9.1 Electric current, charge and drift speed

Name: _____ Class: _____ Date: _____ **Total: 24 marks**

KEY WORDS electric current • charge carrier • quantised • drift speed • number density

Objective

Answer exam questions on **electric current** : current as a flow of **charge carriers** , charge that comes in whole numbers of e, $Q = It$, and the drift-speed equation $I = Anvq$. Syllabus 9.1, learning outcomes 1 to 4.

You must be able to:

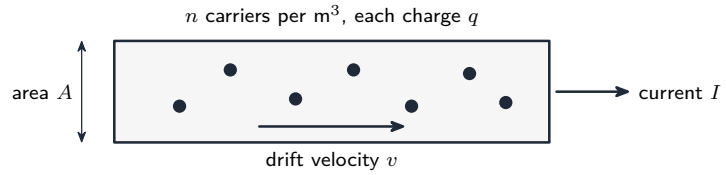
- describe a current as a flow of charge carriers, and state the direction of conventional current
- explain what "charge is quantised" means, and decide whether a charge is possible
- use $Q = It$, and find how many electrons carry a charge
- use $I = Anvq$ to find a drift speed, and compare drift speeds in thick and thin parts of a wire

1 Key knowledge and worked examples

■ Key knowledge: current and charge

Idea	Rule
electric current	a flow of charge carriers: electrons in a metal, ions in a solution or a gas
current and charge	$I = \frac{Q}{t}$, so $Q = It$; 1 A = 1 C s^{-1} and 1 C = 1 A s
quantised	every charge is a whole-number multiple of the elementary charge $e = 1.60 \times 10^{-19}$ C
number of carriers	$N = \frac{Q}{e}$ for electrons; $N = \frac{Q}{2e}$ for ions of charge $2e$
conventional current	the direction positive charge would flow: opposite to the electrons in a wire

■ Key knowledge: the drift-speed equation



$$I = Anvq$$

with A the cross-sectional area, n the number density of carriers, v the drift speed and q the charge of one carrier.

- **number density**: the number of free charge carriers per unit volume, in m^{-3} (copper about 8.5×10^{28} m^{-3})
- drift speeds in metals are tiny, about 10^{-4} m s^{-1}; a lamp still lights at once, because the electrons throughout the circuit start moving together
- the same current through a thinner section: $v = \frac{I}{Anq}$, so a smaller A gives a larger drift speed

■ Worked example: charge and electrons

A current of 0.50 A flows for 2.0 minutes.

1. **Charge** – from $Q = It$, with $t = 120$ s: $Q = It = 0.50 \times 120 = 60$ C.
2. **Electrons** – each carries e: $N = \frac{Q}{e} = \frac{60}{1.60 \times 10^{-19}} = 3.8 \times 10^{20}$.

■ Worked example: a drift speed

A copper wire of cross-sectional area 1.0×10^{-6} m^2 carries 5.0 A; $n = 8.5 \times 10^{28}$ m^{-3}.

1. **Rearrange** – from $I = Anvq$: $v = \frac{I}{Anq}$.
2. **Substitute** – $v = \frac{I}{Anq} = \frac{5.0}{1.0 \times 10^{-6} \times 8.5 \times 10^{28} \times 1.60 \times 10^{-19}} = 3.7 \times 10^{-4}$ m s^{-1}.

■ Worked example: a thin section of wire

A wire narrows from a diameter of 2.0 mm to 1.0 mm. The same current flows through both parts.

1. **Area** – half the diameter gives a quarter of the area, $A \propto d^2$.
2. **Drift speed** – from $v = \frac{I}{Anq}$ with I, n and q unchanged, $v \propto \frac{1}{A}$: the drift speed

in the thin part is **4 times** larger.

- **Worked example: is this charge possible?**

1. 4.8×10^{-19} **C** – $\dfrac{Q}{e} = \dfrac{4.8 \times 10^{-19}}{1.60 \times 10^{-19}} = 3$, a whole number: possible.
2. 4.0×10^{-19} **C** – $\dfrac{Q}{e} = \dfrac{4.0 \times 10^{-19}}{1.60 \times 10^{-19}} = 2.5$: not a whole number of e, so impossible for a free charge.

2 Practice

Now apply the methods above.

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

electric current

2.2 A current of 0.25 A flows for 4.0 minutes. Calculate the charge that passes. [2]

0.25 A

4.0 min

2.3 Calculate the number of electrons in a charge of 12 C. [2]

12 C

2.4 Explain what is meant by the statement "charge is **quantised**". [1]

quantised

2.5 An aluminium wire of cross-sectional area 2.5×10^{-6} m^2 carries a current of 3.0 A. The number density of free electrons in aluminium is 1.8×10^{29} m^{-3}. Calculate the drift speed. [2]

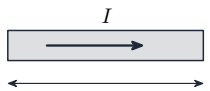
2.5×10^{-6} m^2

3.0 A

3 Exam-style questions

3.1 A current of 3.0 A flows for 10 s. What charge passes? [1]

☐ **A** 0.30 C
B 3.0 C
C 30 C
D 300 C



3.0 A

10 s

3.2 Wires X and Y are made of the same metal and joined end to end in a circuit. The diameter of X is twice the diameter of Y. What is $\dfrac{\text{drift speed in Y}}{\text{drift speed in X}}$? [1]

☐ **A** $\frac{1}{4}$
B $\frac{1}{2}$
C 2
D 4

3.3 A metal wire of cross-sectional area 0.80 mm^2 carries a steady current of 2.4 A. The metal has 8.0×10^{28} free electrons per m^3.

(a) State what is meant by the **number density** of the free electrons. [1]

(b) Calculate the drift speed of the electrons. [3]

0.80 mm^2

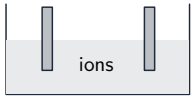
2.4 A

(c) Calculate the charge that passes a point in the wire in 5.0 minutes, and the number of electrons that carry it. [3]

(d) **Explain** why a lamp in the circuit lights as soon as the switch is closed, although the electrons drift very slowly. [1]

3.4 In an electrolysis experiment the current is carried through a solution by ions, each with a charge of $+2e$. A steady current of 0.30 A flows for 20 minutes.

(a) Calculate the total charge that passes through the solution. [2]



$+2e$

0.30 A

(b) Calculate the number of ions that carry this charge, assuming the positive ions carry all of it. [2]

(c) State whether a charge of 2.4×10^{-19} C could be carried by one ion. Explain your answer. [2]