9.3.1 Resistivity, thermistors and LDRs

Name: _____ Class: _____ Date: _____ **Total: 24 marks**

KEY WORDS resistivity • cross-sectional area • thermistor • light-dependent resistor • resistance

Objective

Answer exam questions on **resistivity** and on two sensors, the **thermistor** and the **light-dependent resistor**: $R = \rho L/A$ for wires and blocks, what stretching a wire does, and how the sensors' resistance changes. Syllabus 9.3, learning outcomes 6 to 8.

You must be able to:

- use $R = \dfrac{\rho L}{A}$, with the area of a wire from its diameter
- work out 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 the resistance of an NTC thermistor and of an LDR change with temperature and light

1 Key knowledge and worked examples

Key knowledge: use these earlier methods

- **Charge and current**: $I = Q/t$, so $Q = It$. For a wire, $I = nAqv_d$; n is charge-carrier number per unit volume, A cross-sectional area and v_d drift speed.
- **Power and energy**: $P = VI = I^2R = V^2/R$ for a resistive component; energy transferred $W = Pt = VIt$.
- **Resistance**: $R = V/I$ at the operating point. A filament lamp gets hotter as current rises, so its resistance rises; an I–V graph becomes less steep. A diode carries little reverse current and much more forward current after its threshold.
- Choose the equation from what is known; an operating-point ratio V/I is not automatically the tangent gradient of a non-linear graph.

Key knowledge: resistivity

Idea	Rule
resistivity	$\rho = \dfrac{RA}{L}$, a property of the **material**, in $\Omega\,\mathrm{m}$
resistance of a sample	$R = \dfrac{\rho L}{A}$: L the length the current travels, A the cross-sectional area it passes through
a wire	$A = \pi r^2 = \dfrac{\pi d^2}{4}$; convert mm to m before squaring
stretched to twice the length	the volume is unchanged, so the area halves and R becomes 4 times larger
cut in half	each half has half the resistance
R against L for one wire	a straight line through the origin of gradient $\dfrac{\rho}{A}$, so $\rho = \text{gradient} \times A$

- **NTC thermistor**: its resistance **falls** as its temperature rises
- **LDR**: its resistance **falls** as the light intensity on it rises

Worked example: the resistance of a wire

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

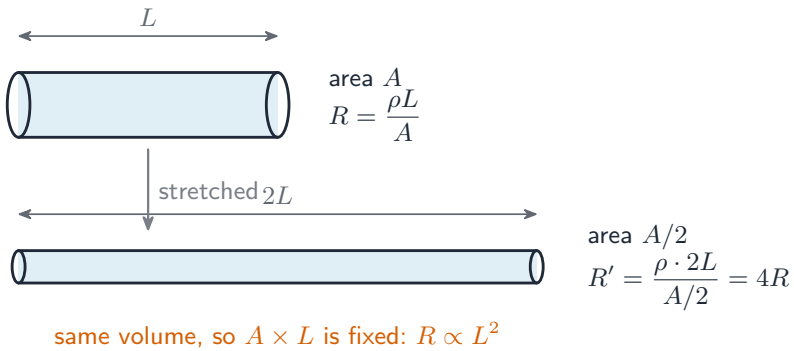
ρ is the resistivity of the **material**, measured in $\Omega\,\mathrm{m}$; L is the length the current travels and A is the **cross-sectional area** it travels through.

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 = 2.0×10^{-4} m, so $A = \pi r^2 = \pi(2.0 \times 10^{-4})^2 = 1.26 \times 10^{-7}\ \mathrm{m}^2$.
2. $R = \dfrac{\rho L}{A} = \dfrac{(4.9 \times 10^{-7})(3.0)}{1.26 \times 10^{-7}} = 12\ \Omega$.

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

Worked example: a stretched wire

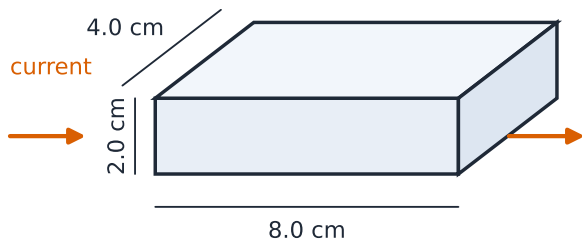


Stretching a wire does not change the volume of metal, so $A \times L$ stays the same.

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. Since $A \propto d^2$, the area falls to $0.90^2 = 0.81$ of its old value; AL is constant, 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.

Worked example: 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.

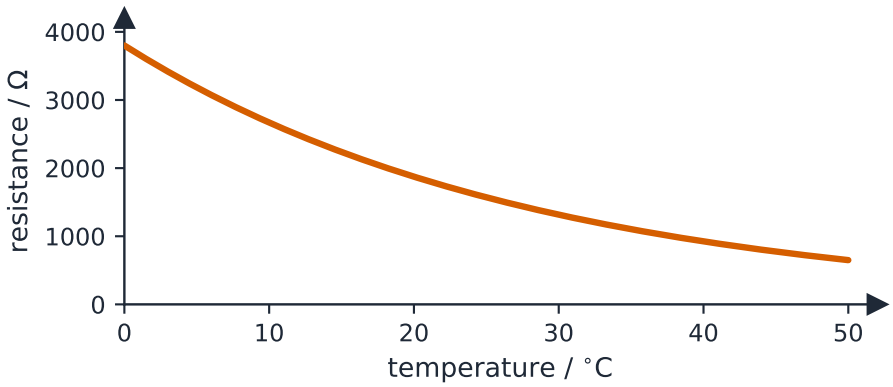
1. In $R = \rho L/A$, L is the distance between the two faces the current enters and leaves, and A is the area of one of those faces.
2. Smallest resistance: the current crosses the shortest edge, $L = 0.020$ m, through the largest faces, $A = 0.040 \times 0.080 = 3.2 \times 10^{-3}\ \text{m}^2$:

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

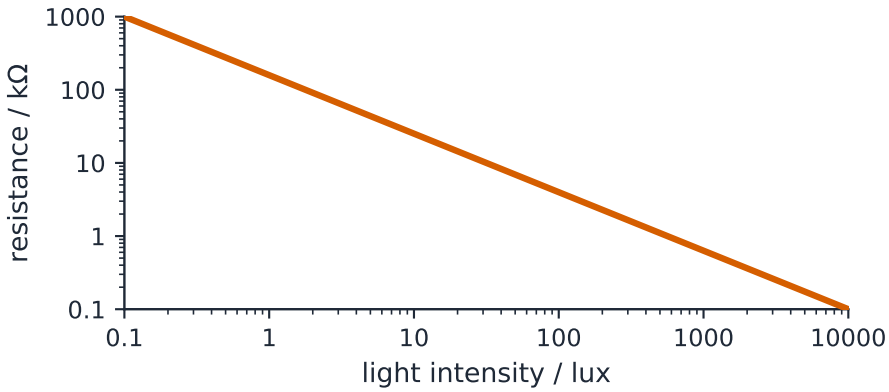
3. Largest resistance: $L = 0.080$ m and $A = 0.020 \times 0.040 = 8.0 \times 10^{-4}$ m^2, 16 times larger:

$$R = \frac{\rho L}{A} = \frac{(1.7 \times 10^{-8})(0.080)}{8.0 \times 10^{-4}} = 1.7 \times 10^{-6}\ \Omega$$

■ **Key knowledge: the two sensors**



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.

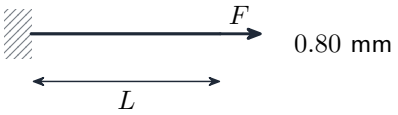
2 Practice

Now use the methods above.

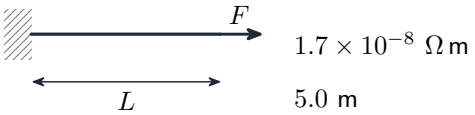
2.1 State what is meant by the resistivity of a material. [1]

resistivity

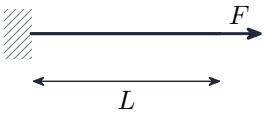
2.2 A wire has a diameter of 0.80 mm. Calculate its cross-sectional area. [2]



2.3 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]



2.4 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]



2.5 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]

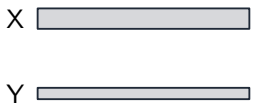
LDR

thermistor

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]

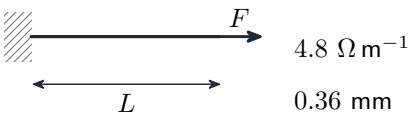
☐ **A** $\frac{1}{4}$
B $\frac{1}{2}$
C 2
D 4



3.2 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 $4.8\ \Omega\,\text{m}^{-1}$. 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]

3.3 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]