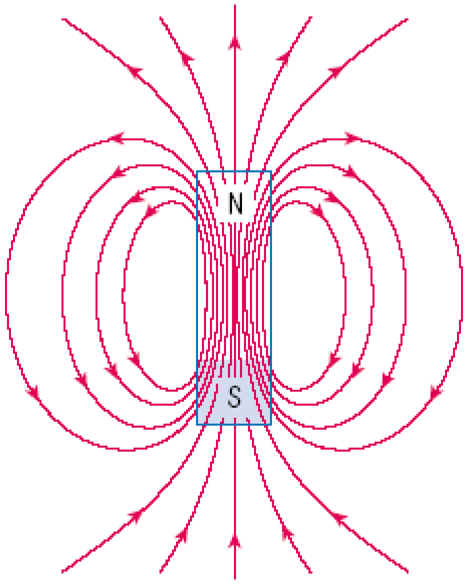
MAGNETIC FIELDS

MAGNETIC FIELD PATTERNS

A magnetic field can be thought of as a region in which invisible magnetic forces exist. Such a field exists, for example, around a permanent magnet.



Magnetic field lines represent the path that an imaginary **North monopole** would follow if it was placed in a magnetic field. Thus, the magnetic field, always points from North to South.

MAGNETIC FORCES ON CURRENT CARRYING CONDUCTORS

When a current, I flows through a wire, it produces a magnetic field around the wire. If the wire is straight, the magnetic field is cylindrical in shape:

Use the **Right Hand Grip Rule** to determine the direction of the magnetic field:

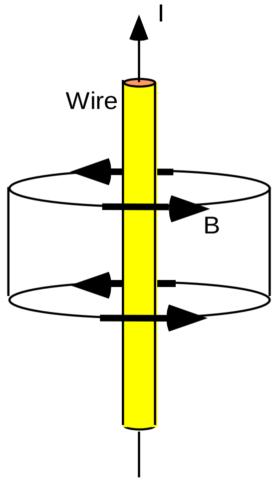
Imagine yourself gripping the wire:

- The thumb is in the direction of the conventional current, I .
- The fingers wrap around the wire in the direction of the magnetic field.

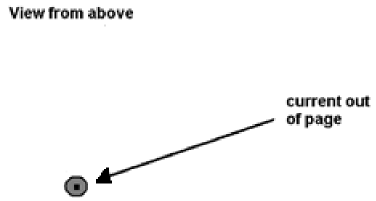
For any given current, the magnetic field becomes weaker as distance from the wire increases. At any given distance from the wire, the magnetic field becomes stronger if I is increased.

The unit of magnetic field strength is the tesla (symbol: T).

Note: Magnetic field strength is sometimes referred to as magnetic flux density.



Let's draw the field around this conductor illustrating its shape, direction and strength……



Moving electric charges within magnetic fields experience a force. It therefore follows that a current carrying wire inside a magnetic field will also experience a force. If the wire is perpendicular to the magnetic field, then:

$$F = B I l$$

Note:

F = force experienced by the wire (newton, N)

B = magnetic field strength, or magnetic flux density (tesla, T)

I = electric current (ampere, A)

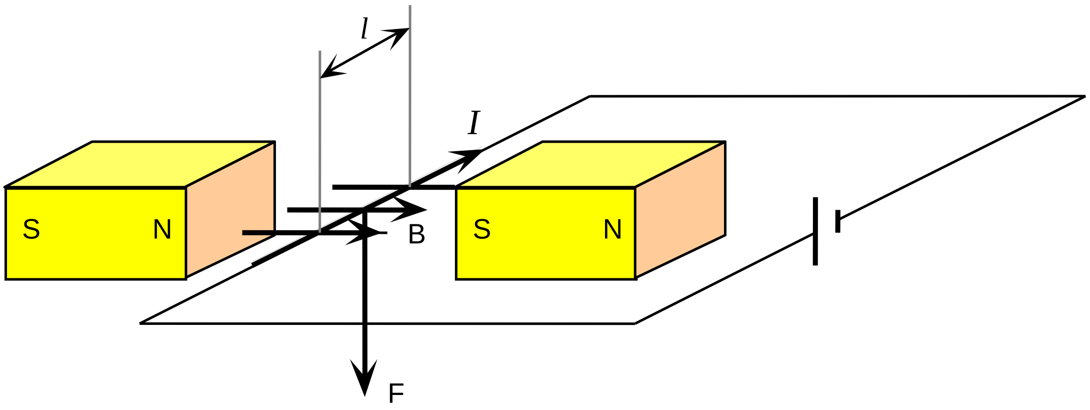
l = length of wire (metres, m)

Note that:

- l is the length of that part of the wire that is actually inside the B field.
- F is always perpendicular to both B and the wire.

Use the **Right Hand Rule** to determine directions:

- Thumb: I
- Fingers: B
- Palm: F



The formula $F = BIl$ only applies for the case where the wire is at right angles to the magnetic field.

If the wire makes an angle θ to the B field, then: $F = BIl\sin\theta$

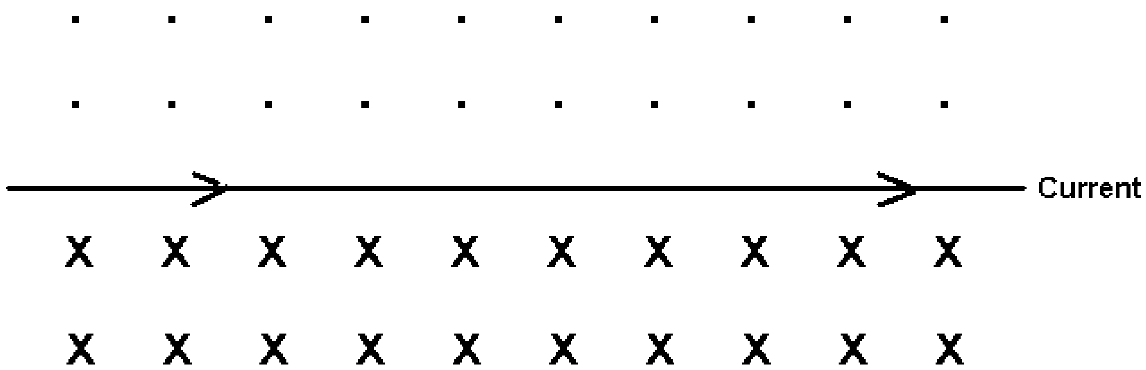
Even though this specific formula is not required for this course, its implications must be known:

- F = 0 if θ = 0, i.e. if the wire is in the same direction as B.
- F is maximum when $\theta = 90^o$ (since sinθ is maximum when $\theta = 90^o$).
- When $\theta = 90^o$ the equation $F = BIl\sin\theta$ reduces to $F = BIl$.

One method of drawing three dimensional diagrams on a page is to use a series of crosses and dots to represent values going into or out of the page. This is a convention that can be used for all sorts of values, such as magnetic field and current.

X X X X	= into the page	. . . .	= out of page

The following diagram demonstrates the layout of the magnetic field around a current carrying conductor. Test it with the RH grip rule.



Two parallel conductors, A and B, have current flowing from left to right. What is the direction of the force that conductor A exerts on conductor B?

In order to answer this question:

1. Select a point on conductor B, any point.

2. Determine the direction of magnetic field at this point. This field will be a result of the current running through conductor A (ignore conductor B as the net field here is zero).

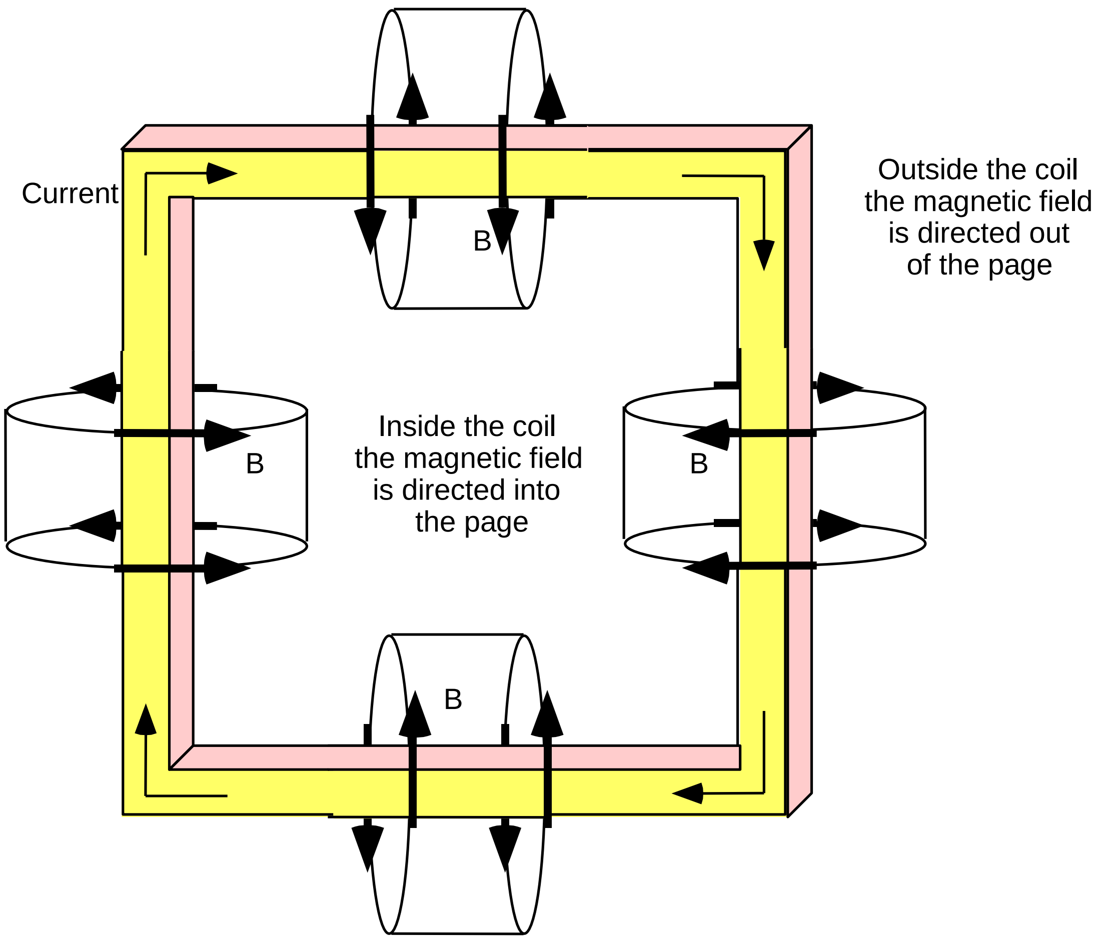
3. Use the RH slap rule to determine the direction of the magnetic force.

What if the conductors have current in opposing directions?

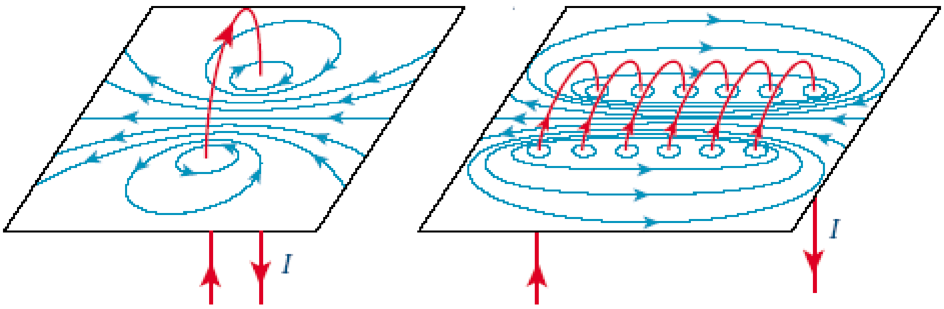
Apply the same three stage process and see what you come up with.

MAGNETIC FIELDS PRODUCED BY CURRENT IN A COIL

Use the **Right Hand Grip Rule** to determine the shape of the magnetic field produced by a current flowing around a coil.



The strength of the magnetic field can be increased by increasing the current or, more significantly, by adding more turns to the coil of wire: the magnetic field strength increases in direct proportion to the number of turns.



Single coil Multiple coils (solenoid)

Note that the pattern of magnetic field lines **resembles the field around a bar magnet**.

Label the north and south ends of each coil.

Some additional points to note:

- The density of the magnetic field is greater inside the loop (or solenoid) than outside.
- If many loops are placed side by side, their magnetic fields add together giving a much stronger effect.
- The strength of the magnetic field can also be increased by increasing the current.
- There is a near uniform magnetic field (i.e. parallel) inside the solenoid.
- If an iron core is placed inside the solenoid the magnetic strength is increased significantly.

Many aspects of the Area of Study on electric power require a clear understanding of magnetic fields, particularly electromagnets.

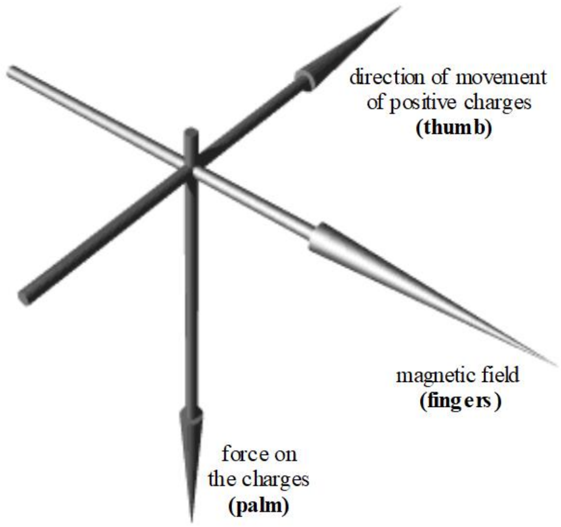
MAGNETIC FORCES ON MOVING PARTICLES

(Only a qualitative understanding is required.)

An electric charge that moves through a magnetic field experiences a force. If the charge is moving at right angles to the magnetic field, then:

$$F = BQv$$

Where: F = force experienced by the charge (newton, N)
B = magnetic field strength, or magnetic flux density (tesla T)
Q = quantity of electric charge (coulomb, C)
v = velocity of the electric charge (m/s)



Use the **Right Hand Rule** to determine the direction of the vectors:

Thumb: v
Fingers: B
Palm: F

Note that:

- v is in the direction of motion of **positive** charge.
- F, B and v are vectors.
- F is always perpendicular to both B and v.

If B and v make an angle θ between them, then:

$$F = BQv\sin\theta$$

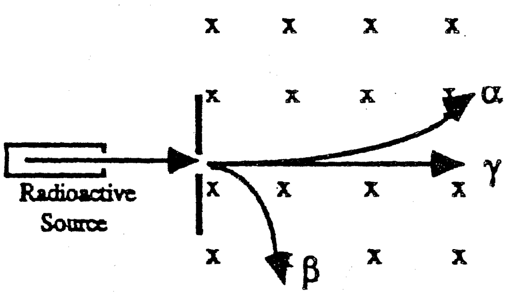
EXAMPLE 5
In 1898 Rutherford used a strong magnetic field to separate nuclear particles.
The following information is given:

Particle	Mass	Charge
Alpha particle $\left({}_{2}^{4}He^{2+}\right)$	$6.640\times10^{-27}\ kg$	$+3.20\times10^{-19}$ Coulomb
Beta particle $\left({}_{-1}^{0}e^{-1}\right)$	$9.019\times10^{-31}\ kg$	-1.60×10^{-19} Coulomb
Gamma ray $\left({}_{0}^{0}\gamma^{0}\right)$	Zero	Zero

Using a magnetic field, how could Rutherford separate the three nuclear products?

Solution

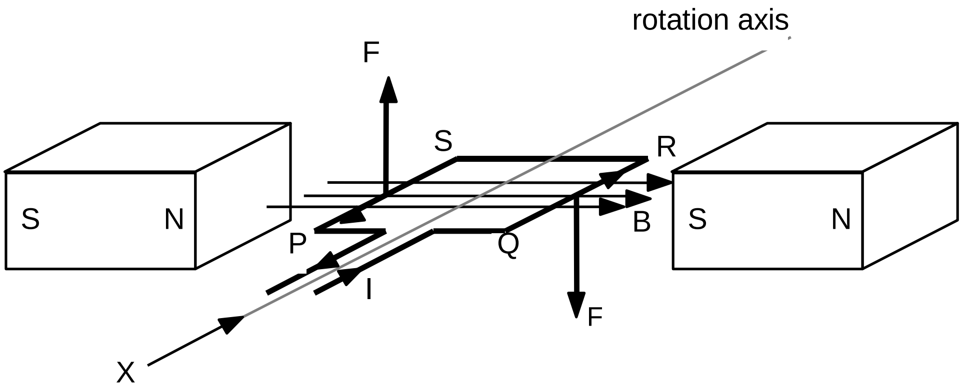
If the magnetic field is into the page.



The gamma ray is unaffected by the magnetic field, whereas the alpha particle is deflected upwards and the beta particle downwards. This can be determined using the right hand slap rule, but note that if the beta particle moves to the right, that current is to the left. Also note the $\frac{mass}{charge}$ ratio is very different for α and β so the amount of deflection is very different.

DC ELECTRIC MOTORS

Motors consist of a current carrying coil placed within a uniform magnetic field. The current is supplied by some external power supply (not shown in the following diagram). The coil is free to rotate.



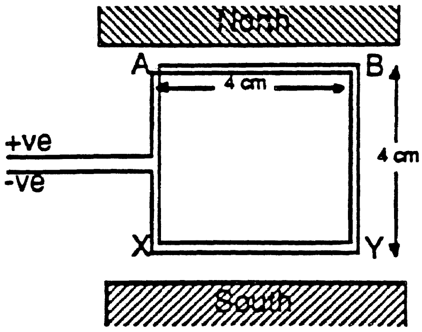
Use the Right Hand Rule to determine the direction of the forces and thus the direction of rotation. In the diagram above we can clearly see that the force on side PS is upwards, and this force, in conjunction with the downward force on side QR, causes the coil to rotate in a clockwise direction.

Use $F = BIl$ to find the magnitude of F .

If the coil has n turns, then the appropriate formula is: $F = nBIl$.

EXAMPLE 6

Two students attempt to construct a simple DC motor by making a square copper loop (ABYX), of side length 4.0 cm and 50 turns, connected to a power pack operating at 6.0 V and 1.5 A. Two magnets are suspended directly above and below the copper loop producing a magnetic field of strength 0.20 T.



(a) Calculate the magnitude of the force on side **AB**.

$F = nBIl$

$n = 50$, $l = 0.04\,m$, $I = 1.5$, $B = 0.20$

$F = 50 \times 0.20 \times 1.5 \times 0.04$
$F = 0.6\ N$

(b) The direction of the force experienced by side **AB** is:

A Left
B Right
C Up
D Down
E Into the Page
F Out of the page
G No force

(c) The direction of the force experienced by side **BY** is:

A Left
B Right
C Up
D Down
E Into the Page
F Out of the page
G No force

(d) What is the magnitude of the net force on the coil?

Solution

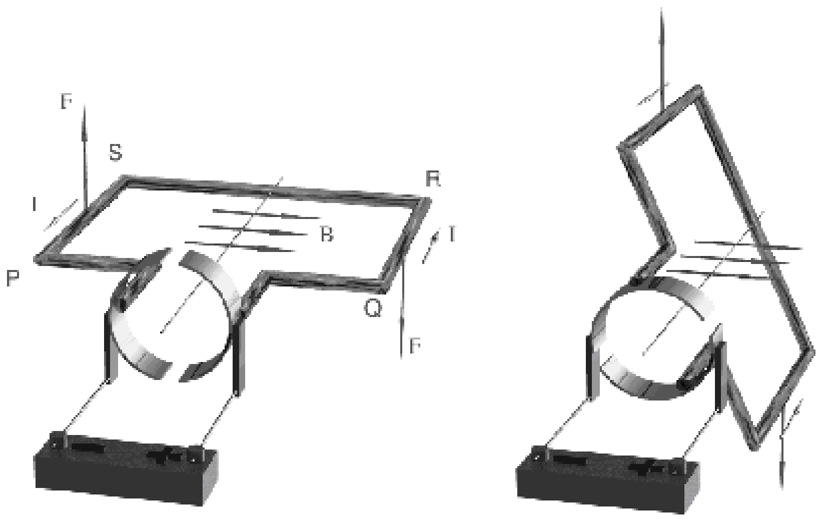
(b) E

(c) G

(d) Net force is zero.

What happens to the magnitude and direction of the force acting on side PS when the coil has rotated a quarter of a turn, such that the loop is now vertically aligned?

The following diagrams show that as the coil rotates the direction of the net force on side PS is still upwards. Side PS remains perpendicular to the field and current direction is unchanged. It follows that both the magnitude and direction of the force must be unchanged.



As the coil moves into the vertical position, the forces on the sides PS and QR are vertical and there is no component of the force in the direction of rotation. Therefore, at this position the applied forces on PS and QR does not contribute to rotation.

At this stage we need to introduce a new concept called torque, or turning force. A turning effect requires a component of the net force in the direction of rotation. Clearly the net force on side PS and the turning effect are quite different.

A force, acting at a distance from the axis of rotation, produces a torque: $\tau = r \times F$

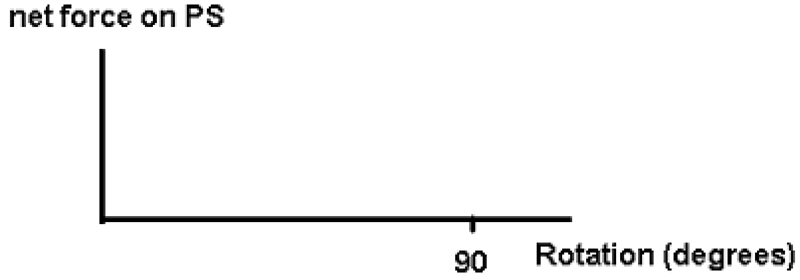
Where τ = Torque (newton metres, Nm)

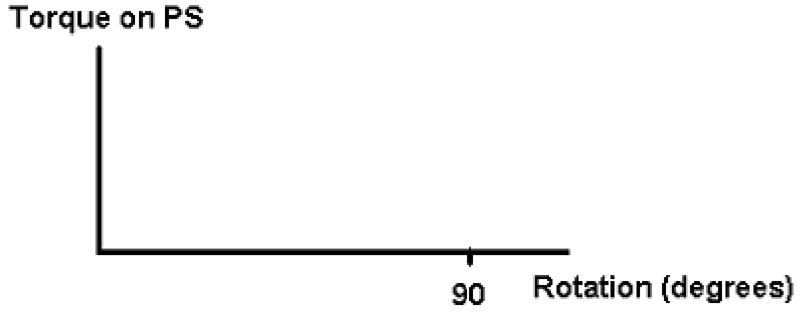
r = Perpendicular distance between the axis of rotation and the line along which the force acts (metres, m)

F = Force (newtons, N)

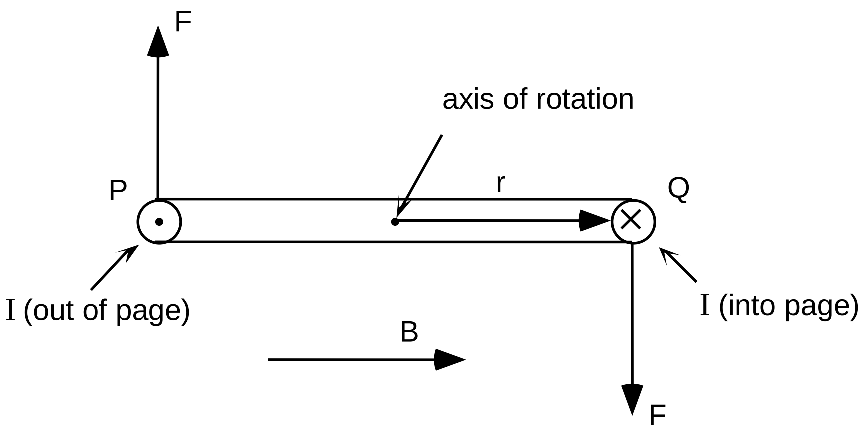
Note: You will not be examined on torque – it is presented here simply to aid in your understanding of how electric motors work.

Complete the following graphs to demonstrate changes in the net force on PS, and torque, over a quarter rotation.





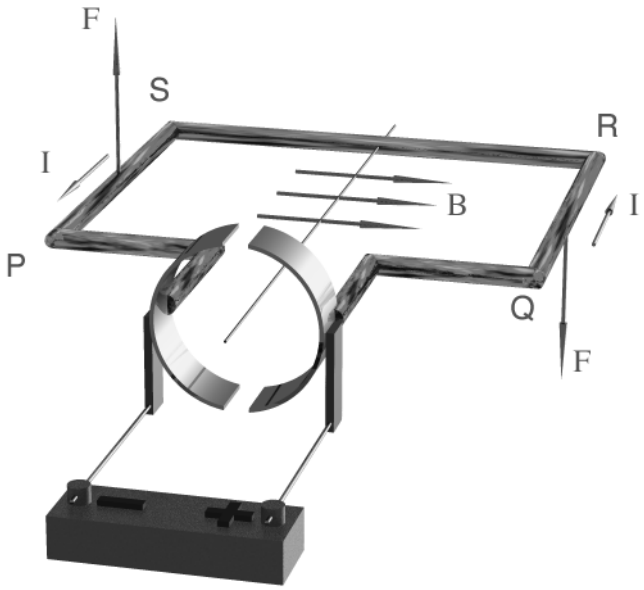
If, in the previous diagram, one was to look along the rotation axis from point X, this is what one would see:

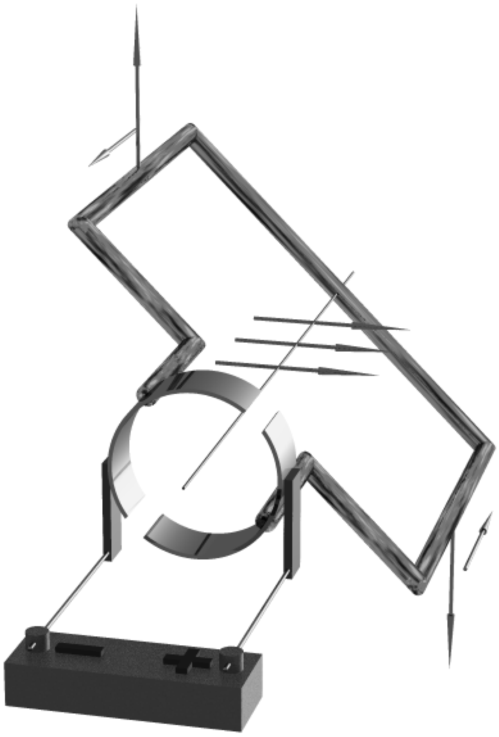


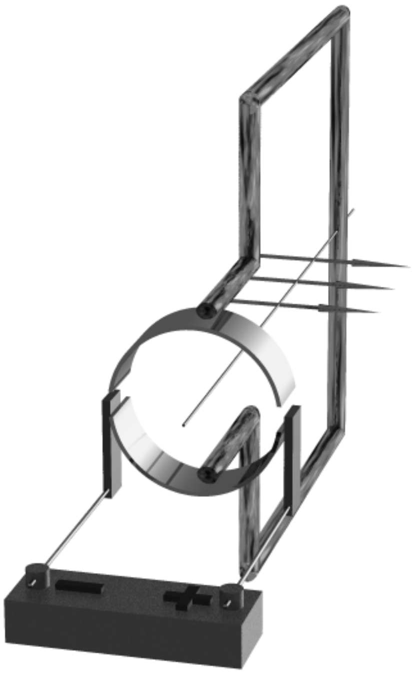
As the coil rotates, F remains constant (and is always perpendicular to the B field) but r varies (causing a change in τ). Torque is maximum when the plane of the coil lies parallel to the B field and reduces to zero when the plane of the coil is perpendicular to B.

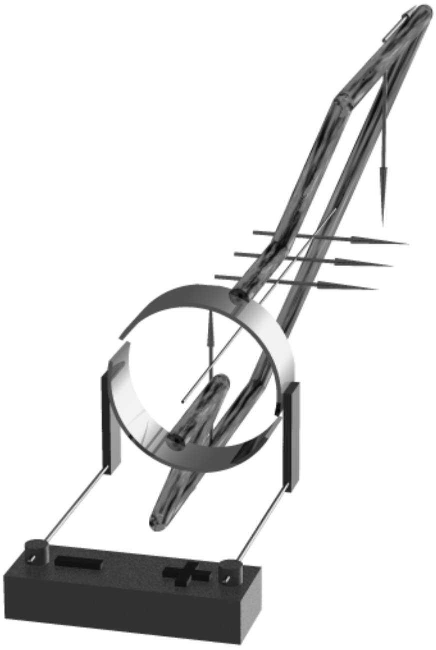
In order to obtain a continuous rotation, a mechanism is required that changes the direction of the current every time the coil rotates to a position perpendicular to the B field. This causes F to change direction and thus the torque remains clockwise.

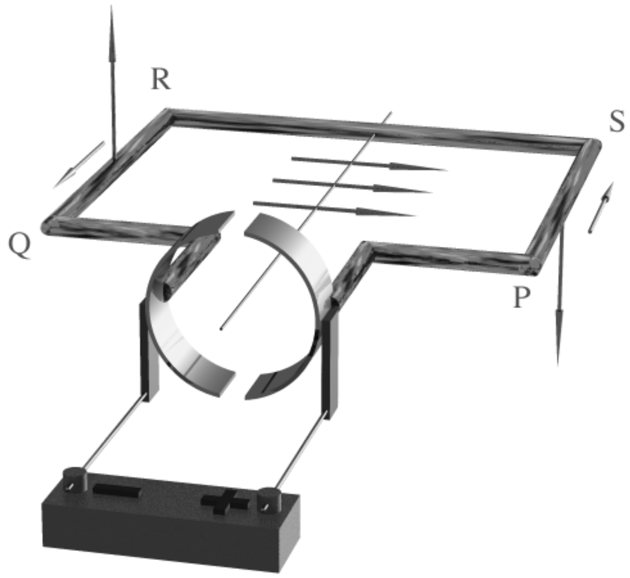
Change of direction of the current is achieved by using a split ring commutator. The following diagrams show a DC motor (with the magnets omitted for clarity). Notice that, in the first diagram, the current is flowing from Q to R and from S to P. Successive diagrams show the coil at 1/16 rotation intervals. Notice the rotation of the split ring – it is attached to the coil and rotates with it. The brushes that make electrical contact with the split ring remain stationary. Change of direction of the current occurs when the coil passes the vertical position. (In the last diagram, which shows the coil after half a rotation, one can see that the current is flowing from R to Q and from P to S.)



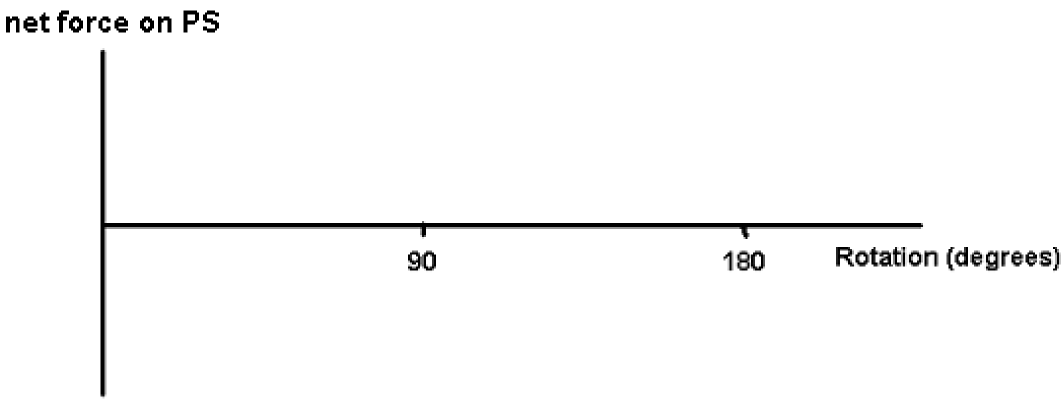


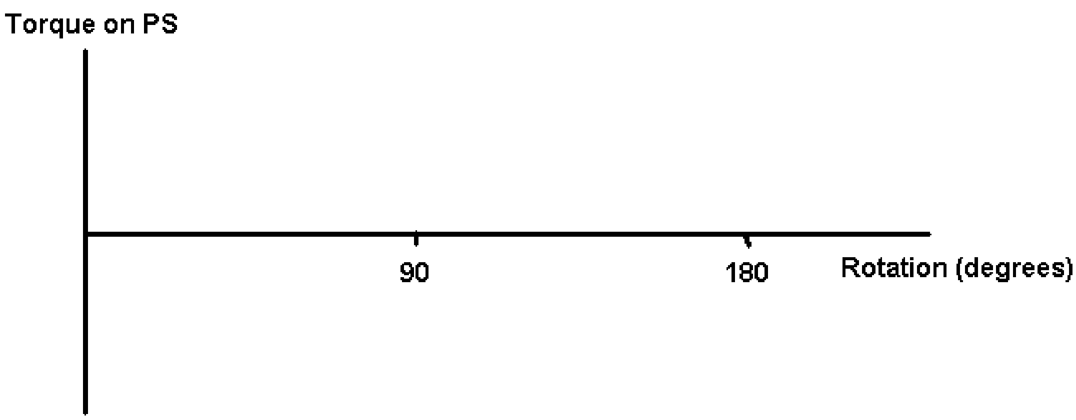




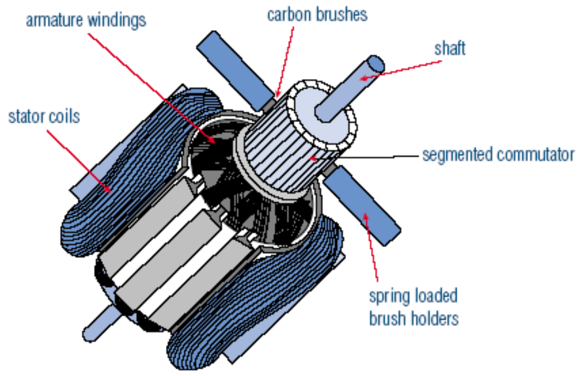

R
S
Q
P

For the set of diagrams just presented, complete the following graphs:





In practice, most electric motors have many sets of coils, called armature windings, aligned at evenly spaced angles. Four, eight, and even more sets of armature windings are routinely used. If the motor had only two sets of coils they would be aligned at right angles.
The commutator would have two segments for each coil, therefore having a total of four segments. Only one pair of commutator segments receiving current at a time.
The commutator distributes electrical power to the coil that is in the position of maximum torque. As that coil moves into a low torque position, the commutator transfers the electrical supply to the other coil as it moves into a high torque position.



The brushes are also an important part of the electrical supply mechanism. Their function is to make electrical contact with the rotating commutator. A common material used for brushes is graphite, which is a good conductor and very slippery, hence making a low friction electrical contact.

Questions 2 to 3 refer to the following information:

Figure 1 shows a simple DC motor consisting of a rectangular coil, free to rotate about an axle and placed in a magnetic field. The axle is at right-angles to the magnetic field. When a current flows in the coil, as shown in Figure 1, there are forces exerted on the coil, which cause a turning effect or torque.

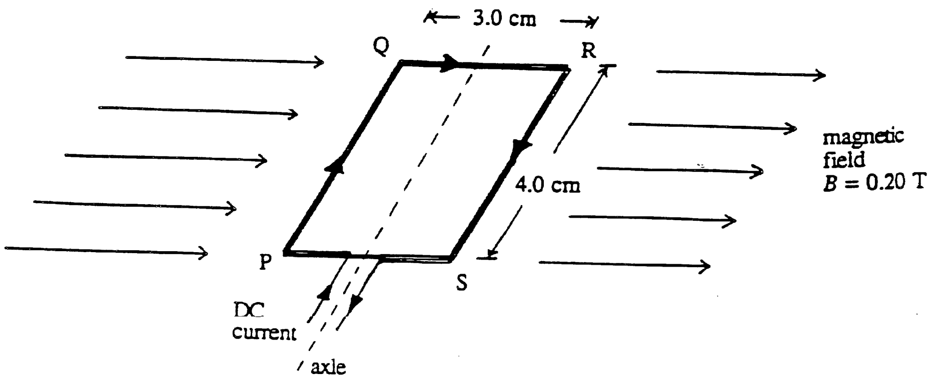


Figure 1

Data for the motor:

The coil is 4.0 cm long and 3.0 cm wide and contains 100 turns of wire. The magnitude of the magnetic field is 0.20 T.

QUESTION 2a
With a DC current of 6.0 A in the coil, what is the magnitude of the force on the side PQ of the coil?

Solution

QUESTION 2b
If the force on the side PQ has magnitude F , which one of the following expressions best describes the net force on the coil?

A Zero

B F

C $\sqrt{2}F$

D $2F$

E $4F$

QUESTION 3
The plane of the coil is parallel to the magnitude field as shown in Figure 1. The lengths of all the sides of the coil are now **doubled** but the current remains the same. Which one of the following statements best describes the change in the net torque on the coil?

A The torque is unchanged.

B The torque is increased by a factor of $\sqrt{2}$.

C The torque is increased by a factor of 2.

D The torque is increased by a factor of 4.

E The torque is increased by a factor of 8.

Questions 4 to 6 refer to the following information:

An electric motor from a toy car contains an armature of 50 turns in a magnetic field, $\overline{B}$, of 0.10 T. Each side of the armature has a length of 2.0 cm:

AB = BC = CD = AD = 2.0 cm

A constant current, I , of 1.5 A flows from A to B to C to D as shown in Figure 1.

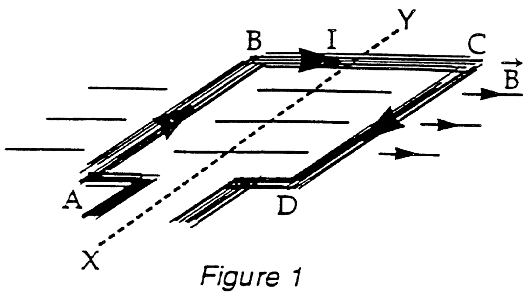


Figure 1

QUESTION 4
Calculate the size and direction of the magnetic force on side AB.

Solution

QUESTION 5
What is the magnitude of the magnetic force on side BC?

Solution

QUESTION 6
The loop is free to rotate around the axis XY. Describe its initial motion.

Solution