Exercise walk-through

Electric current ▪ 9.1

eXercise

You must be able to

- explain current as a flow of **charge carriers** and that charge is **quantised**
- use $Q = It$
- use $I = Anvq$ to find **drift velocity**

Method — Current and charge

A current is a **flow of charge carriers**. Charge is **quantised**: every free charge is a multiple of $e = 1.60 \times 10^{-19}$ C. **Conventional current** flows opposite to the electrons in a wire.

$$I = \frac{Q}{t}, \qquad Q = It \quad (\text{unit A} = \text{C s}^{-1}).$$

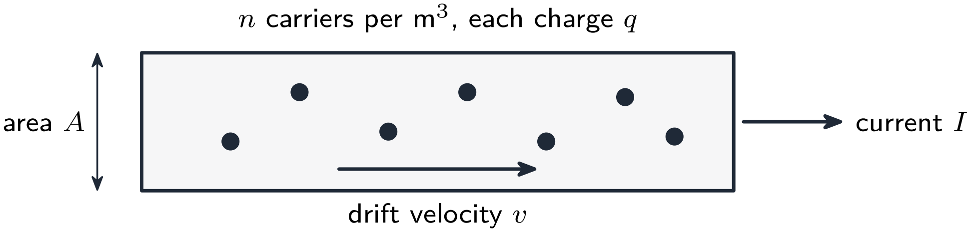
Worked example. 0.50 A for 2.0 min: $Q = It = 0.50 \times 120 = 60$ C; electrons $N = Q/e = 60/(1.6 \times 10^{-19}) \approx 3.8 \times 10^{20}$.

Method — The drift-velocity equation

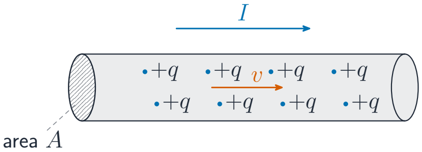
$$I = Anvq,$$

where A = area, n = number density of carriers, v = drift velocity, q = charge per carrier. Rearrange for the drift velocity: $v = \dfrac{I}{Anq}$.

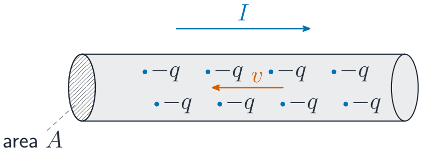
Method — The drift-velocity equation



Method — The drift-velocity equation



(a) positive carriers drift with I



(b) electrons drift against I

Charge carriers drift through a conductor

Practice 2.1 ▪ 1 mark

State what an **electric current** is.

Solution 2.1

Worked steps

A **flow of charge carriers** (the rate of flow of charge) **B1**.

Practice 2.2 ▪ 2 marks

A current of 0.50 A flows for 2.0 minutes. Find the **charge** that passes.

Solution 2.2

Method: Current and charge

Worked steps

$Q = It = 0.50 \times (2.0 \times 60) = 0.50 \times 120 = 60$ C **M1** **A1**.

Practice 2.3 ▪ 1 mark

State the value of the **elementary charge** e.

Solution 2.3

Worked steps

$e = 1.60 \times 10^{-19}$ C **B1**.

Practice 2.4 ▪ 1 mark

State the direction of **conventional current** relative to the flow of electrons in a wire.

Solution 2.4

Method: Current and charge

Worked steps

Opposite to the electron flow (conventional current is the direction positive charge would move) **B1**.

Exam-style 3.1 ▪ 1 mark

A current of 3.0 A flows for 10 s. The charge that passes is:

A 0.30 C

B 3.0 C

C 30 C

D 300 C

Solution 3.1

Method: Current and charge

A 0.30 C

B 3.0 C

C 30 C ✓

D 300 C

Worked steps

C — $Q = It = 3.0 \times 10 = 30$ C.

Exam-style 3.2 ▪ 2 marks

Calculate the number of electrons in a charge of 60 C. ($e = 1.60 \times 10^{-19}$ C.)

Solution 3.2

Method: Current and charge

Worked steps

$N = Q/e = 60/(1.60 \times 10^{-19})$ **M1** $= 3.75 \times 10^{20}$ **A1**.

Exam-style 3.3 ▪ 3 marks

A copper wire of cross-sectional area 1.0×10^{-6} m^2 carries a current of 5.0 A. Copper has $n = 8.5 \times 10^{28}$ free electrons per m^3. Calculate the **drift velocity**.
($e = 1.6 \times 10^{-19}$ C.)

Solution 3.3

Worked steps

$$v = \frac{I}{Anq} = \frac{5.0}{(1.0 \times 10^{-6})(8.5 \times 10^{28})(1.6 \times 10^{-19})}$$ **M1** **M1** $= 3.7 \times 10^{-4}$ m s^{-1} **A1**.

Exam-style 3.4 ▪ 1 mark

State what is meant by "charge is **quantised**".

Solution 3.4

Method: Current and charge

Worked steps

Charge comes only in **whole-number multiples** of the elementary charge e **B1**.

Exam-style 3.5 ▪ 2 marks

A cylindrical copper wire P has length 0.32 m and resistance 4.4 mΩ. The current in it is 0.75 A. The wire contains 3.1×10^{22} free electrons in total. The resistivity of copper is $1.8 \times 10^{-8}\ \Omega\,$m and the elementary charge is 1.6×10^{-19} C.

(a) **Calculate** the potential difference between the ends of the wire.

(b) **Show that** the cross-sectional area of the wire is about 1.3×10^{-6} m^2.

(c) **Show that** the number density of free electrons in the copper is about 7.4×10^{28} m^{-3}.

(d) **Determine** the average drift speed of the electrons, and comment on its size.

(e) A second wire Q is made from the **same volume** of copper, but drawn out so that it is longer and thinner than P. **State and explain** how the resistance of Q compares with that of P.

Solution 3.5

Method: The drift-velocity equation

Worked steps

(a) $V = IR = 0.75 \times 4.4 \times 10^{-3}$ **M1** $= 3.3 \times 10^{-3}$ V **A1**.

(b) $R = \dfrac{\rho L}{A}$, so $A = \dfrac{\rho L}{R} = \dfrac{1.8 \times 10^{-8} \times 0.32}{4.4 \times 10^{-3}}$ **M1** $= 1.3 \times 10^{-6}$ m^2 **A1**.

(c) Number density is the total number divided by the **volume**, and the volume is AL

M1: $n = \dfrac{3.1 \times 10^{22}}{1.31 \times 10^{-6} \times 0.32} = 7.4 \times 10^{28}$ m^{-3} **A1**.

(d) $I = nAvq$, so $v = \dfrac{I}{nAq} = \dfrac{0.75}{7.4 \times 10^{28} \times 1.31 \times 10^{-6} \times 1.6 \times 10^{-19}}$ **M1**

$= 4.8 \times 10^{-5}$ m s^{-1} **A1**. (About 0.2 mm every four seconds: the electrons crawl,

Solution 3.5

while the *signal* travels near the speed of light.)
(e) Q has the **same volume**, so making it longer forces it to be thinner: L increases and A decreases B1 B1. Since $R = \dfrac{\rho L}{A}$, both changes push the resistance the **same way** B1, so Q has a **greater** resistance than P B1.