

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:

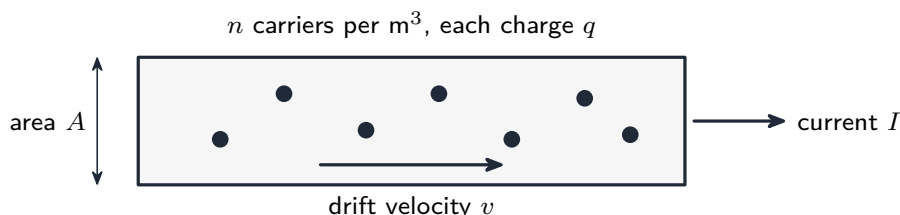
- describe a current as a flow of charge carriers, and state the direction of conventional current
- explain what “charge is quantised” means, and decide whether a charge is possible
- use $Q = It$, and find how many electrons carry a charge
- use $I = Anvq$ to find a drift speed, and compare drift speeds 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 $Q = It$; $1 \text{ A} = 1 \text{ C s}^{-1}$ and $1 \text{ C} = 1 \text{ A s}$
quantised	every charge is a whole-number multiple of the elementary charge $e = 1.60 \times 10^{-19} \text{ C}$
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 $8.5 \times 10^{28} \text{ m}^{-3}$)
- 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 $t = 120 \text{ s}$: $Q = It = 0.50 \times 120 = 60 \text{ C}$.
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 $1.0 \times 10^{-6} \text{ m}^2$ carries 5.0 A; $n = 8.5 \times 10^{28} \text{ m}^{-3}$.

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

■ **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. $4.8 \times 10^{-19} \text{ C} - \frac{Q}{e} = \frac{4.8 \times 10^{-19}}{1.60 \times 10^{-19}} = 3$, a whole number: possible.
2. $4.0 \times 10^{-19} \text{ C} - \frac{Q}{e} = \frac{4.0 \times 10^{-19}}{1.60 \times 10^{-19}} = 2.5$: 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]



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

[2]



2.4 Explain what is meant by the statement “charge is **quantised**”.

[1]

quantised

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

[2]



3 Exam-style questions

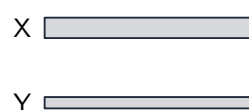
3.1 A current of 3.0 A flows for 10 s. What charge passes? [1]

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



3.2 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 $\frac{\text{drift speed in Y}}{\text{drift speed in X}}$? [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]



(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]