

Electricity

AS Physics ■ Topic 9

A-Level Physics



What we will cover

- 1 Current and charge 9.1
- 2 P.d. and power 9.2
- 3 Resistance and Ohm's law 9.3
- 4 Resistivity and sensors 9.3.1
- 5 Recap





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]**

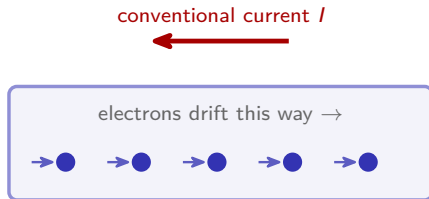
Practise on exercise sheet 9.1, then try the real exam questions on past-paper sheet 9.1.

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:

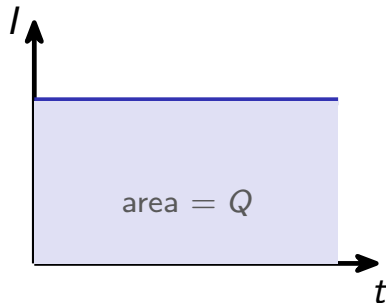
$$I = \frac{Q}{t}, \quad Q = It.$$

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?

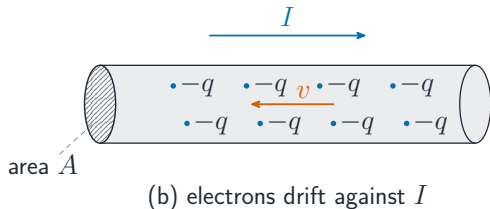
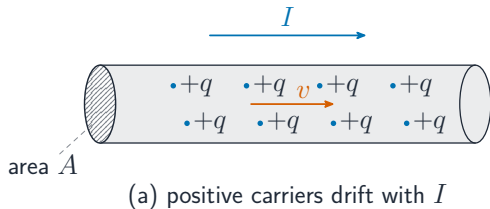
Charge is **quantised**: any free charge is a whole number of elementary charges, $Q = Ne$ with $e = 1.60 \times 10^{-19} \text{ C}$.

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



$$I = Anvq$$

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

A drift speed

Copper: $A = 1.0 \times 10^{-6} \text{ m}^2$, $I = 5.0 \text{ A}$, $n = 8.5 \times 10^{28} \text{ m}^{-3}$

rearrange $I = Anvq$: $v = \frac{I}{Anq}$

$$v = \frac{I}{Anq} = \frac{5.0 \text{ A}}{(1.0 \times 10^{-6} \text{ m}^2)(8.5 \times 10^{28} \text{ m}^{-3})(1.60 \times 10^{-19} \text{ C})} = 3.7 \times 10^{-4} \text{ m s}^{-1}$$

Half the diameter gives a quarter of the area, so the same current drifts **four times** faster in the thin part: $v \propto \frac{1}{A}$.



Sheet 9.2 – what you need to know

You must be able to:

- define **potential difference** and the volt, and use $V = \frac{W}{Q}$
- use $P = VI$, $P = I^2R$ and $P = \frac{V^2}{R}$, whichever fits the data
- find the energy transferred, $W = Pt = VIt$
- compare the power in components in series and in parallel

What the exam asks

“Define electric potential difference across a component.”

[1]

“State and explain which resistor dissipates more power.” **[3]**

Practise on exercise sheet 9.2, then try the real exam questions on past-paper sheet 9.2.

Potential difference and e.m.f.

Voltage is energy transferred per unit charge, measured in **volts** :

$$V = \frac{W}{Q}, \quad [V] = V = \text{J C}^{-1}.$$

e.m.f.

energy given **to** the charge
by the source

p.d.

energy given **up** to a component

Electrical power

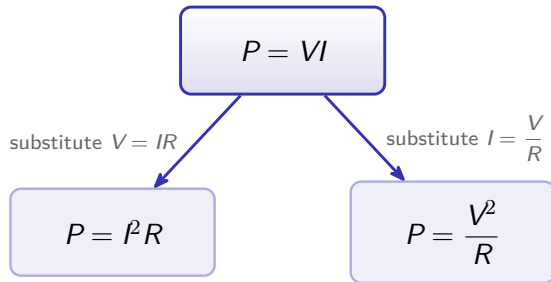
$$P = VI = I^2 R = \frac{V^2}{R}.$$

Pick the form for the quantities you know.

Kettle “2.4 kW, 240 V”

$$I = \frac{P}{V} = \frac{2400 \text{ W}}{240 \text{ V}} = 10 \text{ A}$$

$$R = \frac{V^2}{P} = \frac{(240 \text{ V})^2}{2400 \text{ W}} = 24 \Omega$$



Which resistor takes more power?

In parallel across 12 V: the same p.d.

$$P_{10} = \frac{V^2}{R} = \frac{(12 \text{ V})^2}{10 \Omega} = 14.4 \text{ W}$$

$$P_{20} = \frac{V^2}{R} = \frac{(12 \text{ V})^2}{20 \Omega} = 7.2 \text{ W}$$

Same V : the **smaller** resistance takes more.

In series at 0.40 A: the same current

$$P_{10} = I^2 R = (0.40 \text{ A})^2 (10 \Omega) = 1.6 \text{ W}$$

$$P_{20} = I^2 R = (0.40 \text{ A})^2 (20 \Omega) = 3.2 \text{ W}$$

Same I : the **larger** resistance takes more.

Two words the definitions turn on

E.m.f.

The **electromotive force** (e.m.f.) of a source is the energy given **per unit charge by the source**; potential difference is the energy *delivered* per unit charge to a component.

Potential divider

Put a thermistor or LDR in a **potential divider** and the output voltage changes with temperature or light – the standard sensing circuit.

In parallel

Two resistors in **parallel** across the same **voltage** : the *smaller* resistance takes more power, since $P = V^2/R$.

E.m.f. and p.d. share a unit and a symbol but not a meaning. Say “per unit charge” in both definitions, and name which way the energy goes.



Sheet 9.3 – what you need to know

You must be able to:

- define **resistance** and the ohm, and use $V = IR$
- state **Ohm's law**, and use $R = \frac{V}{I}$ even when it does not hold
- sketch and explain the I – V graphs of a metal, a filament lamp and a diode
- explain why a filament's resistance rises with the current

What the exam asks

“Define resistance.” [1]

“State and explain how the resistance of the lamp changes.” [1]

“State and explain the effect, if any, on the resistance of a filament wire in a lamp as the current in the wire decreases.” [1]

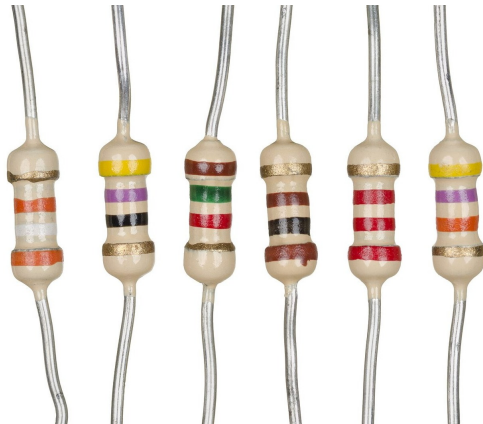
Practise on exercise sheet 9.3, then try the real exam questions on past-paper sheet 9.3.

Resistance and Ohm's law

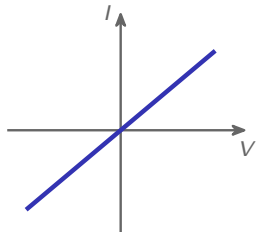
$$R = \frac{V}{I}, \quad [R] = \Omega = \text{V A}^{-1}.$$

Ohm's law: $I \propto V$ at constant temperature – then R is constant (a straight I - V line).

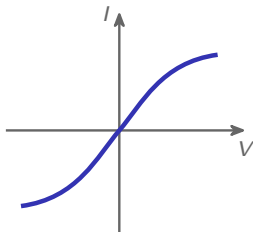
$R = V/I$ defines R for *any* component; only ohmic ones keep it constant. A metal's resistivity **rises** with temperature – more **lattice vibration scatters** the electrons. An **insulator** sits near $10^{15} \Omega \text{ m}$.



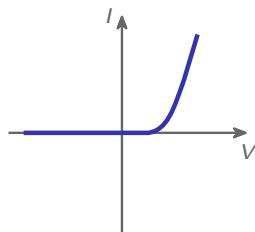
I - V characteristics



metal: straight



lamp: R rises

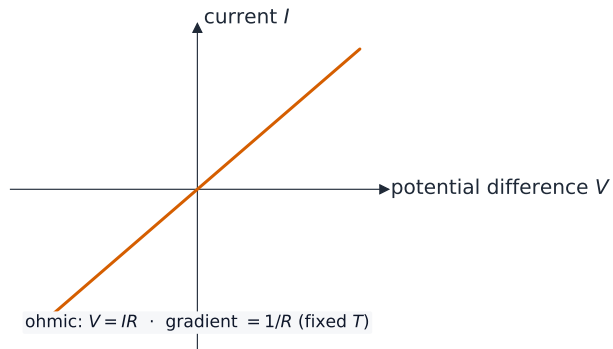


diode: switch-on

A hotter **filament lamp** has more resistance; a **diode** conducts only above $\sim 0.7\text{ V}$.

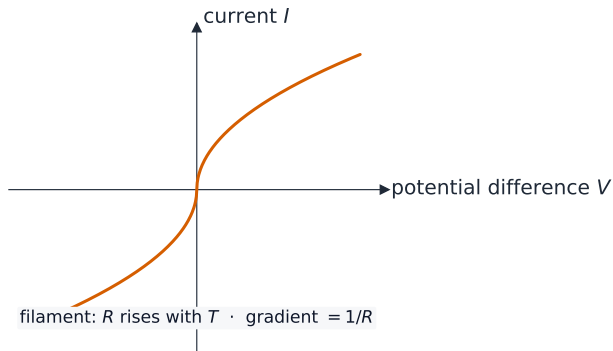
Characteristic 1 – a metal wire

Straight through the origin: R is **constant**, so the wire obeys Ohm's law (provided its temperature does not change).



Characteristic 2 – a filament lamp

The curve **bends over**: as the current heats the filament its resistance rises, so equal steps in V buy less and less current.



A filament lamp's resistance

A lamp takes 0.50 A at 6.0 V and 0.20 A at 1.0 V.

Use $R = \frac{V}{I}$ at the point, **never** the gradient of the I - V graph.

The definition at each point

$$\text{at } 6.0 \text{ V: } R = \frac{V}{I} = \frac{6.0 \text{ V}}{0.50 \text{ A}} = 12 \Omega$$

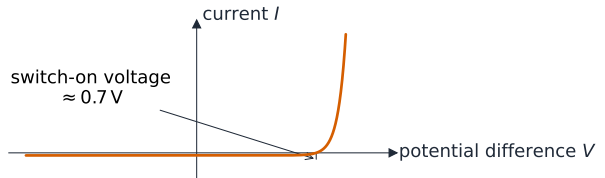
$$\text{at } 1.0 \text{ V: } R = \frac{V}{I} = \frac{1.0 \text{ V}}{0.20 \text{ A}} = 5.0 \Omega$$

a smaller current, a cooler filament, a **lower** resistance

Characteristic 3 – a diode

A **semiconductor diode** conducts **one way only**, and only above about 0.6 V .

In reverse the current is negligible until breakdown – which is why a diode can turn a.c. into d.c.



Si diode: conducts above $\approx 0.7\text{ V}$ · reverse blocks



Sheet 9.3.1 – what you need to know

You must be able to:

- use $R = \frac{\rho L}{A}$, with the area from the diameter
- find the resistance of a stretched wire, and of a block between different faces
- find a resistivity from the gradient of a resistance–length graph
- state how an NTC **thermistor** and an **LDR** respond to heat and light

What the exam asks

“State and explain which resistor is made of wire with the larger cross-sectional area.” [2]

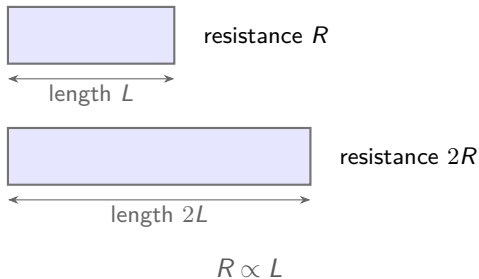
“State the effect of this change on the resistance of the lightning rod.” [1]

“State and explain how the resistance of wire Q compares with the resistance of wire P.” [4]

Practise on exercise sheet 9.3.1, then try the real exam questions on past-paper sheet 9.3.1.

Resistivity

same area A – twice the length gives twice R



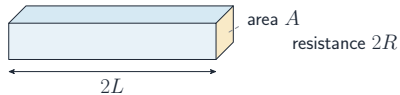
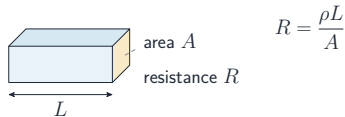
$$R = \frac{\rho L}{A}.$$

ρ is the **resistivity** (a material property, $\Omega \text{ m}$).

Copper: $L = 2.0 \text{ m}$, $A = 1.7 \times 10^{-7} \text{ m}^2$

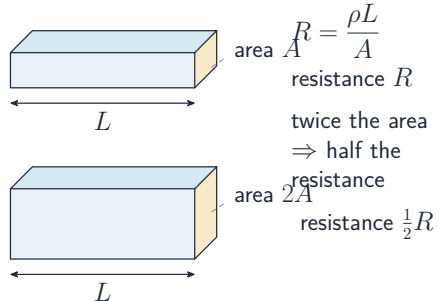
$$\begin{aligned} R &= \frac{\rho L}{A} = \frac{(1.7 \times 10^{-8} \Omega \text{ m})(2.0 \text{ m})}{1.7 \times 10^{-7} \text{ m}^2} \\ &= 0.20 \Omega \end{aligned}$$

What $R = \rho L/A$ is saying



twice the length $\Rightarrow$ twice the resistance

Twice the length, twice the resistance.



Twice the area, half the resistance.

ρ is the **resistivity**, a property of the **material** alone, in $\Omega \text{ m}$; R also depends on the shape.

A stretched wire

Stretching does not change the volume of metal, so AL stays the same: a longer wire is also **thinner**.

Double the length: half the area, so **four times** the resistance.

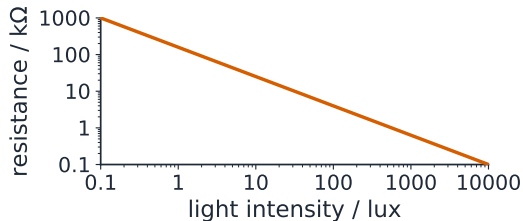
Stretched until its diameter is 90% of the old value

$$A \propto d^2: \frac{A'}{A} = 0.90^2 = 0.81$$

$$AL \text{ constant: } \frac{L'}{L} = \frac{1}{0.81} = 1.23$$

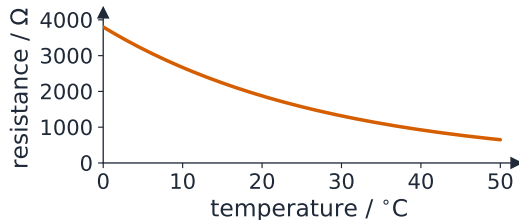
$$R' = \frac{\rho L'}{A'} = \frac{\rho(1.23L)}{0.81A} = 1.5 R$$

Light-dependent resistor and thermistor



LDR: more light $\Rightarrow$ lower R

LDR : R falls as light rises



NTC: R falls as T rises

thermistor : R falls as temp. rises

Both are semiconductors: light or heat **frees more carriers**, so R **falls** – the opposite of a metal.



Exam tips

- Use $I = Q/t$, $V = W/Q$ (energy per unit charge) and $P = VI = I^2R = V^2/R$.
- **Ohm's law** ($V = IR$) applies only to an ohmic conductor at constant temperature – a filament lamp is non-ohmic.
- Sketch and interpret the I - V **characteristics** of a resistor, filament lamp and diode.
- An **LDR's** resistance falls with light; a **thermistor's** falls as temperature rises.

Topic 9 – key takeaways

1

Current

$I = Q/t = Anvq$; conventional = positive flow

2

Power

$$P = VI = I^2R = V^2/R$$

3

Resistance

$R = V/I = \rho L/A$; Ohm's law if T constant

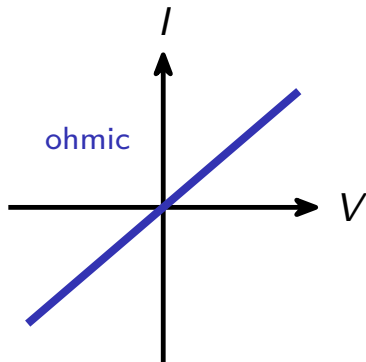
4

Sensors

LDR and thermistor: R falls with light / heat

Check yourself

- 1 Charge passing in 10 s at 2.0 A?
- 2 Three forms of the power equation?
- 3 Why does a filament lamp's I - V line curve?
- 4 What happens to an LDR's R in the dark?



Answers 1. $Q = It = 20 \text{ C}$ 2. VI , $I^2 R$, V^2/R 3. R rises as it heats 4. rises (to $\text{M}\Omega$)