Force on current carrying wire, DC motors

- **investigate and analyse theoretically and practically the force on a current carrying conductor due to an external magnetic field, *F = nBiL*, where the directions of *I* and *B* are either perpendicular or parallel to each other**
- **investigate and analyse theoretically and practically the operation of simple DC motors consisting of one coil, containing a number of loops of wire, which is free to rotate about an axis in a uniform magnetic field and including the use of a split ring commutator.**

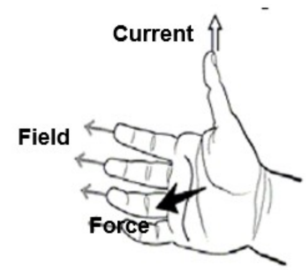
Paper	Multiple choice	Short Answer	Idea	Marks	%	Type
2022		1a	Right hand force rule	2	62%	Concept
		1b	Right hand force rule, current direction	1	66%	Concept
		1c	F = nBiL, find i.	2	84%	Calculation
2022 NHT	2		Current, force direction	1	NA	Concept
2021	5		DC motor, rotation direction	1	51%	Concept
		2b	Current, force direction	1	61%	Concept
		2c	Current, force magnitude	2	24%	Calculation
2021 NHT	1		Force on current in wire	1	NA	Calculation
		4a	RH rules	1	NA	Concept
		4b	Split ring commutator	2	NA	Explanation
2020						
2019		3a	Basic electrical circuits	1	78%	Concept
		3b	RH rule	1	55%	Concept
		3c	Split ring commutator	2	70%	Explanation
		3d	F = nBiL	2	83%	Calculation
2019 NHT	2		RH rule	1	NA	Concept
	3		F = nBiL:	1	NA	Calculation
		3a	F = nBiL	2	NA	Calculation
		3b	Commutator role	3	NA	Explanation
2018	1		F = nBiL	1	89%	Calculation
	2		RH rule	1	78%	Concept
		3a	RH rule	3	67%	Explanation
		3b	Motor principles	2	35%	Explanation
2018 NHT	1		F = nBiL	1	NA	Calculation
2017		3a	F = nBiL	3	70%	Calculation
		3b	Force on wire	2	76%	Explanation

Forces on current carrying wires and DC motors can be grouped into the following ideas.

Forces on current carrying conductors

- If a conductor in a magnetic field has a current flowing in it, there is a force acting on it.
- If a current is flowing in a conductor there is an associated magnetic field.

Any conductor that carries electric current will be surrounded by a magnetic field, given by the right-hand grip rule. When this conductor is placed in a magnetic field, the two magnetic fields will interact, and a force will be produced.



The direction of the force can be determined by the right hand slap rule.

In this rule, the hand is opened flat and the fingers are aligned with the magnetic field. The thumb is pointed in the direction of current flow and the palm is now facing the direction of the force.

The force on a wire carrying a current in a magnetic field is proportional to the current, the length of wire in the field, and the strength of the field.

$F = BiL$. If there is more than one wire, 'n' wires, then $F = nBiL$.

Electromagnetism is a temporary effect caused by the flow of electric current and it disappears when the current flow is stopped.

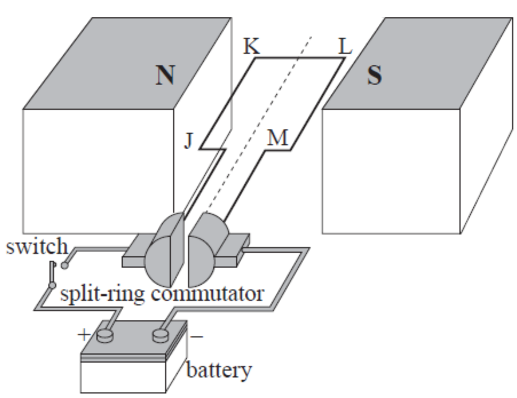
If a conductor is connected to an AC power supply the current direction will alternate and so does the direction of the associated magnetic field.

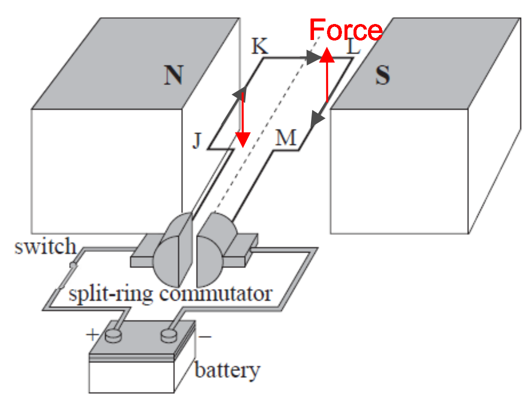
DC motors

A direct current (DC) motor utilises the fact that there is a force between a current carrying conductor and a permanent magnet, and that this force can be arranged to give rise to a rotational motion.
The coil has two pairs of equal and opposite forces acting on its sides.
These forces tend to rotate the coil. The turning force F is constant in size ($F = BiL$) but the torque depends on the distance between the parallel turning forces and the axis of rotation.($\tau = F \times r$).

When the switch is closed the current in the loop is in the direction JKLM. With the field from N to S, this gives the force on JK to be down, and the force on LM to be up. This torque makes the loop rotate in an anticlockwise direction.

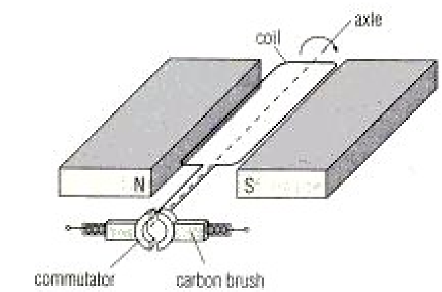
As the current in KL is parallel to the field the force on side KL = 0 N





The split ring commutator

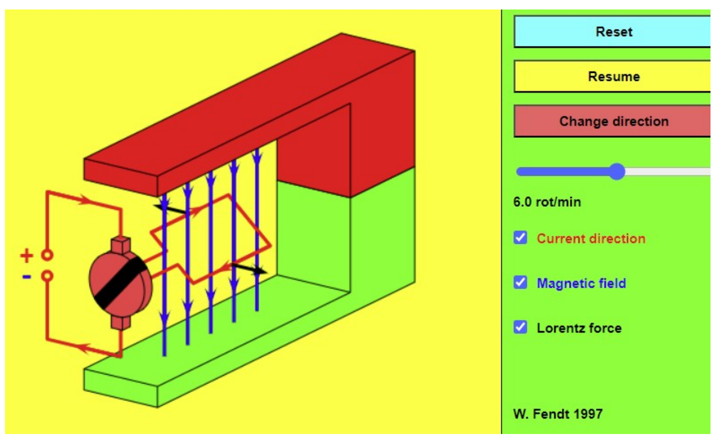
To obtain continuous rotation in a motor, the current in the coil (rotor) is cut just before the plane of the coil is perpendicular to the field, because at this point the forces will act to spread the coil and not to rotate it. The angular momentum of the coil carries it past this position and then the current is switched on again, but the current direction is reversed.



The switching process is carried out automatically by a 'split ring **commutator**' on the motor shaft. A single coil motor would be rather jerky so in most practical motors the magnetic field is provided by an electromagnetic coil, and a radial rather than uniform field is used. This produces a smoother action, ie. a more constant torque.

The role of the commutator is to reverse the direction of the current every half turn, so that the direction of the force on the current carrying wire is reversed every half turn, in order to keep the motor rotating in the same direction. The current changes when the coil is at right angles to the field.

The following applet by Walter Fendt is useful in visualising simple motors.
https://www.walter-fendt.de/html5/phen/electricmotor_en.htm



I suggest that you try to visualise this when you are asked to describe the role of the split ring commutator, and then just describe what is happening.

Worked example 1: Force on a current carrying wire: Right Hand rule.

A 3.0 m long, vertical, copper lightning conductor is located in a region where Earth's magnetic field is horizontal and pointing north. A current of 2 000 A flows down the conductor to Earth during an electrical storm. Force detectors measure a force on the lightning conductor of 0.32 N.

2016 Question 13b, 2 marks

Which one of the following (**A – F**) is the best description of the direction of the magnetic force acting on the lightning conductor? Explain your answer.

A. north

B. south

C. east

D. west

E. vertically up

F. vertically down

Solution

The field (fingers) is to the North, the current (thumb) is down, therefore using the right hand force rule, the force is to the EAST.

∴ C (ANS), (52%)

Current study design:

2022 NHT Question 2

2021 Question 2b (61%)

2019 NHT Question 2

2018 Question 2 (78%)

Worked example 2: Force on a current carrying wire: F = nBiL.

2016 Question 13a, 2 marks

Calculate the magnitude of Earth's magnetic field acting on the lightning conductor.

Solution

Use F = nBiL

0.32 = 1 × B × 2 000 × 3

$$\therefore B = \frac{0.32}{2000 \times 3}$$

∴ B = 5.3×10^{-5} Tesla (ANS), (86%))

Current study design:

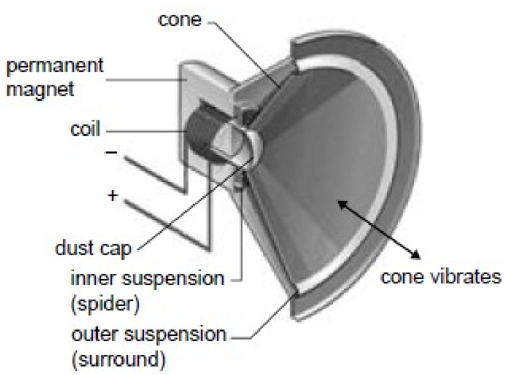
2019 NHT Question 3

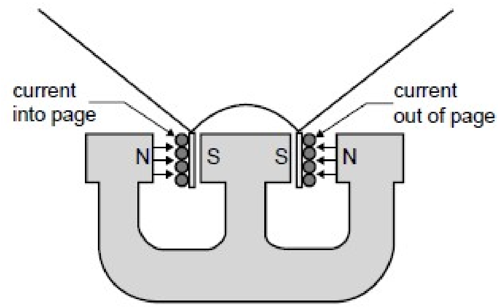
2018 Question 1 (78%)

2018 NHT Question 1

Worked example 3: Force on a current carrying wire: F = nBiL involving π.

A cut-away picture of a loudspeaker is shown below. It basically consists of a coil of wire that is attached to a paper cone, and placed in a strong radial magnetic field. In a sound system this coil would be supplied with an alternating current from an audio amplifier. The section view of the unit (second figure below) shows the direction of the magnetic field relative to the coil more clearly.





The diameter of the coil is 0.04 m, and consists of 200 turns of wire. The uniform radial magnetic field through the coil is 0.4 T.

2004 Question 14, 3 marks

What is the magnitude of the force on the coil when a current of 0.5 A is flowing?

Solution

Use F = nBIL.
The difficulty is calculating 'L'.
In this case it is the length of wire in the field, which is actually the circumference of the wire.

∴ L = π × d

∴ L = π × d

∴ F = 200 × 0.4 × 0.5 π × 0.04

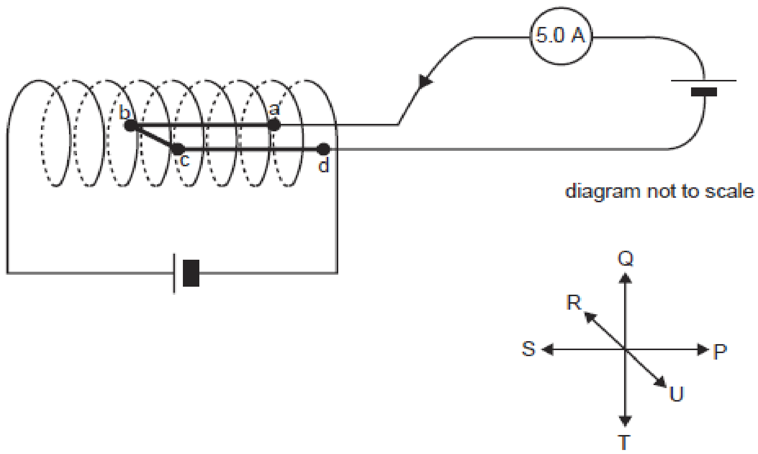
∴ F = 5.03 N (ANS), (56%))

Current study design:

2021 Question 2c (24%)

Worked example 4: Force on a current carrying wire: F = nBiL, B & I parallel.

The magnetic field strength in the solenoid is 2.0×10^{-2} T (Wb m^{-2}). U-shaped conducting wire (a, b, c, d), carrying a current of 5.0 A in the direction a ⟶ d, is placed inside the solenoid as shown below. The highlighted segment, **abcd**, of size 6.0 cm × 2.0 cm is completely immersed in the magnetic field as shown also.



Use the key, PQRSTU, above to indicate direction. If there is no direction, write **none**.

2006 Question 2, 2 marks

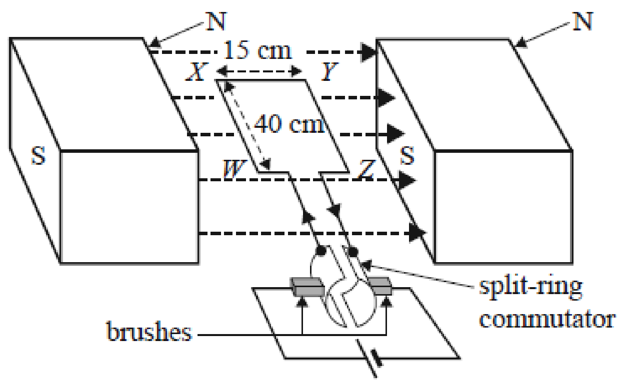
What is the force (magnitude and direction) on the 6.0 cm section of wire, **cd**?

Solution	**Current study design:**
The current in cd is parallel to the field, B. **∴experiences no magnetic force.** **∴ 0 N (ANS), (60%)**	2021 NHT Question 1

Worked example 5: DC motor: Basic concepts.

A model DC motor using permanent magnets is shown below.

The coil can rotate freely between the magnets.



The axis of the motor and the direction of the magnetic field are shown.

2014 Question 17d, 3 marks

As the coil rotates from its starting position, it travels through a vertical position, when its plane is perpendicular to the magnetic field.

In the table below, indicate the direction of the current in the side WX (if there is a current) at the three positions listed. Use only the following directions:

• from W to X

• from X to W

• no current

Position	Current in side WX
before the vertical position	
at the vertical position	
after the vertical position	

Solution

The role of the commutator is to reverse the direction of the current at this point, so that the coil will continue to rotate in the one direction.

∴ **from W to X**
No current
From X to W

At the vertical point, the brushes are not connected to the coil, as they are touching the insulator in the middle section, therefore there isn't a current.

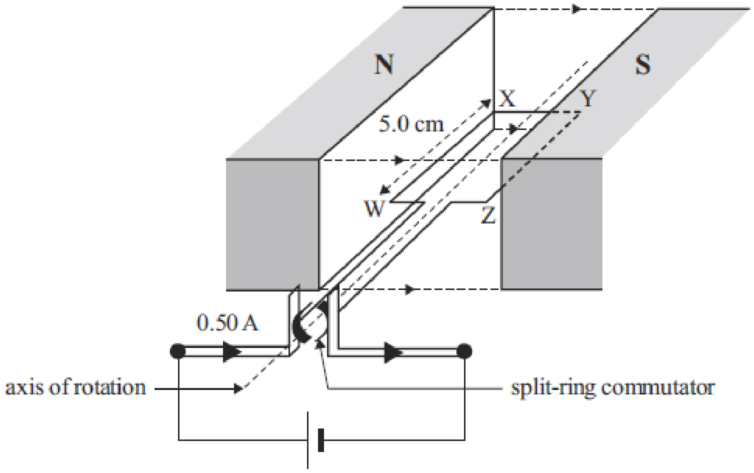
∴ **0 N (ANS), (80%)**

Current study design:

2019 Question 3a (78%)

Worked example 6: DC motor: F = nBiL.

Students build a simple electric motor consisting of a single coil and a split-ring commutator, as shown below. The magnetic field between the pole pieces is a constant 0.02 T.



2017 NHT Question 13a, 2 marks

Calculate the magnitude of the force on the side WX.

Solution	Current study design:
Use F = BiL ∴ **F = 0.02 × 0.5 × 0.05** ∴ **F = 5 × 10^4 N (ANS)**	2022 Question 1c (84%) 2019 Question 3d (83%) 2019 NHT Question 3a 2017 Question 3a (70%)

Worked example 7: DC motor: Force/rotation direction.

2017 NHT Question 13b, 2 marks

Will the coil rotate in a clockwise or anticlockwise direction as seen by an observer at the split-ring commutator? Explain your answer.

Solution	Current study design:
Using the right hand force rule, the force on side WX is down and the force on side YZ is up. Therefore, the loop will rotate anticlockwise **Anticlockwise (ANS)**	2022 Question 1a (62%) 2022 Question 1b (66%) 2021 Question 5 (51%) 2021 NHT Question 4a 2019 Question 3b (55%) 2018 Question 3a (67%)

Worked example 8: DC motor: Split ring commutator.

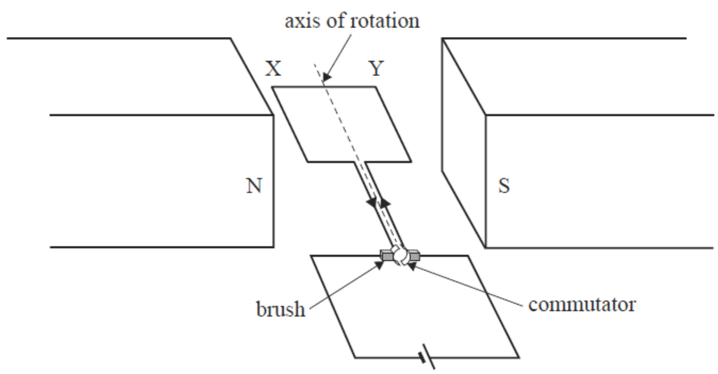
2017 NHT Question 13c, 2 marks

Explain the role of the split-ring commutator in the operation of the electric motor.

Solution	**Current study design:**
The role of the commutator is to reverse the direction of the current every half turn, so that the direction of the force on the current carrying wire is reversed every half turn, in order to keep the motor rotating in the same direction. The direction of the current reverses when the coil is at right angles to the field.	2021 NHT Question 4b 2019 Question 3c (70%) 2019 NHT Question 3b 2018 Question 3b (35%)

Worked example 9: DC motor: F = nBiL, B & I parallel.

Students build a simple electric motor, as shown below.



2016 Question 14a, 1 mark

At what position(s) (**A.–D.**) of the rotating coil is the magnetic force on the side XY zero? One or more answers may be selected.

A. horizontal with the current as shown above

B. horizontal with the current in the opposite direction to that shown above

C. vertical

D. at all orientations of the coil

Solution	**Current study design:**
XY is parallel to the field when it is horizontal. The force is zero when the current in the wire is parallel to the field. ∴ **A, B (ANS)**	2017 Question 3b (76%)
