Magnetic force on a current carrying wire

We have already seen (in connection with the Hall effect) that a magnetic field exerts a sideways force on electrons moving in a wire. This force must then be transmitted to the wire itself, because the conduction electrons cannot escape sideways out of the wire. In Fig. *a*, a vertical wire, carrying no current and fixed in place at both ends, extends through the gap between the vertical pole faces of a magnet. The magnetic field between the faces is directed outward from the page. In fig. *b*, a current is sent upward through the wire; the wire deflects to the right. In Fig.*c*, we reverse the direction of the current and the wire deflects to the left.

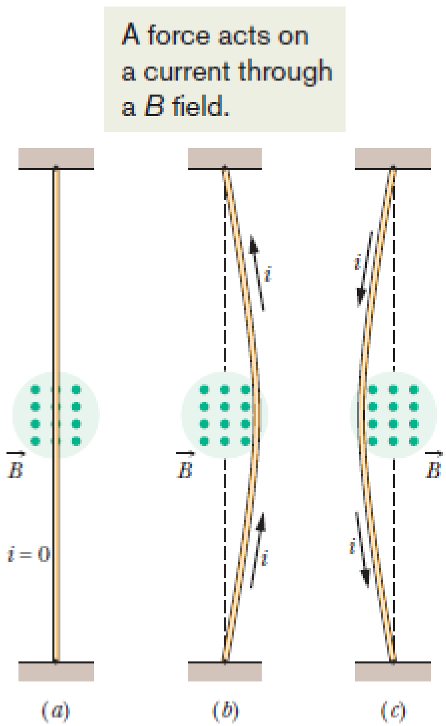
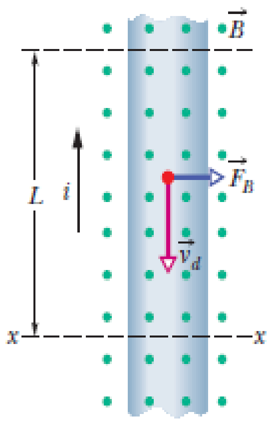


Figure below shows what happens inside the wire of Fig.*b*. We see one of the conduction electrons, drifting downward with an assumed drift speed *vd*. $F=qvB\sin\phi$, in which we must put $\phi=90°$, tells us that a force F_B of magnitude *evdB* must act on each such electron. From Eq. $F=qv\times B$ we see that this force must be directed to the right. We expect then that the wire as a whole will experience a force to the right, in agreement with above Fig. *b*.

If, in Fig., we were to reverse *either* the direction of the magnetic field *or* the direction of the current, the force on the wire would reverse, being directed now to the left. Note too that it does not matter whether we consider negative charges drifting downward in the wire (the actual case) or positive charges drifting upward. The direction of the



t.

deflecting force on the wire is the same. We are safe then in dealing with a current of positive charge, as we usually do in dealing with circuits.

Find the Force. Consider a length *L* of the wire in Fig. above. All the conduction electrons in this section of wire will drift past plane *xx* in Fig. above in a time $t = L/vd$. Thus, in that time a charge given

$$q = it = i\frac{L}{v_d}$$

by will pass through that plane. Substituting this into F=qvBsinϕ yields.

$$F_B = qv_dB\sin\phi = \frac{iL}{v_d}v_dB\sin 90^\circ$$

$$F_B = iLB.$$

Note that this equation gives the magnetic force that acts on a length *L* of straight wire carrying a current *i* and immersed in a uniform magnetic field that is B *perpendicular* to the wire. If the magnetic field is *not* perpendicular to the wire, the magnetic force is given by a generalization of above equation:

$$\vec{F}_B = i\vec{L} \times \vec{B} \quad \text{(force on a current).}$$

Here is L a *length vector* that has magnitude *L* and is directed along the wire segment in the direction of the (conventional) current. The force magnitude F_B is

$$F_B = iLB\sin\phi,$$

where ϕ is the angle between the directions of L and B. The direction of F_B is that of the cross product L×B because we take current *i* to be a positive quantity. F_B is always perpendicular to the plane defined by vectors L and B.

In practice, we define B from because it is much easier to measure the magnetic force acting on a wire than that on a single moving charge.