9.3.1 Resistance, I-V characteristics and resistivity

Name: ______ Class: ______ Date: ______ **Total: 35 marks**

KEY WORDS resistance 电阻 • filament lamp 灯丝灯泡 • diode 二极管 • thermistor 热敏电阻 • light-dependent resistor 光敏电阻

Objective

Build the skills to answer exam questions on **resistance** 电阻 and **resistivity** 电阻率 that sheet 9.3 only starts: what Ohm's law does and does not cover, the I–V characteristics and the resistance behind them, $R = \rho L/A$ when a wire is stretched or a block is turned, and the **thermistor** 热敏电阻 and the **light-dependent resistor** 光敏电阻. This sheet covers syllabus 9.3, learning outcomes 1 to 8.

You must be able to:

- define resistance and state **Ohm's law** 欧姆定律
- recall and use $V = IR$
- sketch the I–V characteristics of a metallic conductor at constant temperature, a **semiconductor diode** 二极管 and a **filament lamp** 灯丝灯泡
- explain that the resistance of a filament lamp increases as the current increases because its temperature increases
- recall and use $R = \rho L/A$, including a wire that is stretched and a block measured between different faces
- understand that the resistance of a light-dependent resistor decreases as the light intensity increases
- understand that the resistance of a thermistor decreases as the temperature increases

1 Worked examples

Study these first. Each one shows a **method** that a question later on this sheet needs.

■ Resistance, the ohm and Ohm's law

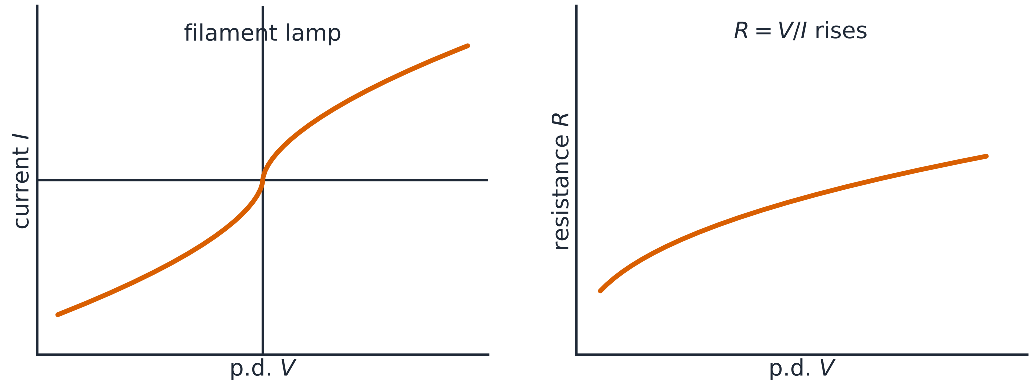
Resistance is the ratio of the **potential difference** 电势差 across a component to the **current** 电流 in it:

$$R = \frac{V}{I}$$

One **ohm** 欧姆 is one volt per ampere. Ohm's law says that the current in a metallic conductor is proportional to the p.d. across it, **provided its temperature stays constant**.

- $R = V/I$ is always true: it is the definition of resistance.
- $I \propto V$ is only true when the I–V graph is a straight line through the origin. A component whose graph curves does not obey Ohm's law.
- A component takes 0.40 A at 6.0 V and 0.25 A at 3.0 V. Its resistance is $6.0/0.40 = 15\ \Omega$ and $3.0/0.25 = 12\ \Omega$: the resistance changes, so the component is not ohmic.

The three characteristics



- **Metallic conductor at constant temperature:** a straight line through the origin, with the same gradient for both directions of current. Its resistance is constant.
- **Filament lamp:** an S-shaped curve through the origin that becomes less steep as the p.d. rises. A larger current heats the filament, its temperature rises, and so its resistance rises. The graph of R against V therefore rises.
- **Semiconductor diode:** almost no current in the reverse direction; in the forward direction almost no current until about 0.6 V, and then the current rises steeply, so the resistance falls.

Resistivity

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

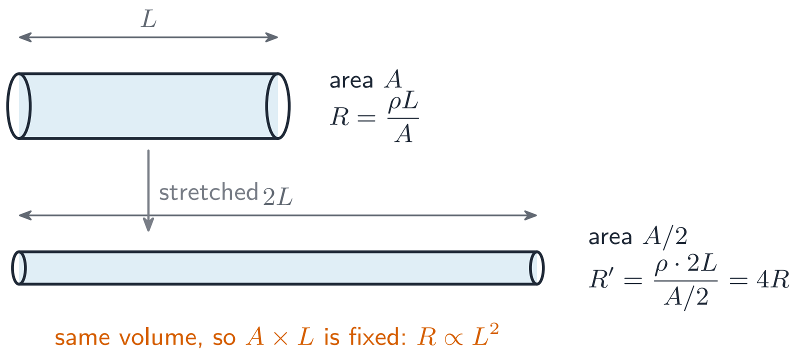
ρ is the resistivity of the **material**, measured in $\Omega\,$m; L is the length the current travels and A is the **cross-sectional area** 横截面积 it travels through.

A constantan wire has $\rho = 4.9 \times 10^{-7}\ \Omega\,$m, a length of 3.0 m and a diameter of 0.40 mm.

1. Radius $= 0.20$ mm $= 2.0 \times 10^{-4}$ m, so $A = \pi r^2 = 1.26 \times 10^{-7}$ m^2.
2. $R = \dfrac{(4.9 \times 10^{-7})(3.0)}{1.26 \times 10^{-7}} = 12\ \Omega$.

- Resistivity belongs to the material; resistance also depends on the shape of the sample.

■ The same wire, a new shape

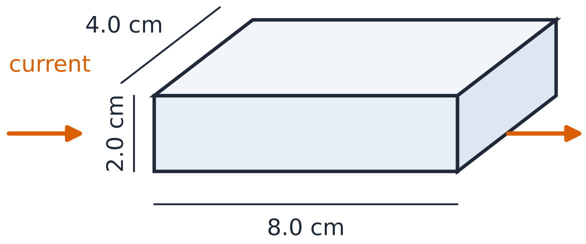


Stretching a wire does not change the volume of metal, so $A \times L$ stays the same.

1. If the length doubles, the area halves, and $R = \rho L/A$ becomes 4 times larger: $R \propto L^2$.
2. A wire is stretched until its diameter is 90% of its old value. The area falls to $0.90^2 = 0.81$ of its old value, so the length rises to $1/0.81 = 1.23$ times its old value.
3. $R' = \dfrac{\rho(1.23L)}{0.81A} = 1.5\,R$.

- Cutting a wire in half is different: the volume changes, and each half has half the resistance.

■ Which faces does the current use?



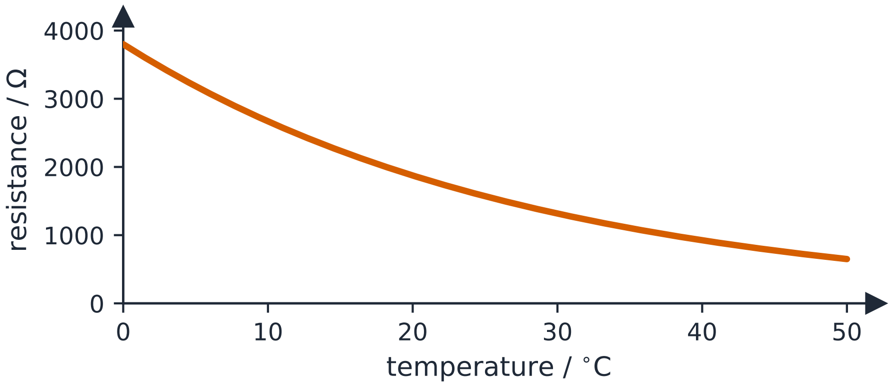
A block of copper ($\rho = 1.7 \times 10^{-8}\ \Omega\,\mathrm{m}$) has edges of 2.0 cm, 4.0 cm and 8.0 cm.

1. In $R = \rho L/A$, L is the distance between the two faces the current enters and leaves, and A is the area of one of those faces.
2. Smallest resistance: the current crosses the shortest edge, $L = 0.020$ m, through the largest faces, $A = 0.040 \times 0.080 = 3.2 \times 10^{-3}$ m^2:

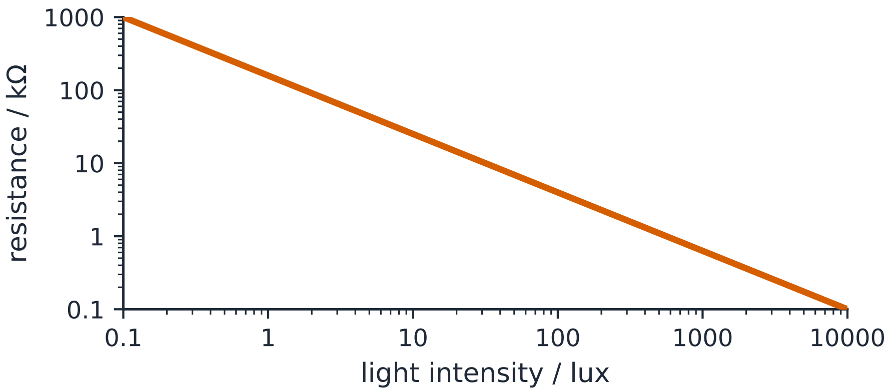
$$R = \frac{(1.7 \times 10^{-8})(0.020)}{3.2 \times 10^{-3}} = 1.1 \times 10^{-7}\ \Omega$$

3. Largest resistance: $L = 0.080$ m and $A = 0.020 \times 0.040 = 8.0 \times 10^{-4}$ m^2, giving $1.7 \times 10^{-6}\ \Omega$, which is 16 times larger.

■ Thermistor and light-dependent resistor



NTC: *R* falls as *T* rises



LDR: more light ⇒ lower *R*

- The resistance of a thermistor **falls** as its temperature rises: on this graph from about 3800 Ω at 0 °C to about 650 Ω at 50 °C.
- The resistance of an LDR **falls** as the light on it gets brighter, from about 1000 kΩ in near darkness to about 0.1 kΩ in bright light.
- Both changes are large, which is what makes these components useful in sensing circuits.

2 Practice

Now use the methods above.

2.1 A component has a p.d. of 12 V across it and a current of 0.25 A in it. Calculate its resistance. [2]

2.2 The resistivity of copper is $1.7 \times 10^{-8}\ \Omega\,\mathrm{m}$. Calculate the resistance of a copper wire of length 5.0 m and cross-sectional area $1.5 \times 10^{-6}\ \mathrm{m}^2$. [2]

2.3 A wire has a diameter of 0.80 mm. Calculate its cross-sectional area. [2]

2.4 State what is meant by the resistivity of a material. [1]

2.5 A second wire is made of the same material and has the same length as the first, but twice the diameter. State how its resistance compares with the first, and why. [2]

2.6 State how the resistance of a thermistor changes as it is warmed, and how the resistance of an LDR changes as the light on it gets brighter. [2]

3 Exam-style questions

3.1 Two wires are made of the same material and have the same mass. Wire X is twice as long as wire Y. What is $\frac{\text{resistance of X}}{\text{resistance of Y}}$? [1]

A B
C D

A $\frac{1}{4}$
B $\frac{1}{2}$
C 2
D 4

3.2 The p.d. across a filament lamp is doubled, and the current in it rises to 1.6 times its previous value. By what factor does the resistance of the lamp change? [1]

A B
C D

A 0.80
B 1.25
C 1.6
D 3.2

3.3 A student measures the resistance R of several different lengths L of the same wire, and plots R against L. The graph is a straight line through the origin with a gradient of $4.8\ \Omega\,\mathrm{m}^{-1}$. The wire has a diameter of 0.36 mm.

(a) Explain why the graph is a straight line through the origin. [2]

(b) Calculate the cross-sectional area of the wire. [2]

(c) Determine the resistivity of the metal. [3]

(d) State one advantage of finding the resistivity from the gradient rather than from one pair of readings. [1]

3.4 A rectangular block of carbon has edges of 1.0 cm, 2.0 cm and 5.0 cm. The resistivity of the carbon is $3.5 \times 10^{-5}\ \Omega\,\mathrm{m}$.

(a) Calculate the largest resistance between a pair of opposite faces. [3]

(b) Calculate the smallest resistance between a pair of opposite faces. [2]

(c) State the ratio of the largest resistance to the smallest, and explain why it has this value. [1]

3.5 A filament lamp is marked ”12 V, 24 W”.

(a) Sketch the I–V characteristic of a semiconductor diode, and state what it shows about the resistance of the diode. [3]

(b) At its normal operating p.d. of 12 V the current in the lamp is 2.0 A. Calculate the resistance of the lamp. [2]

(c) At a p.d. of 3.0 V the current in the same lamp is 0.80 A. Calculate the resistance and explain why it differs from your answer to (b). [3]