physicsUK

Smarter practice. Stronger understanding

SOLUTIONS

ATTEMPT CHECK CORRECT IMPROVE

OCR A AS Kirchhoff Laws and Resistor Networks solutions

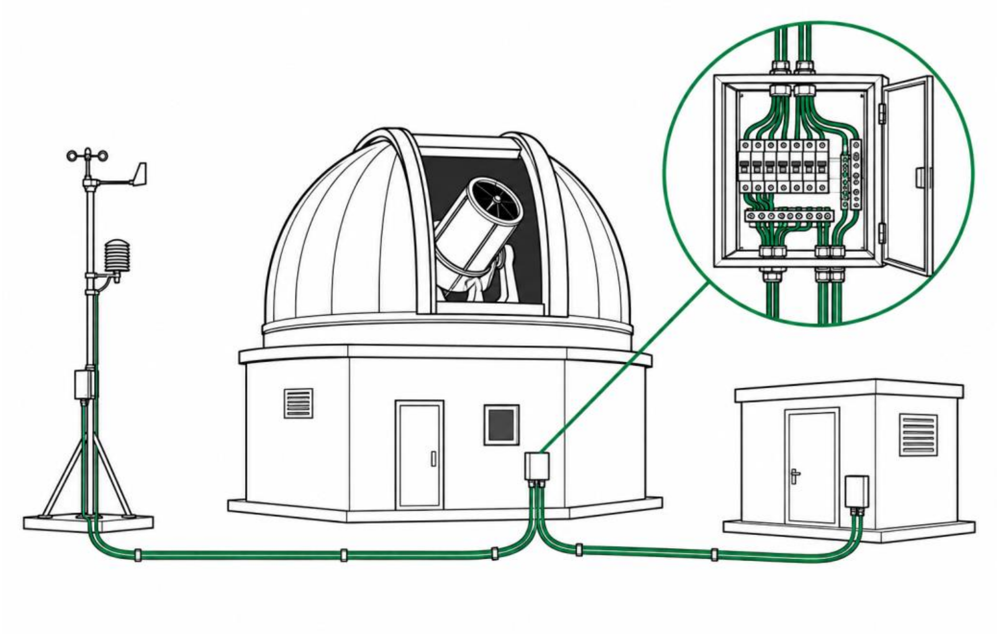
Matching solutions and teaching prompts for the class review

Specification points covered

- 4.3.1(a) Apply Kirchhoff's second law as conservation of energy in electrical circuits.
- 4.3.1(b) Apply Kirchhoff's first and second laws to analyse electrical circuits.
- 4.3.1(c) Calculate total resistance of resistors in series using $R = R_1 + R_2 + \ldots$
- 4.3.1(d) Calculate total resistance of resistors in parallel using $1/R = 1/R_1 + 1/R_2 + \ldots$
- 4.3.1(e) Analyse circuits with components including both series and parallel arrangements.

Teaching focus

Require the full law statements: current into a junction equals current out because charge is conserved; around a closed loop the sum of e.m.f.s equals the sum of p.d.s because energy is conserved.
Insist that pupils identify which quantity is common: current in series and p.d. across parallel branches.



Context diagram: the Solis observatory and its low-voltage distribution system.

1. Kirchhoff laws at the observatory

1. State Kirchhoff's first law and identify the physical quantity conserved. **[2 marks]**

Answer / mark points: At a junction, the sum of the currents entering equals the sum of the currents leaving. This follows from conservation of charge.

Teacher prompt / common error: Use the junction wording and name charge. Current is not used up at a junction.

2. At one junction, a current of 4.80 A enters. Currents of 1.35 A and 2.10 A leave through the camera and heater branches. Calculate the current leaving through the communications branch. **[1 mark]**

Answer / mark points: $I = 4.80 - 1.35 - 2.10 = 1.35$ A leaving through the communications branch.

Teacher prompt / common error: Apply a signed current balance: total current in equals total current out.

3. State Kirchhoff's second law and identify the physical quantity conserved. **[2 marks]**

Answer / mark points: Around a closed loop, the sum of the e.m.f.s is equal to the sum of the p.d.s. The conserved physical quantity is energy.

Teacher prompt / common error: OCR expects a sum of e.m.f.s and a sum of p.d.s around a closed loop, together with conservation of energy.

2. Series circuit for the lens heater

4. A 5.60 Ω lens heater and a cable with resistance 0.400 Ω are connected in series across a 12.0 V supply. Calculate the total resistance and the current in the circuit. [2 marks]

Answer / mark points: Total resistance = 5.60 + 0.400 = 6.00 Ω. $I = V/R = 12.0/6.00 = 2.00$ A.

Teacher prompt / common error: Series resistances add and the same current flows through both components.

5. Calculate the p.d. across the lens heater and across the cable. Show that the values satisfy Kirchhoff's second law. [2 marks]

Answer / mark points: Heater p.d. = $IR = 2.00 \times 5.60 = 11.2$ V. Cable p.d. = $2.00 \times 0.400 = 0.800$ V. The sum is $11.2 + 0.800 = 12.0$ V, equal to the supply e.m.f.

Teacher prompt / common error: Potential difference is across a component. Do not say that voltage flows through it.

6. The cable connector resistance increases from 0.400 Ω to 1.40 Ω while the heater resistance and supply p.d. remain unchanged. Calculate the new current and the new p.d. across the heater. Use your results to describe the change in heating performance. [3 marks]

Answer / mark points: New total resistance = 5.60 + 1.40 = 7.00 Ω. $I = 12.0/7.00 = 1.71$ A. Heater p.d. = $1.71 \times 5.60 = 9.60$ V. Both current and heater p.d. decrease, so the heater transfers energy at a lower rate.

Teacher prompt / common error: At fixed supply p.d., increasing series resistance reduces the circuit current and therefore the heater's p.d.

3. Parallel instrument loads

7. The observatory's 24.0 V distribution rail supplies three parallel loads. The camera controller has resistance 12.0 Ω, the weather station 16.0 Ω and the communications unit 24.0 Ω. Calculate the current in each branch. **[3 marks]**

Answer / mark points: Camera: I = 24.0/12.0 = 2.00 A. Weather station: I = 24.0/16.0 = 1.50 A. Communications unit: I = 24.0/24.0 = 1.00 A.
Teacher prompt / common error: Every parallel branch has the full 24.0 V across it. Currents need not be equal when branch resistances differ.

8. Use Kirchhoff's first law to determine the current supplied by the distribution rail. **[1 mark]**

Answer / mark points: Supply current = 2.00 + 1.50 + 1.00 = 4.50 A.
Teacher prompt / common error: Add branch currents at the junction; do not average them.

9. Determine the equivalent resistance of the three parallel loads. **[1 mark]**

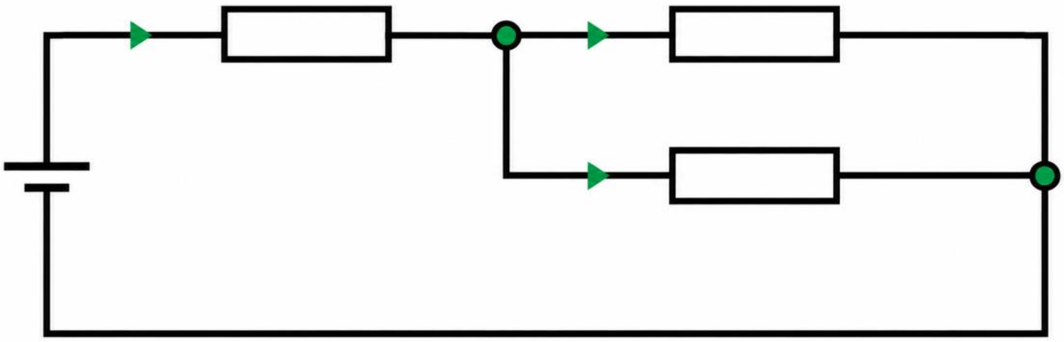
Answer / mark points: Equivalent resistance = V/I = 24.0/4.50 = 5.33 Ω. The reciprocal-resistance equation gives the same value.
Teacher prompt / common error: The equivalent resistance represents the whole parallel network at the same supply p.d.

10. Explain why the equivalent resistance in Question 9 is less than the smallest branch resistance. Predict what happens to the equivalent resistance if another load is connected in parallel. **[2 marks]**

Answer / mark points: Parallel branches provide additional paths for charge, so the total current is greater than the current in any single branch for the same p.d. Since R = V/I, the equivalent resistance is smaller than the smallest branch resistance. Adding another parallel load reduces it further.
Teacher prompt / common error: Explain the lower resistance through increased total current or increased conductance, not by saying current finds an easier route and stops using the others.

4. Mixed dome-control network

11. The circuit shown represents one branch of the dome control system. The ideal supply has e.m.f. 18.0 V. The resistor before the junction has resistance 2.00 Ω. The upper branch resistor is 6.00 Ω and the lower branch resistor is 3.00 Ω. Calculate the equivalent resistance of the parallel section. [1 mark]



Solution diagram: current enters the junction and divides between the two branches.

Answer / mark points: $1/R = 1/6.00 + 1/3.00 = 1/2.00$, so the parallel section has resistance 2.00 Ω.	
Teacher prompt / common error: Take the reciprocal after adding reciprocals. Do not add 6.00 Ω and 3.00 Ω directly.	

12. Calculate the total resistance of the circuit in Question 11 and the current supplied by the source. [2 marks]

Answer / mark points: Total resistance = 2.00 + 2.00 = 4.00 Ω. Source current = 18.0/4.00 = 4.50 A.	
Teacher prompt / common error: First replace the parallel section by its equivalent resistance, then add the series resistor.	

13. Calculate the p.d. across the 2.00 Ω series resistor and the p.d. across the parallel section. [2 marks]

Answer / mark points: Series-resistor p.d. = 4.50 × 2.00 = 9.00 V. Kirchhoff's second law gives the parallel-section p.d. = 18.0 − 9.00 = 9.00 V.	
Teacher prompt / common error: The two parallel resistors share one p.d.; they do not divide the 9.00 V between them.	

5. Current division and an open branch

14. Calculate the current in each parallel branch. Verify that the currents satisfy Kirchhoff's first law at the junction. [3 marks]

Answer / mark points: Upper branch current = 9.00/6.00 = 1.50 A. Lower branch current = 9.00/3.00 = 3.00 A. At the junction, 1.50 + 3.00 = 4.50 A, equal to the current entering.
Teacher prompt / common error: State both branch currents and explicitly compare their sum with the current entering the junction.

15. The lower branch develops an open-circuit fault. Calculate the new source current and the new p.d. across the remaining 6.00 Ω resistor. Explain why the p.d. across the 2.00 Ω series resistor changes. [3 marks]

Answer / mark points: With the lower branch open, the total resistance is 2.00 + 6.00 = 8.00 Ω, so the source current is 18.0/8.00 = 2.25 A. The p.d. across the 6.00 Ω resistor is 2.25 × 6.00 = 13.5 V. The smaller current produces a smaller p.d. of 2.25 × 2.00 = 4.50 V across the series resistor, leaving a larger share of the supply p.d. across the remaining branch.
Teacher prompt / common error: An open branch carries no current. Recalculate the whole circuit because the equivalent resistance has changed.

6. De-icing network design

16. The observatory roof has four identical de-icing strips, each of resistance 24.0 Ω, supplied by 48.0 V. The table shows two proposed connections. Calculate the total resistance and supply current for each design. **[4 marks]**

Design	Connection of four identical 24 Ω strips
A	all four strips connected in series
B	two series pairs connected in parallel

Answer / mark points: Design A: total resistance = 4 × 24.0 = 96.0 Ω and supply current = 48.0/96.0 = 0.500 A. Design B: each series pair has resistance 48.0 Ω; two identical pairs in parallel have total resistance 24.0 Ω, so the supply current is 48.0/24.0 = 2.00 A.

Teacher prompt / common error: Treat each series pair as one 48.0 Ω branch before combining the two branches in parallel.

17. Each de-icing strip is rated at 24.0 V and the supply current must not exceed 2.50 A. Select the suitable design and justify your choice using the p.d. across each strip and the supply current. **[2 marks]**

Answer / mark points: Design B is suitable. Each series pair has 48.0 V across it, so two identical strips share this equally and each has 24.0 V. The 2.00 A supply current is below 2.50 A. In design A, each strip would have only 12.0 V.

Teacher prompt / common error: A design must satisfy both conditions. In series, identical components share the branch p.d. equally.

18. One strip in one branch of the selected design fails open circuit. Calculate the new total current. Explain whether the two strips in the unaffected branch continue to operate at their rated p.d. **[3 marks]**

Answer / mark points: The failed series pair is an open branch and takes no current. The unaffected pair has resistance 48.0 Ω, so the new total current is 48.0/48.0 = 1.00 A. The unaffected branch remains directly across 48.0 V, so its identical strips still have 24.0 V each and continue at their rated p.d.

Teacher prompt / common error: An ideal supply keeps the p.d. across the unaffected parallel branch unchanged even though the total current falls.

Language and method check

Current flows through a component. Potential difference is measured across it.
Current divides at a junction; it is not used up by the first branch.
A parallel network has a lower equivalent resistance because it draws a larger total current at the same p.d.