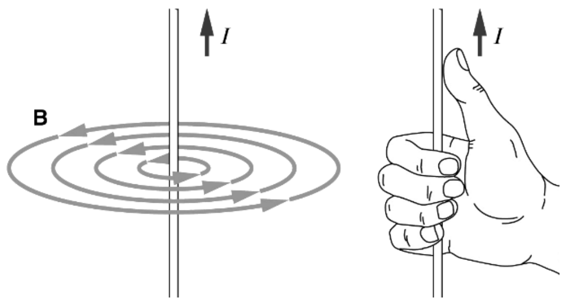
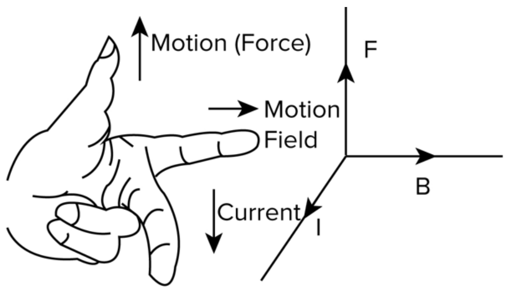
Chapter 21 – Electromagnetism

Content

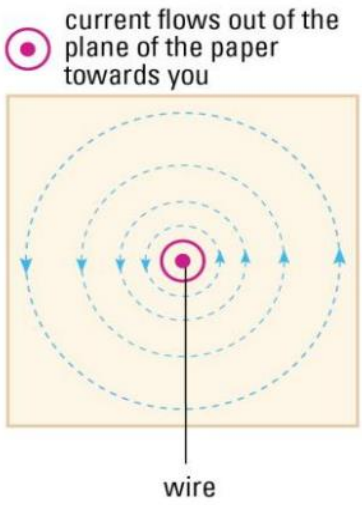
- Magnetic effect of a current
- Applications of the magnetic effect of a current
- Force on a current-carrying conductor
- The d.c. motor

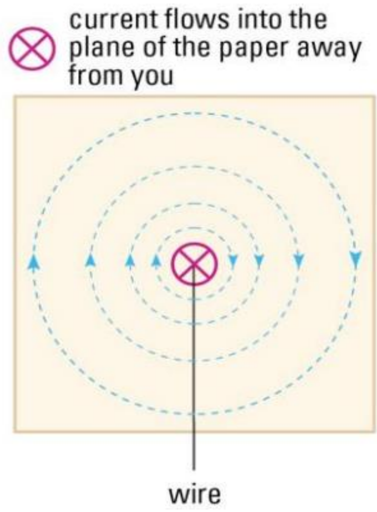
Formulae / principles

Right-hand grip rule	Fleming's left-hand rule
	

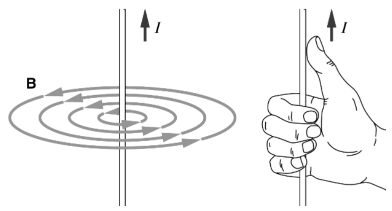
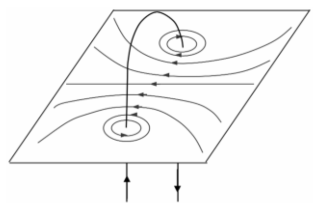
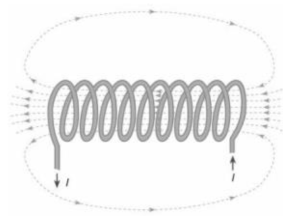
Learning outcomes

- draw <u>pattern of magnetic field</u> due to currents in straight wires and in solenoids
  state effect on magnetic field of changing magnitude and/or direction of current

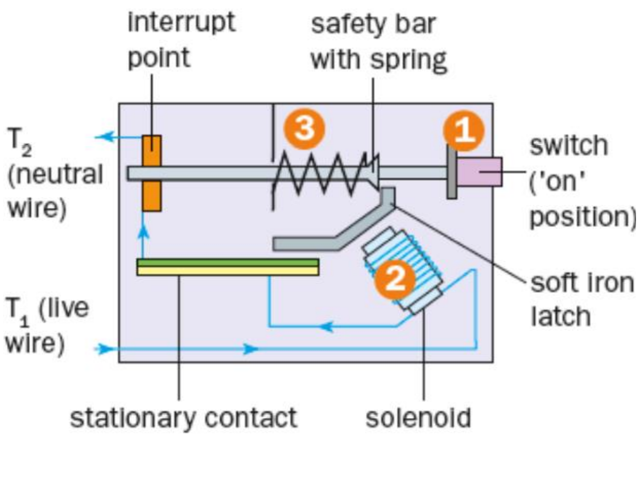
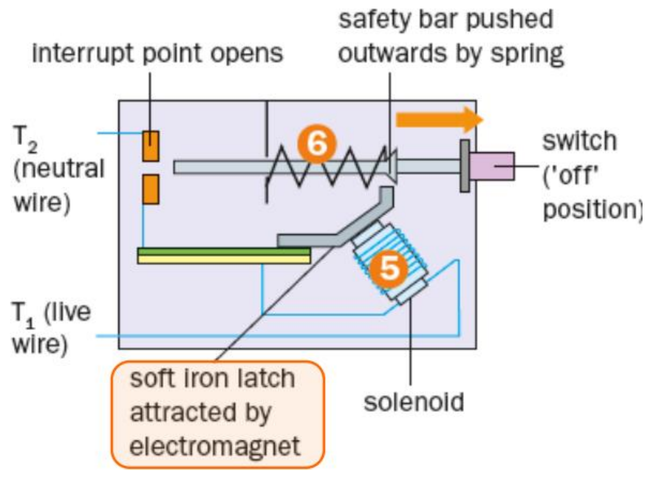




Increase magnetic field strength

Straight wire (current-carrying conductor)	Flat coil	Solenoid
		
1. Increase current	1. Increase current	1. Increase current 2. Increase no. of turns of coil 3. Place soft iron core within solenoid

- describe the application of the magnetic effect of a current in a <u>circuit breaker</u>

<table>
<tr><th>Normal current</th><th>Large current</th></tr>
<tr><td>
</td><td>
</td></tr>
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Switch in ‘on’ position → current flow thru solenoid and stationary contact
Current below limit → magnetic field of solenoid not strong enough to attract soft iron latch
Safety bar stay in position + interrupt point remain closed → current flow normally thru circuit

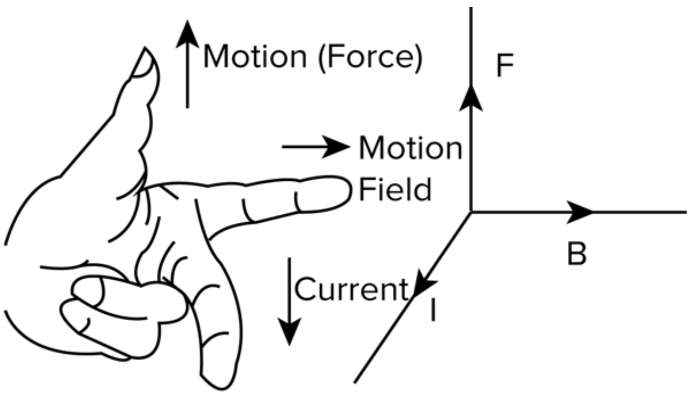
</td><td>

Short circuit / overloading cause surge in current
Larger current → solenoid become strong electromagnet to attract soft iron latch
Release spring → push safety bar outwards → switch in ‘off’ position + interrupt point is open → break circuit → current not flow thru circuit

</td></tr>
</table>

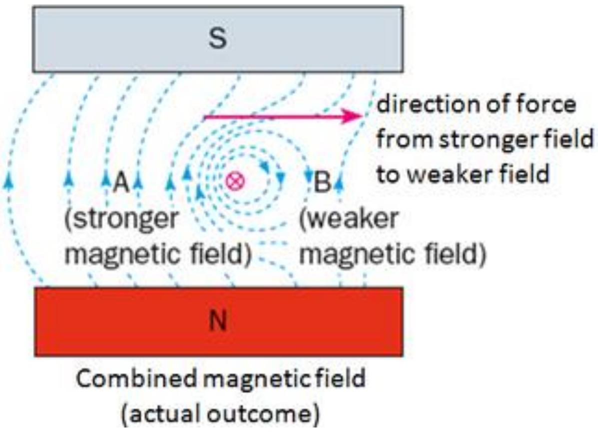
- deduce the relative directions of force, field and current when any two of these quantities are at right angles to each other using Fleming’s left-hand rule

Fleming’s left-hand rule
- Thumb: force
- Index finger: magnetic field
- Middle finger: current



- describe <u>force on a current-carrying conductor</u>

Motor effect: current-carrying conductor placed in magnetic field, conductor experience force

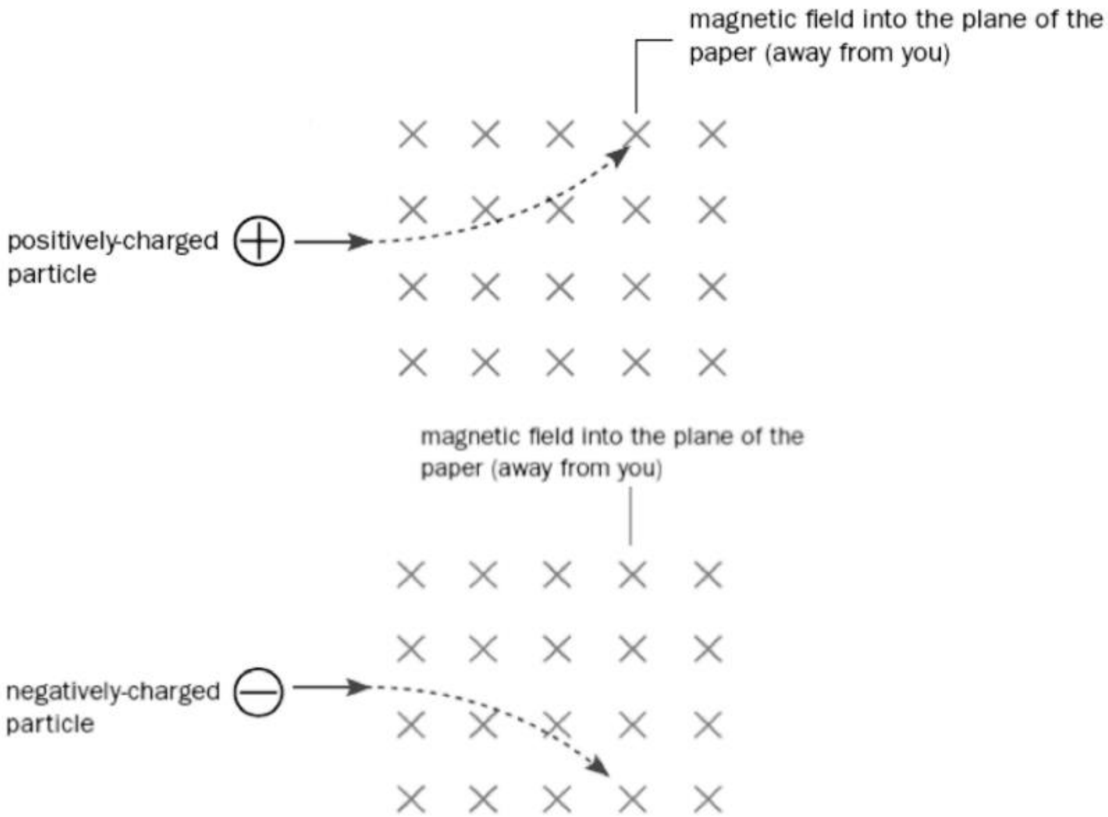


Combined magnetic field
(actual outcome)

Magnetic field due to current + magnet

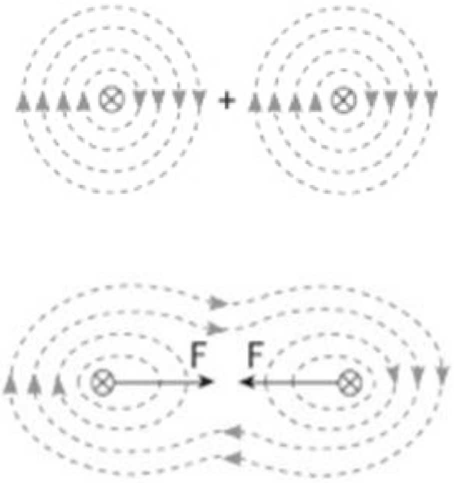
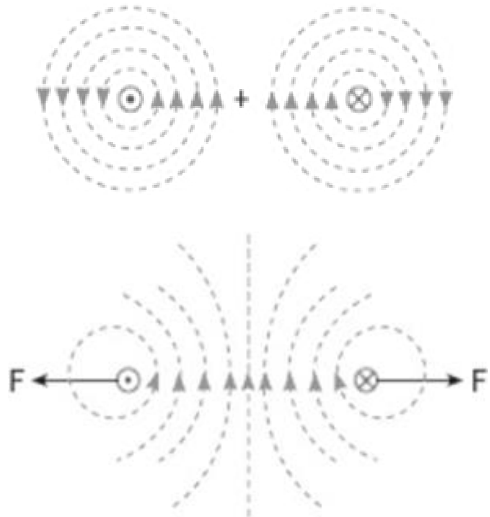
- A: act in same direction → reinforce each other → <u>stronger</u> magnetic field
  B: act in opposite direction → cancel out each other → <u>weaker</u> magnetic field
- <u>Net force</u> act from stronger to weaker field

- describe force on <u>beam of charged particles, in a magnetic field</u>, including effect of reversing
  (i) the current
  (ii) the direction of the field

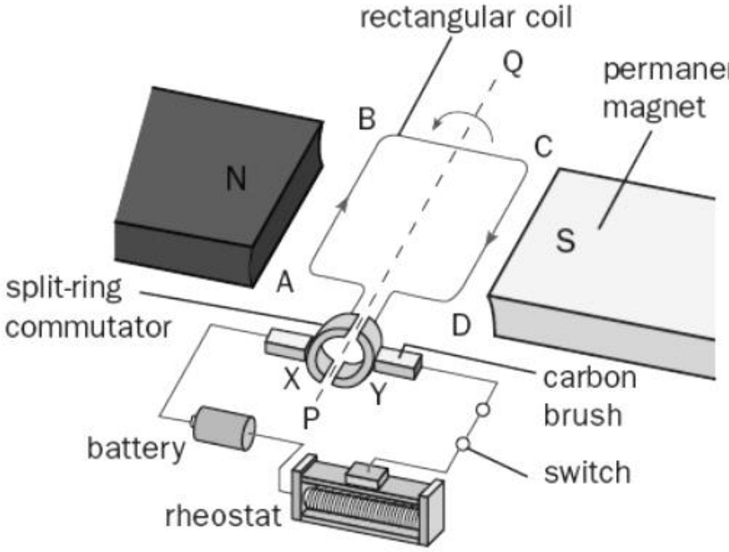


Determine direction of force applied on particle using FLH rule

- describe the <u>magnetic field patterns between currents in parallel conductors</u> and relate these to the forces which exist between the conductors (excluding the Earth's field)

Currents in same direction	Currents in opposite direction
Attract	Repel
	
• Magnetic fields due to currents interact → cancel out • Weak field exist b/w wires + strong field exist on left and right of wire • Force produced from stronger field to weaker field → attract	• Magnetic fields due to currents interact → reinforce • Strong field exist b/w wires + weak field exist on left and right of wire • Force produced from stronger field to weaker field → repel

- explain how a current-carrying coil in a magnetic field experiences a turning effect and that the effect is increased by increasing
  (i) the number of turns on the coil
  (ii) the current
- discuss how this turning effect is used in the action of an electric motor



Coil	Current	Coil
horizontal	Current flow thru coil: interaction b/w magnetic fields → armature rotate • A → B: downward force • C → D: upward force	Two forces produce turning effect → rotate in anticlockwise direction
vertical	Split-ring commutator not in contact with carbon brushes → current cut off	Rotate past vertical position due to inertia
horizontal	Current flow thru coil: interaction b/w magnetic fields → armature rotate • A → B: upnward force • C → D: downward force	Two forces produce turning effect → rotate in anticlockwise direction **[same]**

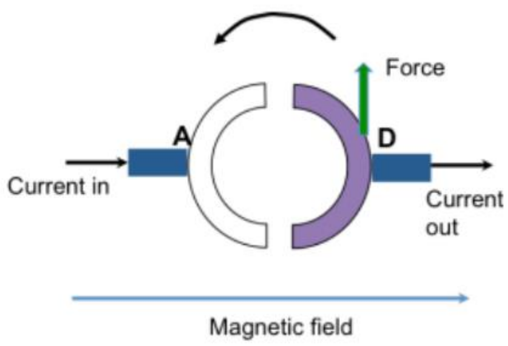
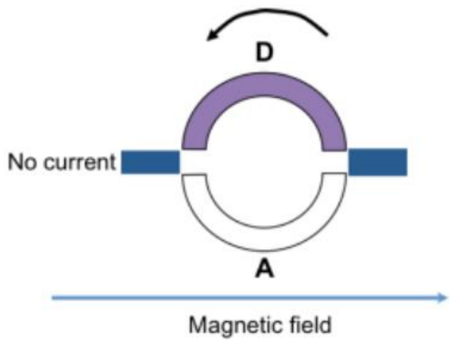
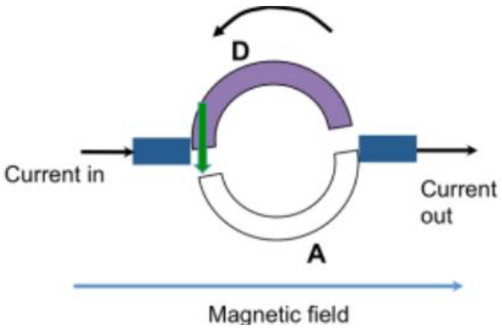
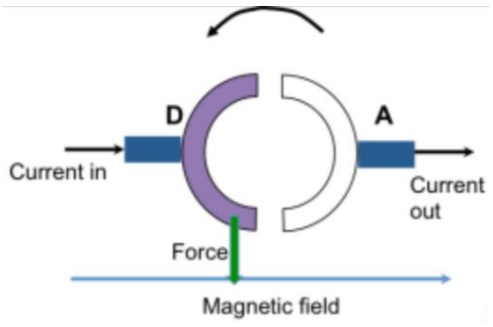
Increase turning effect of coil
1. Increase current
2. Increase no. of turns in coil
3. Insert soft iron core into coil
4. Use stronger permanent magnets

Note:

direction of current & magnetic field	force
parallel	**no**
perpendicular	**maximum**

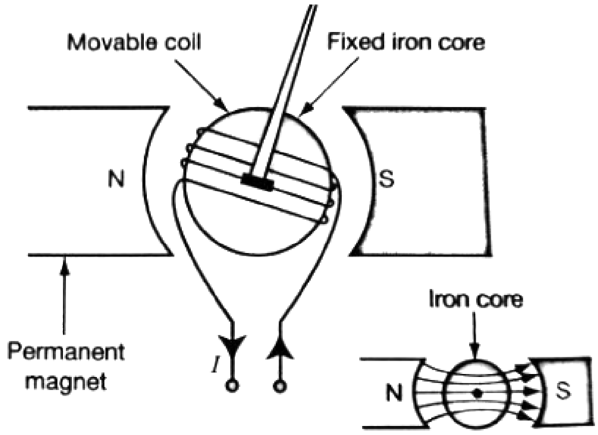
- describe the action of a <u>split-ring commutator</u> in a two-pole, single-coil motor

Split-ring commutator: reverse direction of current in coil every half a revolution
→ direction of coil rotation remain same

Current: ABCD Force on D: upward	Rotate by 90° No current in coil due to split in commutator
	
Continue to rotate due to inertia Current: reverse - DCBA Force on D: downward	Current: DCBA Force on D: downward Direction of moment remain clockwise
	

- describe the effect of winding the coil on to a <u>soft-iron cylinder</u>

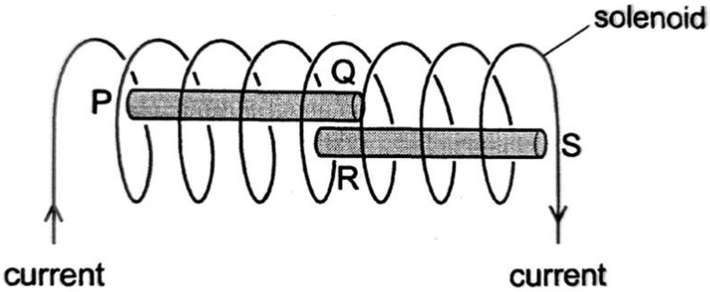
  - Soft iron core concentrate magnetic field lines
  - Transfer magnetic field more efficiently: from permanent magnet → coils



Typical questions

Multiple-choice questions

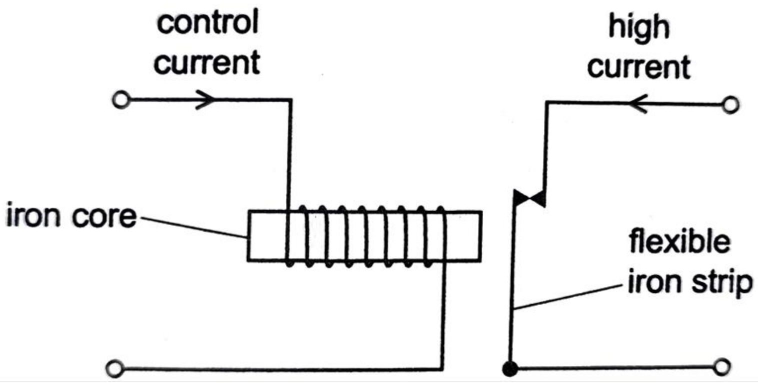
1 Two pieces of soft iron, PQ and RS, are placed inside a solenoid. They become magnetised by the current in the solenoid.



Which poles are found at P, Q, R and S? (2011 P1 Q26)

	P	Q	R	S
A	N pole	N pole	S pole	S pole
B	N pole	S pole	N pole	S pole
C	S pole	N pole	N pole	S pole
D	S pole	S pole	N pole	N pole

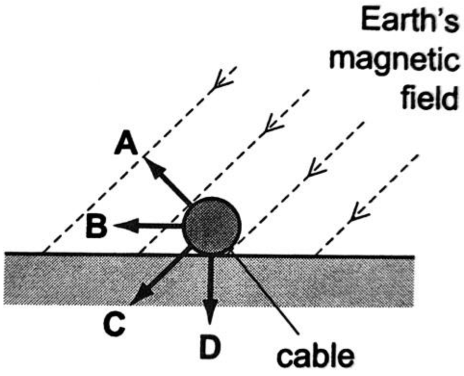
2 In the circuit shown, a control current is used to switch off a high current.



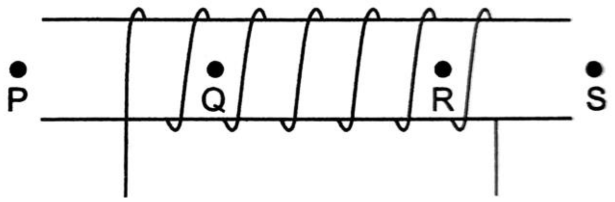
When the control current is switched on, the high current does not switch off.
Which change might switch off the high current? (2014 P1 Q35)

A Moving the strip further away from the iron core
B Reducing the number of turns around the iron core
C Replacing the iron core with a steel core
D Using a larger control current

3 The diagram shows, in cross-section, a cable lying on the ground. There is a direct current in the cable. The Earth's magnetic field is in the direction shown.
Which arrow gives a possible direction for the magnetic force on the cable? (2014 P1 Q36)



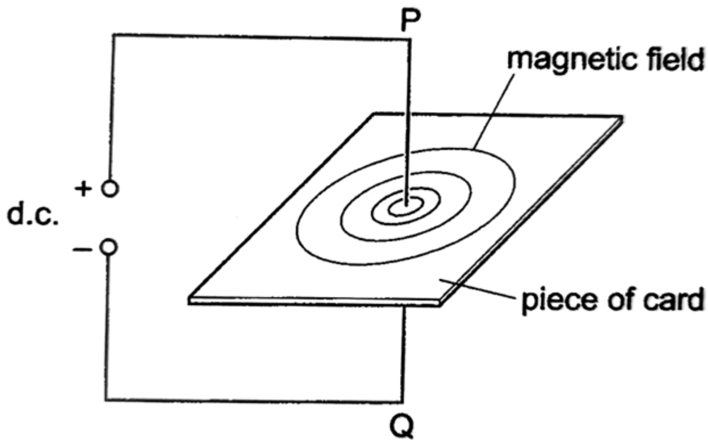
4 A steady current is passed through a solenoid.



P, Q, R and S are four points on the axis of the solenoid. Q and R are inside the solenoid.
Which row indicates a possible direction of the magnetic field due to the current?
(2015 P1 Q37)

	P	Q	R	S
A	→	←	←	→
B	→	←	→	←
C	→	→	→	→
D	→	→	←	←

5 The diagram shows the magnetic field surrounding a wire PQ.

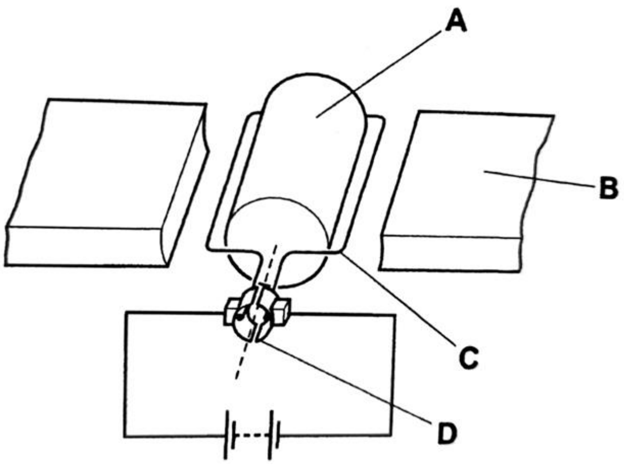


Wire PQ is a current-carrying conductor connected to a direct current (d.c.) power supply.

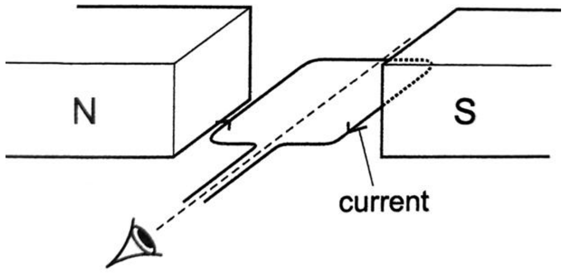
What is the direction of the magnetic field and what happens to the field lines when the current in wire PQ is reduced? (2019 P1 Q36)

	Magnetic field direction (viewed from above)	Spacing of magnetic field lines when current is reduced
A	anticlockwise	closer together
B	anticlockwise	further apart
C	clockwise	closer together
D	clockiwse	further apart

6 The diagram shows a simple d.c. motor.
Which part needs to be made of soft iron to increase the efficiency of the motor?
(2011 P1 Q35)



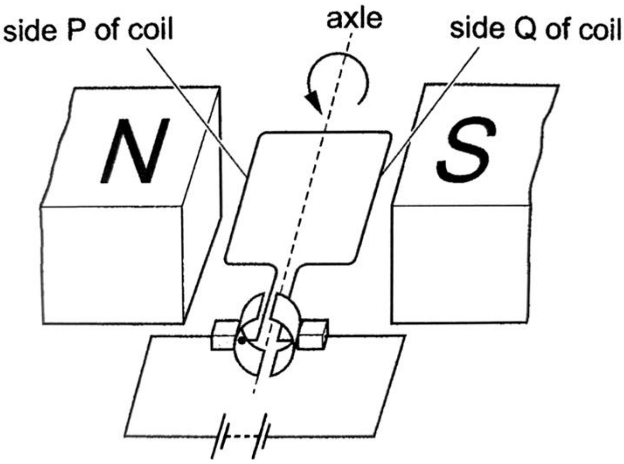
7 The diagram shows a pivoted coil held between the two poles of a magnet. The pivoted coil carries a steady current in the directions shown.



When the coil is released, it rotates and then stops at angle θ to its initial position.
When viewed as shown, in which direction does the coil rotate and what is the value of θ?
(2016 P1 Q37)

	direction	θ
A	anticlockwise	90°
B	anticlockwise	180°
C	clockwise	90°
D	clickwise	180°

8 The diagram shows a d.c. motor.
The magnetic field between the N-pole and the S-pole is uniform.



At the position shown, the forces on sides P and Q are vertical and produce a moment about the axle.
Why does this moment decrease as the coil as the coil turns? (2018 P1 Q37)

A The current in the coil decreases.
B The forces on P and Q change direction and are no longer vertical.
C The forces on the other two sides of the coil start to produce a moment.
D The perpendicular distance between the forces on P and Q decreases.

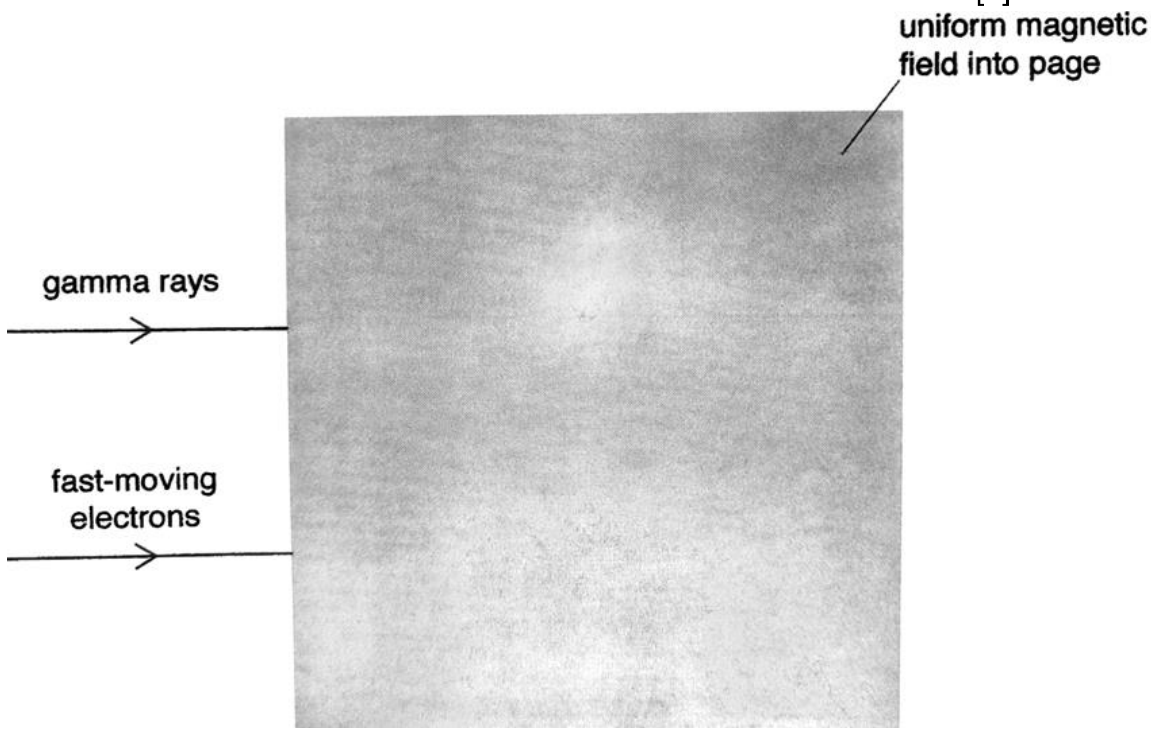
Structured questions

1 (2018 P2 A8)

(a) State the two conditions required for a particle to experience a force in a magnetic field. [2]

1. The particle must be charged.
2. The particle must be moving.

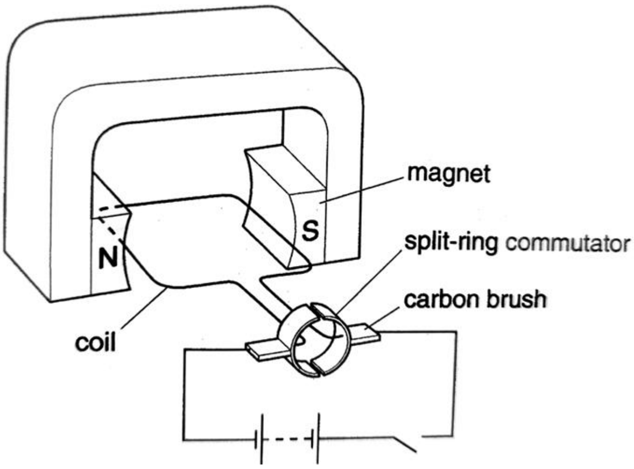
(b) Gamma rays and a beam of fast-moving electrons enter a strong magnetic field, as shown in the figure below.
The magnetic field acts only in the shaded region shown in the figure below. The direction of the magnetic field is into the page.
On the figure below, sketch the paths of the gamma rays and the electrons in the magnetic field. [3]



Note:

- Gamma rays are undeflected as they are electromagnetic waves, which are not charged.
- For the fast-moving electrons, apply Fleming's left-hand rule, which gives a downward force acting on the electrons. Therefore, the electrons move in a parabolic path downwards in the magnetic field. (The direction of conventional current is opposite to the flow of electrons)

2 The figure below shows a d.c. motor.



The coil is horizontal, as shown in the figure above. (2012 P2A Q8)

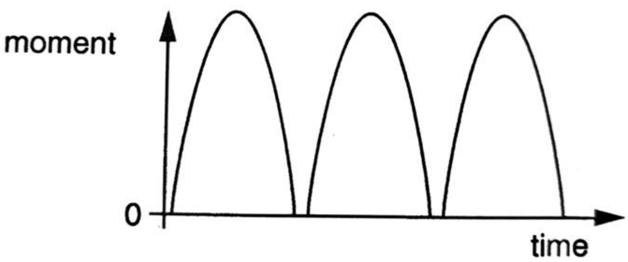
(a) Explain why the coil turns when the switch is closed. [2]

- When the switch is closed, a current flows in the circuit and the coil. Since there is a current in a magnetic field (between the magnets), a force is produced.
- The force produced is downwards on the left side, and upwards on the right side of the coil by Fleming's left-hand rule. As a result, the coil turns.

(b) Explain why the coil continues to turn in the same direction when it has turned 180°. [2]

- After a 90° rotation, the split-ring commutator changes the direction of the current in the coil.
- This causes the force acting on the coil to reverse direction, and ensures that the force on the side of the coil next to the N-pole is always in the same direction, allowing the coil to rotate continuously as the force on the top side of the coil is now downwards and on the bottom side of the coil upwards.

(c) The figure below shows how the moment acting on the coil depends on time.



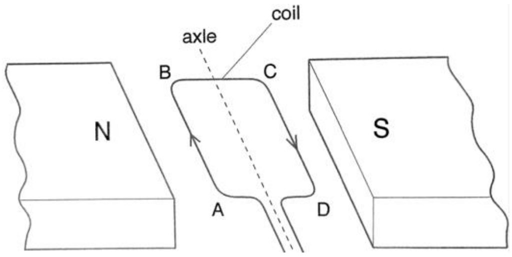
(i) On the figure above, mark with a letter H one time when the coil is horizontal. [1]

Note: The forces acting on the coil are always in a vertical direction. Therefore, when the coil is horizontal, there is the greatest perpendicular distance of the force from the pivot, which causes the greatest moment.

(ii) The e.m.f. of the battery is increased. State two changes that this causes to the figure above. [2]

1. The maximum moment exerted will be greater.
2. The period of the wave will be shorter.

3 The figure below shows the coil of a d.c. motor placed between the poles of a magnet. There is a current in the coil in the direction shown by the arrows on two sides of the coil.



(2017 P2A Q7)

(a) The current in the coil causes a force to act on each side of the coil.

(i) On the figure above, draw the forces that act on sides AB and CD of the coil. [1]

(ii) Describe how you determined the direction of the forces on the sides AB and CD of the coil. [2]

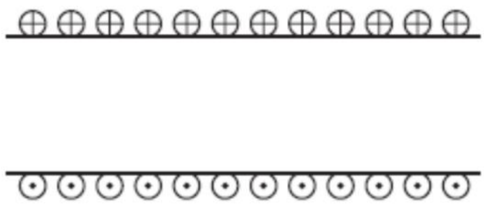
Apply Fleming's left-hand rule, such that the thumb, index and middle fingers are at right angles to one another.

- The index finger points in the direction of the magnetic field (towards the S-pole).
- The middle finger points in the direction of the current.
- The thumb points in the direction of the force.

(b) The coil begins to rotate around the axle and a split-ring commutator ensures that the coil continues to rotate. The split-ring commutator is not shown in the figure above.
With reference to side AB of the coil, explain how the split-ring commutator ensures that the rotation continues. [2]

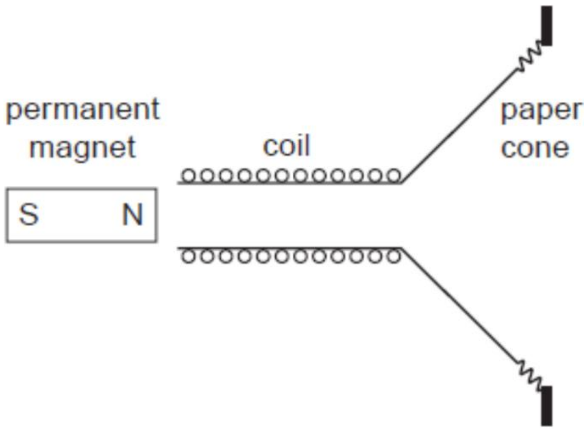
- As side AB moves downwards to the bottom-most point, the force acting on AB is still downwards as the direction of the current is still from A to B. For the coil to rotate continuously, AB will need to have an upward force, combined with the momentum of rotation.
- The split-ring commutator reverses the current in the coil every 180° rotation, such that the current flows from B to A, and hence an upward force is generated on AB. A similar principle is applied when AB reaches the topmost point.

4 The figure below shows a coil of wire wound on a cardboard tube. There is a d.c. current in the coil.



(a) On the figure above, draw the magnetic field produced by the coil.

(b) The figure below shows a simple loudspeaker that uses the coil shown in the figure above attached to a paper cone.



The coil is connected to a signal generator.
There is an alternating current of frequency of 100 Hz in the coil.

(i) State what is meant by a frequency of 100 Hz.

Current oscillates 100 times in one second

(ii) Describe and explain the movement of the coil.

- The coil moves left and right alternately causing the paper cone to vibrate in and out.
- When the current in the coil flows in such a way as to induce the left side to be a North pole, it will be repelled to the right by the North pole of the magnet.
- When the current changes direction such that the left side is a South pole, the coil will be attracted to the left by the North pole of the magnet.