

Exercise walk-through

10.1.1

e.m.f., internal resistance and the V-I graph

A-Level Physics

Sheet 10.1.1 – what you need to know

You must be able to:

- explain **internal resistance** and the lost volts Ir
- use $E = I(R + r)$ and $V = E - Ir$
- read E and r off a graph of V against I
- explain why the terminal p.d. falls as more current is drawn

What the exam asks

“Calculate the internal resistance r of the cell.” [3]

“Show that the terminal potential difference of the battery is 4.8 V.” [2]

“State and explain the effect on the terminal potential difference of the battery.” [3]

Practise on exercise sheet 10.1.1, then try the real exam questions on past-paper sheet 10.1.1.

Internal resistance

A real source has an **internal resistance** r : part of the energy each coulomb is given is lost **inside** it.

$$E = I(R + r) \quad V = E - Ir$$

$I = 0$: $V = E$. Short circuit, $R = 0$:

$I = \frac{E}{r}$, the largest current.

$$E = 1.5 \text{ V}, r = 0.50 \, \Omega, R = 2.5 \, \Omega$$

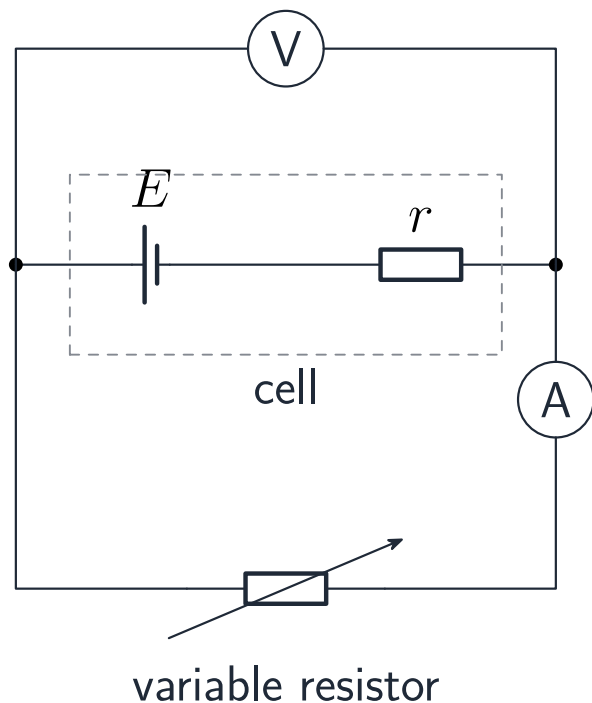
the e.m.f. drives I through **both** resistances:

$$I = \frac{E}{R + r} = \frac{1.5 \text{ V}}{2.5 \, \Omega + 0.50 \, \Omega} = 0.50 \text{ A}$$

the terminal p.d. is what is left after the lost volts:

$$V = E - Ir = 1.5 \text{ V} - (0.50 \text{ A})(0.50 \, \Omega) = 1.25 \text{ V}$$

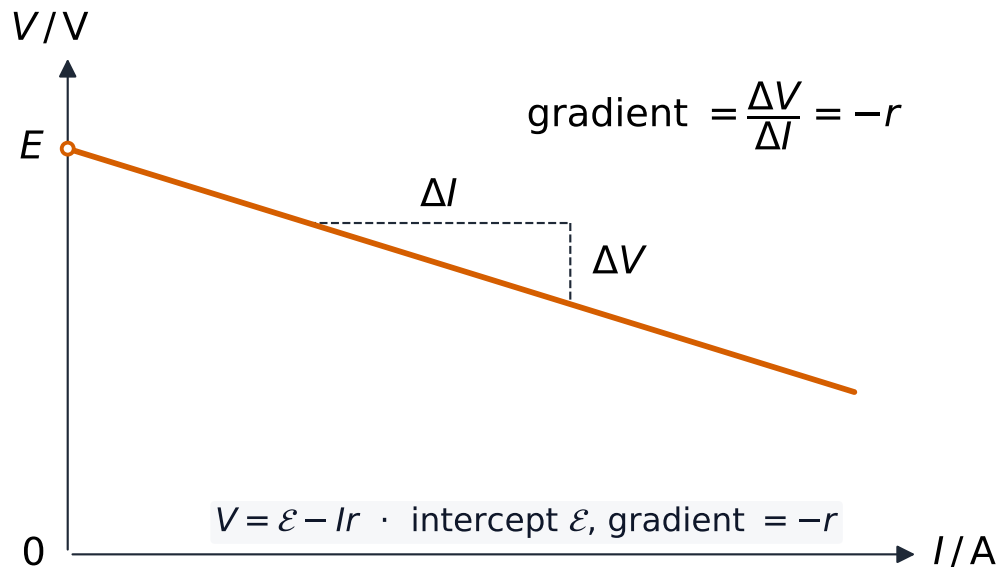
The cell drawn with its own resistance



A real cell is an e.m.f. E in series with r , so the terminal p.d. is $V = E - Ir$.

The terminal p.d. **falls** as more current is drawn, and the **lost volts** Ir heat the cell itself.

Internal resistance, in detail



Plot V against I and you get a straight line: the **intercept** is the e.m.f. E and the **gradient** is $-r$. That is how r is measured.

Reading E and r off the graph

Vary R , record V and I , plot V against I :

$$V = E - rI \quad \text{is} \quad y = c + mx$$

$$\text{intercept} = E; \quad \text{gradient} = -r$$

Two points on the line: $(0.40 \text{ A}, 2.80 \text{ V})$
and $(1.60 \text{ A}, 2.20 \text{ V})$

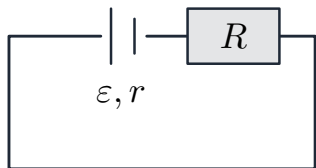
$$\text{gradient} = \frac{\Delta V}{\Delta I} = \frac{2.20 \text{ V} - 2.80 \text{ V}}{1.60 \text{ A} - 0.40 \text{ A}} = -0.50 \Omega$$

$$r = -\text{gradient} = 0.50 \Omega$$

$$E = V + Ir = 2.80 \text{ V} + (0.40 \text{ A})(0.50 \Omega) = 3.00 \text{ V}$$

Exercise 2.1

2.1 A cell of e.m.f. 1.5 V and internal resistance $0.40\ \Omega$ delivers a current of 0.60 A . Calculate the terminal p.d. [2]

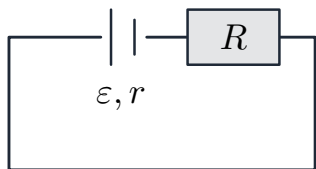


1.5 V

$0.40\ \Omega$

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1.5 V

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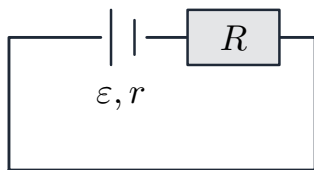
2.1

- use $V = E - Ir$

$$V = E - Ir = 1.5 \text{ V} - (0.60 \text{ A})(0.40 \text{ } \Omega) = \mathbf{1.26 \text{ V}}$$

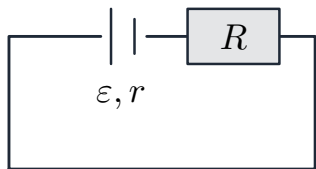
Exercise 2.2

2.2 Explain why the terminal p.d. of a cell falls as the current drawn from it increases. [2]



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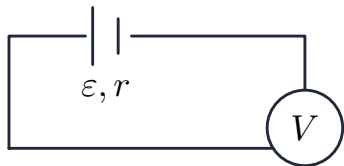


2.2

- a larger current means a larger p.d. Ir across the **internal resistance**
- the e.m.f. is fixed, so with more of it used inside the cell, less is left for the external circuit and $V = E - Ir$ falls

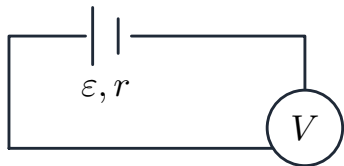
Exercise 2.3

2.3 State the terminal p.d. of a cell when **no** current is drawn from it, and explain your answer. [2]



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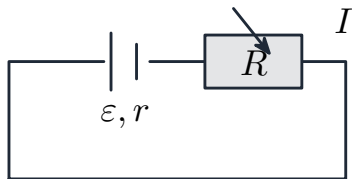


2.3

- the terminal p.d. **equals the e.m.f.**
- with $I = 0$ there is no p.d. across the internal resistance, so nothing is lost inside the cell

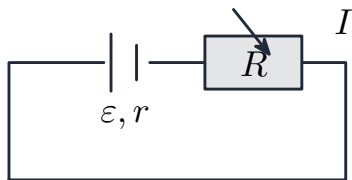
Exercise 2.4

2.4 Calculate the largest current the cell in **2.3** could deliver, and state the condition under which this happens. [2]



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2.4

- the largest current flows when the external resistance is **zero** – the terminals are short-circuited

$$I_{\max} = \frac{E}{r} = \frac{1.5 \text{ V}}{0.40 \text{ } \Omega} = \mathbf{3.75 \text{ A}}$$

Exercise 3.1

3.1 As the current drawn from a cell increases, the terminal potential difference [1]

☐

A increases, because more energy is transferred each second.

B stays the same, because the e.m.f. of the cell is fixed.

C decreases, because more energy is dissipated in the internal resistance.

D decreases, because the e.m.f. of the cell falls.



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D decreases, because the e.m.f. of the cell falls.



3.1 C

- the internal resistance is unchanged, but a larger current gives a larger Ir inside the cell, so less of the fixed e.m.f. is left as terminal p.d.
- D** is the standard error: the e.m.f. does **not** change with current

Exercise 3.2 (a)

3.2 A battery of e.m.f. 6.0 V and internal resistance 0.80Ω is connected to a lamp of resistance 4.0Ω .

(a) Explain why the p.d. across the terminals of the battery is less than its e.m.f. when the lamp is lit. [2]

Exercise 3.2 (a)

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(a) the battery has internal resistance

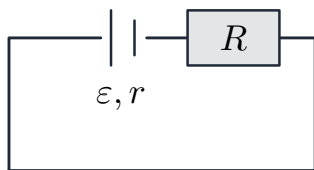
- some of the energy given to each coulomb is transferred to thermal energy inside the battery, Ir per coulomb, so less is left for the lamp

Exercise 3.2 (b)

3.2 A battery of e.m.f. 6.0 V and internal resistance 0.80Ω is connected to a lamp of resistance 4.0Ω .

(b) Calculate the current in the lamp.

[2]



6.0 V

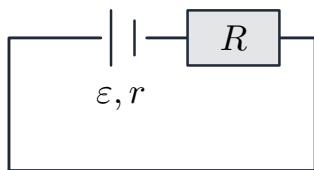
0.80Ω

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(b) Calculate the current in the lamp.

[2]



6.0 V

0.80Ω

(b) the e.m.f. drives the current through both resistances: $I = \frac{E}{R + r}$

$$I = \frac{E}{R + r} = \frac{6.0 \text{ V}}{4.0 \Omega + 0.80 \Omega} = \mathbf{1.25 \text{ A}}$$

Exercise 3.2 (c)

3.2 A battery of e.m.f. 6.0 V and internal resistance $0.80 \, \Omega$ is connected to a lamp of resistance $4.0 \, \Omega$.

(c) Calculate the terminal p.d.

[1]

Exercise 3.2 (c)

3.2 A battery of e.m.f. 6.0 V and internal resistance 0.80Ω is connected to a lamp of resistance 4.0Ω .

(c) Calculate the terminal p.d. [1]

(c) the terminal p.d. is the e.m.f. less the p.d. across the internal resistance, $V = E - Ir$

$$V = E - Ir = 6.0 \text{ V} - (1.25 \text{ A})(0.80 \Omega) = \mathbf{5.0 \text{ V}}$$

Exercise 3.2 (d)

3.2 A battery of e.m.f. 6.0 V and internal resistance $0.80 \, \Omega$ is connected to a lamp of resistance $4.0 \, \Omega$.

(d) Calculate the power wasted inside the battery.

[2]

Exercise 3.2 (d)

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(d) Calculate the power wasted inside the battery. [2]

(d) power in the internal resistance, $P = I^2 r$

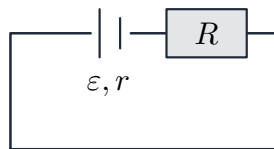
$$P = I^2 r = (1.25\ \text{A})^2 (0.80\ \Omega) = \mathbf{1.25\ W}$$

Exercise 3.3 (a)

3.3 A student varied the resistance of the external circuit and recorded the terminal p.d. V and the current I .

I / A	0.20	0.45	0.70	0.95	1.20
V / V	5.72	5.45	5.18	4.91	4.64

(a) State the equation relating V and I for this circuit, and state what the gradient and the intercept of a graph of V against I represent. [3]

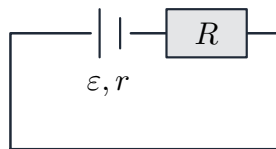


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(a) State the equation relating V and I for this circuit, and state what the gradient and the intercept of a graph of V against I represent. [3]



(a)

- $V = E - Ir$
- the **intercept** on the V axis is the **e.m.f.** E
- the **gradient** is $-r$, so the internal resistance is minus the gradient

Exercise 3.3 (b)

3.3 A student varied the resistance of the external circuit and recorded the terminal p.d. V and the current I .

I / A	0.20	0.45	0.70	0.95	1.20
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(b) Use the first and last pairs of readings to calculate the internal resistance of the source. [3]

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(b)

- the internal resistance is minus the gradient of V against I

$$\text{gradient} = \frac{\Delta V}{\Delta I} = \frac{4.64 \text{ V} - 5.72 \text{ V}}{1.20 \text{ A} - 0.20 \text{ A}} = -1.08 \Omega$$

$$r = -\text{gradient} = -(-1.08 \Omega) = \mathbf{1.08 \Omega}$$

Exercise 3.3 (c)

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(c) Calculate the e.m.f. of the source.

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[2]

(c)

- substitute one pair of readings into $E = V + Ir$

$$E = V + Ir = 5.72 \text{ V} + (0.20 \text{ A})(1.08 \Omega) = \mathbf{5.94 \text{ V}}$$

Exercise 3.3 (d)

3.3 A student varied the resistance of the external circuit and recorded the terminal p.d. V and the current I .

I / A	0.20	0.45	0.70	0.95	1.20
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(d)

- the power dissipated inside the source is $I^2 r$

$$P = I^2 r = (1.20 \text{ A})^2 (1.08 \Omega) = \mathbf{1.6 \text{ W}}$$

Exercise 3.3 (e)

3.3 A student varied the resistance of the external circuit and recorded the terminal p.d. V and the current I .

I / A	0.20	0.45	0.70	0.95	1.20
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(e) Explain why connecting a voltmeter directly across the terminals of the source does not give exactly its e.m.f. [1]

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(e) Explain why connecting a voltmeter directly across the terminals of the source does not give exactly its e.m.f. [1]

(e)

- a real voltmeter draws a small current, so there is a small p.d. Ir inside the cell and the reading is slightly **less** than the e.m.f.