Section 3.1.4 – DC Motors

DC Motors

A **DC Motor** utilises the force generated upon a current carrying wire coil to convert **electrical energy** into **kinetic energy**.

Figure 1 shows the **opposing forces** produced upon either side of the wire coil (predicted by the R.H. Slap rule). Both forces operate at a distance from the centre of rotation, the shaft, producing a rotating **torque.**

Recall:
Current travels from the positive terminal (+) to the negative terminal (-) within the external circuit

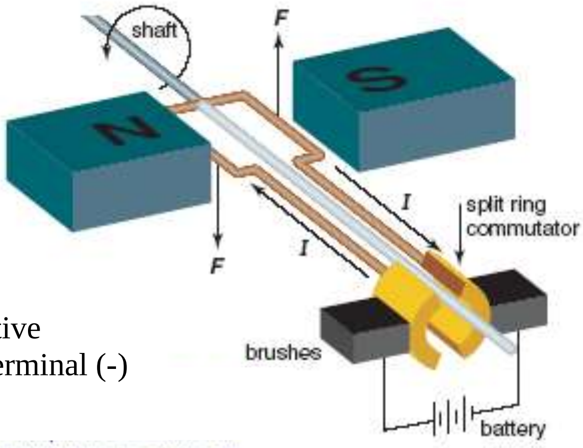


Figure 1

The equation for calculating the magnitude of a torque is:

$\tau = F \times d$

Where t = Torque (Nm)
F = Force (N)
d = Distance (m)

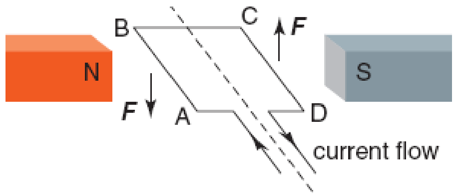
<u>NOT REQUIRED FOR VCAA EXAM</u>

"Pretty useful things, those fridge magnets."

Stages of Coil Rotation – DC Motor

Let's examine the stages of coil rotation and outline the operation of the split ring commutator and brushes.

Position 1



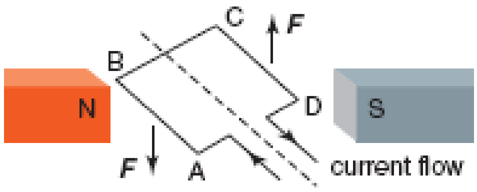
Initial Orientation

R.H. Slap Rule

- Wire AB experiences a downward force
- Wire CD experiences an upwards force
- Wire BC experiences no force

∴ the coil undergoes an **anticlockwise (↺) rotation**

Position 2



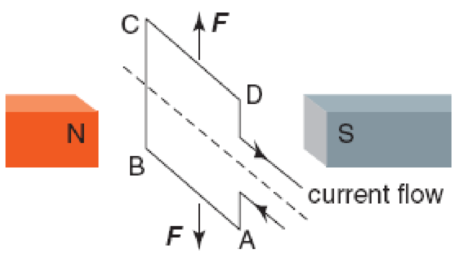
< 90° ↺ Rotation

R.H. Slap Rule

- Wire AB experiences a downward force
- Wire CD experiences an upwards force

∴ the coil continues to undergo an **anticlockwise (↺) rotation**

Position 3



At 90° ↺ Rotation

R.H. Slap Rule

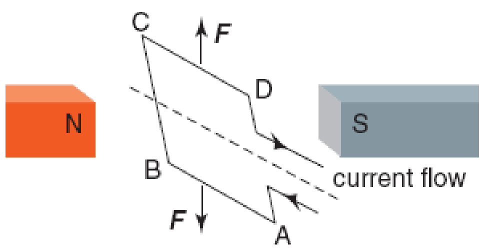
- Wire AB experiences a downward force
- Wire CD experiences an upwards force

Both forces operate in the plane of the axis, effectively "stretching" the coil.

∴**no torque** produced.

Momentum of the coil continues the **anticlockwise (↺) rotation.**

Position 4



Beyond 90° ↺ Rotation

R.H. Slap Rule

- Wire AB experiences a downward force
- Wire CD experiences an upwards force

With the current still travelling from A to D, the coil will now undergo a **clockwise (↻) rotation**, back to position 3

NB: In order to make the DC motor rotate a complete 360° continuously, the **direction** of the **current** in the coil must be **changed twice** every rotation, when the **coil** is at **right angles** to the **magnetic field.**

The Commutator – DC Motor

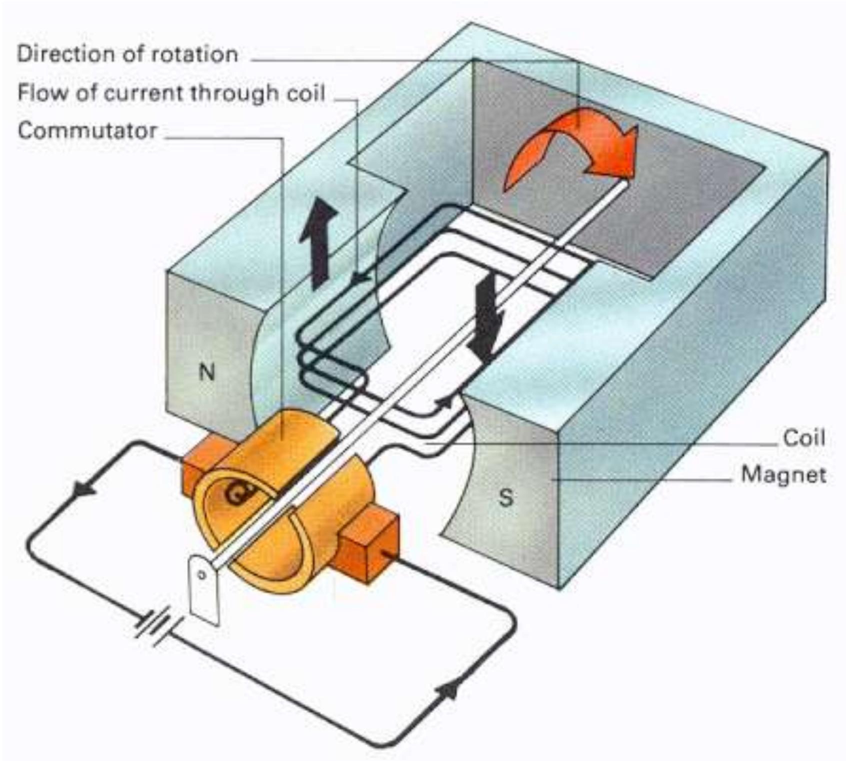
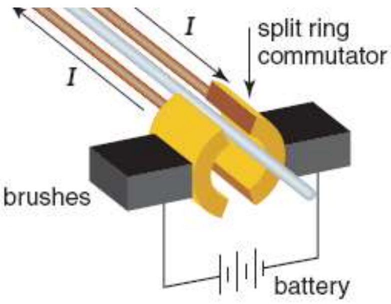


Figure 2

In order to produce a continuous and uninterrupted torque/rotation in one direction, the **direction of the current** needs to be reversed at position 3 (from previous page) and again at a rotation of a further 180°, when the wire coil is aligned **perpendicular** to the magnetic field.



Split Ring Commutator

This device alters the direction of the supply DC current entering into the coil every 180° rotation. It does so when the coil is perpendicular to the magnetic field. Thereby allows a continuous rotation in one direction.

Brushes

This device is made of **graphite**, which provides an electrical contact between the supply battery and the commutator. It is a lubricative material, which produces little of friction (ie. high efficiency).
NB: brushes do wear in DC motors and require replacement.

Segmented Commutator

In a commercial DC motor, there are **multiple coils** present within the **rotor**. Each coil is connected to a **segmented commutator.**

This arrangement provides greater smoothness in rotation and considerably more torque.

Example.1

The following information relates to Questions 1–4

Figure 3 below shows a diagram of a simple DC motor. The single square loop coil TUVW, of side 0.0090 m, is free to rotate about the axis XY. Current is supplied from a battery via the split-ring commutator. The two permanent magnets provide a uniform magnetic field B of magnitude 0.25 T in the region of the coil. The current flowing in the coil is 2.0 amp

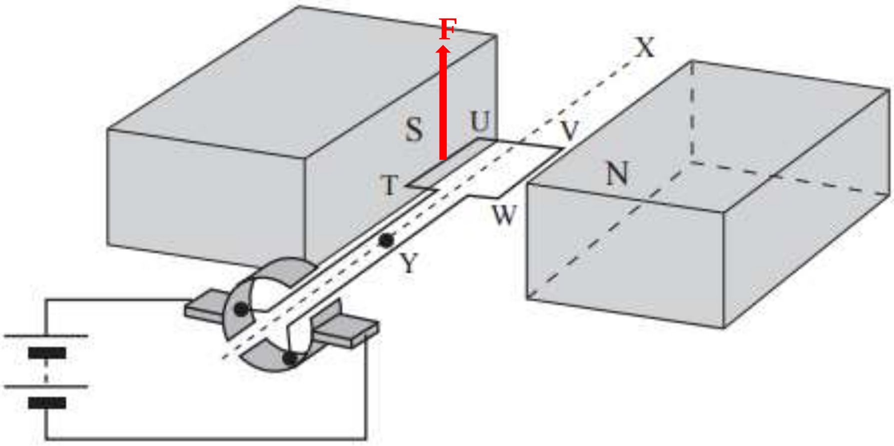


Figure 3

Question 1
Indicate with an arrow the direction of the force on side TU of the coil in Figure 3

Question 2
Calculate the magnitude of the force on the side TU of the coil. Show your working.

F = ? F = BI*l*
B = 0.25 T = 0.25 x 2.0 x 0.0090
I = 2.0 A = 0.0045 N
l = 0.0090 m

0.0045 N

Question 3
What is the magnitude of the force acting on side UV of the coil when in the position shown in Figure 3?

Field and current are in the same direction, so the force is zero.

0 N

Question 4
Explain the purpose of the split-ring commutator

A split ring commutator reverses the current *(1)*, twice every cycle *(1)*, when the plane of the loop is perpendicular to the field *(1)*

Example.2

The following information relates to Questions 1–4

Figure 4 shows a schematic diagram of a DC motor. The motor has a rectangular coil, JKLM, of 50 turns. The permanent magnets provide a uniform magnetic field of 0.30 T in the region of coil JKLM. The commutator with contacts X and Y is connected to a source of constant DC current.

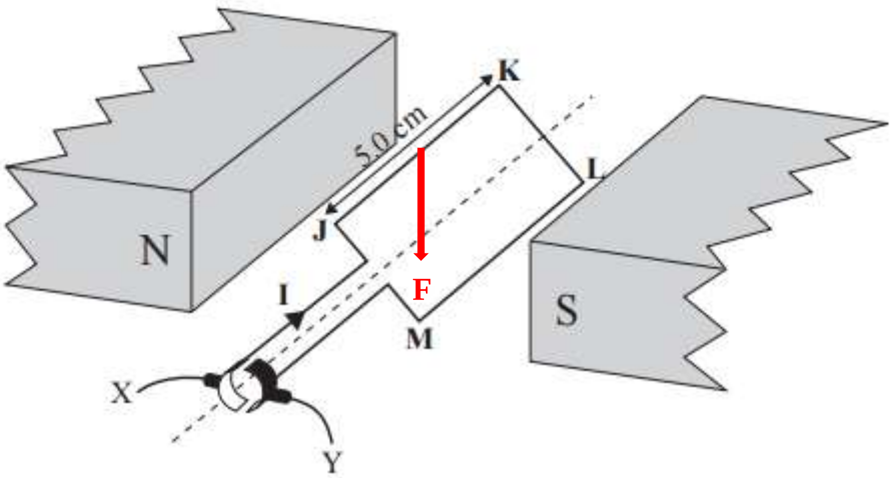


Figure 4

Question 1

A current, I, is flowing through the rectangle coil in the direction shown.
When the coil is in the position shown in the diagram, draw an arrow on side JK to show the direction of the magnetic force on side JK.

Arrow down on the line JK. (1). At JK, the magnetic field is to the right, the current in JK is to the back from J to K, so using your hand rule, the force is downwards.

Question 2

A current of 6.0 A is flowing in the 50 turn rectangular coil. The length of side JK is 5.0 cm. Calculate the magnitude of the magnetic force acting on side JK when it is in the position shown in Figure.4.

F = ? $F = nBIl$
n = 50 turns $= 50 \times 0.30 \times 6 \times 0.05$
B = 0.30 T $= 4.5$ N
I = 6.0 A
l = 0.05 m

4.5 N

Example.3

Figure 5 shows a small DC electric motor, powered by a battery through a split-ring commutator. The rectangular coil has sides KJ and LM of length 6.0 cm, and sides KL and JM of length 3.0 cm. The coil contains 50 turns of insulated wire. The magnetic field between the poles of the magnet is uniform and of strength 0.050 T.

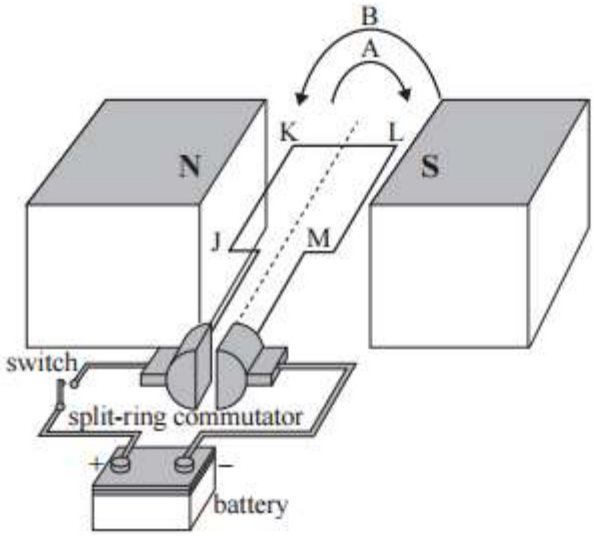


Figure 5

Question 1

The current is switched on when the coil is stationary in the position shown in Figure5.
Which of the following statements best describes the motion of the coil when the current is switched on? You may assume that any frictional forces opposing rotation are very low. Write your answer in the box provided.

A. The coil will rotate in direction A shown in Figure 5.
B. The coil will rotate in direction B shown in Figure 5.
C. The coil will oscillate regularly between directions A and B.
D. The coil will remain stationary.

Magnetic field is to the right, the current in JK is from J to K, so using the hand rule, the direction of the force on JK is down, producing rotation in direction B.

B

Question 2

The current drawn from the battery is 2.0 A. Calculate the magnitude of the force on the side KJ of the motor when the coil is in the position shown in Figure 5.

F = ?	$F = nBIl$
n = 50 turns	$= 50 \times 0.05 \times 2.0 \times 0.06$
B = 0.05 T	$= 0.30$ N
I = 2.0 A	
$l = 0.06$ m	

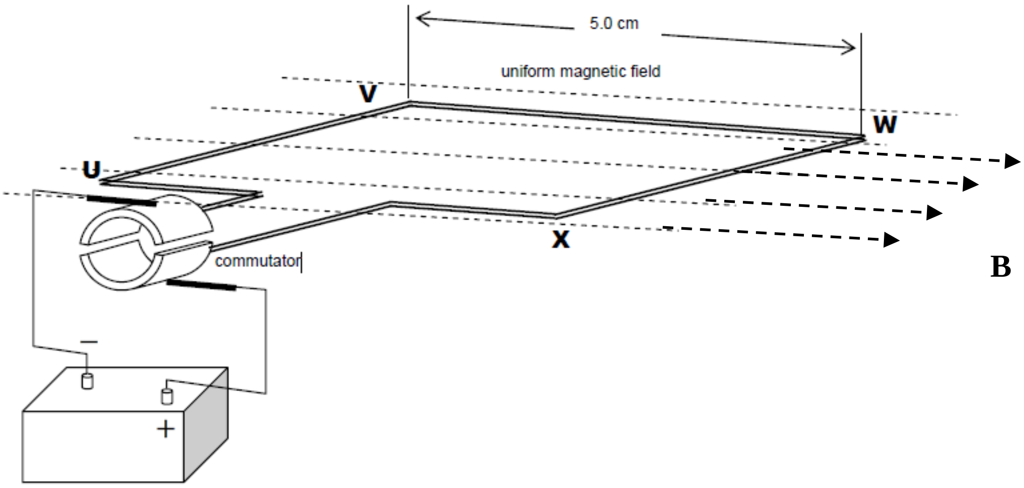
0.30 N

Exam Style Questions

Questions 1 - 3 relate to the following information.

A small DC motor is dismantled to observe how it operates. A simplified diagram of the motor is shown below. In this model the single square loop is attached to a commutator and allowed to rotate freely in a uniform magnetic field. The loop is a square of side length 5.0 cm.

A current of 50 mA is supplied by the battery to the square loop.



Question 1.
The side of the loop XW experiences a force vertically down when the loop is oriented as shown in the diagram. On the diagram place arrows on the magnetic field lines (the dashed lines) indicating the direction of the magnetic field.

Question 2.
With the loop in the position shown above, what forces is experience in section VW?
No force is experienced as the magnetic field and the current are travelling parallel to one another.

Question 3.
The side of the loop XW experiences a force of 2.0×10^{-4} N down. What is the size of the magnetic field strength?

B = ?
$l = 5.0 \times 10^{-2}$ m
$F = 2.0 \times 10^{-4}$ N
n = 1
$I = 50 \times 10^{-3}$ A

F = nBIl

$$\therefore B = \frac{F}{nIl}$$

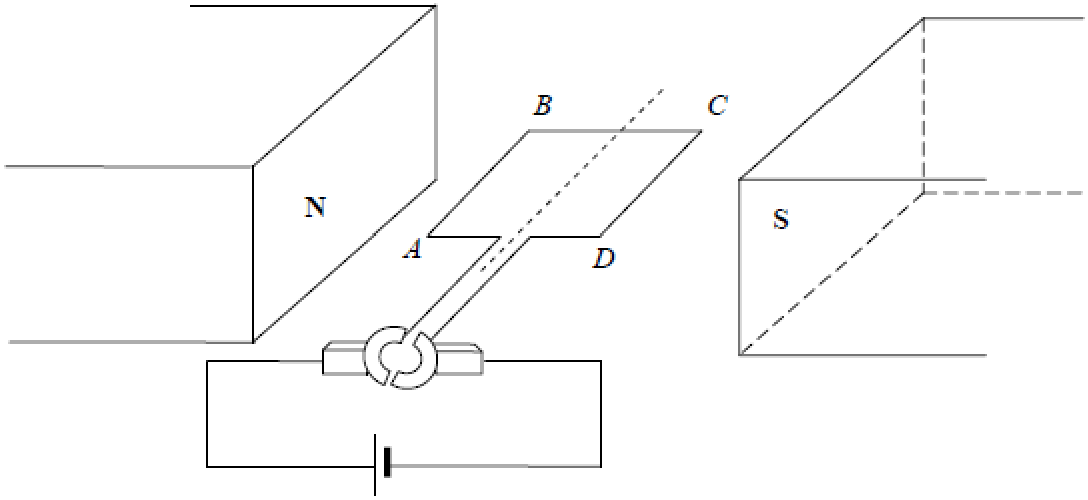
$$B = \frac{2.0 \times 10^{-4}}{1 \times 50 \times 10^{-3} \times 5.0 \times 10^{-2}}$$

= <u>0.08 T</u>

0.08 T

Use the following information to answer Questions 4

A simple DC motor has a square coil with sides of 5 cm. It has 50 turns and carries a current of 1.5 A in a uniform magnetic field of strength 5 mT, which is provided between two poles of a permanent magnet. Initially, it is positioned as shown in the figure below.



Question 4
What is the magnitude and direction of force on the side AB when the coil is in the position shown?

Worked solution

F = ?
n = 50 turns
$B = 5.0 \times 10^{-3}$ T
I = 1.5 A
$l = 0.05$ m

$F = nBIl$
$= 50 \times 5.0 \times 10^{-3} \times 1.5 \times 0.05$
$= 0.019$ N

Right hand slap rule predicts that the direction of the force on section AB is **downwards**.

0.019 N

Mark allocation
- 1 mark for the correct numerical answer.
- 1 mark for the direction.