Question 21 **(18 marks)**

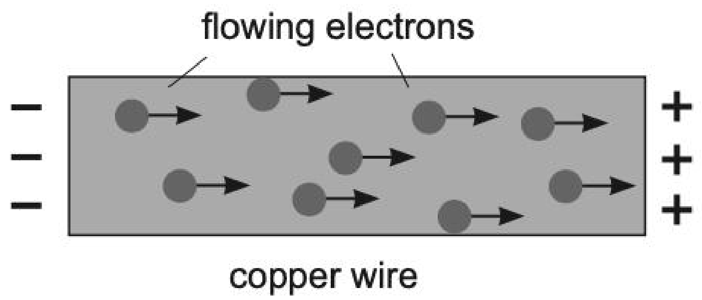
Drift velocity

When you turn on a light, it comes on as soon as the circuit is complete. The energy flowing in the circuit is transferred almost instantly. But how fast do the charged particles, which carry that energy, move? It turns out that they move extremely slowly. This velocity is called the drift velocity and it depends on several factors. The equation is given below:

$$v_D = \frac{I}{nAq}$$

where,

- I is the current flowing through the conductor, measured in amperes
- n is the electron density in m^{-3}
- A is the area of the cross-section of the conductor, measured in m^2
- v_D is the drift velocity of the electrons, measured in m s^{-1}
- q is the charge of an electron, measured in coulombs.



(a) Calculate the drift velocity of electrons if a current of 3.00 A is flowing in a copper wire with a cross-sectional area of 1.00 mm^2. (3 marks)

For copper, $n = 8.50 \times 10^{28}$ m^{-3}.

Answer ____________________ m s^{-1}

Another way of measuring drift velocity uses what is called the Hall Effect. This occurs when a current flows through a flat piece of metal placed in an external magnetic field. This is shown in the diagram below.

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The negatively charged particles experience a force due to the magnetic field and move to one side of the metal strip. This sets up a potential difference, and therefore an electric field, between the sides of the strip. This potential difference can be measured by a voltmeter (V_H). Dividing V_H by the width of the strip (w) will give us the strength of the electric field created:

$$E = \frac{V_H}{w}$$

If the strip is moved with the same velocity as the charge carriers but in the opposite direction, their relative velocity in the field is now zero; and therefore, there is no force placed upon them by the magnetic field. At this stage, the voltmeter would read 0 V. By measuring how fast the strip is moving, we can calculate drift velocity.

The magnetic force on the charged particles is:

$$F_M = qv_DB$$

where v_D is the drift velocity of the charge.

When the strip is not moving and the system reaches equilibrium, V_H remains constant and the force exerted on the charge carriers by the magnetic field (F_M) is equal to the force due to the electric field between the edges of the strip (F_E). By substitution, it can be shown that:

$$F_E = \frac{V_H q}{w}$$

(b) With reference to the text, explain why V_H reduces to zero when the strip is moved in the correct direction at the correct speed. (4 marks)

(c) Explain why increasing the magnitude of the magnetic field will increase V_H for a stationary strip when equilibrium is restored. (3 marks)

(d) The article says: '*By substitution, it can be shown that:* $F_E = \dfrac{V_H q}{w}$'. Derive this equation from information supplied in the article. (2 marks)

(e) Calculate V_H if the dimensions of the copper strip are w = 3.00 cm and d = 0.100 cm, B = 3.50 T and I = 26.0 A. Use electrons as the charge carriers in your calculation. (6 marks)

For copper, $n = 8.50 \times 10^{28}\ \text{m}^{-3}$.

Answer ______________ V