

AQA AS Series and parallel circuits

Matching solutions and teaching prompts for the class review

Specification points covered

• 3.5.1.4 Circuits: resistors in series and parallel; current, potential difference and resistance relationships; conservation of charge and energy in dc circuits.

• 3.5.1.4 Circuits: cells in series and identical cells in parallel; energy $E = IVt$ and power $P = IV = I^2R = V^2/R$; constructing circuits and measuring current and potential difference.

Teaching focus

Use conservation of charge for current relationships and conservation of energy for voltage relationships. Require the correct component current or voltage in every power calculation. Contrast a simple parallel network with branches sharing a series resistor. Treat cell-bank operating times as ideal-model predictions.

Testing a series circuit

1. A remote weather station is tested using a $6.0\ \Omega$ resistor and an $18\ \Omega$ resistor connected in series to a $12\ \text{V}$ supply. Calculate their total resistance. [1 mark]

Answer / mark points: $R(\text{total}) = 6.0 + 18 = 24\ \Omega$. [1]

Teacher prompt / common error: Add series resistances; the same current has only one path.

2. For the test circuit in Question 1, calculate (a) the current in each resistor and (b) the potential difference across the $18\ \Omega$ resistor. [2 marks]

Answer / mark points: $I = V/R(\text{total}) = 12/24 = 0.50\ \text{A}$ in each resistor. [1] $V(18\ \Omega) = IR = 0.50 \times 18 = 9.0\ \text{V}$. [1] The other resistor has $3.0\ \text{V}$ across it.

Teacher prompt / common error: The series current is equal in both components, not divided between them.

3. Explain why the currents in the two series resistors are equal and why their potential differences add to $12\ \text{V}$. Refer separately to conservation of charge and conservation of energy. [2 marks]

Answer / mark points: Charge does not accumulate between the resistors, so the same charge passes each resistor per second and their currents are equal. [1] The source transfers $12\ \text{J}$ per coulomb; that energy per coulomb is transferred across the two resistors, so their potential differences add to $12\ \text{V}$. [1] Current is not used up; energy is transferred, not charge consumed.

Teacher prompt / common error: Require charge per second and energy per coulomb. 'Electricity is conserved' is too vague.

4. A technician claims that both series resistors receive $12\ \text{V}$ because they are connected to a $12\ \text{V}$ supply. Use the energy transferred by a $2.0\ \text{C}$ charge in the circuit to show why this claim cannot be correct. [2 marks]

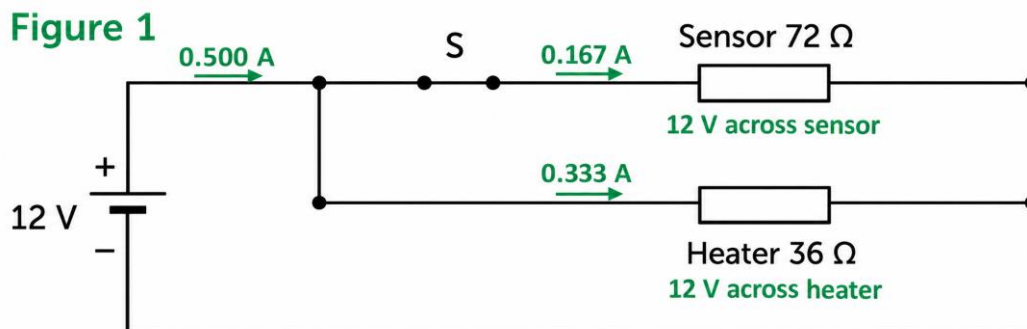
Answer / mark points: The supply transfers $E = QV = 2.0 \times 12 = 24\ \text{J}$ to this charge. [1] If both resistors had $12\ \text{V}$, they would transfer $24 + 24 = 48\ \text{J}$ from the same charge, exceeding the $24\ \text{J}$ supplied and violating conservation of energy. [1] In the actual circuit the transfers are $6\ \text{J}$ and $18\ \text{J}$.

Teacher prompt / common error: Follow the same charge around one loop. Compare total transferred energy with energy supplied.



Keeping the sensor and heater independent

5. Figure 1 models the weather station's sensor electronics and frost heater as constant resistances. Switch S is initially closed. Calculate the current in each branch. [2 marks]



Answer / mark points: Each branch has 12 V across it. Sensor: $I = 12/72 = 0.167$ A. [1] Heater: $I = 12/36 = 0.333$ A. [1] Accept 0.17 A and 0.33 A, retaining unrounded values for later work.

Teacher prompt / common error: Parallel branches share potential difference, not necessarily current.

6. Calculate (a) the current supplied to the circuit in Figure 1 and (b) the combined resistance of the two branches. Check that the combined resistance is smaller than either branch resistance. [2 marks]

Answer / mark points: $I(\text{total}) = 12/72 + 12/36 = 0.500$ A. [1] $R(\text{total}) = 12/0.500 = 24.0$ Ω, smaller than 36 Ω and 72 Ω. [1] Equivalently, $1/R(\text{total}) = 1/72 + 1/36 = 1/24$. Do not add parallel resistances directly.

Teacher prompt / common error: At a junction, total current is the sum of branch currents; adding a path lowers equivalent resistance.

7. The supply can deliver at most 0.800 A. A third resistive branch is added in parallel with the two existing branches. Calculate the minimum resistance of this new branch that keeps the total current within the limit. [2 marks]

Answer / mark points: Maximum extra-branch current = $0.800 - 0.500 = 0.300$ A. [1] $R(\text{minimum}) = V/I(\text{maximum}) = 12/0.300 = 40.0$ Ω. [1] A lower resistance would exceed the supply-current limit; a higher resistance draws less current.

Teacher prompt / common error: The 0.800 A rating applies to the whole supply, not the new branch alone.

8. The frost heater in Figure 1 operates for 5.00 minutes. Calculate the energy transferred to the heater. Assume its resistance remains constant. [2 marks]

Answer / mark points: $P = V^2/R = 12^2/36 = 4.00$ W and $t = 5.00 \times 60 = 300$ s. [1 for power and correct time conversion] $E = Pt = 4.00 \times 300 = 1.20 \times 10^3$ J. [1] Alternatively use $E = IVt$ with the heater current, not the total supply current.

Teacher prompt / common error: Use the current of the component whose energy transfer is requested. Convert minutes to seconds.

9. Switch S in Figure 1 is opened. State the new sensor current, heater current and total supply current. Explain why the heater's power does not change under the stated ideal-supply assumptions. [3 marks]

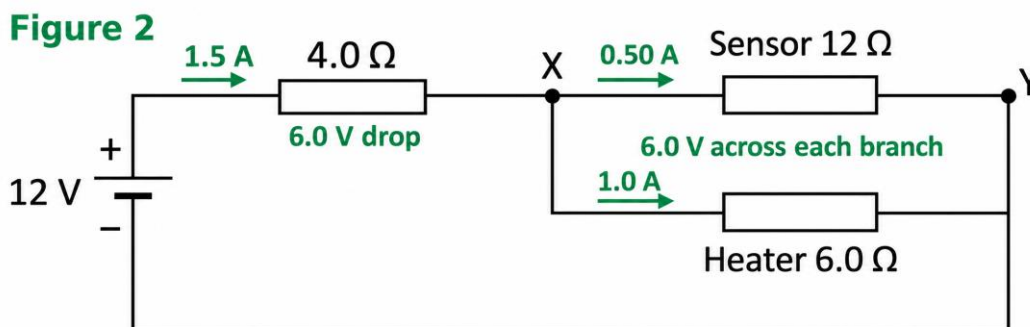
Answer / mark points: Sensor current = 0 A. [1] Heater current remains 0.333 A, so the new total supply current is 0.333 A. [1 for both] The heater remains directly across the ideal 12 V supply; its resistance and voltage are unchanged, so $P = V^2/R$ remains 4.00 W. [1] This conclusion relies on the ideal fixed-voltage supply.

Teacher prompt / common error: Opening a branch is not a short circuit. The other branch still has a complete path across 12 V.



When the branches share a series resistor

10. Figure 2 shows an alternative test circuit. The $4.0\ \Omega$ resistor is in series with the parallel combination of a $12\ \Omega$ sensor model and a $6.0\ \Omega$ heater model. Calculate the total resistance seen by the supply. [2 marks]



Answer / mark points: $1/R(\text{parallel}) = 1/12 + 1/6 = 1/4$, so $R(\text{parallel}) = 4.0\ \Omega$. [1] $R(\text{total}) = 4.0 + 4.0 = 8.0\ \Omega$. [1] The first $4.0\ \Omega$ is one actual component; the second is the equivalent resistance of the two branches.

Teacher prompt / common error: Reduce the parallel pair first. Do not treat all three components as being in series or in parallel.

11. For Figure 2, calculate (a) the supply current and (b) the potential difference between junctions X and Y. [2 marks]

Answer / mark points: $I(\text{supply}) = 12/8.0 = 1.5\ \text{A}$. [1] The series-resistor drop is $1.5 \times 4.0 = 6.0\ \text{V}$, leaving $V(XY) = 12 - 6.0 = 6.0\ \text{V}$. [1] Equivalently $V(XY) = I(\text{supply})R(\text{parallel})$.

Teacher prompt / common error: The branch pair shares the voltage remaining after the common series component.

12. Calculate the currents in the $12\ \Omega$ and $6.0\ \Omega$ branches in Figure 2. Show that your results satisfy conservation of charge at X. [2 marks]

Answer / mark points: $I(\text{sensor}) = 6.0/12 = 0.50\ \text{A}$. [1] $I(\text{heater}) = 6.0/6.0 = 1.0\ \text{A}$, and $0.50 + 1.0 = 1.5\ \text{A}$, equal to the current entering X. [1 for heater current with the junction check] Do not use $12\ \text{V}$ across either branch.

Teacher prompt / common error: Conservation of charge concerns currents at a junction, not equality of all component currents.

13. Calculate the power dissipated in each of the three resistors in Figure 2. Show that their total equals the power supplied by the $12\ \text{V}$ source. [4 marks]

Answer / mark points: $4.0\ \Omega$ resistor: $P = I^2R = 1.5^2 \times 4.0 = 9.0\ \text{W}$. [1]

$12\ \Omega$ sensor: $P = V^2/R = 6.0^2/12 = 3.0\ \text{W}$. [1]

$6.0\ \Omega$ heater: $P = 6.0^2/6.0 = 6.0\ \text{W}$. [1]

Total = $9.0 + 3.0 + 6.0 = 18\ \text{W} = VI(\text{supply}) = 12 \times 1.5$, consistent with conservation of energy. [1] Accept correct equivalent power expressions.

Teacher prompt / common error: Use $1.5\ \text{A}$ only in the common series resistor; use the individual branch currents elsewhere.

14. The $6.0\ \Omega$ heater branch in Figure 2 fails open-circuit. Calculate the new supply current and the new power dissipated in the $12\ \Omega$ sensor model. Explain why this sensor is now at greater risk of overheating. [3 marks]

Answer / mark points: The remaining resistors are in series: $R(\text{total}) = 4.0 + 12 = 16\ \Omega$, so $I(\text{supply}) = 12/16 = 0.75\ \text{A}$. [1] $P(\text{sensor}) = I^2R = 0.75^2 \times 12 = 6.75\ \text{W}$. [1] Its power has increased from $3.0\ \text{W}$ to $6.75\ \text{W}$ because the common series-resistor drop falls to $3.0\ \text{V}$, leaving $9.0\ \text{V}$ across the sensor; it therefore heats more strongly. [1] Total supply current decreases even though sensor current increases.

Teacher prompt / common error: Trace the changed topology. A lower total current does not imply a lower current in every component.

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Choosing an emergency cell bank

15. The station has four identical cells, each providing a constant 1.50 V. Draw two circuit diagrams, each connected to a single 6.0 Ω test heater: arrangement A has all four cells in series; arrangement B has all four cells in parallel. Show cell polarity correctly and label A and B. [2 marks]

Answer / mark points: A: four cell symbols joined end-to-end, all aiding in the same sense, in one closed loop with the 6.0 Ω heater. [1]
B: four cell symbols on separate branches between the same two junctions, all positive terminals connected to one junction and all negative terminals to the other, with the heater connected across those junctions. [1]
Accept correctly labelled standard-symbol sketches. Opposed cells or a wire shorting either cell bank are incorrect.

Teacher prompt / common error: Check long cell plates for positive polarity and trace complete load paths. A cell is not a resistor rectangle.

16. Calculate the potential difference across, and current through, the 6.0 Ω heater for each cell arrangement in Question 15. Assume ideal identical cells and ideal connecting wires. [4 marks]

Answer / mark points: A: $V = 4 \times 1.50 = 6.00$ V. [1] $I = 6.00/6.0 = 1.00$ A. [1]
B: $V = 1.50$ V, unchanged by adding identical cells in parallel. [1] $I = 1.50/6.0 = 0.250$ A. [1] A parallel connection does not add cell voltages.

Teacher prompt / common error: Aiding cells in series add voltages. Identical cells in parallel maintain a single-cell voltage.

17. In arrangement B, the four identical cells share the supply current equally. Calculate the current supplied by one cell. [1 mark]

Answer / mark points: $I(\text{one cell}) = 0.250/4 = 0.0625$ A. [1] This equal sharing is assumed for identical cells, not inferred for arbitrary unequal cells.

Teacher prompt / common error: Separate heater current from the current contributed by one parallel cell.

18. Each cell can supply 4.00 A h of charge before it is exhausted. Using the cell currents for arrangements A and B, calculate the operating time of each arrangement in hours. Calculate the ratio of heater powers $P(A)/P(B)$, and explain why comparing operating times alone is misleading. Assume constant cell voltage, complete use of the quoted charge and constant heater resistance. [4 marks]

Answer / mark points: A: every cell supplies 1.00 A, so $t = 4.00 \text{ A h} / 1.00 \text{ A} = 4.00$ h. [1]
B: each cell supplies 0.0625 A, so $t = 4.00/0.0625 = 64.0$ h. [1]
 $P(A)/P(B) = (6.00/1.50)^2 = 16.0$; equivalently $6.00 \text{ W} / 0.375 \text{ W} = 16.0$. [1]
B lasts longer but delivers only one sixteenth of the heating power, so operating time alone is not a like-for-like comparison of performance. [1] Both banks contain the same total ideal stored energy: $4 \times 1.50 \times (4.00 \times 3600) = 86\,400$ J. These times are ideal-model predictions, not real-cell guarantees.

Teacher prompt / common error: Ampere-hours measure charge, not current or energy. Runtime must be compared alongside output power.

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Designing and testing the final circuit

19. For a constant-resistance heater, start with $P = IV$ and $V = IR$ to derive both $P = I^2R$ and $P = V^2/R$. Show the substitution used for each expression. [2 marks]

Answer / mark points: Substitute $V = IR$ into $P = IV$: $P = I(IR) = I^2R$. [1] Rearrange $V = IR$ to $I = V/R$, then substitute into $P = IV$: $P = (V/R)V = V^2/R$. [1] These forms use the current through and voltage across the same resistance.

Teacher prompt / common error: Show algebraic substitutions; merely writing the three power expressions is not a derivation.

20. Return to Figure 1 with S closed. The $36\ \Omega$ heater is replaced by a heater designed to transfer $6.00\ \text{W}$ at $12\ \text{V}$. Calculate its required resistance and the new total supply current. Decide whether the $0.800\ \text{A}$ supply limit is met. [3 marks]

Answer / mark points: $R = V^2/P = 12^2/6.00 = 24.0\ \Omega$. [1] $I(\text{heater}) = P/V = 0.500\ \text{A}$; $I(\text{total}) = 0.500 + 12/72 = 0.667\ \text{A}$. [1] The limit is met because $0.667\ \text{A} < 0.800\ \text{A}$. [1] The unchanged sensor branch still draws $0.167\ \text{A}$.

Teacher prompt / common error: The heater's power is not the power of the whole station. Include the sensor current when checking the supply.

21. Plan a low-voltage bench test of the series and parallel resistance rules using two known resistors, an ammeter and a voltmeter. Describe meter placement, the readings and analysis for each arrangement, and one precaution to keep the resistor temperatures approximately constant. [4 marks]

Answer / mark points: Connect the two known resistors in series and then in parallel to a suitable low-voltage dc supply; put the ammeter in series with the whole resistor combination and the voltmeter in parallel across the combination. [1 for correct configurations and both meter placements]

For each arrangement record paired total V and I and calculate $R(\text{measured}) = V/I$; repeat readings to check consistency. [1]

Compare the measured series value with $R_1 + R_2$ and the measured parallel value with $1/(1/R_1 + 1/R_2)$, allowing for measurement uncertainty. [1]

Use small currents/short measurement periods and switch off between readings so self-heating is limited and resistor temperature stays approximately constant. [1]

Equivalent workable methods are acceptable. Do not connect an ammeter directly across the supply.

Teacher prompt / common error: Both meters must refer to the same resistor combination. Temperature changes can invalidate the resistance comparison.

22. A loose wire makes a direct connection between the two supply terminals, bypassing the loads. Explain why this is a short circuit and give one protective device that should be fitted to the real weather station. [2 marks]

Answer / mark points: The direct wire path has very low resistance and bypasses the loads, so it would draw an excessive current from a real supply. [1] Fit a correctly rated fuse or circuit breaker in series with the supply to disconnect an excessive current. [1] The ideal zero-resistance source model cannot give a finite numerical short-circuit current; do not claim it would be the normal load current.

Teacher prompt / common error: A short circuit adds a low-resistance bypass; an open circuit removes a conducting path.

Language and method check

Award the stated independent points, with error-carried-forward for consistent later calculations.

Require precise references to current, potential difference, charge and energy. Accept equivalent correct methods.

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