A-LEVEL PHYSICS • EXERCISE SHEET

9.1 Electric current

Name: ____________ Class: _________ Date: ___________ **Total: 25 marks**

KEY WORDS charge carrier 载流子 • number density 数密度 • electric current 电流 • elementary charge 基本电荷 • conventional current 常规电流

Objective

Build the skills to answer exam questions on **electric current** — charge carriers, $Q = It$, and the $I = Anvq$ equation.

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**

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

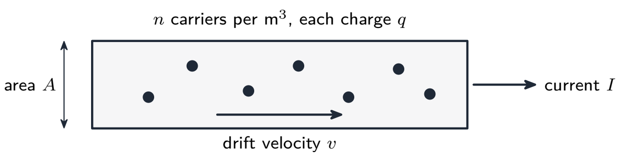
■ Current and charge

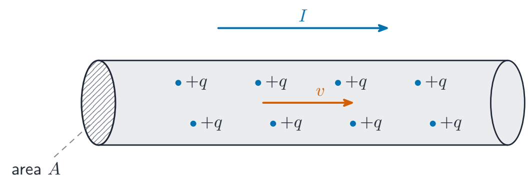
A current is a **flow of charge carriers**. Charge is **quantised**: every free charge is a multiple of $e = 1.60 \times 10^{-19}$ C. **Conventional current** flows opposite to the electrons in a wire.

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

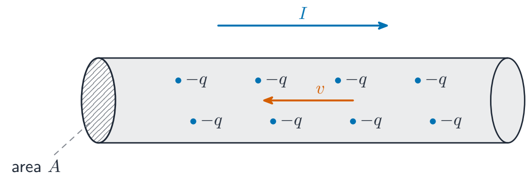
Worked example. 0.50 A for 2.0 min: $Q = It = 0.50 \times 120 = 60$ C; electrons $N = Q/e = 60/(1.6 \times 10^{-19}) \approx 3.8 \times 10^{20}$.

■ The drift-velocity equation





(a) positive carriers drift with I



(b) electrons drift against I

Charge carriers drift through a conductor

$$I = Anvq,$$

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

2 Practice

Now apply the methods above.

2.1 State what an **electric current** is. [1]

2.2 A current of 0.50 A flows for 2.0 minutes. Find the **charge** that passes. [2]

2.3 State the value of the **elementary charge** e. [1]

2.4 State the direction of **conventional current** relative to the flow of electrons in a wire. [1]

3 Exam-style questions

3.1 A current of 3.0 A flows for 10 s. The charge that passes is: [1]

- **A** 0.30 C
- **B** 3.0 C
- **C** 30 C
- **D** 300 C

3.2 Calculate the number of electrons in a charge of 60 C. ($e = 1.60 \times 10^{-19}$ C.) [2]

3.3 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.) [3]

3.4 State what is meant by “charge is **quantised**”. [1]

3.5 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 1.8×10^{-8} Ω m and the elementary charge is 1.6×10^{-19} C.

(a) **Calculate** the potential difference between the ends of the wire. [2]

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

(c) **Show that** the number density of free electrons in the copper is about 7.4×10^{28} m^{-3}. [2]

(d) **Determine** the average drift speed of the electrons, and comment on its size. [3]

(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. [4]

Solutions

Each answer shows the steps, then the **result**.

2.1

- a current is a **flow of charge carriers** (the rate of flow of charge)

2.2

- $I = 0.50$ A, $t = 2.0$ min $= 120$ s
- $Q = It$

$$Q = (0.50\text{ A})(120\text{ s}) = \mathbf{60}\text{ C}$$

2.3

- $e = \mathbf{1.60 \times 10^{-19}}$ C

2.4

- **opposite** to the electron flow (the direction positive charge would move)

3.1 C

- $Q = It$

$$Q = (3.0\text{ A})(10\text{ s}) = \mathbf{30}\text{ C}$$

- **A** divides instead of multiplying; **B** drops a factor of 10; **D** uses $t = 100$ s

3.2

- $Q = 60$ C, $e = 1.60 \times 10^{-19}$ C
- $N = Q/e$

$$N = \frac{60\text{ C}}{1.60 \times 10^{-19}\text{ C}} = \mathbf{3.75 \times 10^{20}}$$

3.3

- $I = 5.0$ A, $A = 1.0 \times 10^{-6}$ m^2, $n = 8.5 \times 10^{28}$ m^{-3}, $q = e = 1.6 \times 10^{-19}$ C
- $I = Anvq$, so $v = I/(Anq)$

$$v = \frac{5.0\text{ A}}{(1.0 \times 10^{-6}\text{ m}^2)(8.5 \times 10^{28}\text{ m}^{-3})(1.6 \times 10^{-19}\text{ C})} = \mathbf{3.7 \times 10^{-4}}\text{ m s}^{-1}$$

3.4

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

3.5

(a) $I = 0.75$ A, $R = 4.4$ m$\Omega = 4.4 \times 10^{-3}\ \Omega$

- $V = IR$

$$V = (0.75\text{ A})(4.4 \times 10^{-3}\ \Omega) = \mathbf{3.3 \times 10^{-3}}\text{ V}$$

(b) $R = \rho L/A$, so $A = \rho L/R$

$$A = \frac{(1.8 \times 10^{-8}\ \Omega\,\text{m})(0.32\ \text{m})}{4.4 \times 10^{-3}\ \Omega} = 1.31 \times 10^{-6}\ \text{m}^2 \approx \mathbf{1.3 \times 10^{-6}\ m^2}$$

(c) number density = total number / volume, and $V = AL$

$$n = \frac{3.1 \times 10^{22}}{(1.31 \times 10^{-6}\ \text{m}^2)(0.32\ \text{m})} = \mathbf{7.4 \times 10^{28}\ m^{-3}}$$

(d) $I = nAvq$, so $v = I/(nAq)$

$$v = \frac{0.75\ \text{A}}{(7.4 \times 10^{28}\ \text{m}^{-3})(1.31 \times 10^{-6}\ \text{m}^2)(1.6 \times 10^{-19}\ \text{C})} = \mathbf{4.8 \times 10^{-5}\ m\ s^{-1}}$$

- about 0.2 mm every four seconds: the electrons crawl, while the *signal* travels near c

(e) Q has the **same volume**, so making it longer forces it to be thinner: L **increases** and A **decreases**

- $R = \rho L/A$, so both changes raise R
- **Q has a greater resistance than P**