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.

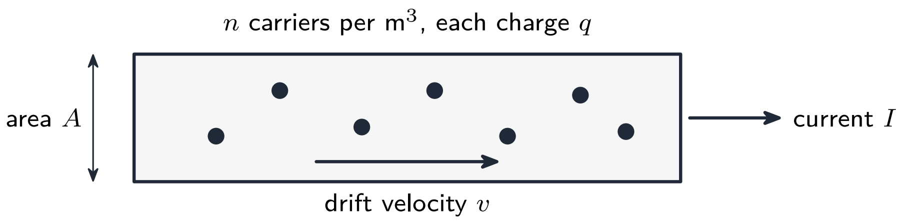
Current and charge

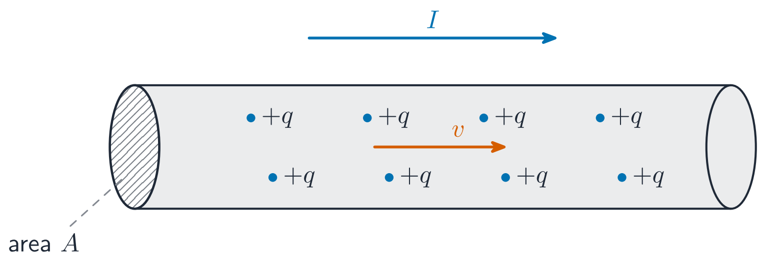
A current is a **flow of charge carriers**. Charge is **quantised**: every free charge is a multiple of $e = 1.60 \times 10^{-19}$ C. **Conventional current** flows opposite to the electrons in a wire.

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

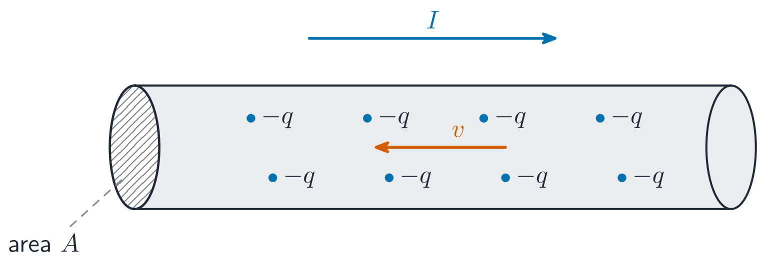
Worked example. 0.50 A for 2.0 min: $Q = It = 0.50 \times 120 = 60$ C; electrons $N = Q/e = 60/(1.6 \times 10^{-19}) \approx 3.8 \times 10^{20}$.

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 $1.8 \times 10^{-8}\ \Omega\,\mathrm{m}$ 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 $1.3 \times 10^{-6}\ \mathrm{m}^2$. [2]

(c) **Show that** the number density of free electrons in the copper is about $7.4\times10^{28}\ \mathrm{m}^{-3}$. [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

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

2.2 $Q = It = 0.50 \times (2.0 \times 60) = 0.50 \times 120 = 60$ C.

2.3 $e = 1.60 \times 10^{-19}$ C.

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

3.1 **C** — $Q = It = 3.0 \times 10 = 30$ C.

3.2 $N = Q/e = 60/(1.60 \times 10^{-19}) = 3.75 \times 10^{20}$.

3.3 $v = \dfrac{I}{Anq} = \dfrac{5.0}{(1.0 \times 10^{-6})(8.5 \times 10^{28})(1.6 \times 10^{-19})} = 3.7 \times 10^{-4}\ \mathrm{m\ s^{-1}}$.

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

3.5 (a) $V = IR = 0.75 \times 4.4 \times 10^{-3} = 3.3 \times 10^{-3}$ V.
(b) $R = \dfrac{\rho L}{A}$, so $A = \dfrac{\rho L}{R} = \dfrac{1.8 \times 10^{-8} \times 0.32}{4.4 \times 10^{-3}} = 1.3 \times 10^{-6}\ \mathrm{m^2}$.
(c) Number density is the total number divided by the **volume**, and the volume is AL:
$n = \dfrac{3.1 \times 10^{22}}{1.31 \times 10^{-6} \times 0.32} = 7.4 \times 10^{28}\ \mathrm{m^{-3}}$.
(d) $I = nAvq$, so $v = \dfrac{I}{nAq} = \dfrac{0.75}{7.4 \times 10^{28} \times 1.31 \times 10^{-6} \times 1.6 \times 10^{-19}} = 4.8 \times 10^{-5}\ \mathrm{m\ s^{-1}}$.
(About 0.2 mm every four seconds: the electrons crawl, 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. Since $R = \dfrac{\rho L}{A}$, both changes push the resistance the **same way**, so Q has a **greater** resistance than P.