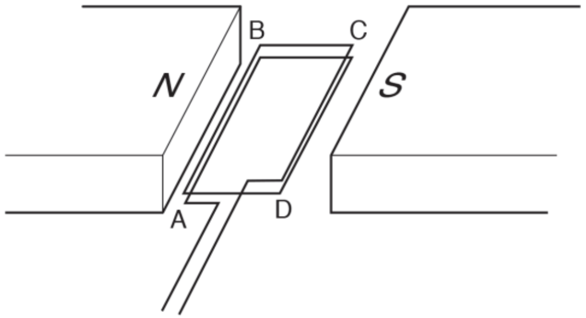

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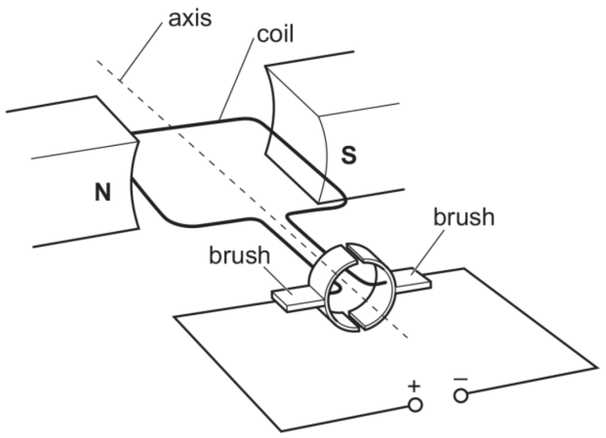
decreased by factor of 3			
decreased by factor of 2			✓
no change			
increased by factor of 2			
increased by factor of 3	✓	✓	
increased by factor of 4			

[3]

[Total: 3]

Study question #3

The diagram shows a simple direct current (d.c.) electric motor. The coil rotates about the axis when there is a current in the coil. The coil is connected to the rest of the circuit by the brushes.



(a) On the diagram, draw a pair of arrows to show which way the coil rotates. Explain the direction you have chosen.

....

....

.... [3]

(b) On the diagram, draw an arrow to show the direction in which electrons flow through the coil. [1]

(c) Explain why the electrons flow in the direction you have shown in **(b)**.

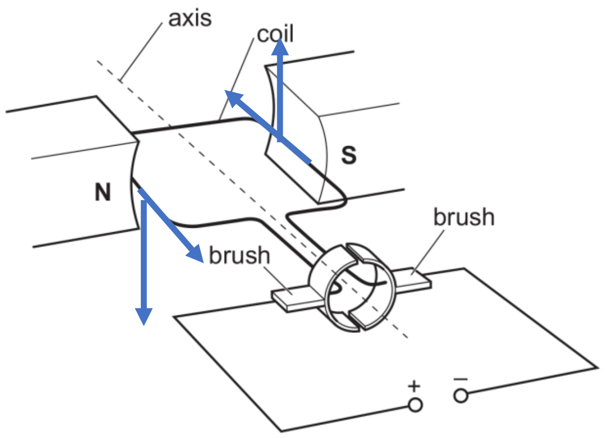
....

.... [1]

[Total: 5]

Study question #3

The diagram shows a simple direct current (d.c.) electric motor. The coil rotates about the axis when there is a current in the coil. The coil is connected to the rest of the circuit by the brushes.



(a) On the diagram, draw a pair of arrows to show which way the coil rotates. Explain the direction you have chosen.

anti-clockwise (seen from brushes) (1)

current flows in on left and out on right (1)

F down on left and up on right (1) [3]

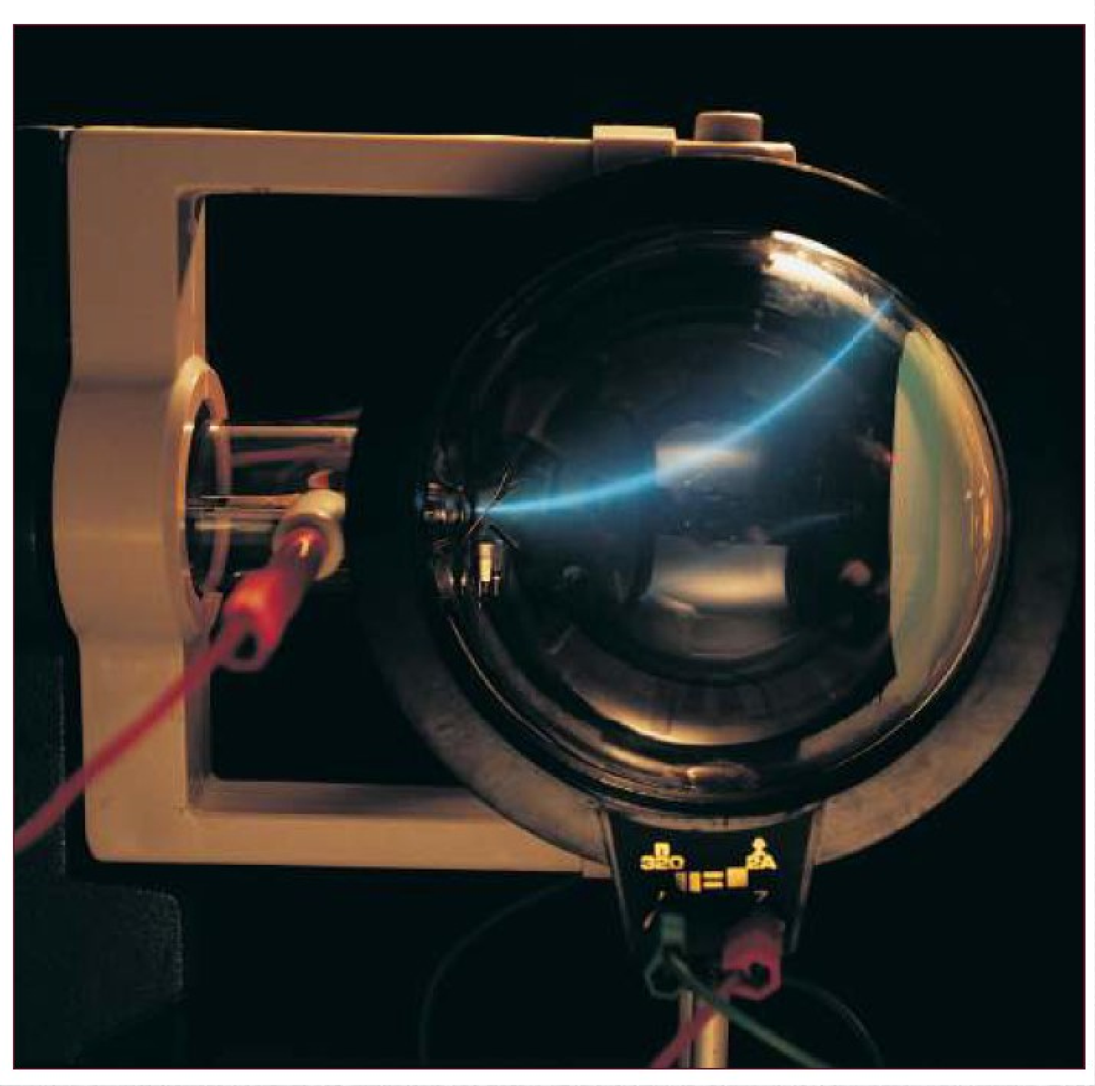
(b) On the diagram, draw an arrow to show the direction in which electrons flow through the coil. [1]

(c) Explain why the electrons flow in the direction you have shown in **(b)**.

electrons are negative charged particles, so they are repelled from –ve connection of supply [1]

[Total: 5]

Electron beams and magnetic fields



A magnetic field can also be used to deflect a beam of electrons. This can be demonstrated in the laboratory using a vacuum tube. In this photograph, an electron beam is travelling from left to right in a spherical vacuum tube. Two electromagnet coils (front and back) produce a horizontal magnetic field. The electrons feel an upward force, and this causes the beam to curve.

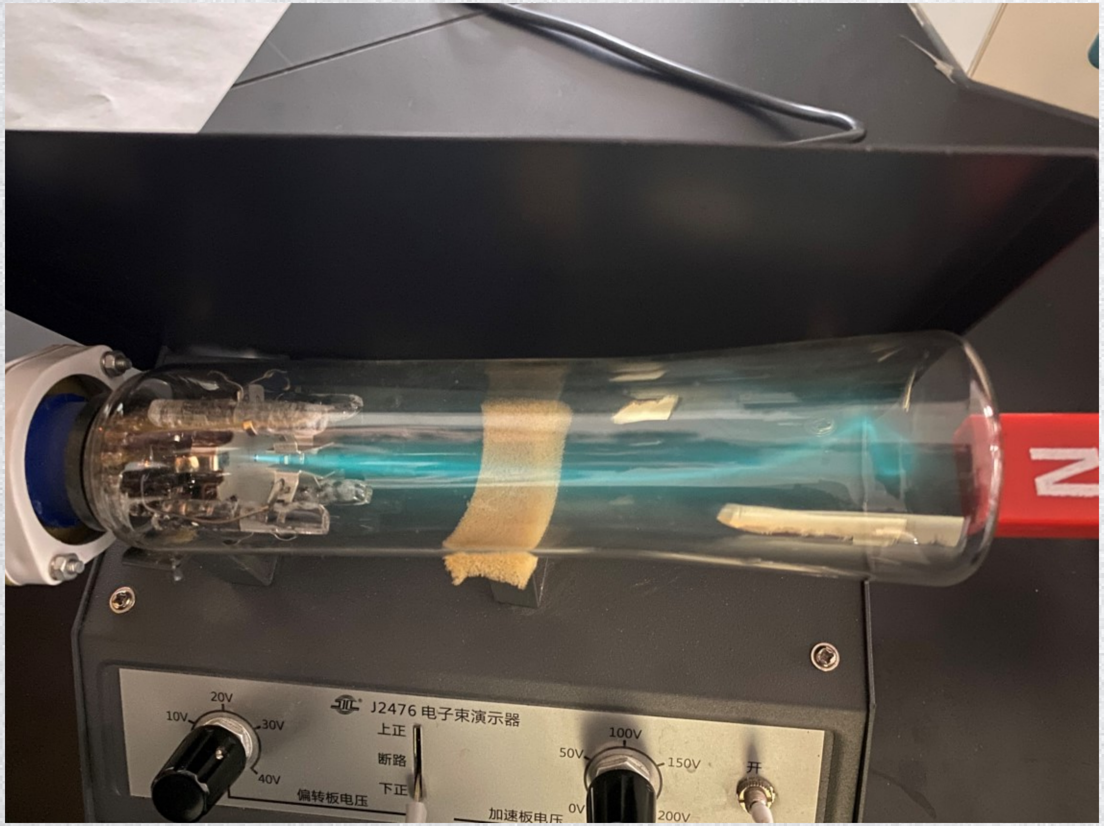
Electron beams and magnetic fields

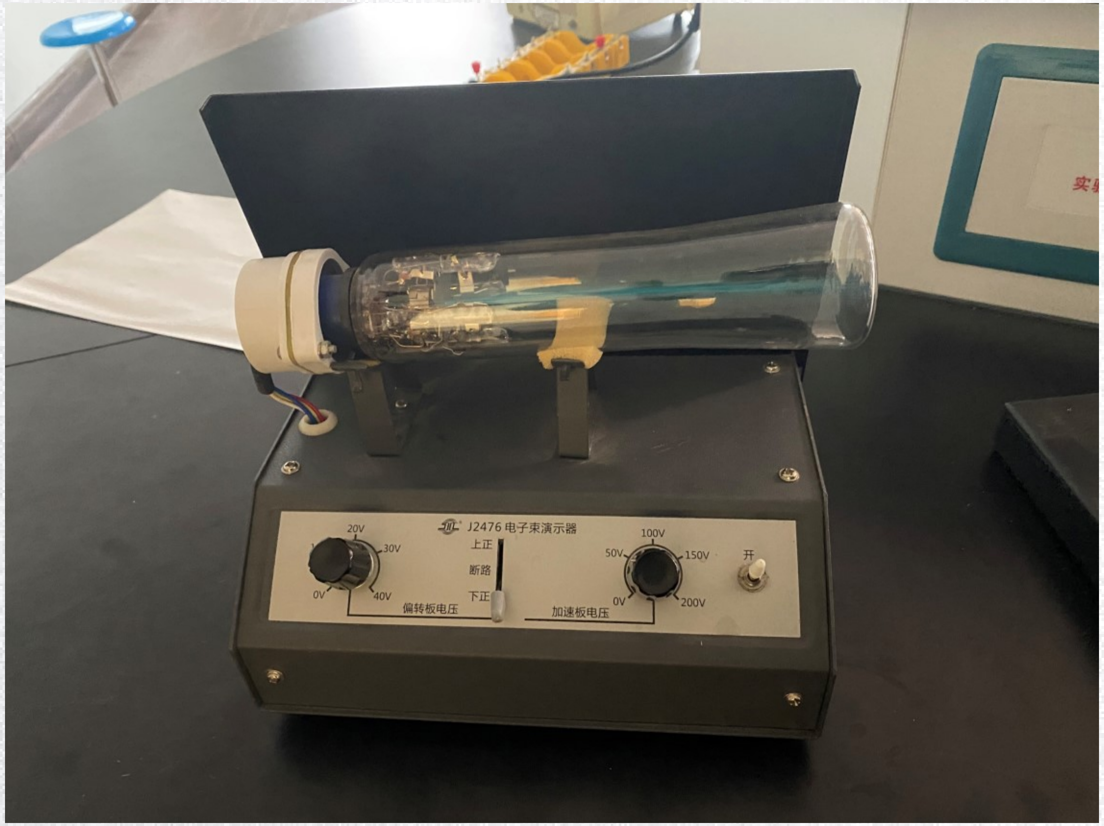
The electrons feel the same force as we saw earlier for a current-carrying conductor in a magnetic field. The direction of the force is given by Fleming's left-hand rule (but recall that the conventional current is in the opposite direction to the electron flow).

The electrons are moving from left to right, so the conventional current is right to left; the magnetic field is pointing towards the front; so the force must be upwards.

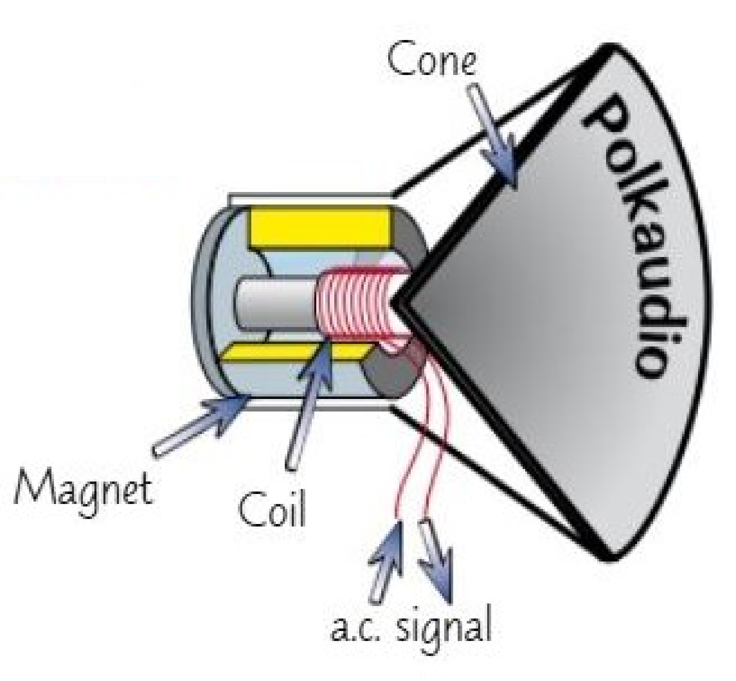
In fact, when a current-carrying conductor is placed in a magnetic field, it is the electrons that feel the force. They then transmit it to the conductor.

Electron beams and magnetic fields





Loudspeakers



Loudspeakers work because of the **motor effect**:

- a.c. electrical signals from an amplifier are fed to a coil of wire in the speaker, which is wrapped round the base of a cone.
- The coil is surrounded by a permanent magnet, so the a.c. signals cause a force on the coil and make it move back and forth.
- These movements make the cone vibrate and this creates sounds.

THANK YOU