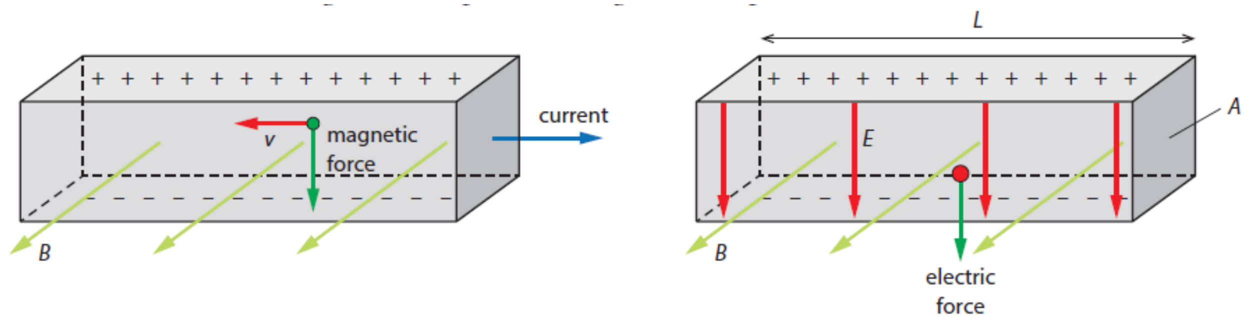
Teacher notes
Topic D

How does the force on the electrons in a current carrying wire translate into a force on the wire itself?

Consider a wire carrying a current in a region of magnetic field. The figure shows one electron (green dot) that moves with speed *v* inside the wire. The electron experiences a magnetic force that pushes it downwards. The magnetic force on the moving charges makes electrons accumulate at the bottom of the wire, leaving an excess positive charge at the top of the wire.



a   b

a Electrons in the wire experience a magnetic force. **b** The electric force on the fixed positive charges means there is a force on the wire itself.

The positive and negative charges at the top and bottom of the wire exert an electric force on the electrons so that no new electrons move towards the bottom of the wire: the magnetic force on the electrons is balanced by an electric force, $qE = qvB$.

So, it appears that since the magnetic force on the electrons is balanced by an electric force there seems to be a zero net force on the wire. However, the electric field E between the top and bottom sides of the wire exerts an **electric** force on the fixed positive charges inside the wire (the protons in the nuclei). So, the net force on the wire, is the external magnetic force on the electrons, an electric force on the electrons and an electric force on the protons. The **net** force on the wire is therefore the magnetic force on the electrons since the electric forces on the electrons and the protons cancel out as must be the case for internal forces.

Let n be the density of negative (or positive) charges within the wire (number of charges per unit volume). The number of charges within a length L of cross-sectional area A is $N = nAL$ and so the force on this length of wire is:

$F = (nAL)qE$

But $qE = qvB$, so:

$F = (nAL)qvB = (nAqv)BL$

Using $nAqv = I$

we get:
$F = BIL$ as expected!