Since force, current, length and angle are already defined and their units are known, we can use these terms to define **magnetic flux density**.

Magnetic flux density is defined by the equation

$$B = \frac{F}{IL\sin\theta}$$

Rearranging this equation gives $F = BIL\sin\theta$.

Provided F is in newtons, I is in amperes and L is in metres, B will be in **tesla**. One tesla, T, is the magnetic flux density when a wire of length one metre and carrying a current of one ampere at a right angle to the field experiences a force of one newton.

Note that if the field and the wire are in the same direction, $\sin\theta$ will be zero, and the force will be zero. When the wire and the field are at right angles to one another, $\sin\theta$ will be 1, and the force will be at its maximum value. One tesla is a large magnetic flux density. In magnetic resonance machines the magnetic field has to be up to 2 T. A good strong bar magnet will have a flux density near its poles of around 20 milliteslas, mT. The magnetic flux density of the Earth in the UK is around 5×10^{-5} T, or 50 µT.

Key definition

Magnetic flux density B is defined by the equation

$F = BIL\sin\theta$

where F is the force on a wire of length L carrying a current I at an angle θ to the field.

Key definition

One tesla, T, is the magnetic flux density when a wire of length one metre and carrying a current of one ampere at a right angle to the field experiences a force of one newton.

The force on a charged particle moving in a magnetic field

Consider a charge $+Q$ travelling with velocity v at right angles to a magnetic field of magnetic flux density B. In a time t the charge will have moved a distance $L = vt$, and the current I, the charge flowing per unit time, will be Q/t. Using the equation $F = BIL$ and substituting gives for the charged particle

$$F = B \times \frac{Q}{t} \times vt = BQv$$

As with a current in a wire, the force acts in a direction given by Fleming's left-hand rule. The force is at right angles to both the magnetic field and the direction of travel of the particle. You need to be careful when applying Fleming's left-hand rule to charged particles. If the particle is negatively charged, an electron for example, the direction of the current is in the opposite direction to the direction in which it is travelling.

If the particle is initially not travelling at right angles to the field, the situation is as shown in Figure 3, in which a charge Q moves with velocity v at an angle θ to the magnetic field of flux density B. Consider the two components of the velocity. One component, at right angles to the field, has magnitude $v\sin\theta$, and the other in the direction of the field has magnitude $v\cos\theta$. The component at right angles to the field results in the charge experiencing a force $BQv\sin\theta$, and the component in the direction of the field will have no effect whatsoever on the particle's path.

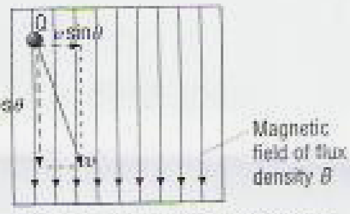

Figure 3 A charged particle moving at an angle θ to the magnetic field will experience a force $BQv\sin\theta$

Key definition

The force F on a charge Q moving with velocity v at an angle θ to a magnetic field of flux density B is given by $F = BQv\sin\theta$.

Questions

1 Show that the units of magnetic flux density, usually T (tesla), can be written as $N\,s\,C^{-1}\,m^{-1}$.

2 Figure 4 shows the directions of the current I in a short section of wire and the magnetic flux density B at the wire.

(a) The current is in the direction H–G. In which direction is the force on the wire?

(b) The free electrons are drifting in the direction G–H. In which direction is the average force on them?

(c) The wire carries a current of 0.24 A. The length of wire in the magnetic field is 60 mm. The magnetic flux density B is 30 mT. Calculate the force on the wire.

(d) Through what angle must the wire be rotated and in which plane to reduce the force on the wire to (i) half the value in (c) and (ii) zero?

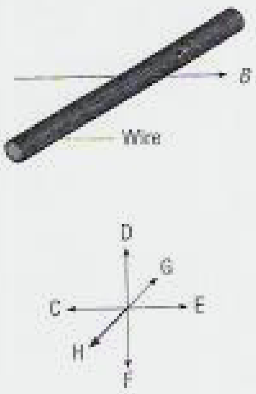

Figure 4

only No. 2 is to be done