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

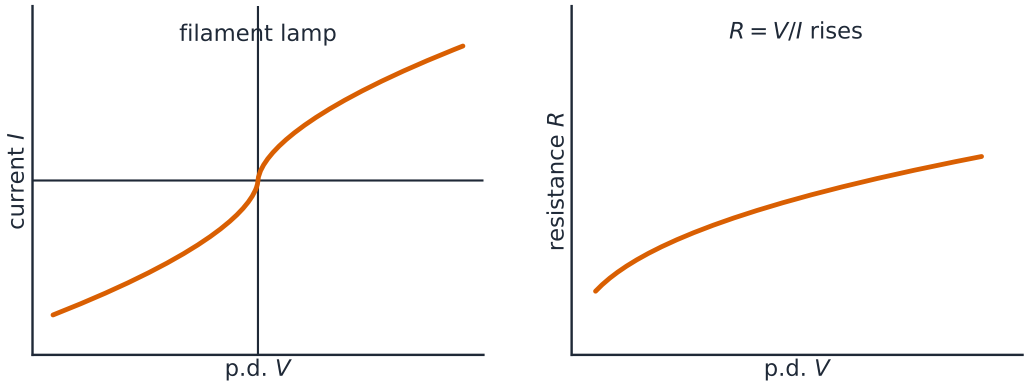
Resistance is the ratio of the **potential difference** 电势差 across a component to the **current** 电流 in it:

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

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

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

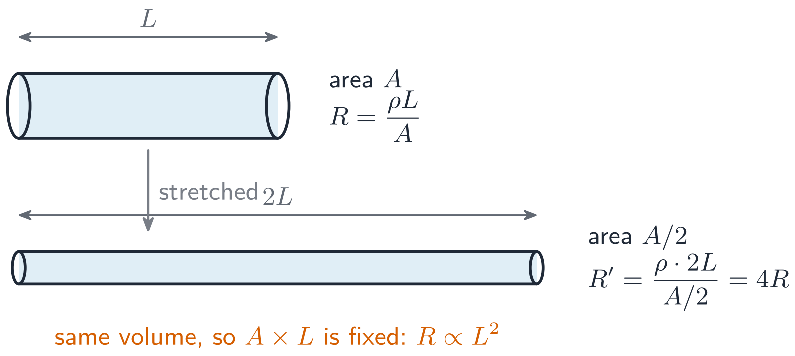
ρ is the resistivity of the **material**, measured in $\Omega\,\mathrm{m}$; L is the length the current travels and A is the **cross-sectional area** 横截面积 it travels through.

A constantan wire has $\rho = 4.9 \times 10^{-7}\ \Omega\,\mathrm{m}$, 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 $A = \pi r^2 = 1.26 \times 10^{-7}\ \mathrm{m}^2$.
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

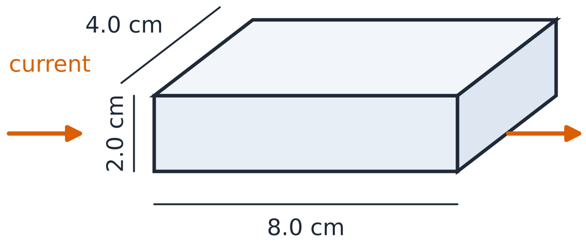


Stretching a wire does not change the volume of metal, so $A \times L$ stays the same.

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?



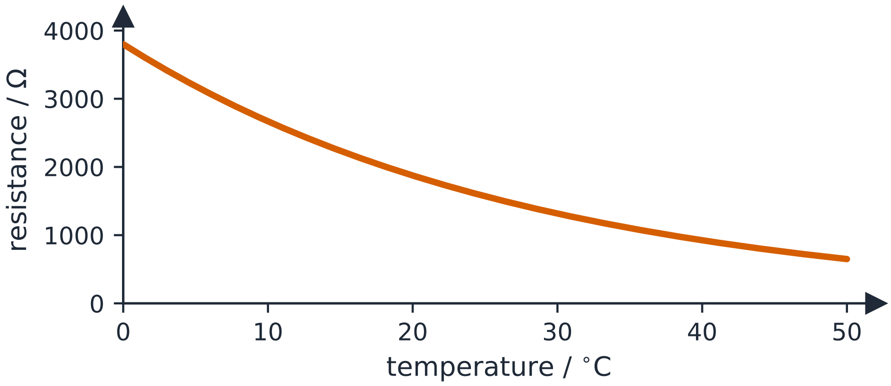
A block of copper ($\rho = 1.7 \times 10^{-8}\ \Omega\,\text{m}$) has edges of 2.0 cm, 4.0 cm and 8.0 cm.

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:

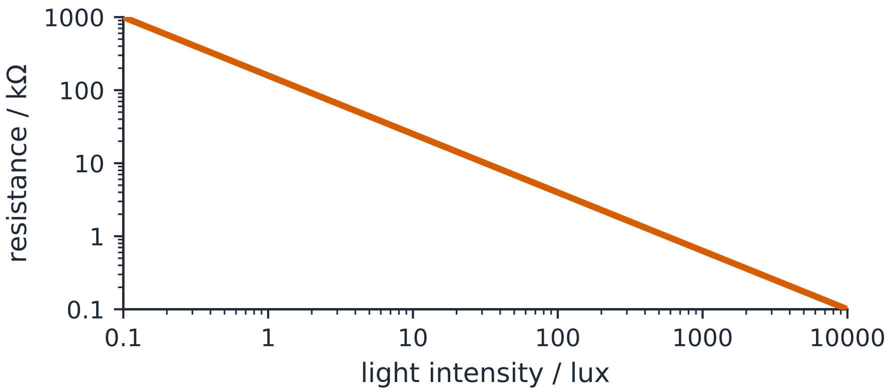
$$R = \frac{(1.7 \times 10^{-8})(0.020)}{3.2 \times 10^{-3}} = 1.1 \times 10^{-7}\ \Omega$$

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 $1.7 \times 10^{-8}\ \Omega\,\text{m}$. Calculate the resistance of a copper wire of length 5.0 m and cross-sectional area $1.5 \times 10^{-6}\ \text{m}^2$. [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 $\dfrac{\text{resistance of X}}{\text{resistance of Y}}$? [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]

Solutions

Each answer shows the steps, then the **result**.

2.1

- $R = V/I$

$$R = \frac{12}{0.25} = \mathbf{48}\ \Omega$$

2.2

- $R = \rho L/A$

$$R = \frac{(1.7 \times 10^{-8})(5.0)}{1.5 \times 10^{-6}} = \mathbf{0.057}\ \Omega$$

2.3

- radius $= 0.40$ mm $= 4.0 \times 10^{-4}$ m, and $A = \pi r^2$

$$A = \pi(4.0 \times 10^{-4})^2 = \mathbf{5.0 \times 10^{-7}\ m^2}$$

2.4

- the resistivity is $\rho = RA/L$: the property of the material that, with the length and the cross-sectional area, fixes the resistance of a sample

2.5

- twice the diameter gives four times the area, since $A = \pi d^2/4$
- $R = \rho L/A$, so the resistance is **one quarter** of the first wire's

2.6

- the resistance of the thermistor **decreases** as it is warmed
- the resistance of the LDR **decreases** as the light gets brighter

3.1 D

- the same mass of the same material means the same volume, so twice the length gives half the area
- $R = \rho L/A$ then rises by $2 \times 2 = 4$

3.2 B

- $R = V/I$, so the factor is $\frac{2}{1.6} = 1.25$
- the resistance rises because the filament is hotter

3.3

(a) $R = \rho L/A$, and ρ and A are the same for every length

- so R is proportional to L: a straight line whose intercept is zero, because a wire of zero length has no resistance

(b) radius $= 0.18$ mm $= 1.8 \times 10^{-4}$ m

$$A = \pi(1.8 \times 10^{-4})^2 = \mathbf{1.0 \times 10^{-7}\ m^2}$$

(c) the gradient is ρ/A

- $\rho =$ gradient $\times A = 4.8 \times 1.02 \times 10^{-7}$
- $\rho = \mathbf{4.9 \times 10^{-7}}\ \Omega\,\mathrm{m}$

(d) the gradient uses every reading, so a single wrong reading matters less, and any constant error in measuring the length shows up as an intercept instead of changing the gradient

3.4

(a) the largest resistance uses the longest edge and the smallest faces: $L = 0.050$ m and $A = 0.010 \times 0.020 = 2.0 \times 10^{-4}$ m^2

$$R = \frac{(3.5 \times 10^{-5})(0.050)}{2.0 \times 10^{-4}} = \mathbf{8.8 \times 10^{-3}}\ \Omega$$

(b) the smallest uses $L = 0.010$ m and $A = 0.020 \times 0.050 = 1.0 \times 10^{-3}$ m^2

$$R = \frac{(3.5 \times 10^{-5})(0.010)}{1.0 \times 10^{-3}} = \mathbf{3.5 \times 10^{-4}}\ \Omega$$

(c) the ratio is **25**: the length is 5 times larger and the area is 5 times smaller, and $R = \rho L/A$

3.5

(a) almost no current in the reverse direction

- in the forward direction almost no current until about 0.6 V, then a steep rise
- so the resistance is very large in reverse and below the switch-on p.d., and small once the diode conducts

(b) $R = V/I$

$$R = \frac{12}{2.0} = \mathbf{6.0}\ \Omega$$

(c) $R = \dfrac{3.0}{0.80} = \mathbf{3.75}\ \Omega$

- at the lower p.d. the current is smaller, so the filament is cooler and its resistance is lower