Chapter 17 – Current of Electricity

Subject content

Content
- Conventional current and electron flow
- Electromotive force
- Potential difference
- Resistance

Learning outcomes
(a) state that current is a rate of flow of charge and that it is measured in amperes
(b) distinguish between conventional current and electron flow
(c) recall and apply the relationship charge = current × time to new situations or to solve related problems
(d) define electromotive force (e.m.f.) as the work done by a source in driving unit charge around a complete circuit
(e) calculate the total e.m.f. where several sources are arranged in series
(f) state that the e.m.f. of a source and the potential difference (p.d.) across a circuit component are measured in volts
(g) define the p.d. across a component in a circuit as the work done to drive unit charge through the component
(h) state the definition that resistance = p.d./ current
(i) apply the relationship R = V/ I to new situations or to solve related problems
(j) describe an experiment to determine the resistance of a metallic conductor using a voltmeter and an ammeter, and make the necessary calculations
(k) recall and apply the formulae for the effective resistance of a number of resistors in series and in parallel to new situations or to solve related problems
(l) recall and apply the relationship of the proportionality between resistance and the length and cross sectional area of a wire to new situations or to solve related problems
(m) state Ohm's Law
(n) describe the effect of temperature increase on the resistance of a metallic conductor
(o) sketch and interpret the I/V characteristic graphs for a metallic conductor at constant temperature, for a filament lamp and for a semiconductor diode

Definitions

Term	Definition	Symbol	SI unit
Electrical current	Rate of flow of electric charge	I	A
Electromotive force (e.m.f.)	Work done by electrical energy source to drive a unit charge around a complete circuit	ε	V
Potential difference (p.d.)	Work done to drive a unit charge through a component in electric circuit	V	V J C^{-1}
Resistance	Ratio of potential difference across a material to the current flowing through it	R	Ω

Ohm's Law	The current passing through a metallic conductor is directly proportional to the potential difference across it (physical conditions remain constant)		
Resistivity	electrical resistance of a conductor of unit cross-sectional area and unit length	ρ	Ω m

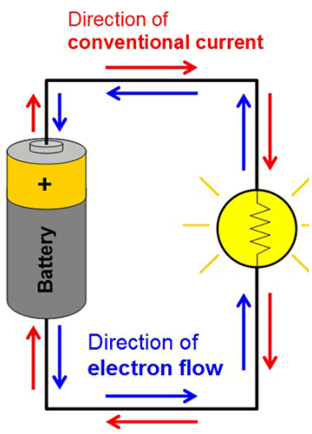
Formulae

Electrical current	Electromotive force	Potential difference
$I = \frac{Q}{t}$	$\varepsilon = \frac{W}{Q}$	$V = \frac{W}{Q}$
Ohm's Law	**Resistance**	**Resistivity**
$I \propto V$	$R = \frac{V}{I}$	$R = \rho \frac{l}{A}$

17.1 Electric Current

Conventional current and electron flow

Electric current	Direction	Description
1. **Conventional current**	+ → –	'movement' of positive charges
2. **Electron flow**	– → +	flow of electrons: –ve → +ve terminal (electrons repelled by –ve terminal & attracted to +ve terminal)



Electric current

Electric current

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

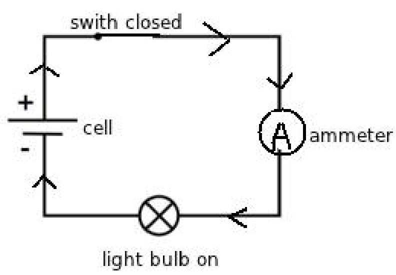
where I = current (in A)
Q = charge (in C)
t = time taken (in s)

1 ampere = electric current when 1 coulomb of charge passes a point in a conductor in 1 second

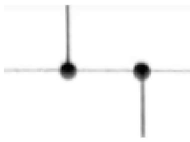
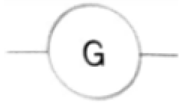
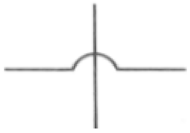
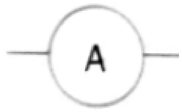
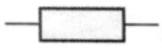
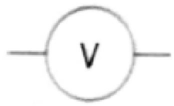
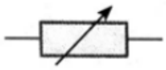
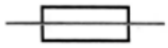
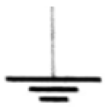
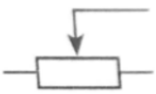
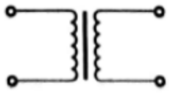
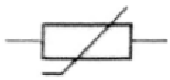
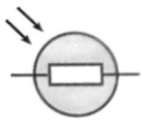
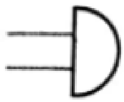
Drawing circuit diagrams

Main components of electric circuit:

1. **source** of e.m.f : drive electric current (e.g. battery)
2. **load** : moving charges can do useful job (e.g. bulb)
3. **conductor** : connect components together (e.g. copper wire)
4. **switch** : open / close circuit

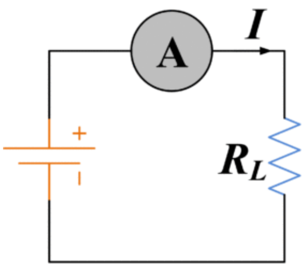


Circuit symbols for electrical components:

Symbol	Device	Symbol	Device	Symbol	Device
	switch		wires joined		galvanometer
	cell		wires crossed		ammeter
	battery		fixed resistor		voltmeter
	d.c. power supply		variable resistor (rheostat)		two-way switch
	a.c. power supply		fuse		earth connector
	light bulb		coil of wire		capacitor
	potentiometer		transformer		thermistor
	light-dependent resistor		semiconductor diode		bell

<u>Ammeter</u>

Ammeter: connected in <u>series</u>



17.2 Electromotive Force and Potential Difference

Electromotive force

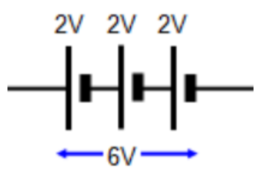
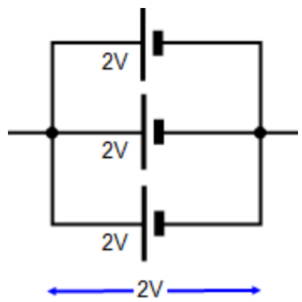
Electromotive force

$$\varepsilon = \frac{W}{Q}$$

where ε = e.m.f. of electrical energy source (in V)
W = work done, i.e. amount of non-electrical energy converted to electrical energy (in J)
Q = amount of charge (in C)

1 volt = 1 joule of work done by source to drive 1 coulomb of charge completely around circuit

Cell arrangement affect resultant e.m.f.

Series	Parallel
	
Resultant e.m.f. = sum of e.m.f. ● Charges gain energy as they pass through each cell ● Cells last for shorter time	Resultant e.m.f. = e.m.f. of a single cell ● Charges gain only a portion of energy from each cell ● Cells last for longer time

Potential difference

Potential difference

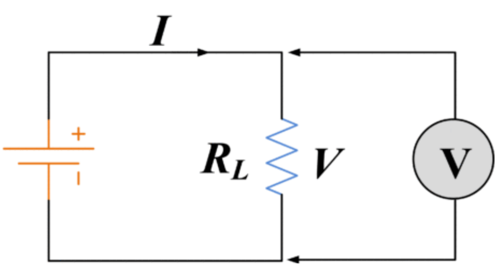
$$V = \frac{W}{Q}$$

where V = p.d. or voltage across a component (in V)
W = work done, i.e. amount of electrical energy converted to non-electrical energy (in J)
Q = amount of charge (in C)

1 volt = 1 joule of work is done to drive a unit charge through component

Voltmeter

Voltmeter: connected in parallel



17.3 Resistance

<u>Resistance</u>

Resistance

$$R = \rho \frac{l}{A}$$

where R = resistance of wire (in Ω)
ρ = resistivity of material (in Ω m)
l = length of wire (in m)
A = cross-sectional area (in m^2)

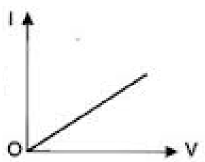
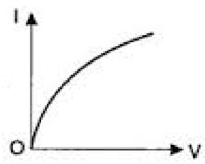
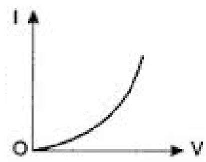
<u>Ohm's Law</u>

Ohm's Law

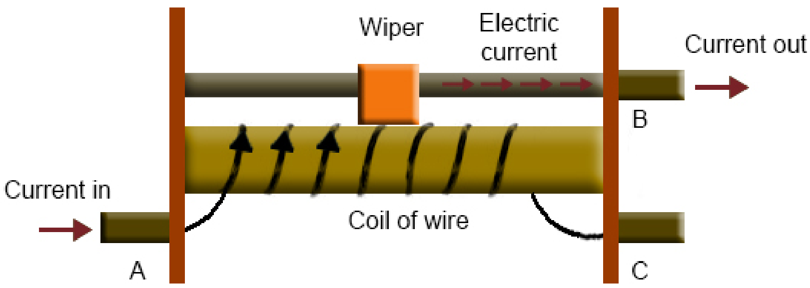
Current passing through metallic conductor (I) is directly proportional to potential difference across it (V), provided that physical conditions remain constant

$$I \propto V$$

<u>Resistors</u>

Aspect	**Ohmic resistor**	**Non-ohmic resistor**	
Obey Ohm's Law	✓	✗	✗
Example	metallic conductor	filament lamp	semiconductor diode
Characteristic	**R** constant under steady physical conditions	I ↑: generate more heat → temp ↑ → R ↑	p.d. applied in forward direction: I ↑ → R ↓ p.d. applied in backward direction: I ↓ → R ↑
I–V graph (gradient = $\frac{V}{I}$ = $\frac{1}{R}$)	 Straight line pass through origin	 Graph is not straight line (curved)	 Graph is not straight line (curved)

Variable resistor: vary length of wire (l) which current flows



Typical questions

Multiple choice questions

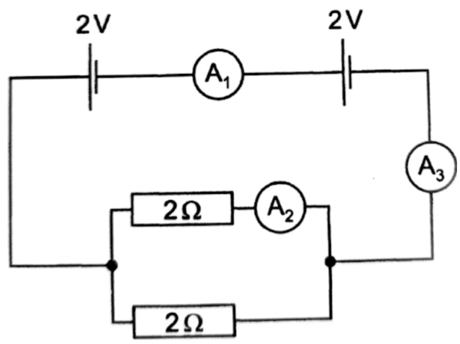
1 A resistor with resistance R is made from a length L of resistance wire with a cross-sectional area A.

A second resistor with resistance 2R is made from wire of the same material with a cross-sectional area of 0.25A.

What length of wire is needed for the second resistor? (2011 P1 Q29)

A 0.5 L
B L
C 2 L
D 8 L

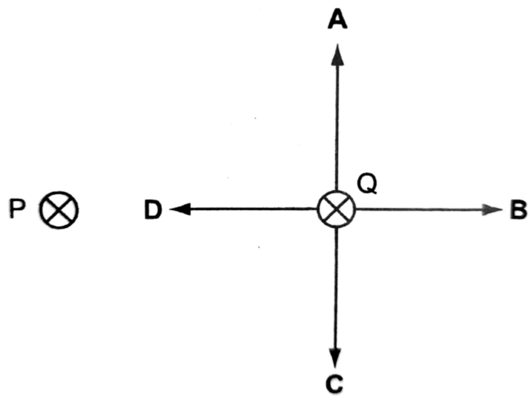
2 In the circuit shown, the cells and ammeters all have negligible resistance.



What are the readings on the ammeters A_1, A_2 and A_3? (2011 P1 Q31)

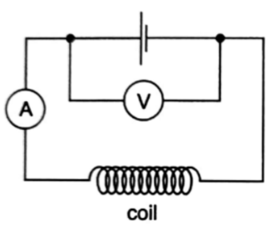
	reading on A_1 / A	reading on A_2 / A	reading on A_3 / A
A	2	1	2
B	2	1	4
C	4	2	2
D	4	2	4

3 P and Q represent two separate, parallel, straight wires carrying currents into the plane of the paper. In which direction is the force on Q? (2011 P1 Q34)

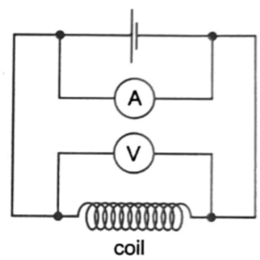


4 A circuit is used to find the resistance of a coil wire.
Which diagram shows the correct positions for the voltmeter and ammeter in the circuit?
(2013 P1 Q33)

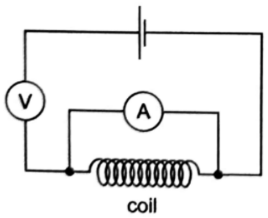
A



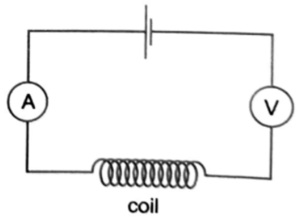
B



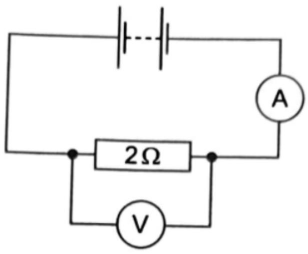
C



D

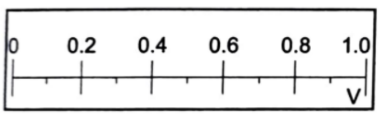


5 The diagram shows a circuit in which the ammeter reads 190 mA.

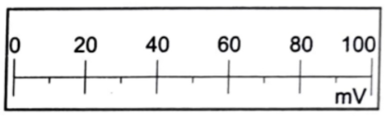


Which voltmeter scale is best to measure the potential difference across the resistor?
(2014 P1 Q29)

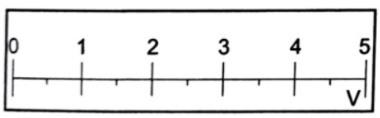
A



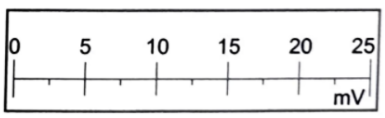
B



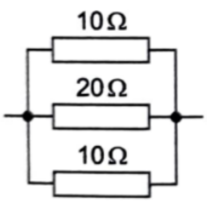
C



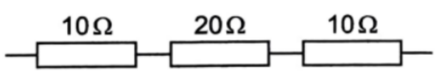
D



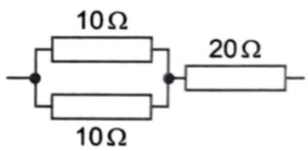
6 Three resistors are connected together to form three different networks.



network W



network X



network Y

What is the correct order, going from the network with the smallest resistance to the network with the largest resistance? (2015 P1 Q32)

A W → X → Y
B W → Y → X
C X → W → Y
D Y → X → W

7 A 12 V car battery is fully charged. It is connected in series to a lamp labelled 12 V, 24 W. The lamp shines at normal brightness for 25 hours.
What is the size of the charge that passes through the lamp at this time? (2016 P1 Q30)

A 3 000 C
B 45 000 C
C 180 000 C
D 1 100 000 C

8 Which quantity is equal to the potential difference (p.d.) across a component in a circuit? (2017 P1 Q33)

A the power used in driving one electron through the component
B the power used in driving unit charge through the component
C the work done in driving one electron through the component
D the work done in driving unit charge through the component

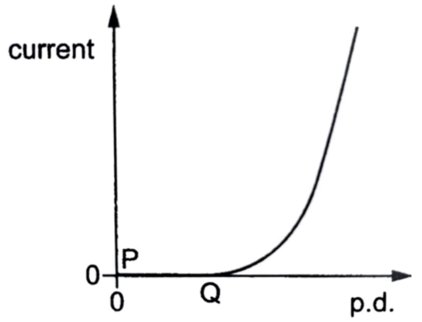
9 Wire X has a resistance of 9.0 Ω.
Wire Y is made of the same material as X but is twice as long and has a diameter three times larger.
What is the resistance of wire Y? (2018 P1 Q31)

A 2.0 Ω
B 6.0 Ω
C 54 Ω
D 160 Ω

10 Which statement about electric current is true? (2019 P1 Q31)

A It is the rate of flow of charge and its unit is the ampere.
B It is the rate of flow of charge and its unit is the coulomb.
C It is the rate of flow of electrons and its unit is the ampere.
D It is the rate of flow of electrons and its unit is the coulomb.

11 The diagram shows how the current in a semiconductor diode varies as the potential difference (p.d.) across it increases from zero.



What is the resistance of the diode between P and Q, and how does it change as the p.d. increases from Q? (2019 P1 Q32)

	resistance between P and Q	resistance after Q
A	very large	decreases
B	very large	increases
C	zero	decreases
D	zero	increases

Structured questions

1 A student investigates how the current in a filament lamp varies as the potential difference (p.d.) across it is changed from 0 to 12 V. The student uses a 12 V battery, an ammeter, a voltmeter and a variable potential divider (potentiometer) for the experiment.
There is a constant current of 0.20 A in the lamp. The electrical energy input to the lamp is 390 J in 4.0 minutes. (2012 P2B Q10)

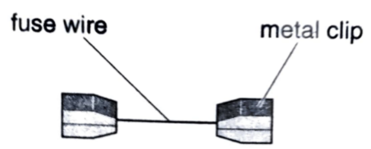
(a) Calculate the charge that flows through the lamp in 4.0 minutes. [2]

t = 4.0 minutes = 4 × 60 = 240 seconds
Q = I × t = (0.20)(240) = **48 C**

(b) Calculate the p.d. across the lamp. [2]

V = W / Q = 390 / 48 = **8.13 V**

2 A length of fuse wire is cut into two pieces X and Y. Each piece of wire is clamped, in turn, between two metal clips, as shown in the figure below.



The length of wire between the clips is 1.5 cm for wire X and 0.4 cm for wire Y.

(2015 P2B Q9)

(a) The potential difference (p.d.) across each wire is slowly increased. The p.d. is measured at various values of current until the wire melts. Table 1 shows the readings obtained.

current / A	**p.d. across wire X / V**	**p.d. across wire Y / V**
0	0	0
0.5	0.15	0.04
1.0	0.30	0.08
1.5	0.49	0.14
2.0	0.77	0.23
2.5	1.19	0.37
3.0	1.99	0.70
3.5	2.98	1.10
3.8	melts	1.50
4.0		melts

(i) Using data from Table 1, describe the relationship between the current in X and the p.d. across X

1. at low [1]

For low currents, the p.d. across the wires is proportional to the current.
For example, when the current was doubled from 0.5 to 1.0 A, the p.d. across X and Y was doubled from 0.15 V to 0.30 V and 0.04 to 0.08 V respectively.

2. at high [1]

For high currents, the p.d. across the wires increases when the current is increased. It is observed that the increase in p.d. is more significant compared to the increase in current.
For example, for wire X, the p.d. is almost doubled from 1.19 to 1.99 V when the current was increased from 2.5 to 3.0 A.

(ii) The data in Table 1 provides some evidence of a relationship between the length of the wire and the current that causes it to melt. State this possible relationship. [1]

The shorter the fuse wire, the greater the current is needed to melt it.

(b) The experiment is repeated with a strong wind blowing over the wires. Table 2 shows the new readings obtained at low currents.

current / A	p.d. across wire X / V	p.d. across wire Y / V
0.5	0.14	0.03
1.0	0.28	0.06

(i) Suggest a reason why the values of the p.d. at the same current are lower in Table 2 than in Table 1. [1]

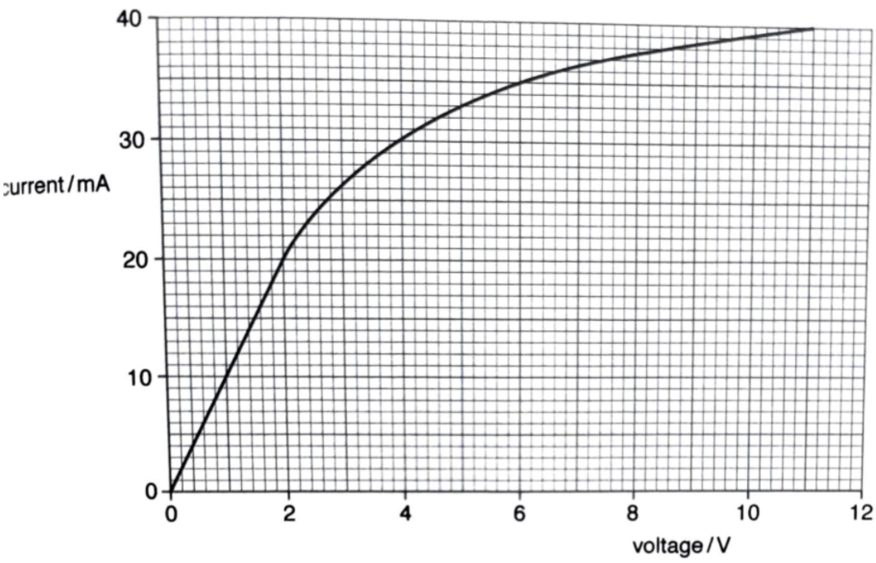
With a strong wind blowing, the heat dissipated due to the resistance of the wires would be spread quickly, thus the wires would be at a lower temperature compared to previously, and have a lower p.d.

(Note: Recall that resistance increases when temperature is increased.)

(ii) Suggest one other difference that is seen when readings at values of current greater than 1.0 A are compared to those in Table 1. [1]

Both wires would melt at a higher current.

3 The figure below shows the I/V characteristic graph for a filament lamp.



(2016 P2B Q10)

(a) The filament lamp does not obey Ohm's Law.

(i) State how the graph shows that the filament lamp does not obey Ohm's law. [1]

The current-voltage graph is a curve, rather than a straight line.

(ii) State why the filament lamp does not obey Ohm's law. [1]

The resistance of the filament lamp is not constant.

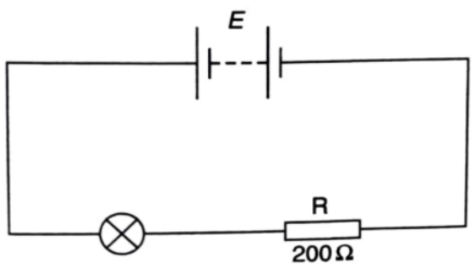
As the filament lamp heats up, the resistance increases.

As a result, the voltage is not directly proportional to the current passing through.

(b) There is a potential difference (p.d.) of 6.0 V across the lamp. Determine the resistance of the lamp. [2]

From the graph, when V = 6.0 V, I = 35 mA
R = V / I = 6 / (35 × 10^{-3}) = **171 Ω**

(c) The filament lamp is connected to a battery of electromotive force (e.m.f.) *E* and a fixed resistor R, as shown in the figure below.



(i) Define e.m.f. [1]

e.nm.f. is the work done by an electrical energy source in driving a unit charge around a complete circuit.

(ii) On the graph above, draw the I/V characteristic graph for resistor R. [2]

(iii) The lamp is operating at normal brightness with a p.d. of 6.0 V across it. Determine the value of *E*. [2]

Since the lamp and R are connected in series, they will have the same current passing through.
When the current is 35 mA, the voltage for R is 7.0 V.
e.m.f. = sum of p.d. = 6.0 + 7.0 = **13 V**