



ANSWER BOOK

EMF and internal resistance

Electricity · Year 12

AQA 3.5.1.6 · CIE 10.1.3, 10.1.4, 10.1.5

OCR A 4.2.2(b), 4.2.2(c), 4.2.2(d), 4.3.2(a), 4.3.2(b), 4.3.2(c)(i), 4.3.2(c)(ii)

19 questions · 58 marks

NAVY EDITION

SECTION A · Warm-up

- A1** The emf is the energy transferred to each unit of charge by the source, $\varepsilon = W/Q$ (1). It is measured in volts, or joules per coulomb (1). [2]
- A2** $V = \varepsilon - Ir = 6.0 - 0.50 \times 1.0$ (1) [2]
 $V = 5.5 \text{ V}$ (1)
- A3** $\varepsilon = I(R + r)$ (1), where R is the external resistance and r the internal resistance (1). [2]
- A4** When no current flows ($I = 0$), since the lost volts Ir are then zero (1). [1]
- A5** Lost volts = $\varepsilon - V = 9.0 - 8.4 = 0.6 \text{ V}$ (1); the energy is dissipated in the internal resistance, warming the battery (1). [2]
- A6** The voltmeter draws almost no current from the cell (1), so the lost volts Ir are negligible and the terminal pd is (almost) equal to ε (1). [2]

SECTION B · Standard

- B1** $I = \varepsilon / (R + r)$ (1) [3]
 $I = 12 / (5.0 + 1.0)$ (1)
 $I = 2.0 \text{ A}$ (1)
- B2** (a) $I = 9.0 / (4.0 + 0.50) = 2.0 \text{ A}$ (1) [4]
 (b) $V = IR = 2.0 \times 4.0$ (1)
 $V = 8.0 \text{ V}$ (1)
 (c) $P_{\text{internal}} = I^2 r = 2.0^2 \times 0.50 = 2.0 \text{ W}$ (1)
- B3** Lost volts = $\varepsilon - V = 1.5 - 1.35 = 0.15 \text{ V}$ (1) [3]
 $r = (\varepsilon - V) / I = 0.15 / 0.30$ (1)
 $r = 0.50 \Omega$ (1)
- B4** $I = \varepsilon / r$ (1) [2]
 $I = 6.0 / 0.20 = 30 \text{ A}$ (1)
- B5** Write $V = \varepsilon - Ir$ for each reading (1); subtracting: $5.7 - 5.1 = r \times (1.8 - 0.60)$, so $r = 0.50 \Omega$ (1); substitute back: $\varepsilon = 5.7 + 0.60 \times 0.50$ (1) = 6.0 V (1). [4]

B6 $r = 0.025 \, \Omega$ (1); $V = \varepsilon - Ir = 12.6 - 160 \times 0.025 = 8.6 \, \text{V}$ (1); fraction = $IV/I\varepsilon = V/\varepsilon$ (1) [4]
 $= 8.6/12.6 = 0.68$ (1).

B7 External resistance = $5.0/2 = 2.5 \, \Omega$ (1); $I = \varepsilon/(R + r) = 6.0/(2.5 + 0.50) = 2.0 \, \text{A}$ (1); [3]
 $V = IR = 2.0 \times 2.5 = 5.0 \, \text{V}$ (1).

SECTION C · Stretch

C1 From $V = \varepsilon - Ir$, the intercept is the emf, so $\varepsilon = 1.5 \, \text{V}$ (1) [4]
 The gradient is $-r$, so $r = 0.5 \, \Omega$ (1)
 At $I = 1.0 \, \text{A}$: $V = 1.5 - 0.5 \times 1.0$ (1)
 $V = 1.0 \, \text{V}$ (1)

C2 Lost volts = $12 - 10 = 2.0 \, \text{V}$ (1) [4]
 $I = (\varepsilon - V)/r = 2.0/2.0 = 1.0 \, \text{A}$ (1)
 $R = V/I = 10/1.0$ (1)
 $R = 10 \, \Omega$ (1)

C3 Some energy per unit charge is used driving the current through the battery's [3]
 own internal resistance, giving 'lost volts' Ir (1). As the current increases, Ir increases (1),
 so the terminal pd $\varepsilon - Ir$ available to the external circuit falls (1).

C4 Connect the cell in series with the variable resistor, a switch and the ammeter, [6]
 with the voltmeter across the cell's terminals (1). Vary the resistance to obtain a wide
 range of currents, recording V and I each time, opening the switch between readings to
 limit heating (1). Plot terminal pd V against current I ; $V = \varepsilon - Ir$ gives a straight line (1).
 The intercept on the V axis equals the emf (1) and the magnitude of the gradient equals
 the internal resistance r (1). The intercept extrapolates to $I = 0$, where there are no lost
 volts, whereas a voltmeter always draws a small current and so reads slightly below ε
 (1).

C5 P: $V = 6.0 - 2.0 \times 0.90 = 4.2 \, \text{V}$ (1); Q: $V = 5.0 - 2.0 \times 0.20 = 4.6 \, \text{V}$ (1); only Q's [4]
 terminal pd exceeds the 4.4 V required, while P falls short (1); choose Q: despite its lower
 emf, its much lower internal resistance leaves more pd for the motor (1).

C6 Total emf = $3.0 \, \text{V}$ and total internal resistance = $0.60 \, \Omega$, since both add in [3]
 series (1); $I = 3.0/(2.4 + 0.60) = 1.0 \, \text{A}$ (1); $V = IR = 1.0 \times 2.4 = 2.4 \, \text{V}$ (1).