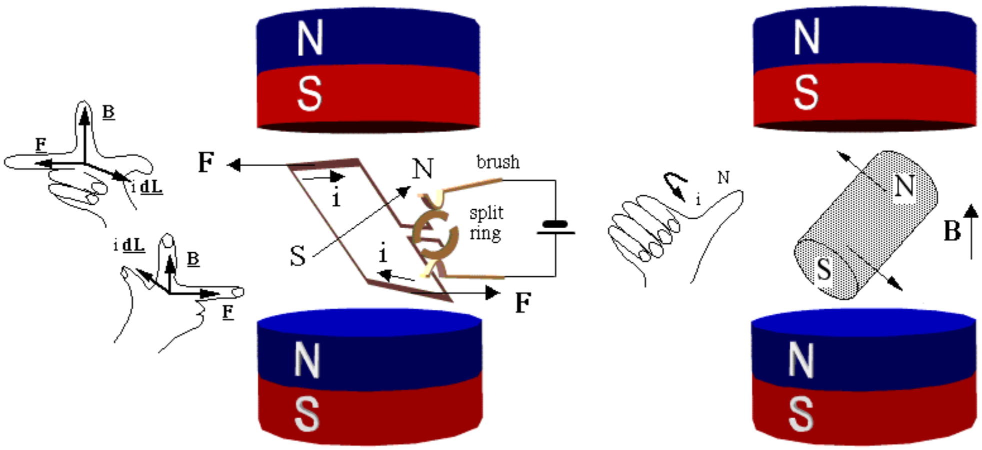
# DC motors

A simple DC motor has a coil of wire that can rotate in a magnetic field. The current in the coil is supplied via two brushes that make moving contact with a split ring. The coil lies in a steady magnetic field. The forces exerted on the current-carrying wires create a torque on the coil.




The force F on a wire of length L carrying a current i in a magnetic field B is iLB times the sine of the angle between B and i, which would be 90° if the field were uniformly vertical. The direction of F comes from the right hand rule*, as shown here. The two forces shown here are equal and opposite, but they are displaced vertically, so they exert a torque. (The forces on the other two sides of the coil act along the same line and so exert no torque.)

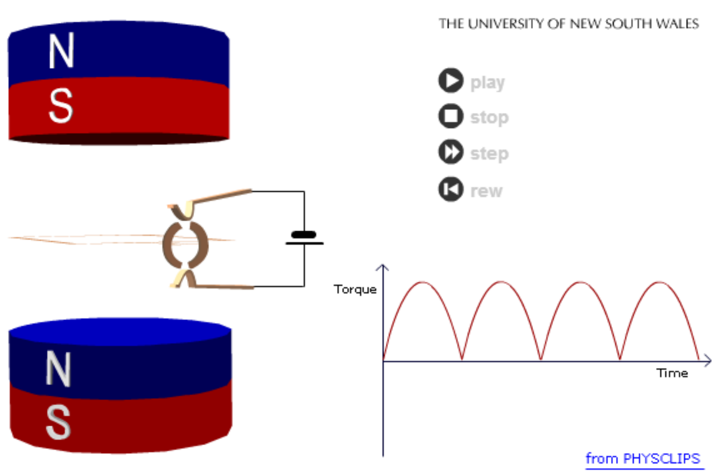
* A number of different nmemonics are used to remember the direction of the force. Some use the right hand, some the left. For students who know vector multiplication, it is easy to use the Lorentz force directly: $\mathbf{F} = q\,\mathbf{v} \times \mathbf{B}$, whence $\mathbf{F} = i\,\mathbf{dL} \times \mathbf{B}$. That is the origin of the diagram shown here.

The coil can also be considered as a magnetic dipole, or a little electromagnet, as indicated by the arrow SN: curl the fingers of your right hand in the direction of the current, and your thumb is the North pole. In the sketch at right, the electromagnet formed by the coil of the rotor is represented as a permanent magnet, and the same torque (North attracts South) is seen to be that acting to align the central magnet.

Throughout, we use blue for the North pole and red for the South. This is just a convention to make the orientation clear: there is no difference in the material at either end of the magnet, and they are usually not painted a different colour.

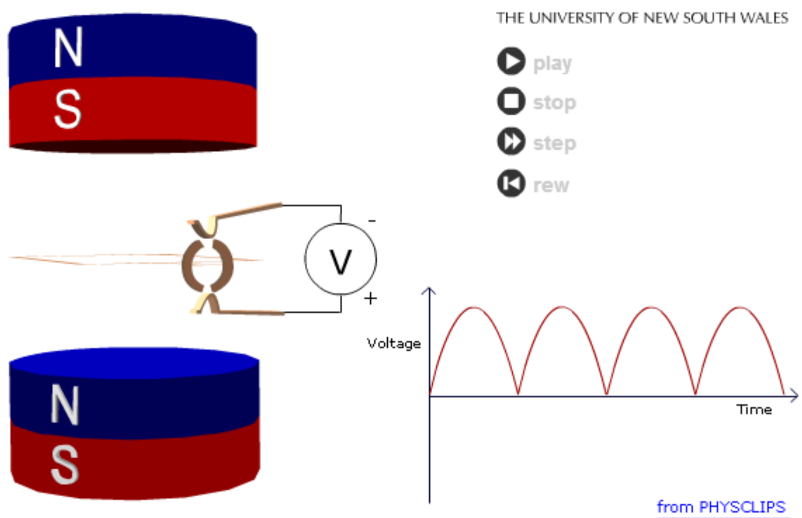
Note the effect of the **brushes** on the **split ring**. When the plane of the rotating coil reaches horizontal, the brushes will break contact (not much is lost, because this is the point of zero torque anyway – the forces act inwards). The angular momentum of the coil carries it past this break point and the current then flows in the opposite direction, which reverses the magnetic dipole. So, after passing the break point, the rotor continues to turn anticlockwise and starts to align in the opposite direction. In the following text, I shall largely use the 'torque on a magnet' picture, but be aware that the use of brushes or of AC current can cause the poles of the electromagnet in question to swap position when the current changes direction.

The torque generated over a cycle varies with the vertical separation of the two forces. It therefore depends on the sine of the angle between the axis of the coil and field. However, because of the split ring, it is always in the same sense. The animation below shows its variation in time, and you can stop it at any stage and check the direction by applying the right hand rule.



**Motors and generators**

Now a DC motor is also a DC generator. Have a look at the next animation. The coil, split ring, brushes and magnet are exactly the same hardware as the motor above, but the coil is being turned, which generates an emf.




If you use mechanical energy to rotate the coil (N turns, area A) at uniform angular velocity ω in the magnetic field **B**, it will produce a sinusoidal emf in the coil. emf (an emf or electromotive force is almost the same thing as a voltage). Let θ be the angle between **B** and the normal to the coil, so the magnetic flux φ is NAB.cos θ. Faraday's law gives:

$$\text{emf} = - d\varphi/dt = - (d/dt)\ (NBA \cos \theta)$$

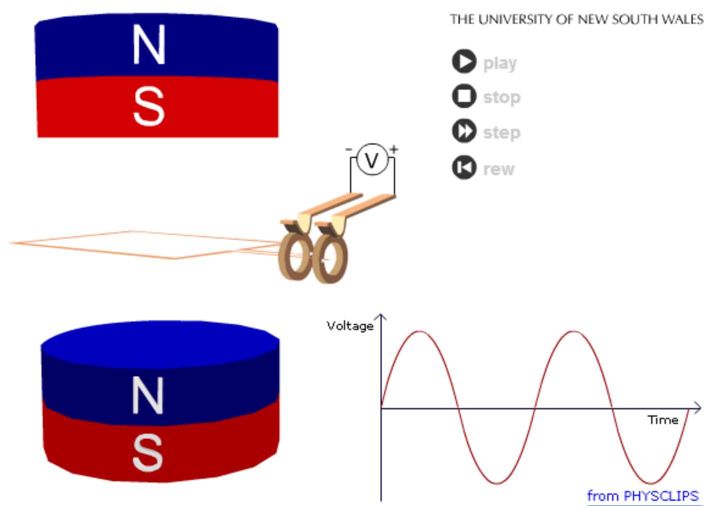
$$= NBA \sin \theta\ (d\theta/dt) = NBA\omega \sin \omega t.$$

The animation above would be called a DC generator. As in the DC motor, the ends of the coil connect to a split ring, whose two halves are contacted by the brushes. Note that the brushes and split ring 'rectify' the emf produced: the contacts are organised so that the current will always flow in the same direction, because when the coil turns past the dead spot, where the brushes meet the gap in the ring, the connections between the ends of the coil and external terminals are reversed. The emf here (neglecting the dead spot, which conveniently happens at zero volts) is |NBAω sin ωt|, as sketched.

### An alternator

If we want AC, we don't need recification, so we don't need split rings. (This is good news, because the split rings cause sparks, ozone, radio interference and extra wear. If you want DC, it is often better to use an alternator and rectify with diodes.)

In the next animation, the two brushes contact two continuous rings, so the two external terminals are always connected to the same ends of the coil. The result is the unrectified, sinusoidal emf given by NBAω sin ωt, which is shown in the next animation.




Source: http://www.animations.physics.unsw.edu.au/jw/electricmotors.html