AS Level Physics

Chapter 7 – Electrons, Waves and Photons

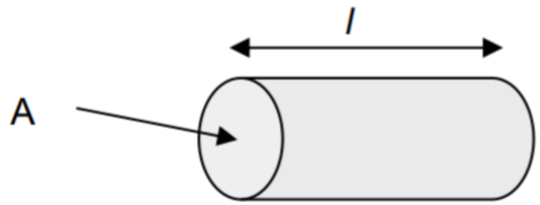
7.1.2 Charge and Current

Worked Examples

Charge and Current

Exam Style Question 1

a) Name the charge carries responsible for electric current in a metal and in an electrolyte.



b) The diagram above shows a copper rod of length $l = 0.080\ m$, having a cross-sectional area $A = 3.0 \times 10^{-4}\ m^2$.

The resistivity of copper is $1.7 \times 10^{-8}\ \Omega\ m$.

The copper rod is used to transmit large currents. A charge of $650\ C$ passes along the rod every $5.0\ s$. Calculate:

1) The current in the rod.

2) The total number of electrons passing any point in the rod per second.

CHARGE AND CURRENT

Exam Style Question 1

a) Name the charge carries responsible for electric current in a metal and in an electrolyte.

- Electric current in a metal is electrons.
- Electric current in an electrolyte is ions.

b1) The current in the rod.

Use: $I = \frac{Q}{t}$

$$I = \frac{650\ C}{5\ s}$$
$$I = 130\ A$$

b2) The total number of electrons passing any point in the rod per second.

Remember that current is just the rate of flow of charge. In other words how many electrons are flowing past a point per second. Therefore:

$$no.electrons\ per\ second = \frac{current}{charge\ of\ an\ electron}$$
$$no.electrons\ per\ second = \frac{130\ A}{1.6 \times 10^{-19}\ C}$$
$$no.electronsper\ second = 8.125 \times 10^{20}$$

So the total number of electrons passing any point in the rod per second is 8.1×10^{20}.

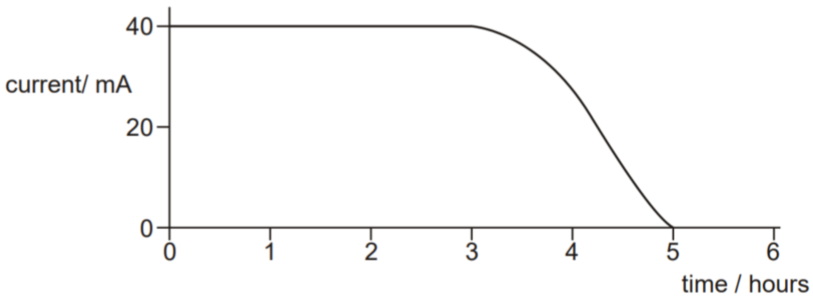
Charge and Current

Exam Style Question 2

A small radio receiver uses a battery that is capable of delivering a constant current of $40\ mA$ for a period of $5.0\ hours$.

a) Calculate the total charge delivered by the battery.

b) Below is the graph of current against time for a different battery.



Explain whether the charge delivered by this battery is the same as, greater than or less than your answer to (a).

CHARGE AND CURRENT

Exam Style Question 2

a) Calculate the total charge delivered by the battery.

Use: $Q = It$

$$Q = (40 \times 10^{-3}\ A)(5hours \times 60mins \times 60secs)$$
$$Q = 0.040\ A \times 1.8 \times 10^{4}\ s$$
$$Q = 720\ C$$

b) Explain whether the charge delivered by this battery is the same as, greater than or less than your answer to (a).

The charge delivered by the new battery is less than the battery in the radio receiver. This is because the battery in the radio receiver delivers $40\ mA$ for $5.0\ hours$. However, the new battery delivers $40\ mA$ for 3 hours and then the current drops.

Charge and Current

Exam Style Question 3

A battery charger contains a microprocessor circuit so that it can charge an AA rechargeable cell at a constant current of $450\ mA$. It takes $4\ hours\ 40\ minutes$ to charge a $1.5\ V$ cell from a fully discharged state.

a) Calculate the charge Q passing through the cell during the charging process.

Fig. 3.1 shows the cell of internal resistance $0.90\ \Omega$ connected to the battery charger. Assume that the e.m.f. of the cell is $1.5\ V$.

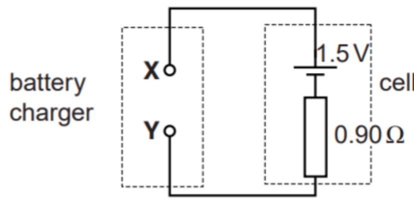


Fig. 3.1

b) State whether the terminal X of the battery charger is positive or negative.

c) Mark the direction of the current in the circuit on Fig. 3.1. Label your arrow I. Give a reason for your choice.

CHARGE AND CURRENT

Exam Style Question 3

a) Calculate the charge Q passing through the cell during the charging process.

Use: $Q = It$

Step 1: Convert 4 hours and 40 minutes into seconds

$$4\ hours \times 60\ minutes \times 60\ sec = 14400\ seconds$$

$$40\ minutes \times 60\ seconds = 2400\ seconds$$

Therefore: $4\ hours\ 40\ minutes = 16800\ sec$

Step 2: Sub $16800\ sec$ into $Q = It$

$$Q = (450 \times 10^{-3}\ A)(16800\ s)$$

$$Q = 7560\ C$$

b) State whether the terminal X of the battery charger is positive or negative.

Terminal X is connected to the positive terminal of the $1.5\ V$ cell therefore terminal X is positive.

c) Mark the direction of the current in the circuit on Fig. 3.1. Label your arrow I. Give a reason for your choice.

Clockwise:

Because energy is transferred from the battery charger to the cell and conventional current is from positive to negative this means the direction of the current is clockwise.

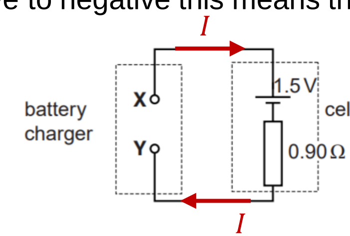


Fig. 3.1

Exam Style Question 4

a) State Kirchhoff's first law.

b) Fig. 3.1 shows part of an electrical circuit.

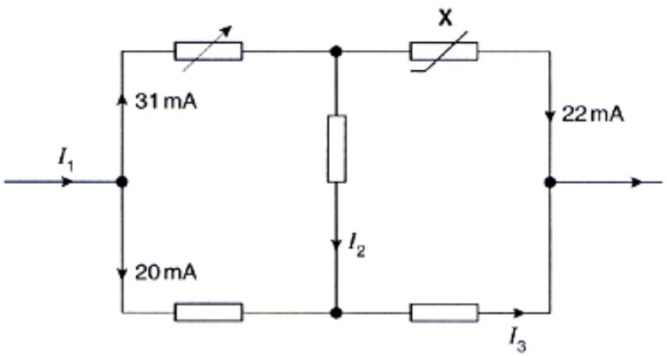


Fig. 3.1

i) Name the component marked X.

ii) Determine the magnitude if the currents I_1, I_2 and I_3.

CONSERVATION OF CURRENT

Exam Style Question 4

a) State Kirchhoff's first law.
Sum of the current into a junction is equal to the sum of the current out.

bi) Name the component marked X.
Thermistor.

bii) Determine the magnitude if the currents I_1, I_2 and I_3.
Step 1: Label all the junctions:

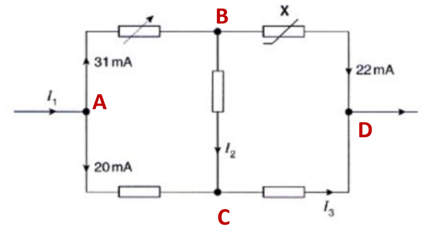


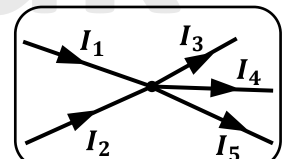
Fig. 3.1

Step 2: Remember Kirchhoff's first law.

$$Sum\ of\ current\ in = Sum\ of\ current\ out$$

$$\sum I_{in} = \sum I_{out}$$

$$I_1 + I_2 = I_3 + I_4 + I_5$$



Step 3: Calculate I_1.
I_1 enters junction A and splits into $31\ mA$ and $20\ mA$. Therefore, the total current in must be:

$$I_1 = 31\ mA + 20\ mA = 51\ mA$$

Step 4: Calculate I_2
$31\ mA$ goes into junction B where I_2 and $22\ mA$ come out. As we know total current in equals total current out, so:

$$31\ mA = I_2 + 22\ mA$$

$$\therefore I_2 = 31\ mA - 22\ mA = 9\ mA$$

Step 5: Calculate I_3.
In junction C $20\ mA$ and I_2 enter it and I_3 comes out. Therefore:

$$20\ mA + I_2 = I_3$$

$$20\ mA + 9\ mA = I_3$$

$$I_3 = 29\ mA$$

Drift Velocity

Exam Style Question 5

a) A $12\ V$ $36\ W$ lamp is lit to normal brightness using a $12\ V$ car battery of negligible internal resistance. The lamp is switched on for one hour $(3600\ s)$. For the time of $1\ hour$, calculate:

i) The charge passing through the lamp.

ii) The total number of electrons passing through the lamp.

b) The wire connecting the $36\ W$ lamp to the $12\ V$ battery are made of copper. They have a cross-sectional area of $1.1 \times 10^{-7}\ m^2$. The current in the wire is $3.0\ A$. The number n of free electrons per m^3 for copper is $8.0 \times 10^{28}\ m^{-3}$.

i) Describe what is meant by the term mean drift velocity of the electrons in the wire.

ii) Calculate the mean drift velocity v of the electrons in this wire.

Drift Velocity

Exam Style Question 5

ai) Calculate the charge passing through the lamp.
Find the current of the lamp using: $P = IV$

$$36\ W = I \times 12\ V$$
$$I = \frac{36\ W}{12\ V} = 3\ A$$

Use: $Q = It$

$$Q = 3\ A \times 3600\ s$$
$$Q = 10800\ C$$
$$Q = 1.1 \times 10^4\ C$$

aii) Calculate the total number of electrons passing through the lamp.
To calculate the total number of electrons use the formula below:

$$no.electrons = \frac{charge}{charge\ of\ an\ electron}$$
$$no.electrons = \frac{1.1 \times 10^4\ C}{1.6 \times 10^{-19}\ C}$$
$$no.electrons = 6.9 \times 10^{22}$$

Therefore the total number of electrons passing through the lamp is 6.9×10^{20}.

bi) Describe what is meant by the term mean drift velocity of the electrons in the wire.
The average distance travelled by the electrons along the wire per second (in other words average velocity). Over time the electrons move slowly in one direction through the metal because they collide with the metallic ions. The electrons move in one direction when there is a potential difference (or voltage) across the wire

bii) Calculate the mean drift velocity v of the electrons in this wire.
Use: $I = nAev$ and rearrange for v

$$v = \frac{I}{nAe} = \frac{3.0\ A}{(8.0 \times 10^{28}\ m^{-3})(1.1 \times 10^{-7}\ m^2)(1.6 \times 10^{-19} C)}$$
$$v = 2.13068 \ldots \times 10^{-3}$$
$$\therefore v = 2.1 \times 10^{-3}\ m\ s^{-1}$$

Drift Velocity

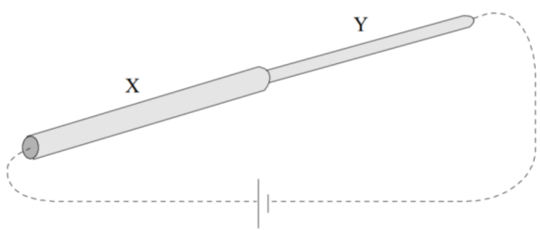
Exam Style Question 6

a) The current I through a metal wire of cross-sectional area A is given by the formula

$$I = nAve$$

Where e is the electronic charge on the electron. Define the symbols n and v.

Two pieces of copper wire, X and Y, are joined end-to-end and connected to a battery by wires which are shown as dotted lines in the diagram. The cross-sectional area of X is double that of Y.



b) In the table below, n_x and n_y denote the values of n in X and Y, and similarly for the other quantities. Write in the table the value of each ratio, and alongside it explain your answer.

Ratio	Value	Explanation
$\frac{n_y}{n_x}$		
$\frac{I_y}{I_x}$		
$\frac{v_y}{v_x}$		

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Drift Velocity

Exam Style Question 6

a) Define the symbols n and v.

n = number of electrons per unit volume (in m^{-3})
v = drift velocity (in $m\ s^{-1}$)

b) Write in the table the value of each ratio, and alongside it explain your answer.

Ratio	Value	Explanation
$\frac{n_y}{n_x}$	1	Same material.
$\frac{I_y}{I_x}$	1	As the wires are connected in series and because of Kirchhoff's first law and the conservation of charge the current is the same.
$\frac{v_y}{v_x}$	2	Because the area A of Y is halved the drift velocity v is doubled.

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Drift Velocity

Exam Style Question 7

The current I through a conductor of cross-sectional area A is given by the formula

$$I = nAve$$

Where Q is the charge on a charge carrier, n is the number of electrons per unit volume and v is the drift velocity.

a) Show that the equation is homogeneous with respect to units.

b) With reference to the equation, explain the difference between a metal conductor and a plastic insulator.

Drift Velocity

Exam Style Question 7

a) Show that the equation is homogeneous with respect to units.

I = Current measured in Amps, A.
n = number density measured in m^{-3}.
A = cross-sectional area measured in m^2.
v = mean drift velocity measured in ms^{-1}.
e = electron charge measured in couloumbs, C

1 Amp = 1 $C\ s^{-1}$
So substituting the units in the equation below we have to show that the units on the left is the same as the units on the right.

$$I = nAve$$
$$A = m^{-3} \times m^2 \times m\ s^{-1} \times C$$
$$C\ s^{-1} = m^{-3} \times m^2 \times m\ s^{-1} \times C$$

The m powers cancel each other out therefore:

$$C\ s^{-1} = C\ s^{-1}$$

Use the law of indices:
$m^{-3} \times m^2 \times m$
$= \mathrm{m}^{(-3+2+1)}$
$= m^0 = 1$

b) With reference to the equation, explain the difference between a metal conductor and a plastic insulator.

For a metal conductor n is large and so there is a current.
For an insulator n is very small (negligible) and so less current flows through it.
Therefore the current in the metal conductor is larger.

Please see **'7.1.1 Charge and Current notes'** pack for revision notes.

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