

## AQA AS Resistivity thermistors and superconductivity

Matching solutions and teaching prompts for the class review

### Specification points covered

• 3.5.1.3 Resistivity:  $\rho = RA/L$ ; temperature effects in metal conductors and NTC thermistors; thermistors as temperature sensors and R-temperature graphs.

• 3.5.1.3 Superconductivity: zero resistivity at/below a material-specific critical temperature; strong magnetic fields and reduced transmission losses. Required practical 5: wire resistivity using a micrometer, ammeter and voltmeter.

### Teaching focus

Distinguish a material's resistivity from a wire's resistance; track the squared diameter and match voltage contacts to measured length.  
Require precise NTC and superconductivity language. Use the practical response to connect measurements, controlled temperature and analysis.

### Choosing the aircraft power leads

#### 1. Use $\rho = RA/L$ to obtain the SI unit of resistivity. [1 mark]

**Answer / mark points:** Unit =  $\Omega \times m^2 / m = \Omega m$ . [1] Resistivity is not measured in  $\Omega m^{-1}$ .

**Teacher prompt / common error:** Keep  $\Omega m$  together: this is resistance multiplied by length, not resistance per metre.

#### 2. A copper power lead has a circular cross-section of diameter 2.40 mm. Calculate its cross-sectional area in $m^2$ . [2 marks]

**Answer / mark points:**  $d = 2.40 \times 10^{-3} m$ . [1]  $A = \pi d^2/4 = \pi(2.40 \times 10^{-3})^2/4 = 4.52 \times 10^{-6} m^2$ . [1] Unrounded area =  $4.5239 \times 10^{-6} m^2$ ; retain it for later calculations.

**Teacher prompt / common error:** A millimetre conversion is squared when finding area. Diameter is twice radius.

#### 3. The lead in Question 2 is 3.00 m long. Copper has resistivity $1.72 \times 10^{-8} \Omega m$ at the test temperature. Calculate the resistance of this lead. [1 mark]

**Answer / mark points:**  $R = \rho L/A = (1.72 \times 10^{-8} \times 3.00)/(4.5239 \times 10^{-6}) = 0.0114 \Omega$ . [1] This is the resistance of one lead, not the pair.

**Teacher prompt / common error:** Use the tested one-lead length and the unrounded area; distinguish  $\rho$  from  $R$ .

#### 4. A replacement copper lead is 4.50 m long and has diameter 3.60 mm. Both leads are at the same temperature. Calculate the ratio $R(\text{replacement})/R(\text{original})$ , showing how both dimensions affect the result. [2 marks]

**Answer / mark points:** For a circular wire at fixed resistivity,  $R \propto L/d^2$ . The length factor is  $4.50/3.00 = 1.50$  and the area factor is  $(3.60/2.40)^2 = 2.25$ . [1 for accounting correctly for the squared diameter]  $R(\text{replacement})/R(\text{original}) = 1.50/2.25 = 0.667 = 2/3$ . [1] The longer replacement has the lower resistance because its increased area outweighs the length increase.

**Teacher prompt / common error:** Compare the length factor with the area factor. Doubling diameter would quadruple area.

#### 5. An engineer says, 'Making the copper lead thicker reduces the copper's resistivity.' Correct this statement, distinguishing resistance from resistivity. [2 marks]

**Answer / mark points:** Resistivity remains unchanged for the same material at the same temperature. [1] Making the lead thicker increases its cross-sectional area, so its resistance decreases because  $R = \rho L/A$ . [1] Resistivity is a material property; resistance also depends on geometry.

**Teacher prompt / common error:** State the unchanged conditions: same material and temperature. Geometry changes  $R$ , not  $\rho$ .

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## Equal resistance does not mean equal mass

Table 1 Cable-material data at the comparison temperature. Density is mass per unit volume.

| Material  | Resistivity / $\Omega \text{ m}$ | Density / $\text{kg m}^{-3}$ |
|-----------|----------------------------------|------------------------------|
| Copper    | $1.72 \times 10^{-8}$            | 8960                         |
| Aluminium | $2.82 \times 10^{-8}$            | 2700                         |

**6. The aircraft team considers an aluminium lead with the same length and resistance as the copper lead in Question 3. Use Table 1 to calculate the aluminium lead's cross-sectional area and diameter. [3 marks]**

**Answer / mark points:**  $A = \rho L/R = (2.82 \times 10^{-8} \times 3.00)/0.0114061$ . [1]  $A = 7.42 \times 10^{-6} \text{ m}^2$ . [1]  $d = \sqrt{(4A/\pi)} = 3.07 \times 10^{-3} \text{ m} = 3.07 \text{ mm}$ . [1]  
Accept values obtained consistently from the rounded  $0.0114 \Omega$  in Question 3.

**Teacher prompt / common error:** Aluminium needs a larger area at equal length and resistance because its resistivity is greater.

**7. The aircraft needs two identical leads, each 3.00 m long. Calculate the total mass of metal for (a) the copper design and (b) the aluminium design from Question 6. Which design gives the lower mass for this equal-resistance comparison? Use mass = density  $\times$  cross-sectional area  $\times$  total length. Ignore insulation and connectors. [3 marks]**

**Answer / mark points:** Total length = 6.00 m. Copper:  $m = 8960 \times 4.5239 \times 10^{-6} \times 6.00 = 0.243 \text{ kg}$ . [1] Aluminium:  $m = 2700 \times 7.4171 \times 10^{-6} \times 6.00 = 0.120 \text{ kg}$ . [1] Aluminium gives the lower metal mass (about half the copper mass) while meeting the same length and resistance requirement. [1] This comparison alone does not establish mechanical or connection suitability.

**Teacher prompt / common error:** Both designs have two leads. Lower resistivity does not automatically mean lower mass.

**8. After a sustained flight, the copper leads are hotter and their resistance has increased. Explain this increase in terms of lattice ions and conduction electrons. [2 marks]**

**Answer / mark points:** The hotter lattice ions vibrate with greater amplitude. [1] Conduction electrons undergo more frequent collisions/scattering with the lattice, making current flow more difficult and increasing resistance. [1] Do not describe the ions as travelling along the wire or say that charge is used up.

**Teacher prompt / common error:** Use the sequence: temperature increases  $\rightarrow$  lattice vibrations increase  $\rightarrow$  electron scattering increases  $\rightarrow$  resistance increases.

**9. A spare alloy wire is tested at room temperature. The measured length is 0.800 m and its diameter is 0.400 mm. The current is 0.800 A and the potential difference across that length is 0.384 V. Calculate the wire's resistivity. [3 marks]**

**Answer / mark points:**  $R = V/I = 0.384/0.800 = 0.480 \Omega$ . [1]  $A = \pi(0.400 \times 10^{-3})^2/4 = 1.2566 \times 10^{-7} \text{ m}^2$ . [1]  $\rho = RA/L = 0.480 \times 1.2566 \times 10^{-7} / 0.800 = 7.54 \times 10^{-8} \Omega \text{ m}$ . [1]

**Teacher prompt / common error:** First obtain resistance from paired electrical readings, then remove the effect of wire geometry.

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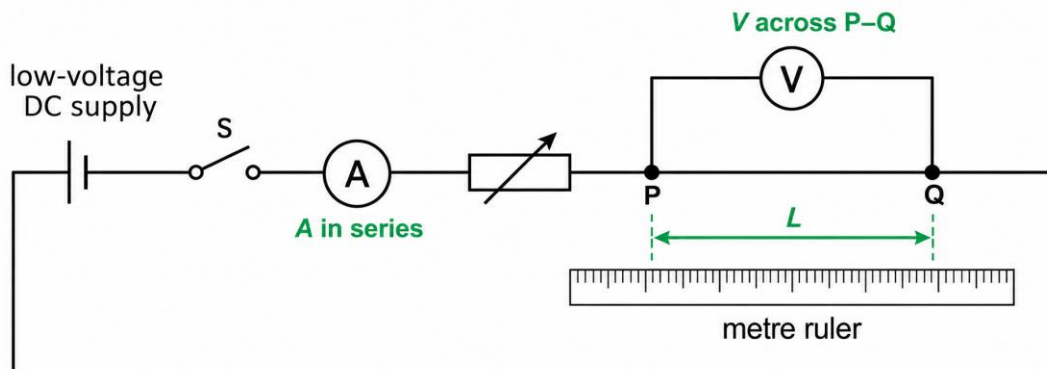
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## Required practical 5 Measuring wire resistivity

10. Figure 1 shows the bench circuit used to test the spare wire. Explain why the voltmeter is connected between P and Q. State which length must be used in  $\rho = RA/L$ . Switch S is closed while taking readings. [2 marks]



**Answer / mark points:** The voltmeter measures the potential difference across the tested wire section only, not across other series components. [1] L is the separation of the electrical contacts P and Q along the wire, matching that measured potential difference. [1] It is not the whole circuit length or the ruler length.

**Teacher prompt / common error:** The electrical and geometrical boundaries must match. Trace precisely where the voltage probes touch.

11. A micrometer gives zero-corrected diameters of 0.398 mm, 0.402 mm and 0.400 mm at different positions along a uniform wire. Calculate its mean diameter and the cross-sectional area to use in the resistivity calculation. [2 marks]

**Answer / mark points:** Mean  $d = (0.398 + 0.402 + 0.400)/3 = 0.400$  mm. [1]  $A = \pi(0.400 \times 10^{-3})^2/4 = 1.26 \times 10^{-7}$  m<sup>2</sup>. [1] Average the diameter readings before calculating the circular area.

**Teacher prompt / common error:** Repeats along the wire reduce the influence of random diameter variation; they do not remove an uncorrected zero error.

12. A technician forgets to correct a micrometer zero error and uses 0.420 mm instead of the true diameter 0.400 mm. The current, potential difference and length are correct. Calculate the percentage error in the calculated resistivity and state whether it is too high or too low. [2 marks]

**Answer / mark points:** With V, I and L fixed, calculated  $\rho \propto d^2$ . The ratio is  $(0.420/0.400)^2 = 1.1025$ , giving a 10.25% error (accept 10.3%). [1] Resistivity is overestimated. [1] A 5% diameter error produces about a 10% resistivity error, not a 5% error.

**Teacher prompt / common error:** The measured diameter enters squared. A systematic zero offset can bias every repeat in the same direction.

13. Write a method to determine the resistivity of a uniform metal wire using the apparatus in Figure 1 and a micrometer. Scaffold your six-mark-style response under these headings: wire dimensions; electrical measurements; temperature control and reliability; calculation or graph analysis. Explain how the measurements give resistivity, not just resistance. [6 marks]

**Answer / mark points:** 1. Check the micrometer for zero error and correct any offset. Use its ratchet to avoid excessive compression. [1]  
2. Measure diameter at at least three positions along the wire, preferably also in different orientations. Calculate the mean diameter and  $A = \pi d^2/4$ . [1]  
3. Measure L between contacts P and Q with a metre ruler. Read the ammeter in series and voltmeter in parallel across exactly that section; record paired V and I. [1]  
4. Repeat the readings and average consistent results, ideally obtaining R for several measured lengths of the same wire. [1]  
5. Use low currents and short measurement periods; switch off between readings and allow recovery so the wire temperature remains approximately constant. [1]  
6. Calculate  $R = V/I$  then  $\rho = RA/L$ . Alternatively plot R vertically against L horizontally, find gradient g and use  $\rho = gA$ ; a constant contact-resistance contribution appears in the intercept. [1]

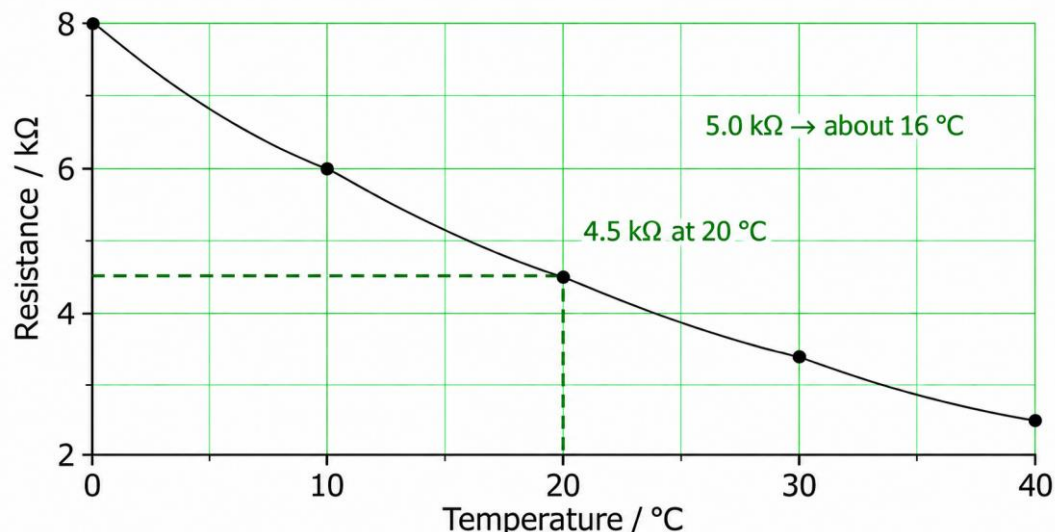
Accept an equivalent workable method. These are six distinct indicative marking points, not an official AQA mark scheme. The method must connect dimensions, electrical measurements and analysis.

**Teacher prompt / common error:** Insist on a micrometer, multiple diameter positions/orientations and a mean. Heating changes the quantity being measured.



## Calibrating the refrigerated cargo sensor

14. An NTC thermistor monitors the refrigerated medical-cargo pod. Figure 2 shows its calibration. Describe how its resistance changes as temperature increases, including whether the relationship is linear. [2 marks]



**Answer / mark points:** Resistance decreases as temperature increases. [1] The relationship is non-linear; the decrease per degree becomes smaller at higher temperatures in the shown range. [1] Say 'resistance decreases', not 'resistance decelerates'.

**Teacher prompt / common error:** Name the changing quantity and its direction; 'NTC' does not mean temperature decreases.

15. At 20 °C the potential difference across the thermistor is 0.0900 V. Read its resistance from Figure 2 and calculate the current through it. [2 marks]

**Answer / mark points:** At 20 °C,  $R = 4.5 \text{ k}\Omega = 4500 \text{ }\Omega$ . [1]  $I = V/R = 0.0900/4500 = 2.0 \times 10^{-5} \text{ A} = 20 \text{ }\mu\text{A}$ . [1] Accept appropriate rounding for the graph reading.

**Teacher prompt / common error:** Read the ordinate carefully: the shown graph starts at 2 kΩ, not zero. Convert kΩ before using volts.

16. The pod's alarm should activate when its temperature exceeds 8 °C. The thermistor resistance is 5.0 kΩ. Estimate the temperature from Figure 2 and decide whether the alarm should activate, giving a reason. [2 marks]

**Answer / mark points:** Temperature is approximately 16 °C; accept 14–18 °C from the printed curve. [1] The alarm should activate because this is above 8 °C. [1] For an NTC device, the lower resistance corresponds to a higher temperature, not a colder pod.

**Teacher prompt / common error:** Use the curve rather than a straight-line interpolation over the entire range. Accept sensible graph-reading precision.

17. Describe how to obtain an R–temperature calibration for this thermistor using a water bath. Include paired measurements, thermal equilibrium and a precaution against self-heating. [3 marks]

**Answer / mark points:** Measure the bath temperature using a thermometer and the thermistor resistance using an ohmmeter (or paired V and I to obtain  $R = V/I$ ), repeating across a suitable temperature range to plot R against temperature. [1]

Stir the bath and wait for thermal equilibrium/steady readings at each temperature. [1]

Use a small measuring current or short readings to minimise self-heating of the thermistor. [1] Accept repeated measurements as an additional reliability improvement, but not in place of the requested equilibrium or self-heating controls.

**Teacher prompt / common error:** A sensor should measure the bath, not its own electrically raised temperature. Waiting and stirring address equilibrium.

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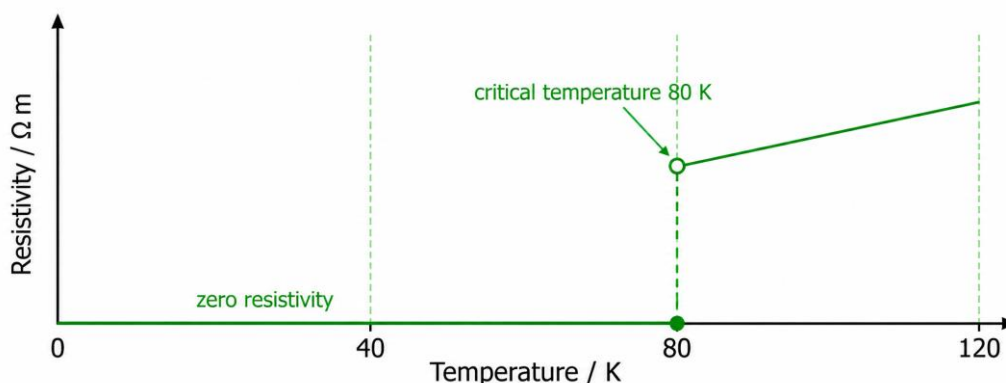
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## A superconducting ground charging link

18. For a proposed ground charging link, material S has a critical temperature of 80 K. Sketch its qualitative resistivity–temperature graph on Figure 3 from 0 to 120 K. Show clearly what happens at and below 80 K and immediately above 80 K. [2 marks]



**Answer / mark points:** Resistivity is exactly zero at and below 80 K. [1] Immediately above 80 K it is finite/non-zero, with an abrupt transition rather than a gradual fall to zero. [1] See the qualitative solution sketch; no numerical resistivity values or critical magnetic-field details are required.

**Teacher prompt / common error:** Zero means zero, not ‘very small’. The critical temperature marks a transition, not an ordinary-metal extrapolation.

19. Two alternative materials have critical temperatures of 90 K and 35 K. Both are cooled to 77 K. State which, if either, is superconducting and justify your choice. [2 marks]

**Answer / mark points:** Only the material with critical temperature 90 K is superconducting. [1] 77 K is below 90 K but above 35 K, so only the first material is at or below its own critical temperature. [1] The critical temperature depends on the material.

**Teacher prompt / common error:** Compare operating temperature with each material’s own critical temperature, not with 0 °C.

20. Superconducting coils are used to produce strong magnetic fields. Explain why superconductivity permits a large current with no resistive heating in the superconducting coil itself. [2 marks]

**Answer / mark points:** The coil has zero resistance, so no energy is dissipated by resistive heating ( $I^2R = 0$ ). [1] A large current can therefore be sustained without that heating loss, and a large current produces a strong magnetic field. [1] Cooling equipment can still consume energy; do not claim that the whole installation needs no power.

**Teacher prompt / common error:** Separate a coil’s resistive heating from the energy used to keep the installation cold.

21. A conventional ground charging cable has resistance 0.0400 Ω and carries 500 A. Its heating loss is given by  $P(\text{loss}) = I^2R$ . A replacement superconducting cable has zero resistance but requires a cooling plant using 2.00 kW. Calculate the reduction in total power loss and explain why the whole system is not loss-free. Ignore all other losses. [3 marks]

**Answer / mark points:** Conventional heating loss =  $500^2 \times 0.0400 = 10\,000\text{ W} = 10.0\text{ kW}$ . [1] New cable heating loss = 0, so the reduction in total loss =  $10.0 - 2.00 = 8.00\text{ kW}$ . [1] The cooling plant still uses 2.00 kW, so the whole system is not loss-free. [1] Distinguish cable resistive loss from total system energy use.

**Teacher prompt / common error:** Count the cooling power in the new total. Zero cable resistance does not imply 100% system efficiency.

22. An engineer suggests replacing the aircraft’s copper power leads with superconducting leads. Give two practical difficulties that must be considered even if the superconducting leads have zero resistivity. [2 marks]

**Answer / mark points:** Award any two independent context-linked difficulties [1 each]: maintaining the leads at/below their material’s critical temperature; the mass/volume of cooling equipment or coolant on the aircraft; cooling energy reducing flight endurance; added cost or practical insulation/cryogenic-safety requirements. Do not credit ‘the resistivity is only almost zero’ or a claim that all materials become superconducting at the same temperature.

**Teacher prompt / common error:** A valid limitation must apply to the proposed aircraft installation; critical-field theory is not required here.

### Language and method check

Award independent physics points only, with error-carried-forward where appropriate.

Review graph-reading precision and the distinction between zero cable resistance and total installation energy use.

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