12 DC Electric Motors

- **• 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**
- **• investigate, qualitatively, the effect of current, external magnetic field and the number of loops of wire on the torque of a simple motor**

The force on a current carrying wire in a magnetic field
Remember that

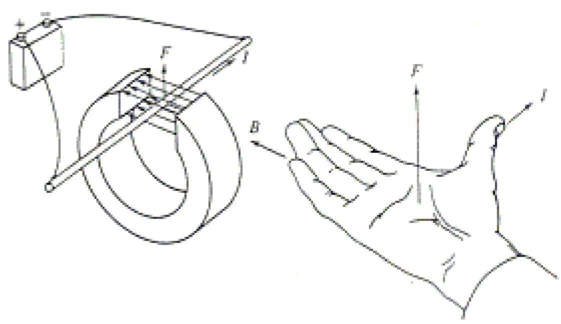
- For a current-carrying conductor there is an associated magnetic field.

(The direction of the field is given by the right-hand grip rule)

A consequence of this is that

- For a current-carrying conductor <u>in a magnetic field</u> there is a force acting on it.

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

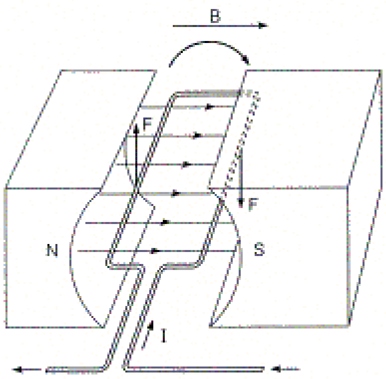


Motors

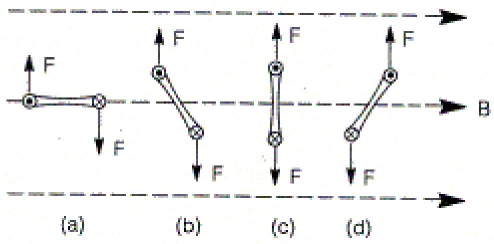
A direct current (D.C.) motor converts electrical energy (using the current through a coil of wire) into mechanical energy (by spinning the coil.)

Current in a wire ⇨ Creates its own magnetic field ⇨ Interacts with another field ⇨ Force on the current carrying wire ⇨ Rotational motion

A 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 current through the far side of the coil is always parallel to the field direction, so there is no force acting on this side.



The current on the right side of the coil is **always** in the opposite direction to the current on the left side of the coil.

This means that the forces on these sides of the coil will be always **opposite** (up or down).

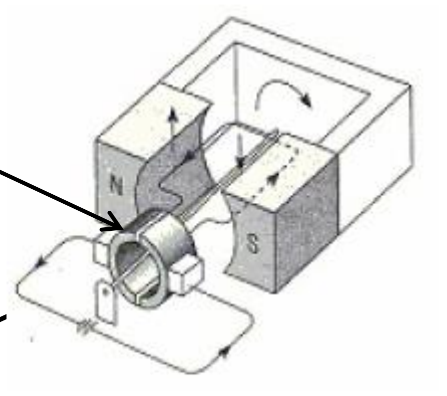
This will allow the coil to **spin**.

We can see that in (a) and (b), the coil begins to spin clockwise. However, after being in the vertical position (c), the forces now act to cause the coil to spin in the opposite direction, because the forces are still in the same direction as they were at the start.

To get this motor to spin continuously, we need to change the direction of the forces every half cycle.
We could do this by either

- reversing the direction of the current (this is the easier), or
- reversing the direction of the magnetic field,
- but not both

To achieve this we use a split-ring commutator



The commutator ensures that whichever side of the coil is nearest the north pole will always be pushed up, and whichever side of the coil is nearest the south pole is always pushed down.

There are two splits in the ring. (They are seen top and bottom.) These cut the current to the coil twice every complete cycle.

There are two carbon brushes on either side of the ring. When in contact with the ring, they complete the circuit and allow current to flow through the coil

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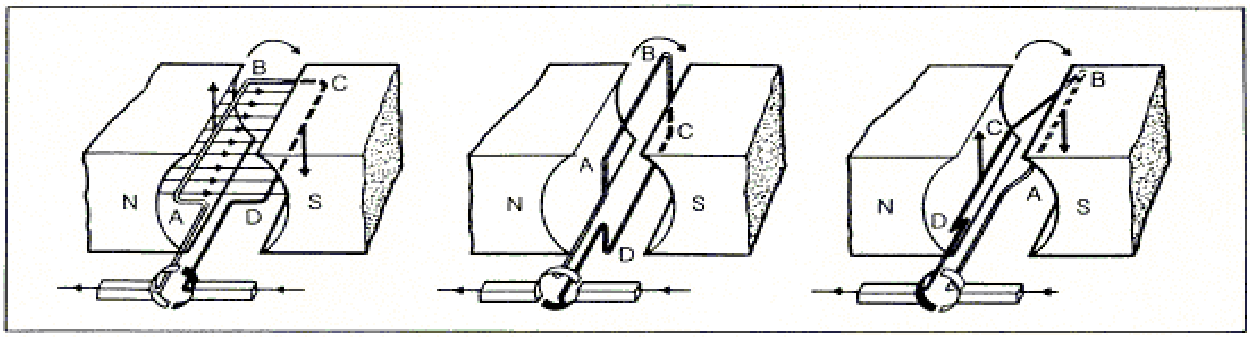
How the commutator works

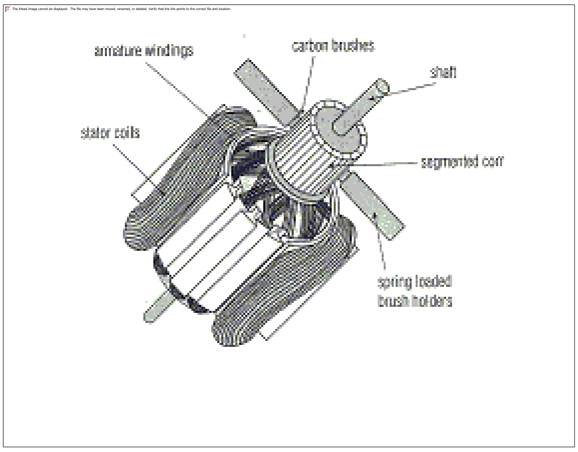


In the first position, the coil is horizontal. The D edge of the coil is connected to the right (+) brush at this point, and so current flows from D to A. This causes the force directions as shown, causing a clockwise rotation.	When the coil becomes vertical as shown in the second position, the split in the commutator is lined up with the brushes, meaning that no current is flowing through the coil. This means that that there is momentarily no force acting on the coil, and the coil continues to rotate clockwise, due to its momentum.	After passing the vertical position, the D edge of the coil now makes contact with the left (–) brush, so that current now flows from A to D. This change in current direction means that there is now an upward force on the CD side. This causes a continued rotation in the clockwise direction.

In the middle position above, the current is cut from the circuit. 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 (remember that Newton said that a body will remain in motion unless a force acts on it) and then the current is switched on again but its direction is reversed.

How real motors work

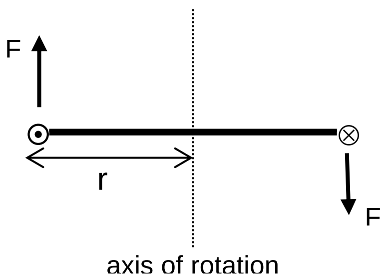
A single coil motor would be rather jerky so in most practical motors the magnetic field is provided by an electromagnetic coil, and a radial rather than uniform field is used. This can be done by ‘focusing’ the field through a soft iron core and by using the stronger stationary electromagnet (stator) instead of a permanent magnet. This means that whatever the position of the coil the turning forces are perpendicular to the plane of one of the many coils and so the torque does not vary with coil position. Normally a motor consists of a series of coils (at different orientations rather than a single coil, this produces a smoother action, ie. a more constant torque.

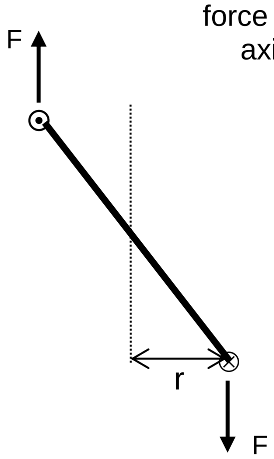


The difference between force and torque

A coil has a pair of equal and opposite forces acting on its sides. These forces tend to rotate the coil. The turning force F is <u>constant</u> in size (**F** = **BIL**) at all points in the cycle.

We need to distinguish between the force and the spin caused by the force. This is called the torque. The torque depends on the distance between the parallel turning forces and the axis of rotation, and so is <u>not constant</u> at all points in the cycle, as shown below.





The turning moment or torque (τ) of a force **F** acting at a distance **r** from the axis of rotation of a rigid body is defined as

$$\tau = \mathbf{F} \times r$$

In both positions, the size of the force is equal.

However, as the coil rotates closer to a vertical position, the line of action of the force moves closer to the axis of rotation (reducing r)
Hence, the torque decreases

Torque
The unit for τ is Nm

$$\tau = \mathbf{F} \times r \qquad \text{and} \quad \mathbf{F} = n\,\mathbf{B}IL$$

Hence $\boldsymbol{\tau} = n \times B \times I \times L \times r$

Speed is directly proportional to the torque. Hence, the speed of an electric motor can be increased by:

1. Increasing the length of the conductor in the magnetic field. (**L or N**)
   This is most effectively done by using a large number of turns in the coil. This can make the motor heavy.
2. Increasing the size of the current that flows through the coil. (**I**)
   This may cause overheating, and is limited by the resistance of the wire used in the coil.
3. Increasing the magnetic field strength of the permanent magnets. (**B**)
   This is limited by the quality of the materials used in the manufacture of the stator. It is not a very efficient way of increasing the torque.
4. Increasing the lever arm of the torque. (**r**)
   This means making the motor bigger physically. This is often inconvenient.

World's Simplest Homopolar motor
