

Exercise walk-through

9.3.1

Resistance, I-V characteristics and resistivity

A-Level Physics

9.3.1 Resistivity, thermistors and LDRs

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

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

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

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	$\rho = \frac{RA}{L}$, a property of the material , in $\Omega \text{ m}$
resistance of a sample	$R = \frac{\rho L}{A}$: L the length the current travels, A the cross-sectional area it passes through
a wire	$A = \pi r^2 = \frac{\pi d^2}{4}$; 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 $\frac{\rho}{A}$, 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

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

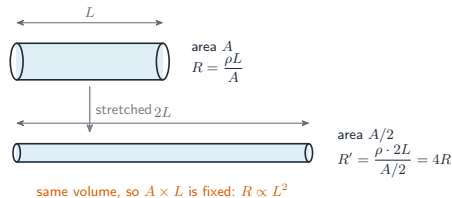
ρ is the resistivity of the **material**, measured in $\Omega \text{ m}$; L is the length the current travels and A is the **cross-sectional area** it travels through.

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

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

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

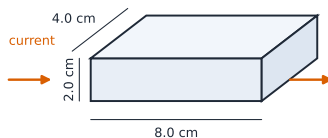
■ Worked example: a stretched wire



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

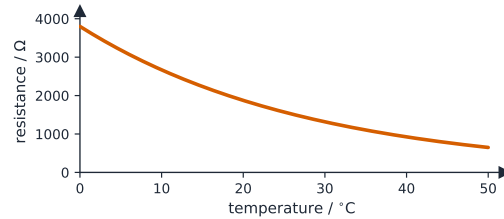
1. In $R = \rho L/A$, L is the distance between the two faces the current enters and leaves, and A is the area of one of those faces.
2. Smallest resistance: the current crosses the shortest edge, $L = 0.020 \text{ m}$, through the largest faces, $A = 0.040 \times 0.080 = 3.2 \times 10^{-3} \text{ m}^2$:

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

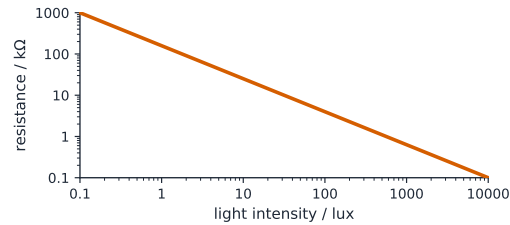
3. Largest resistance: $L = 0.080 \text{ m}$ and $A = 0.020 \times 0.040 = 8.0 \times 10^{-4} \text{ m}^2$, 16 times larger:

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

■ Key knowledge: the two sensors



NTC: R falls as T rises



LDR: more light $\Rightarrow$ lower R

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

Exercises 2.1·2.2

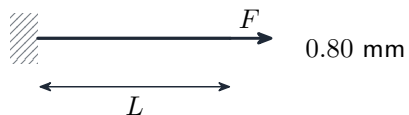
2.1 State what is meant by the resistivity of a material.

[1]

resistivity

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

[2]



Exercises 2.1·2.2

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[1]

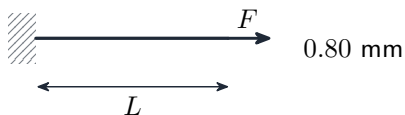
resistivity

2.1

- 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

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

[2]



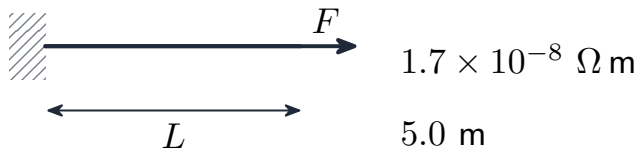
2.2

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

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

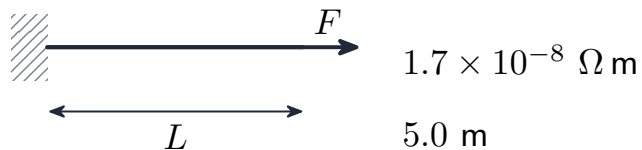
Exercise 2.3

2.3 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]



Exercise 2.3

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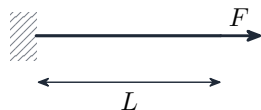
2.3

- $R = \rho L / A$

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

Exercises 2.4·2.5

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]



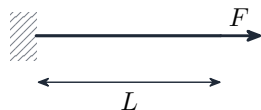
2.5 State how the resistance of a thermistor changes as it is warmed, and how the resistance of an LDR changes as the light on it gets brighter. [2]

LDR

thermistor

Exercises 2.4·2.5

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2.4

- 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

2.5 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]



2.5

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

Exercise 3.1

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

X

Y

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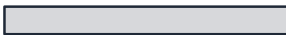
☐

A $\frac{1}{4}$

B $\frac{1}{2}$

C 2

D 4

X 

Y 

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 a factor $\frac{L'}{L} \times \frac{A}{A'} = 2 \times 2 = 4$

Exercise 3.2 (a)

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]

Exercise 3.2 (a)

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]

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

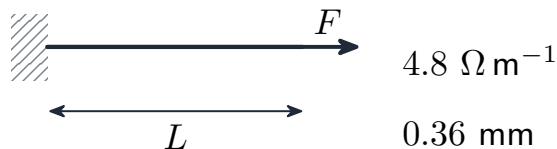
- so R is proportional to L : a straight line whose intercept is zero, because a wire of zero length has no resistance

Exercise 3.2 (b)

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 .

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

[2]

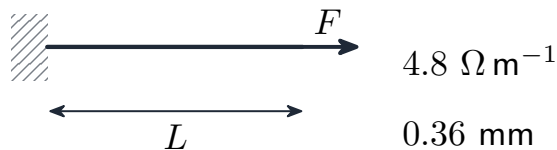


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(b) Calculate the cross-sectional area of the wire.

[2]



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

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

Exercise 3.2 (c)

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 .

(c) Determine the resistivity of the metal.

[3]

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(c) Determine the resistivity of the metal.

[3]

(c) the gradient is ρ/A

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

Exercise 3.2 (d)

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.

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

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

(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

Exercise 3.3 (a)

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 $3.5 \times 10^{-5} \Omega \text{ m}$.

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



1.0 cm

2.0 cm

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



1.0 cm

2.0 cm

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

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

Exercise 3.3 (b)

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 $3.5 \times 10^{-5} \Omega \text{ m}$.

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

[2]

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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 $3.5 \times 10^{-5} \Omega \text{ m}$.

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

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

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

Exercise 3.3 (c)

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 $3.5 \times 10^{-5} \Omega \text{ m}$.

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

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