

Exercise walk-through

9.1

Electric current

A-Level Physics

Sheet 9.1 – what you need to know

You must be able to:

- describe a current as a flow of **charge carriers**
- say whether a charge is possible: charge is **quantised**
- use $Q = It$, and count the electrons that carry a charge
- use $I = Anvq$ to find a drift speed, in thick and thin wires

What the exam asks

“Determine an expression, in terms of some or all of the symbols e , L , N , R and V , for the current in the wire.” **[1]**

“State and explain whether the average drift speed of the free electrons in wire Y is greater than, the same as, or less than that in wire X.” **[3]**

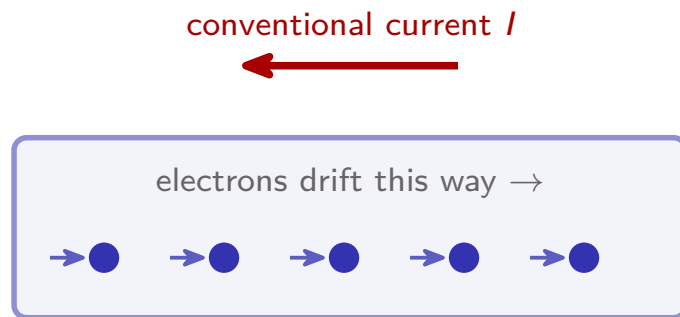
Practise on exercise sheet 9.1, then try the real exam questions on past-paper sheet 9.1.

Electric current

Current is a flow of **charge carriers**.

- metal: conduction **electrons**
- electrolyte: positive & negative **ions**

Conventional current flows the way **positive** charge would – opposite to the electrons in a wire.



Charge and current

Charge is **quantised** : every free charge is a whole-number multiple of the **elementary charge** $e = 1.60 \times 10^{-19} \text{ C}$, measured in **coulombs** . **Current** is the **rate of flow of charge** past a point:

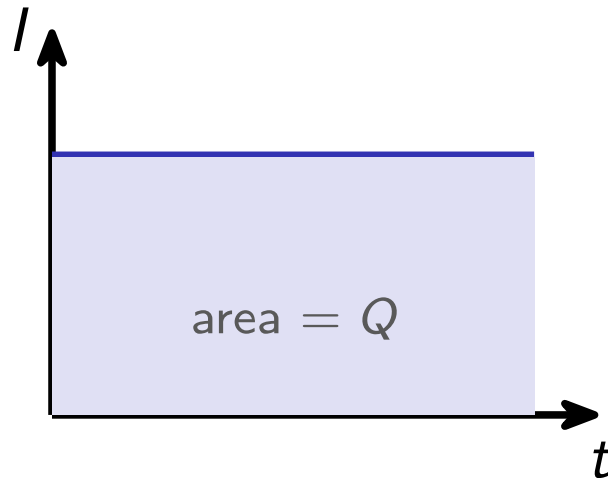
$$I = \frac{Q}{t}, \quad Q = It.$$

0.50 A for 2.0 min

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

$$N = \frac{Q}{e} = \frac{60 \text{ C}}{1.60 \times 10^{-19} \text{ C}} \approx 3.8 \times 10^{20}$$

electrons



Is this charge possible?

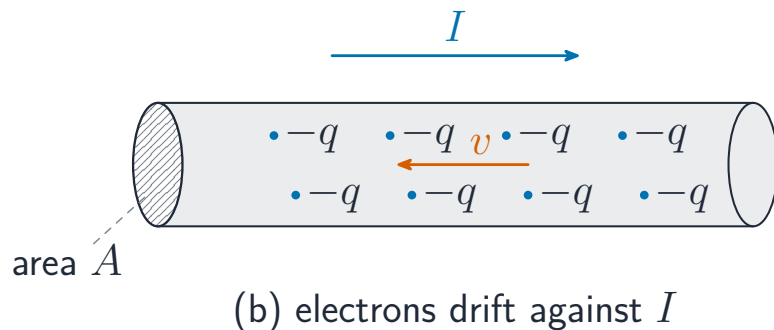
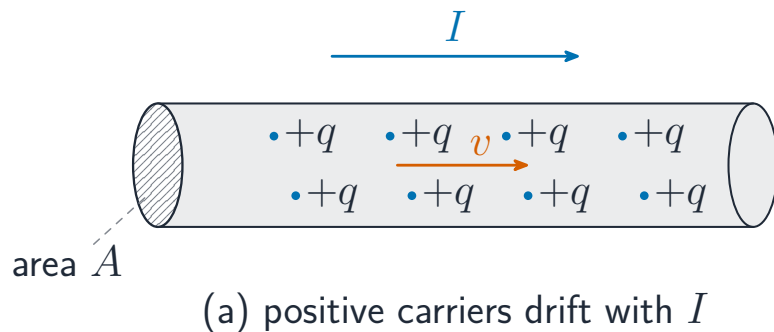
Charge is **quantised**: any free charge is a whole number of elementary charges, $Q = Ne$ with $e = 1.60 \times 10^{-19} \text{ C}$.

Divide by e and look for a whole number

$$N = \frac{Q}{e} = \frac{4.8 \times 10^{-19} \text{ C}}{1.60 \times 10^{-19} \text{ C}} = 3: \text{ possible}$$

$$N = \frac{Q}{e} = \frac{4.0 \times 10^{-19} \text{ C}}{1.60 \times 10^{-19} \text{ C}} = 2.5: \text{ impossible}$$

Drift velocity



$$I = A n v q$$

A is the **cross-sectional area**, n the **number density** of carriers, q their charge and v the **drift velocity**.

A thinner wire at the same I needs a **faster** drift. In **series**, I is the same everywhere, so nv must change to compensate.

Copper, $A = 10^{-6} \text{ m}^2$, $I = 5.0 \text{ A}$

$v \approx 3.7 \times 10^{-4} \text{ m s}^{-1}$ – under 1 mm per second

Exercises 2.1·2.2

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

Exercises 2.1·2.2

2.1 State what is meant by an **electric current**.

[1]

electric current

2.1

- a flow of charge carriers (the rate of flow of charge)
-

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

2.2

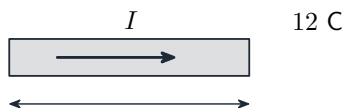
- $Q = It$, with $t = 240$ s

$$Q = It = 0.25 \text{ A} \times 240 \text{ s} = \mathbf{60 \text{ C}}$$

Exercises 2.3·2.4

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**”.

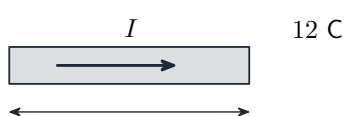
[1]

quantised

Exercises 2.3·2.4

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

[2]



2.3

- each electron carries e : $N = \frac{Q}{e}$

$$N = \frac{Q}{e} = \frac{12}{1.60 \times 10^{-19}} = 7.5 \times 10^{19}$$

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

[1]

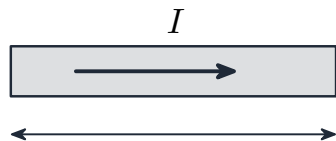
quantised

2.4

- charge exists only in whole-number multiples of the elementary charge e

Exercise 2.5

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]

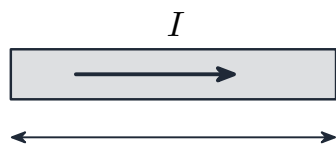


$$2.5 \times 10^{-6} \text{ m}^2$$

$$3.0 \text{ A}$$

Exercise 2.5

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]



$$2.5 \times 10^{-6} \text{ m}^2$$

$$3.0 \text{ A}$$

2.5

- from $I = Anvq$: $v = \frac{I}{Anq}$

$$v = \frac{I}{Anq} = \frac{3.0}{2.5 \times 10^{-6} \times 1.8 \times 10^{29} \times 1.60 \times 10^{-19}} = \mathbf{4.2 \times 10^{-5} \text{ m s}^{-1}}$$

Exercise 3.1

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

[1]

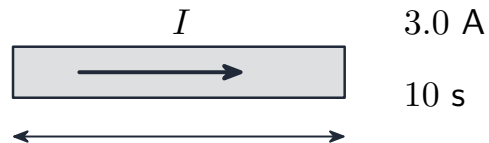
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A 0.30 C

B 3.0 C

C 30 C

D 300 C



Exercise 3.1

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

[1]

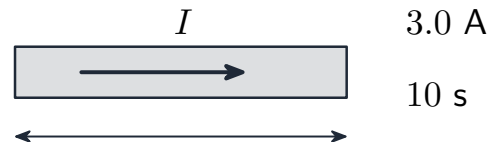
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A 0.30 C

B 3.0 C

C 30 C

D 300 C



3.1 C

- $Q = It = 3.0 \times 10 = 30\text{ C}$
- **A** divides instead of multiplying

Exercise 3.2

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

X

Y

Exercise 3.2

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

X Y 

3.2 D

- the same current in both; $v = \frac{I}{Anq}$, so $v \propto \frac{1}{A} \propto \frac{1}{d^2}$
- Y has half the diameter, a quarter of the area, and four times the drift speed; **C** forgets to square

Exercise 3.3 (a)

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]

Exercise 3.3 (a)

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

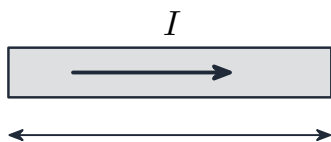
(a) the number of free electrons (charge carriers) per unit volume

Exercise 3.3 (b)

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 .

(b) Calculate the drift speed of the electrons.

[3]



0.80 mm^2

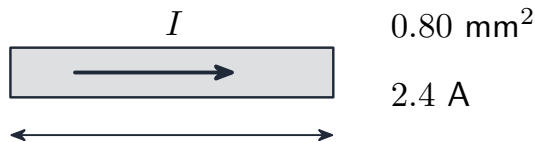
2.4 A

Exercise 3.3 (b)

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 .

(b) Calculate the drift speed of the electrons.

[3]



(b) $A = 0.80 \times 10^{-6} \text{ m}^2$; from $I = Anvq$, $v = \frac{I}{Anq}$

$$v = \frac{I}{Anq} = \frac{2.4}{0.80 \times 10^{-6} \times 8.0 \times 10^{28} \times 1.60 \times 10^{-19}} = \mathbf{2.3 \times 10^{-4} \text{ m s}^{-1}}$$

Exercise 3.3 (c)

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 .

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

Exercise 3.3 (c)

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 .

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

(c) $Q = It = 2.4 \times 300 = \mathbf{720 \text{ C}}$

- $$N = \frac{Q}{e} = \frac{720}{1.60 \times 10^{-19}} = \mathbf{4.5 \times 10^{21}}$$

Exercise 3.3 (d)

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 .

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

Exercise 3.3 (d)

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 .

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

(d) the free electrons all around the circuit start to drift at the same moment, so charge flows through the lamp at once

Exercise 3.4 (a)

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

Exercise 3.4 (a)

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

(a) $Q = It$, with $t = 1200\text{ s}$

$$Q = It = 0.30 \times 1200 = \mathbf{360\text{ C}}$$

Exercise 3.4 (b)

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.

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

Exercise 3.4 (b)

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.

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

(b) each ion carries $2e = 3.2 \times 10^{-19}$ C: $N = \frac{Q}{2e}$

$$N = \frac{Q}{2e} = \frac{360}{3.2 \times 10^{-19}} = 1.1 \times 10^{21}$$

Exercise 3.4 (c)

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.

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

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

(c) **no**

- $\frac{Q}{e} = \frac{2.4 \times 10^{-19}}{1.60 \times 10^{-19}} = 1.5$: not a whole-number multiple of e , and charge is quantised