

EMF, internal resistance and practical analysis solutions

AQA AS 7407 and first-year A Level 7408 | OCR A AS H156 and A Level H556

Matching solutions and teaching prompts for the class review

Specification points covered

AQA 7407 / 7408: 3.5.1.6 emf and internal resistance; 3.5.1.4 selected source combinations and energy; 3.1.2 selected uncertainty and experimental analysis. Required practical 6 preparation.

OCR A H156 / H556: 4.3.1(f), 4.3.2(a), (b), (c)(i)–(ii); 1.1.3(d)(i)–(ii), 1.1.4(d)–(e), selected practical analysis and improvement.

Asteria checks whether a research balloon battery can keep its instrument controller running during launch and high-altitude operation. Follow the explicitly separate ideal-source checks, real-battery operating tests and laboratory measurements to evaluate the supply model.

1. Energy supplied by a real source [4 marks]

Asteria develops a battery system for a high-altitude research balloon. In an initial test, the source transfers 25.2 J to each 2.10 C passing through it.

(a) Calculate the emf of this source. [1 mark]

(b) Define terminal potential difference and lost volts for a source supplying a current. [2 marks]

(c) A high-resistance voltmeter reads 12.6 V across an otherwise disconnected battery. Explain why this is a good estimate of its emf. [1 mark]

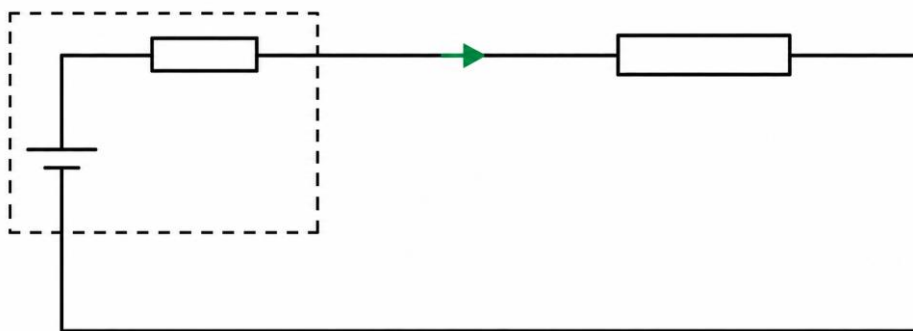
Answer / mark points: (a) $E = W/Q = 25.2/2.10 = 12.0 \text{ V}$. [1] (b) Terminal p.d. is the energy transferred to the external circuit per unit charge. [1] Lost volts is the energy transferred internally per unit charge, equal to Ir for this model. [1] (c) The meter draws negligible current, so the internal voltage drop Ir is negligible and terminal p.d. is approximately the emf. [1]

Teacher prompt / common error: Emf and potential difference are energy per charge, not forces. Lost volts is not lost charge.



2. The launch-day operating tests [7 marks]

For these tests the battery is modelled by emf $E = 12.6 \text{ V}$ and internal resistance $r = 0.600 \Omega$. The initial external resistance is 5.70Ω . The diagram distinguishes the internal and external parts.



- (a) Calculate the current in the complete circuit. [1 mark]
- (b) Calculate the lost volts and terminal p.d. Check the terminal p.d. using the external resistance. [2 marks]
- (c) The external resistance is changed to 1.50Ω . Calculate the new current and terminal p.d. [2 marks]
- (d) For the 6.00 A test, calculate the power dissipated inside the battery and the percentage of the source power transferred to the external circuit. [2 marks]

Answer / mark points: (a) $I = E/(R + r) = 12.6/(5.70 + 0.600) = 2.00 \text{ A}$. [1] (b) $Ir = 2.00 \times 0.600 = 1.20 \text{ V}$. [1] $V = E - Ir = 11.4 \text{ V}$; independently $IR = 2.00 \times 5.70 = 11.4 \text{ V}$. [1] (c) $I = 12.6/(1.50 + 0.600) = 6.00 \text{ A}$. [1] $V = 6.00 \times 1.50 = 9.00 \text{ V}$. [1] (d) $P_{\text{internal}} = I^2 r = 6.00^2 \times 0.600 = 21.6 \text{ W}$. [1] External power/source power $= IV/(IE) = 9.00/12.6 = 0.714$, or 71.4% . [1]

Teacher prompt / common error: Total circuit resistance determines current. Terminal p.d. is not the emf when appreciable current flows.

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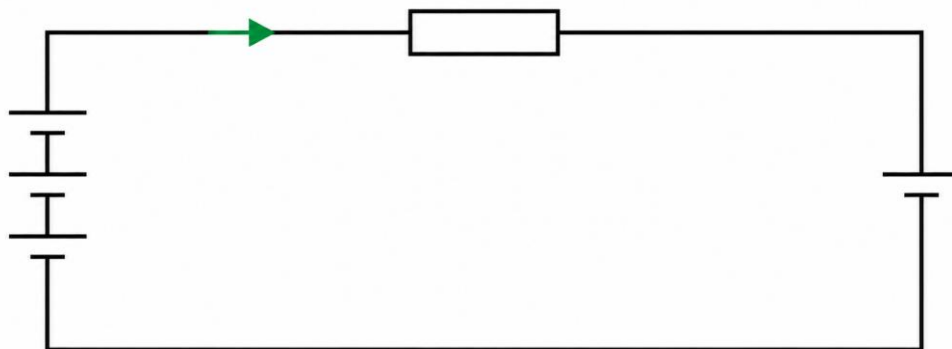
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3. An opposing backup source [4 marks]

In a separate idealised check, the main source has emf 12.0 V and the backup source has emf 3.00 V . Their internal resistances are negligible. They are connected as shown, with an $18.0\ \Omega$ external resistor.



- (a) Determine the resultant emf and the current through the resistor. [2 marks]
 (b) Describe the energy balance for each coulomb passing around this circuit. [1 mark]
 (c) The backup source is reversed so that the two emfs aid. Calculate the new current. [1 mark]

Answer / mark points: (a) The positive terminals oppose, so resultant emf = $12.0 - 3.00 = 9.00\text{ V}$. [1] $I = 9.00/18.0 = 0.500\text{ A}$, driven by the main source. [1] (b) The main source supplies 12.0 J per coulomb; 3.00 J per coulomb is transferred into the backup source and 9.00 J per coulomb to the resistor. [1] (c) $I = (12.0 + 3.00)/18.0 = 0.833\text{ A}$. [1]

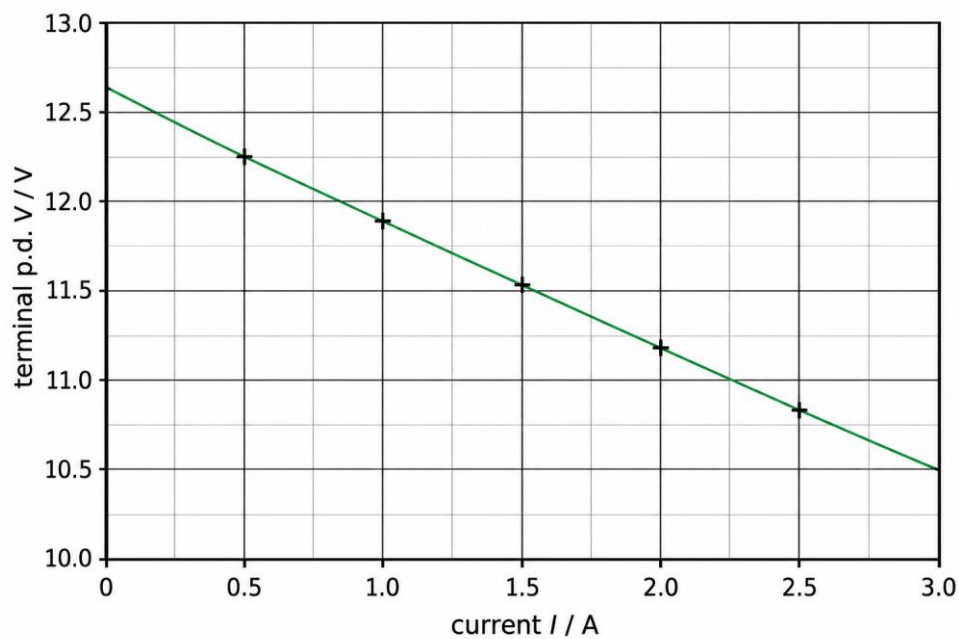
Teacher prompt / common error: Source polarity determines whether emfs add or subtract. Do not combine the two ideal-source test values with the real battery data.



4. Load-test graph and data checks [9 marks]

A laboratory test uses a different battery. At 1.50 A an initial reading of 10.70 V is questioned. Repeat readings are 11.54 V and 11.56 V; the table uses their mean, 11.55 V. Treat this test as having constant emf and internal resistance.

Current I / A	Terminal p.d. V / V
0.50	12.25
1.00	11.90
1.50	11.55
2.00	11.20
2.50	10.85



- (a) Write an equation relating terminal p.d. V to current I , emf E and internal resistance r . State what the intercept and gradient of a V – I graph represent. [2 marks]
- (b) Plot the five table readings and draw a straight line of best fit over the measured trend. [3 marks]
- (c) Explain why the initial 10.70 V reading should be investigated and repeated rather than simply deleted because it does not fit the line. [1 mark]
- (d) Use a large gradient triangle to determine the internal resistance. [2 marks]
- (e) Determine the emf from the graph. [1 mark]

Answer / mark points: (a) $V = E - Ir$. [1] Vertical intercept is E and gradient is $-r$, so r is the negative of the gradient. Both identifications required. [1] (b) Five small crosses correctly plotted, allowing reasonable reading tolerance. [2] One balanced straight fit rather than point-to-point joining. [1] Vertical scale starts at 10.0 V, not zero. (c) It could reflect a genuine changed condition rather than a recording fault; repeats under checked conditions are needed to justify treating it as anomalous. [1] (d) For example, gradient = $(10.85 - 12.25)/(2.50 - 0.50) = -0.700 \text{ V A}^{-1}$. [1] $r = -\text{gradient} = 0.700 \Omega$. [1] Allow a sensible graph-derived range, approximately 0.66 – 0.74Ω . (e) Extrapolate the fit to $I = 0$: $E \approx 12.60 \text{ V}$; allow approximately 12.56 – 12.64 V for a valid fit. [1]

Teacher prompt / common error: Do not use V/I for internal resistance. Read the extrapolated intercept on the labelled non-zero-start voltage axis.

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5. Uncertainty and the reset limit [6 marks]

The laboratory graph gives $E = (12.60 \pm 0.04) \text{ V}$. Its best gradient is -0.700 V A^{-1} , with limiting gradients -0.660 and -0.740 V A^{-1} . Use half their range as the absolute gradient uncertainty. The controller resets if its terminal supply falls below 8.00 V .

- (a) Give r with its absolute uncertainty and calculate its percentage uncertainty. [2 marks]
- (b) In a separate regulated-current check the controller draws exactly 6.00 A . Use the lowest E and largest r in the stated intervals to calculate the lowest predicted terminal p.d. and decide whether a reset is predicted. [2 marks]
- (c) At altitude another test has $E = 12.6 \text{ V}$, $r = 1.50 \Omega$ and a fixed external resistance of 1.50Ω . Calculate the terminal p.d. and decide whether the controller resets. [2 marks]

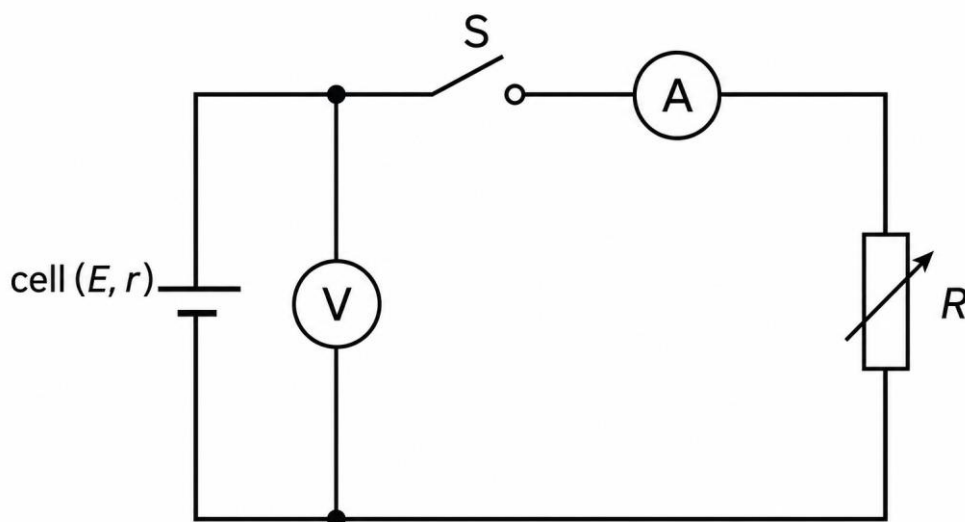
Answer / mark points: (a) $r = (0.700 \pm 0.040) \Omega$ from half-range $(0.740 - 0.660)/2$. [1] Percentage uncertainty $= 0.040/0.700 \times 100 = 5.71\%$. [1] (b) $V_{\min} = 12.56 - 6.00 \times 0.740 = 8.12 \text{ V}$. [1] This is above 8.00 V , so the model predicts no reset within those intervals. It is not a guarantee under all conditions. [1] (c) $I = 12.6/(1.50 + 1.50) = 4.20 \text{ A}$, so $V = IR = 6.30 \text{ V}$. [1] This is below 8.00 V , so a reset is predicted. [1]

Teacher prompt / common error: The regulated-current check and fixed-resistance altitude test are different operating conditions. A larger internal resistance reduces the useful terminal supply.



6. A scaffolded six-mark practical plan [6 marks]

A school team investigates the emf and internal resistance of a low-voltage cell. Plan the experiment using the three prompts. The complete method is worth six marks.



- (a) Draw a circuit using the cell, switch, ammeter, variable resistor and voltmeter. Use standard circuit symbols. [2 marks]
- (b) Describe how to collect a suitable set of paired current and terminal-p.d. readings reliably. [2 marks]
- (c) Describe how to use a graph to obtain both E and r . [2 marks]

Answer / mark points: (a) Cell, switch, ammeter and variable resistor form one series load circuit. [1] Voltmeter is connected in parallel across the cell terminals, not in series. [1] The solution figure shows this topology. (b) Change the variable resistance to obtain at least five well-spread paired I and V readings, and repeat/check readings. [1] Use low currents, close the switch only while reading and allow cooling/rest so cell temperature and state change as little as possible; avoid short circuit. [1] (c) Plot V vertically against I horizontally, with labelled units and one straight best-fit line; obtain E from the extrapolated $I = 0$ intercept. [1] Use a large gradient triangle; $r = -\text{gradient}$, taking care of current units. [1]

Teacher prompt / common error: A high-resistance voltmeter draws little current. The ammeter and switch are assumed to have negligible resistance; V is measured at the cell terminals.

7. Validity of one straight-line model [3 marks]

During a long sequence the cell warms and its state of charge changes.

- (a) Explain why fitting one straight line may no longer give a valid single E and r . [1 mark]
- (b) Suggest two checks or improvements linked to this drift. [2 marks]

Answer / mark points: (a) The relation assumes constant E and r ; warming/discharge can change these parameters during the run, so measurements no longer describe one unchanged source. [1] (b) Use brief low-current readings with rest/cooling between readings to limit changes. [1] Repeat a reference-current reading at the start and end (or interleave it) to test systematic drift; randomise order and repeat after rest rather than assuming the drift is random scatter. [1]

Teacher prompt / common error: An unexplained trend should be investigated, not removed by selectively excluding inconvenient readings.

Review: identify the correct operating test, distinguish emf from terminal p.d., obtain r from the negative gradient, and qualify supply decisions using the stated model and uncertainties.

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