

Potential dividers solutions

AQA AS and A level Physics 7407 and 7408

Museum display protection and control

Matching questions with worked solutions and teaching prompts 41 marks

Specification points covered

3.5.1.5 Potential dividers supplying constant or variable pd; variable resistors, LDRs and thermistors; circuit design and investigation.

3.5.1.3 Selected content: NTC thermistors as temperature sensors.

3.5.1.4 Selected content: series and parallel resistance, current and pd relationships, electrical power and conservation of charge.

1 Limiting light exposure

A museum display uses a motorised blind to limit light exposure. A sensor measures illuminance in lux (lx). The regulated supply holds the rails in Figure 1 at 6.00 V and 0 V. V_{out} is the pd of M relative to B. The blind is commanded to close when $V_{\text{out}} \leq 2.00$ V. Initially $R = 12.0$ k Ω and the controller draws negligible current. Table 1 gives the LDR data before the blind moves.

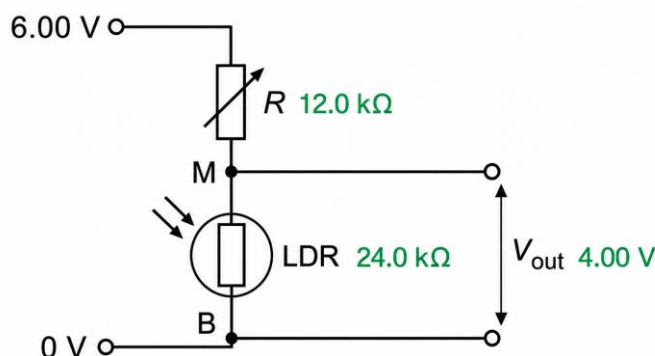


Figure 1 50 lx operating point; not to scale

Table 1

Illuminance / lx	20	50	100	200	400
LDR R_L / k Ω	48.0	24.0	12.0	6.00	3.00

1(a) At an illuminance of 50 lx, calculate the current through the LDR. Give your answer in mA. [1 mark]

Answer and mark points

At 50 lx, $R_L = 24.0$ k Ω . $I = 6.00 / (12.0 + 24.0) = 0.166667$ mA = 0.167 mA. A1

Teaching prompt

Use the total resistance to find the series current. V_s / R_L alone would incorrectly put all the supply pd across the LDR.

1(b) Calculate the output potential difference at 50 lx. [1 mark]

Answer and mark points

$V_{\text{out}} = I R_L = (0.166667 \text{ mA})(24.0 \text{ k}\Omega) = 4.00$ V. A1 Accept the potential-divider ratio.

Teaching prompt

The output is the pd of M relative to B, across the lower component, not the upper resistor.

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1 Selecting the light response

1(c) Starting with $V = IR$, show that $V_{\text{out}} = V_s R_L / (R + R_L)$, where R_L is the LDR resistance. State the condition about output current needed for this result. **[2 marks]**

Answer and mark points

With negligible output current, the same current I passes through R and the LDR. $V_s = I(R + R_L)$, so $I = V_s / (R + R_L)$. M1 $V_{\text{out}} = I R_L$ gives $V_{\text{out}} = V_s R_L / (R + R_L)$. A1 Award this mark only when the substitution is shown and the negligible-output-current condition is stated.

Teaching prompt

The formula assumes equal current in both components. A connected load can invalidate it.

1(d) Calculate the output potential difference at 100 lx and at 400 lx. For each value, state whether the blind is commanded to close. **[2 marks]**

Answer and mark points

At 100 lx, $V_{\text{out}} = 6.00 \times 12.0 / (12.0 + 12.0) = 3.00$ V. This is above 2.00 V, so no closing command is sent. A1
At 400 lx, $V_{\text{out}} = 6.00 \times 3.00 / (12.0 + 3.00) = 1.20$ V. This is below 2.00 V, so the blind is commanded to close. A1 Each mark requires the matching correct decision.

Teaching prompt

Apply the stated trigger rule; the threshold need not be half the supply pd.

1(e) Explain why the output potential difference decreases when the light intensity increases, even though the current from the supply increases. **[2 marks]**

Answer and mark points

Greater light intensity decreases R_L ; the total series resistance decreases, so the supply current increases. B1
 $R_L / (R + R_L)$ decreases, so a smaller fraction of the fixed 6.00 V appears across the LDR. Equivalently, I increases so the pd across the fixed R increases, leaving a smaller pd across the LDR. B1

Teaching prompt

More current need not mean more pd when that component resistance also changes.

1(f) Determine the setting of R required for the blind to start closing at 200 lx when V_{out} reaches 2.00 V. **[2 marks]**

Answer and mark points

At 200 lx, $R_L = 6.00$ k Ω . $2.00 = 6.00 \times 6.00 / (R + 6.00)$, with resistance values in k Ω . M1
 $R + 6.00 = 18.0$, giving $R = 12.0$ k Ω . A1 A derivation by current or voltage ratios is equally valid.

Teaching prompt

At a specified trigger condition, use the sensor resistance at that condition, not at an arbitrary room-light reading.

1(g) A technician swaps the positions of R and the LDR, but still measures the output from M to B and uses the same closing rule. Explain why this would not give the intended response as the light intensity increases. **[2 marks]**

Answer and mark points

The output is now across R . Increasing light intensity lowers the LDR resistance and increases I , so $V_{\text{out}} = IR$ increases rather than decreases. B1
The rule $V_{\text{out}} \leq 2.00$ V therefore closes the blind at low light rather than high light. B1

Teaching prompt

Identify which component has the measured pd across it before describing the response. Swapping components reverses the output trend.

1(h) Return to Figure 1 with R fixed at 12.0 k Ω . In very intense light the LDR resistance approaches zero. Determine the maximum power dissipated in R and decide whether a resistor rated at 0.010 W is suitable. **[2 marks]**

Answer and mark points

As R_L approaches zero, almost all 6.00 V is across R . $P_{\text{max}} = V_s^2 / R = 6.00^2 / (12.0 \times 10^3) = 3.00 \times 10^{-3}$ W. M1
3.00 mW < 10.0 mW, so the 0.010 W resistor is suitable under the stated ideal model. A1

Teaching prompt

A power rating is the maximum permitted dissipation, not the actual operating power.

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2 Monitoring the display temperature

A separate divider monitors the display case temperature (Figure 2). The top component T is an NTC thermistor. The lower variable resistor is set to $R = 9.00 \text{ k}\Omega$. The output is again the pd of M relative to B, now across R. A cooling fan is commanded to run when $V_{\text{out}} \geq 3.60 \text{ V}$. The fan is powered separately; the control input draws negligible current. Table 2 gives the thermistor calibration.

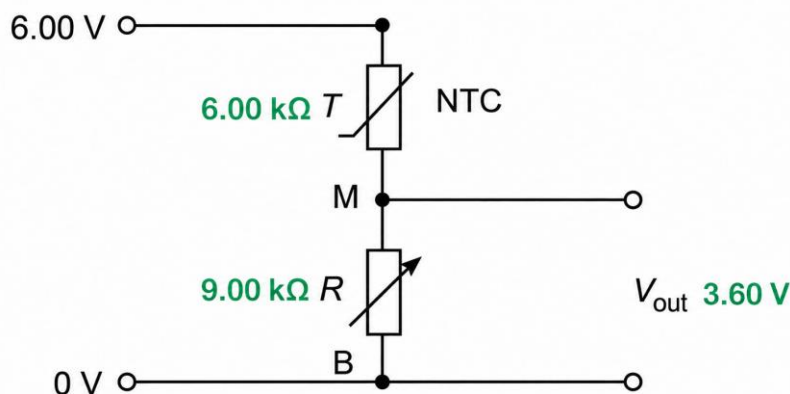


Figure 2 40 °C trigger condition; not to scale

Table 2

Temperature / °C	20	30	40	50
Thermistor R_T / $\text{k}\Omega$	24.0	12.0	6.00	3.00

2(a) Calculate the output potential difference when the thermistor is at 30 °C. [1 mark]

Answer and mark points

At 30 °C, $R_T = 12.0 \text{ k}\Omega$. $V_{\text{out}} = 6.00 \times 9.00 / (12.0 + 9.00) = 2.57 \text{ V}$. A1

Teaching prompt

The output is across R, unlike the LDR output in Figure 1. The numerator must match the output terminals.

2(b) Explain why increasing the thermistor temperature increases the output potential difference in Figure 2. [2 marks]

Answer and mark points

For an NTC thermistor, resistance decreases as temperature increases. B1

The total series resistance decreases, increasing I. The output is across the unchanged R, so $V_{\text{out}} = IR$ increases. B1

Accept an equivalent argument using the increasing fraction $R/(R_T + R)$.

Teaching prompt

Write resistance decreases and output pd increases. Avoid saying that voltage or current is used up.

2(c) Identify the lowest temperature listed in Table 2 at which the fan is commanded to run. Support your answer with output potential differences at this temperature and the preceding listed temperature. [2 marks]

Answer and mark points

At 30 °C the output is 2.57 V, below the 3.60 V trigger. M1

At 40 °C, $V_{\text{out}} = 6.00 \times 9.00 / (6.00 + 9.00) = 3.60 \text{ V}$. Hence 40 °C is the first listed temperature that commands the fan to run. A1

Teaching prompt

At the threshold itself, the given rule includes equality. Check both sides of a claimed first listed trigger temperature.

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2 Calibrating and installing the sensor

2(d) The museum wants the fan to start at a lower temperature without changing its 3.60 V trigger. Should R be increased or decreased? Explain your answer. **[2 marks]**

Answer and mark points

Increase R. This increases the fraction $R/(R_T + R)$, so the output is greater at the same temperature. B1

The 3.60 V threshold is then reached with a larger thermistor resistance, which corresponds to a lower temperature. B1 A higher current is not the correct explanation when R itself is increased.

Teaching prompt

Increasing R raises the output fraction but reduces the series current at a fixed temperature. Use the ratio to explain the output change.

2(e) Describe a laboratory method to calibrate the complete temperature-divider circuit before installation. Include how temperature and output potential difference are measured, how dependable readings are obtained, and how the readings are used to find the fan trigger temperature. **[4 marks]**

Answer and mark points

Use a gently warmed, stirred water bath with the thermistor and a thermometer close together. Keep the supply and other components out of the water. Use a waterproof probe if needed. B1

Keep the regulated supply at 6.00 V and R at its chosen setting. Connect a high-resistance voltmeter between M and B, in parallel with R, and measure V_{out} . B1

Take several paired temperature and voltage readings over a range either side of the trigger. Allow thermal equilibrium at each step; repeat readings or repeat during slow cooling and check agreement. Avoid appreciable thermistor self-heating. B1

Plot V_{out} against measured temperature or use sufficiently close readings to interpolate where $V_{out} = 3.60$ V. Check the fan command at that temperature. B1 Accept another workable controlled-temperature method. Maximum 4 marks, not one mark per apparatus item.

Teaching prompt

Calibration needs paired measurements of the actual output and temperature, not just a list of thermistor resistances. Wait for thermal equilibrium.

2(f) The fan must respond to the air temperature inside the display case. A technician attaches the thermistor directly to the warm lamp housing. Explain why this could start the fan too early and suggest a better sensor position. **[2 marks]**

Answer and mark points

The thermistor measures its own local temperature. The lamp housing can be hotter than the case air, so the sensor can reach the trigger before the air does. B1

Place it in representative case air, away from direct contact with the lamp and shielded from direct heating by lamp radiation, while allowing air to circulate around it. B1

Teaching prompt

A correct electronic threshold is not sufficient if the sensor is sampling the wrong physical location.

Using the mark scheme

B1 is an independent statement mark, M1 a method or reasoning mark, and A1 an answer mark. Each denotes one mark; each part is capped at its stated total.

Accept correct equivalent methods. Follow through an earlier numerical error when later reasoning remains physically consistent. Do not credit an incorrect switching decision that contradicts the result used.

A correct numerical answer with suitable units can receive full calculation credit unless working, a derivation or an explanation is explicitly requested. The conditions for each decision are part of the answer.

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3 Setting a reference potential difference

Figure 3 sets an adjustable controller reference. Uniform track AB is 60.0 mm long with resistance 12.0 k Ω . A is at 6.00 V and B at 0 V. Sliding contact C draws negligible current. The output is the pd of C relative to B. Do not measure the diagram.

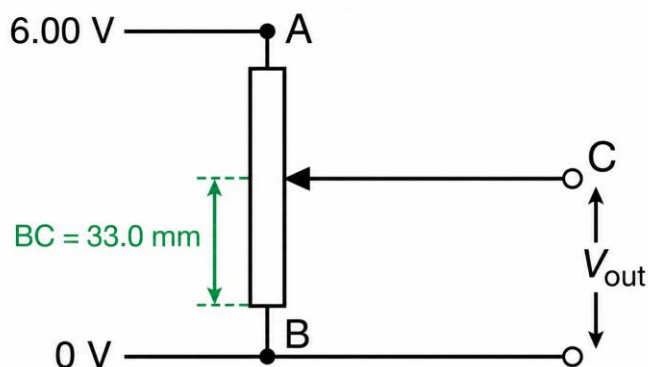


Figure 3 Not to scale

3(a) The controller requires a reference of 3.30 V. Determine the distance from B to C along the resistive track. **[2 marks]**

Answer and mark points

For a uniform track and negligible output current, $V_{\text{out}}/6.00 = R_{\text{BC}}/R_{\text{AB}} = \text{BC}/60.0 \text{ mm}$. M1
 $\text{BC} = (3.30/6.00) \times 60.0 = 33.0 \text{ mm}$ from B towards A. A1 The distance from A would be 27.0 mm.

Teaching prompt

Reference the slider distance to the 0 V end B. The drawn slider position is schematic and must not be measured.

3(b) An alternative places a variable resistor, maximum 12.0 k Ω , in series with a 4.00 k Ω input across 6.00 V. Calculate the minimum pd across the input. Explain why the unloaded three-terminal slider is preferable for a reference adjustable from 0 V to 6.00 V. **[2 marks]**

Answer and mark points

The minimum pd across the input is $6.00 \times 4.00/(12.0 + 4.00) = 1.50 \text{ V}$, not zero. A1
 The unloaded three-terminal slider takes any fraction of the supply: 0 V with C at B through to 6.00 V with C at A. It therefore provides the required full reference range. B1

Teaching prompt

A series rheostat can leave a nonzero minimum pd across an input of finite resistance. A three-terminal unloaded divider has two fixed end potentials.

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4 Investigating controller loading

The replacement blind controller behaves as a $12.0\text{ k}\Omega$ resistor across M and B (Figure 4). It still commands closing when $V_{\text{out}} \leq 2.00\text{ V}$. Set the upper R to $12.0\text{ k}\Omega$. Use the same 6.00 V supply and Table 1, with negligible LDR self-heating. Analyse the light level before the blind moves.

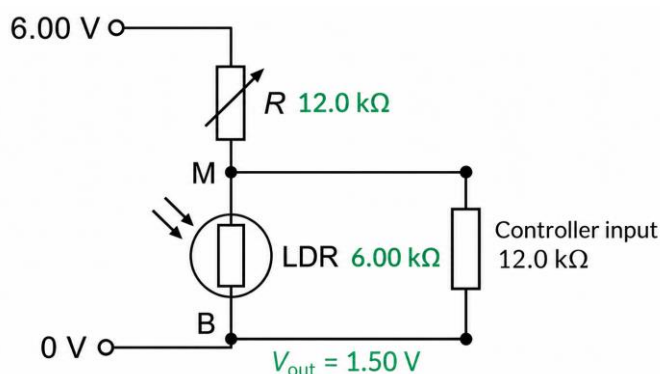


Figure 4 200 lx operating point; not to scale

4(a) At 200 lx, determine the effective resistance between M and B and the loaded output potential difference. State whether the blind is commanded to close. **[3 marks]**

Answer and mark points

The LDR and controller are in parallel: $R_p = (6.00 \times 12.0)/(6.00 + 12.0) = 4.00\text{ k}\Omega$. M1

$V_{\text{out}} = 6.00 \times 4.00/(12.0 + 4.00) = 1.50\text{ V}$. A1

Since $1.50\text{ V} \leq 2.00\text{ V}$, the blind is commanded to close. B1

Teaching prompt

Combine the controller and LDR in parallel before applying the divider ratio.

4(b) Determine the LDR resistance when the loaded circuit first reaches the 2.00 V closing threshold. Use Table 1 to identify the corresponding illuminance and explain how this changes the intended operation. **[3 marks]**

Answer and mark points

At threshold, $2.00 = 6.00 R_p/(12.0 + R_p)$, so $R_p = 6.00\text{ k}\Omega$. M1

$1/R_L = 1/6.00 - 1/12.0$ (in $\text{k}\Omega^{-1}$), giving $R_L = 12.0\text{ k}\Omega$. A1

Table 1 gives 100 lx, so the blind closes too early: at 100 lx rather than 200 lx. B1

Teaching prompt

Convert the new LDR resistance into a light level to judge whether the trigger is correct.

4(c) A replacement controller has an input resistance of $12.0\text{ M}\Omega$. At 200 lx, calculate its loaded output potential difference and percentage difference from the unloaded value. Decide whether it meets a requirement that loading changes the output by less than 1%. **[2 marks]**

Answer and mark points

$R_p = (6000 \times 12.0 \times 10^6)/(6000 + 12.0 \times 10^6) = 5997.0015\text{ }\Omega$. $V_{\text{out}} = 6.00 R_p/(12000 + R_p) = 1.99933\text{ V}$. M1

The unloaded value is 2.00 V . Percentage change = $(2.00 - 1.99933)/2.00 \times 100 = 0.0333\%$. This is below 1%, so the replacement meets the requirement. A1

Teaching prompt

Use consistent units. A high input resistance reduces loading; the input remains in parallel.

4(d) Compare the currents with the unloaded divider at the same illuminance of 200 lx. Explain why connecting the $12.0\text{ k}\Omega$ controller increases the current from the supply but decreases the current through the LDR. **[2 marks]**

Answer and mark points

Adding the parallel branch lowers the total resistance from $18.0\text{ k}\Omega$ to $16.0\text{ k}\Omega$. Supply current therefore rises from $6.00/18.0 = 0.333\text{ mA}$ to $6.00/16.0 = 0.375\text{ mA}$, using resistances in $\text{k}\Omega$. B1

The LDR pd falls from 2.00 V to 1.50 V at unchanged resistance, $6.00\text{ k}\Omega$. Its current falls from 0.333 mA to $1.50/6.00 = 0.250\text{ mA}$. The other 0.125 mA flows through the controller. B1

Teaching prompt

The current from the supply divides at M. Charge is conserved: $0.375\text{ mA} = 0.250\text{ mA} + 0.125\text{ mA}$.

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