

## OCR A AS Potential Dividers and Sensor Circuits solutions

*Matching solutions and teaching prompts for the class review*

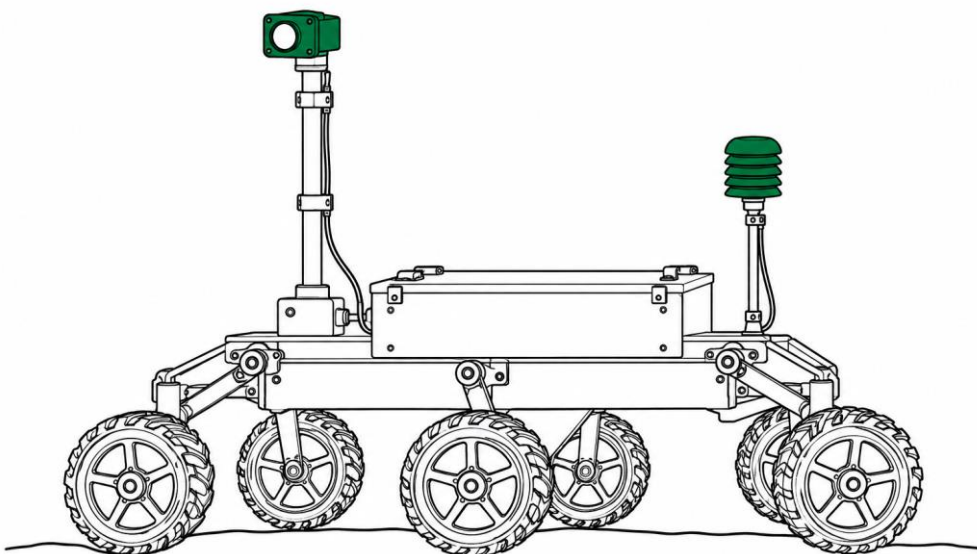
### Specification points covered

- 4.3.3(a) Describe potential divider circuits with fixed components and potentiometers.
- 4.3.3(b) Describe potential divider circuits with variable components such as LDRs or thermistors.
- 4.3.3(c)(i) Use  $V_{\text{out}} = [R_2/(R_1 + R_2)]V_{\text{in}}$  and  $V_1/V_2 = R_1/R_2$ .
- 4.3.3(c)(ii) Use techniques and procedures to investigate potential divider circuits including sensors.

### Teaching focus

Require pupils to identify the reference rail and the component directly across  $V_{\text{out}}$  before they calculate or describe a change.

For sensor explanations, use the sequence: environmental quantity changes, sensor resistance changes, current or voltage share changes,  $V_{\text{out}}$  changes.



*Context diagram: the Kestrel rover and its light and temperature sensing systems.*

**Complete the Module 4 end-of-topic exam**

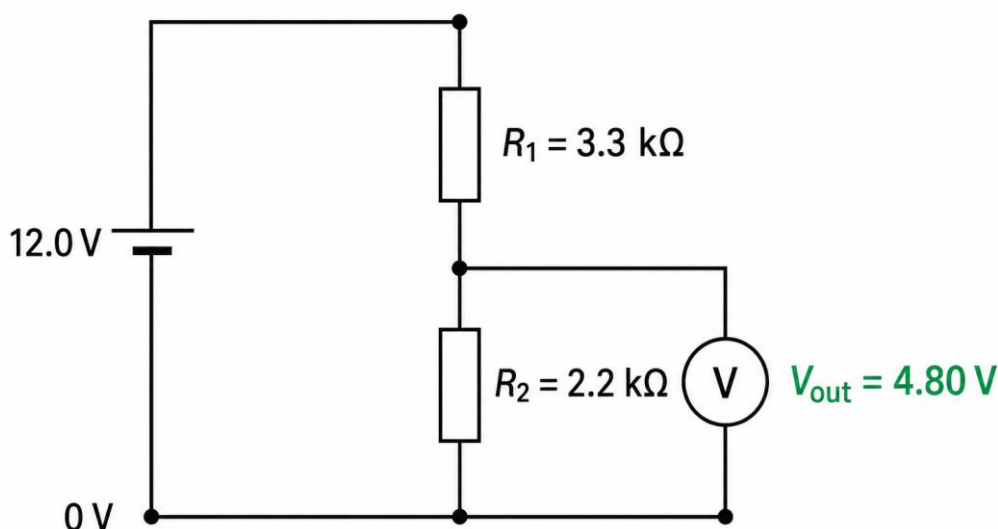
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## 1 Fixed potential dividers

1. The diagram shows a fixed potential divider on the rover's calibration panel. Calculate  $V_{\text{out}}$  and the p.d. across  $R_1$ . [2 marks]



*Solution circuit: the voltmeter is across  $R_2$ , so its reading is the p.d. across  $R_2$ .*

**Answer / mark points:**  $V_{\text{out}} = [R_2/(R_1 + R_2)]V_{\text{in}} = [2.2/(3.3 + 2.2)] \times 12.0 = 4.80 \text{ V}$ . The p.d. across  $R_1$  is  $12.0 - 4.80 = 7.20 \text{ V}$ .

**Teacher prompt / common error:** The resistor across which  $V_{\text{out}}$  is measured must be in the numerator. Here that is  $R_2$ , the lower resistor.

2. Calculate the current through  $R_1$  and  $R_2$  in the circuit in Question 1. [1 mark]

**Answer / mark points:**  $I = V_{\text{in}}/(R_1 + R_2) = 12.0/(5.5 \times 10^3) = 2.18 \times 10^{-3} \text{ A} = 2.18 \text{ mA}$ . The same current passes through both series resistors.

**Teacher prompt / common error:** The two resistors are in series, so one current passes through both. Convert kilohms to ohms before giving current in amperes.

3. The engineers keep  $R_1 = 3.3 \text{ k}\Omega$  but require  $V_{\text{out}} = 7.20 \text{ V}$  from the 12.0 V supply. Calculate the required value of  $R_2$ . [2 marks]

**Answer / mark points:**  $7.20/12.0 = R_2/(3.3 + R_2)$ , with resistances in  $\text{k}\Omega$ . Hence  $0.600(3.3 + R_2) = R_2$ , so  $R_2 = 4.95 \text{ k}\Omega$ .

**Teacher prompt / common error:** Do not assume that 60% of the input voltage requires 60% of  $R_1$ . Solve using the whole divider resistance.

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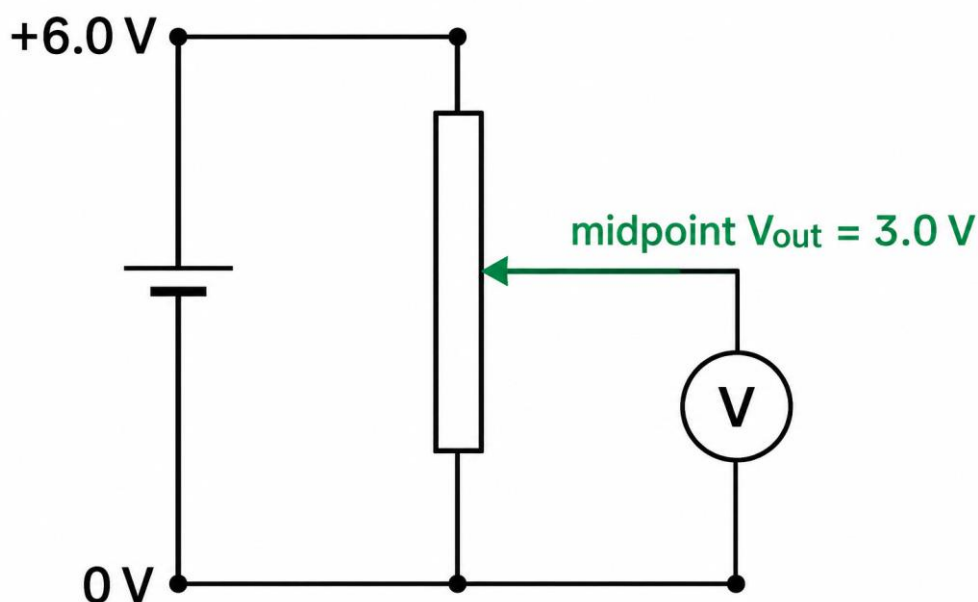
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## 2 Potentiometer control

4. The rover uses the potentiometer shown to set a reference voltage. State  $V_{\text{out}}$  when the wiper is at the midpoint. Explain why moving the wiper allows  $V_{\text{out}}$  to vary continuously from approximately 0 V to 6.0 V. [2 marks]



*Solution circuit: a midpoint wiper divides the track resistance equally.*

**Answer / mark points:** At the midpoint, the track is divided into equal resistances, so  $V_{\text{out}} = 3.0 \text{ V}$ . Moving the wiper changes the resistance between the wiper and each end; from the 0 V end to the +6.0 V end, the output can be adjusted continuously from approximately 0 V to 6.0 V.

**Teacher prompt / common error:** A potentiometer is one continuous resistive track with a third, movable wiper connection. The output is measured from the wiper to the chosen reference end.

5. The potentiometer track has total resistance 10.0 k $\Omega$ . The wiper is 25% of the track length from the +6.0 V end. Calculate  $V_{\text{out}}$  measured from the wiper to 0 V. [1 mark]

**Answer / mark points:** The resistance below the wiper is 75% of the track: 7.50 k $\Omega$ .  $V_{\text{out}} = (7.50/10.0) \times 6.0 = 4.50 \text{ V}$ .

**Teacher prompt / common error:** Because  $V_{\text{out}}$  is measured to 0 V, use the resistance below the wiper: 75% of the track, not 25%.

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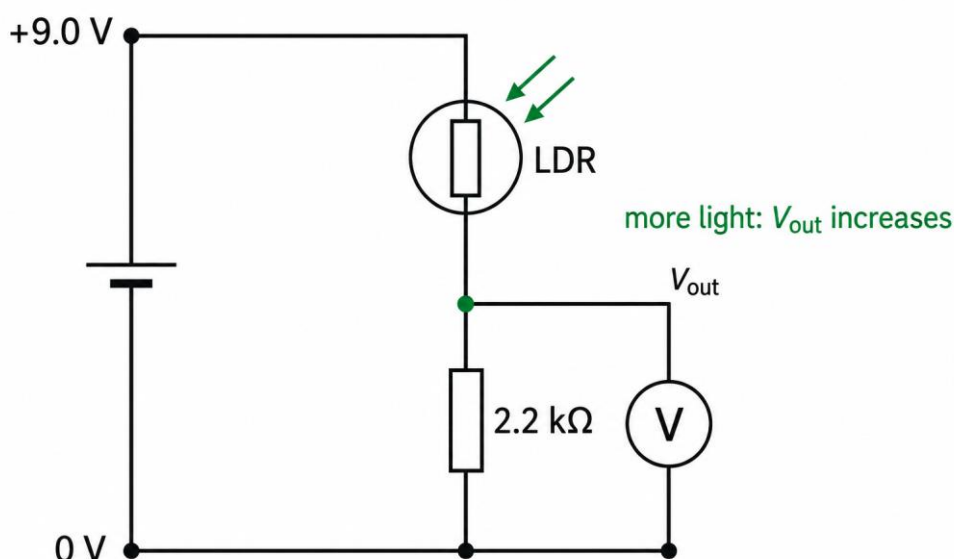
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### 3 Cave entry light sensor

6. The diagram and table describe the rover's cave-entry light sensor. Calculate  $V_{\text{out}}$  when the rover is in very dark conditions. [2 marks]



*Solution circuit: more light reduces  $R_{\text{LDR}}$  and increases the p.d. across the lower fixed resistor.*

| Lighting condition     | LDR resistance / kΩ |
|------------------------|---------------------|
| Very dark              | 18.0                |
| Bright inspection lamp | 0.680               |

**Answer / mark points:** In darkness  $R_{\text{LDR}} = 18.0 \text{ k}\Omega$ .  $V_{\text{out}} = [2.2 / (18.0 + 2.2)] \times 9.0 = 0.980 \text{ V}$ .

**Teacher prompt / common error:** Keep both resistances in the same unit. A high upper resistance leaves only a small p.d. across the lower resistor.

7. Calculate  $V_{\text{out}}$  when the inspection lamp shines brightly on the LDR. State whether  $V_{\text{out}}$  increases or decreases compared with Question 6. [2 marks]

**Answer / mark points:** In bright light  $R_{\text{LDR}} = 0.680 \text{ k}\Omega$ .  $V_{\text{out}} = [2.2 / (0.680 + 2.2)] \times 9.0 = 6.88 \text{ V}$ .  $V_{\text{out}}$  increases.

**Teacher prompt / common error:** An LDR's resistance decreases as light intensity increases. Do not reverse this relationship.

8. Without simply quoting the potential-divider equation, explain why  $V_{\text{out}}$  increases when more light reaches the LDR. [3 marks]

**Answer / mark points:** Greater light intensity decreases the resistance of the LDR. The total series resistance decreases, so the circuit current increases. The lower fixed resistance is unchanged, so its p.d.  $V_{\text{out}} = IR$  increases. Equivalently, it receives a larger share of the fixed supply p.d.

**Teacher prompt / common error:** Use the full causal chain: light intensity, LDR resistance, current or voltage share, then  $V_{\text{out}}$ .

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## 4 Selecting and reversing the light sensor

9. The controller must receive  $V_{\text{out}}$  greater than 6.0 V in bright light but less than 1.0 V in very dark conditions. The available fixed resistors are 1.0 k $\Omega$ , 2.2 k $\Omega$  and 4.7 k $\Omega$ . Select the resistor that meets both conditions and justify your choice with calculations. [3 marks]

**Answer / mark points:** The 2.2 k $\Omega$  resistor is the only suitable choice. Bright:  $V_{\text{out}} = [2.2/(0.680 + 2.2)] \times 9.0 = 6.88$  V, which is greater than 6.0 V. Dark:  $V_{\text{out}} = [2.2/(18.0 + 2.2)] \times 9.0 = 0.980$  V, which is less than 1.0 V. For comparison, 1.0 k $\Omega$  gives only 5.36 V when bright, while 4.7 k $\Omega$  gives 1.86 V when dark.

**Teacher prompt / common error:** Test both environmental conditions. A resistor that passes only the bright condition is not a valid design.

10. The LDR and fixed resistor are exchanged, and  $V_{\text{out}}$  is now measured across the LDR. Describe and explain how  $V_{\text{out}}$  changes when the light intensity increases. [2 marks]

**Answer / mark points:** With  $V_{\text{out}}$  across the LDR, increasing light intensity decreases  $R_{\text{LDR}}$ . Its share of the total series resistance and therefore its share of the supply p.d. decrease, so  $V_{\text{out}}$  decreases.

**Teacher prompt / common error:** Swapping the components reverses the sensor response because the output is now measured across the component whose resistance decreases.

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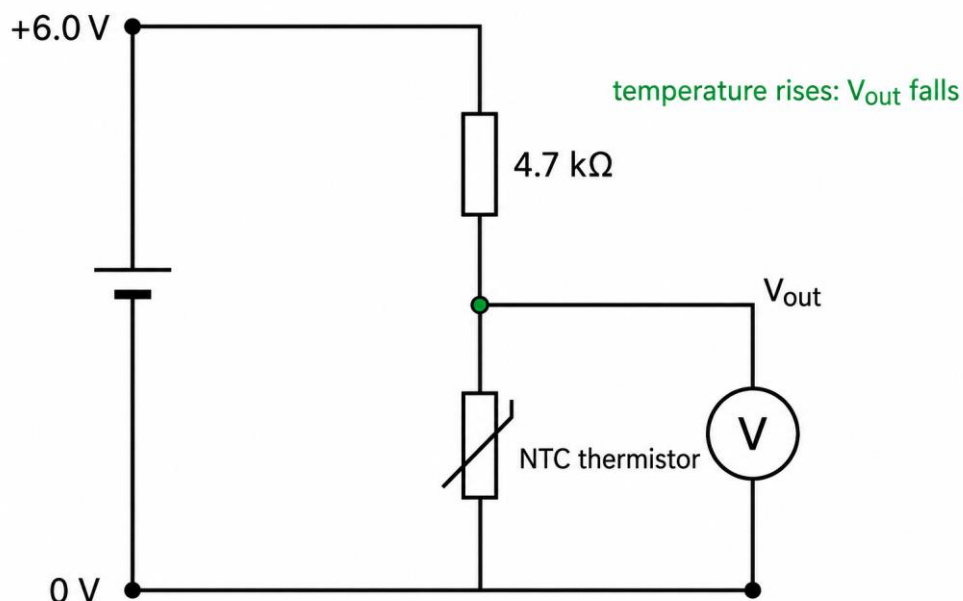
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## 5 Electronics bay temperature sensor

11. The diagram and table describe the electronics-bay temperature sensor. Calculate  $V_{\text{out}}$  at 20 °C and at 60 °C. [2 marks]



*Solution circuit: heating reduces the NTC resistance and therefore reduces  $V_{\text{out}}$  across it.*

| Temperature / °C | NTC resistance / kΩ |
|------------------|---------------------|
| 20               | 12.0                |
| 30               | 8.0                 |
| 40               | 4.7                 |
| 50               | 3.0                 |
| 60               | 2.0                 |

**Answer / mark points:** At 20 °C,  $V_{\text{out}} = [12.0 / (4.7 + 12.0)] \times 6.0 = 4.31 \text{ V}$ . At 60 °C,  $V_{\text{out}} = [2.0 / (4.7 + 2.0)] \times 6.0 = 1.79 \text{ V}$ .

**Teacher prompt / common error:** The voltmeter is across the thermistor, so the thermistor resistance belongs in the numerator.

12. The controller activates a cooling fan when  $V_{\text{out}}$  falls to 3.0 V. Use the divider equation and the table to determine the activation temperature. [2 marks]

**Answer / mark points:** For  $V_{\text{out}} = 3.0 \text{ V}$  from 6.0 V, the thermistor and 4.7 kΩ resistor must have equal resistance. The table shows  $R_{\text{NTC}} = 4.7 \text{ kΩ}$  at 40 °C, so the fan activates at 40 °C.

**Teacher prompt / common error:** Half the input voltage occurs when the two series resistances are equal.

13. Explain why  $V_{\text{out}}$  falls as the temperature of the NTC thermistor rises. Refer to resistance, current or voltage sharing in your answer. [3 marks]

**Answer / mark points:** An NTC thermistor's resistance decreases as temperature rises. The total series resistance decreases and the current increases, but the thermistor becomes a smaller fraction of the total resistance. Its p.d.  $V_{\text{out}}$  therefore falls.

**Teacher prompt / common error:** Do not say the voltage is used up. Describe the p.d. across the thermistor or its share of the fixed supply p.d.

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## 6 Setting a temperature threshold

14. A different controller requires an output that increases as temperature rises. State how the thermistor and fixed resistor should be rearranged, and explain the resulting change in  $V_{\text{out}}$ . [2 marks]

**Answer / mark points:** Place the NTC thermistor above the junction and the fixed resistor below it, with  $V_{\text{out}}$  measured across the fixed resistor. As temperature rises,  $R_{\text{NTC}}$  decreases, the current increases and the p.d. across the unchanged fixed resistor increases.

**Teacher prompt / common error:** To make the output rise with temperature, measure across the unchanged fixed resistor while the upper NTC resistance falls.

15. At 30 °C the NTC thermistor has resistance 8.0 k $\Omega$ . It is used as the upper component of a 6.0 V divider. Calculate the lower fixed resistance required to give  $V_{\text{out}} = 4.0$  V. [2 marks]

**Answer / mark points:**  $4.0/6.0 = R/(8.0 + R)$ . Therefore  $4(8.0 + R) = 6R$  and  $R = 16.0$  k $\Omega$ .

**Teacher prompt / common error:** Use the lower fixed resistance in the numerator because  $V_{\text{out}}$  is measured across it.

16. Engineers replace the lower fixed resistor in Question 15 with a potentiometer. Explain one advantage of this change and state what happens to  $V_{\text{out}}$  when the resistance below the wiper is increased. [2 marks]

**Answer / mark points:** The potentiometer allows the threshold or calibration voltage to be adjusted without replacing a resistor. Increasing the resistance between the wiper and 0 V increases the fraction of  $V_{\text{in}}$  measured as  $V_{\text{out}}$ , so  $V_{\text{out}}$  increases.

**Teacher prompt / common error:** A potentiometer changes the divider ratio and therefore calibrates the output or threshold.

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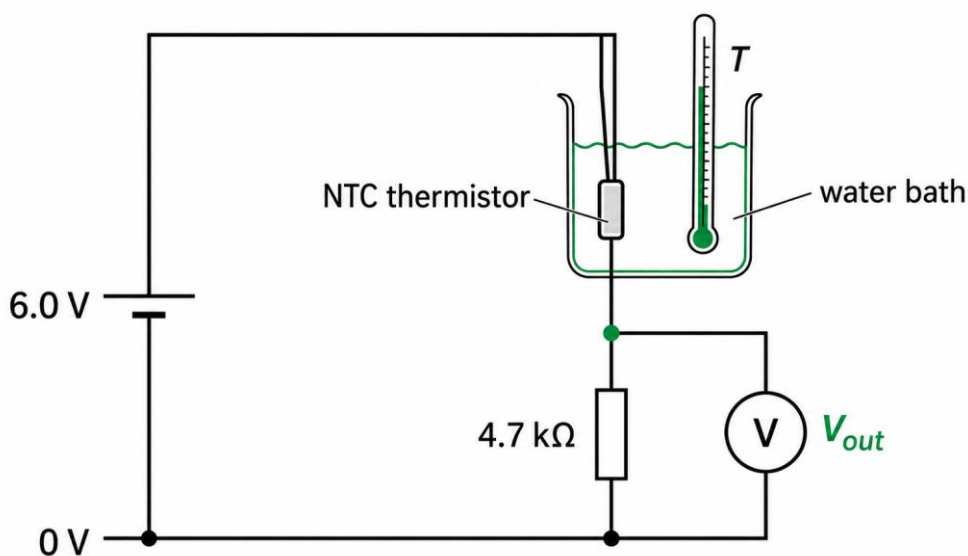
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## 7 Investigating and calibrating a sensor divider

17. Before deployment, engineers investigate how  $V_{\text{out}}$  from an NTC-thermistor potential divider varies with temperature. Describe a complete method. Include a correctly connected circuit, how temperature is varied and measured, the readings taken, the graph plotted and steps used to improve reliability. [6 marks]



*One valid calibration arrangement: record temperature and  $V_{\text{out}}$  while keeping the supply p.d. constant.*

**Answer / mark points:** Indicative Level 3 content: connect an NTC thermistor and fixed resistor in series across a stable low-voltage d.c. supply; connect a high-resistance voltmeter across the chosen lower component; immerse the thermistor and a thermometer in a stirred water bath without allowing electrical connections to contact the water; vary temperature over a suitable range using warm water and cooling, and wait for thermal equilibrium; record paired temperature and  $V_{\text{out}}$  readings at regular intervals; keep  $V_{\text{in}}$  and the fixed resistance constant; repeat readings or take readings during both warming and cooling; plot  $V_{\text{out}}$  on the y-axis against temperature on the x-axis and draw a smooth calibration curve; keep current low or use brief readings to reduce self-heating. Level 2 gives a workable circuit and measurements with some processing. Level 1 gives limited apparatus or procedure.

**Teacher prompt / common error:** Essential marks are a correct series divider, a voltmeter across one component, paired temperature and  $V_{\text{out}}$  readings, a controlled supply, a suitable graph and reliability precautions.

18. Explain two precautions that reduce error caused by self-heating or thermal lag during the investigation in Question 17. [2 marks]

**Answer / mark points:** Use a sufficiently large, stirred water bath and wait until the thermometer and thermistor readings are steady before recording; this reduces temperature gradients and thermal lag. Use a low supply p.d. or take brief readings so current does not significantly heat the thermistor itself. Credit any two clear precaution-and-reason links.

**Teacher prompt / common error:** Name the source of error and link each precaution to it. 'Repeat the experiment' alone does not address self-heating or lag.

### Language and method check

Potential difference is measured across a component; it does not flow through the component.

An LDR's resistance decreases as light intensity increases, and an NTC thermistor's resistance decreases as temperature increases.

A potentiometer has a resistive track and a movable wiper; the output depends on the resistance between the wiper and the chosen reference end.

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