A-LEVEL PHYSICS • EXERCISE SHEET

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

Name: ______________ Class: __________ Date: ____________ **Total: 30 marks**

KEY WORDS resistance 电阻 • internal resistance 内阻 • potential difference 电势差 • terminal p.d. 端电压 • circuit symbols 电路符号

Objective

Sheet 10.1 is the thinnest sheet in this subject – four one-mark definitions – against a unit that the exam asks eleven-mark questions on. This sheet is the rest of 10.1: reading and **drawing circuit diagrams** 电路图 with the standard symbols, the **energy** definitions of **e.m.f.** 电动势 and **potential difference** 电势差 and the difference between them, what the **internal resistance** 内阻 of a source does to the **terminal p.d.** 端电压, and the V–I experiment that measures both at once. This sheet covers syllabus 10.1.

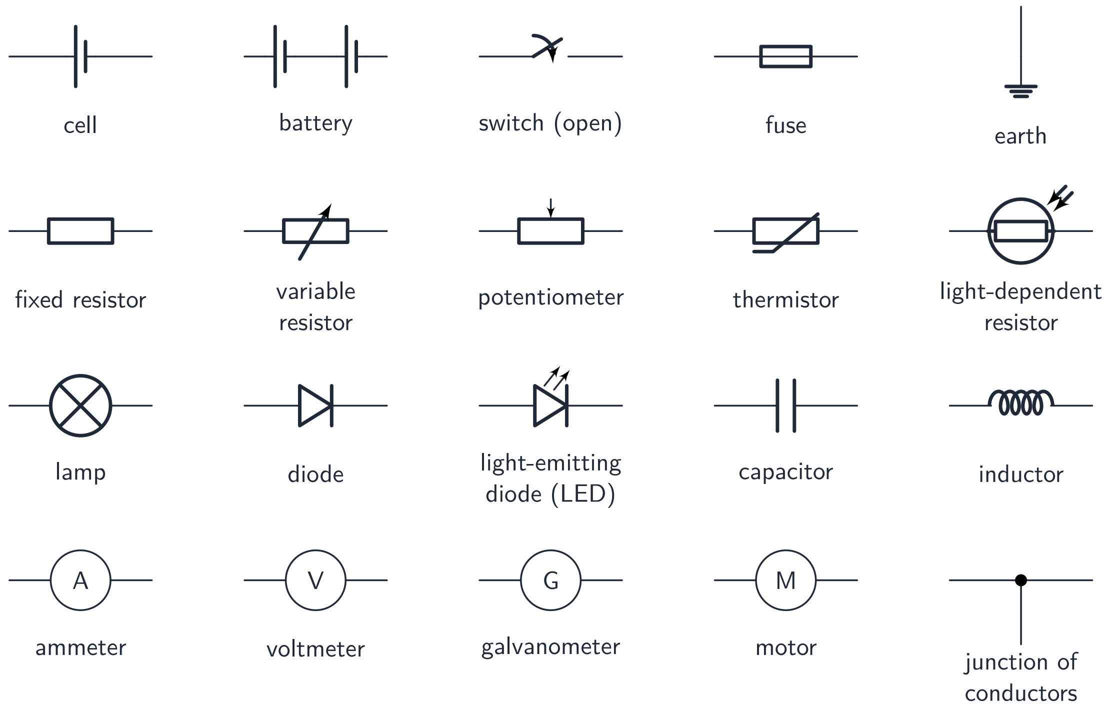
You must be able to:

- recall, draw and interpret the standard **circuit symbols** 电路符号 and circuit diagrams
- define the e.m.f. of a source as the **energy transferred per unit charge** in driving charge round a complete circuit
- distinguish between e.m.f. and potential difference in terms of energy
- understand the effect of the internal resistance of a source on the terminal potential difference

1 Worked examples

Study these first. Each one shows a **method** that a question later on this sheet needs.

> ■ **The symbols, and how a diagram is marked**



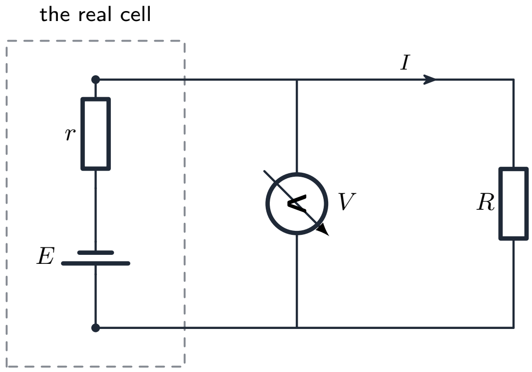
- Draw with a **ruler**, with straight wires and square corners; a wire that simply ends is a lost mark.
- An **ammeter** goes **in series** with the component whose current you want; a **voltmeter** goes **in parallel** across the component whose p.d. you want. Swapping them is the commonest diagram error.
- Junctions that are connected get a **dot**; wires that cross without connecting do not.

■ Two definitions, and they differ only in direction

	definition	**where the energy goes**
electromotive force (e.m.f.) E	the energy transferred **to** each unit of charge, from some other form into electrical, in driving it around a complete circuit	chemical → electrical, inside the source
p.d. V	the energy transferred **from** each unit of charge into another form, in a component	electrical → thermal, light, kinetic, in the component

- Both are **joules per coulomb**, so both are measured in **volts**. That is why the distinction has to be made in words about **energy**, and why “e.m.f. is the voltage of the battery” earns nothing.
- E.m.f. is **not a force**, despite its name.

A real cell: an ideal source with a resistance in series



V is the **terminal p.d.**: what the rest of the circuit actually receives

Each coulomb is given E joules by the source, gives up Ir joules inside the cell and V joules outside it, so $E = V + Ir$, or $V = E - Ir$. Nothing is lost – the missing energy is dissipated *inside* the cell, which is why a battery gets warm.

Follow one coulomb round the circuit:

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

- It is given E joules by the source.
- It gives up Ir joules **inside** the cell, warming it – these are sometimes called the ”lost volts”.
- It gives up V joules **outside**, in the rest of the circuit. V is the **terminal p.d.**: what the circuit actually receives.

Two limiting cases the exam likes:

situation	**what happens**
no current drawn ($I = 0$)	$V = E$: the terminal p.d. **equals** the e.m.f., because nothing is lost inside
terminals shorted ($R = 0$)	$I = \frac{E}{r}$, the **largest current** the cell can deliver, and all of the energy is wasted inside it

Worked example. A cell of e.m.f. 1.5 V *and internal resistance* 0.50 Ω *is connected to a* 2.5 Ω *resistor. Find the current and the terminal p.d.*

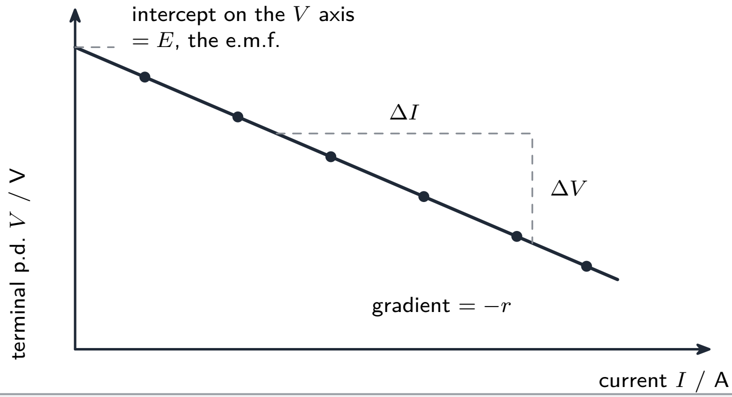
- the e.m.f. drives the current through **both** resistances

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

- then the terminal p.d. is what is left after the internal drop

$$V = E - Ir = 1.5\ \text{V} - 0.50\ \text{A} \times 0.50\ \Omega = \mathbf{1.25}\ \text{V}$$

■ **The experiment: one graph, two answers**



Vary the external resistance, plot V against I, and $V = E - Ir$ gives a straight line: the **intercept** is the e.m.f. and the **gradient** is minus the internal resistance. Extrapolating back to $I = 0$ is how you measure an e.m.f. you can never read directly, because any real voltmeter draws some current.

Vary the external resistance, record V and I each time, and plot V against I. Since

$$V = E - rI$$

is $y = c + mx$:

- the **intercept** on the V axis is the **e.m.f.** E;
- the **gradient** is $-r$, so the internal resistance is **minus** the gradient, and it is positive.
- This is how an e.m.f. is measured, because a real voltmeter always draws a **small current**, so the reading straight across the cell is always slightly **less** than E. The graph extrapolates to the $I = 0$ case that cannot quite be reached.
- **Power:** the source supplies EI in total, of which I^2r is wasted inside and VI is delivered outside.

2 Practice

Now use the methods above.

2.1 Define the **e.m.f.** of a source. [2]

2.2 Explain, in terms of energy, the difference between the e.m.f. of a cell and the potential difference across a resistor. [2]

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

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

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

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

3 Exam-style questions

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

A	B
C	D

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.

3.2 A battery of e.m.f. 12 V and internal resistance 0.50 Ω is connected to a 2.5 Ω resistor in series with a parallel combination of a 6.0 Ω and a 3.0 Ω resistor.

(a) Draw a circuit diagram of this arrangement, including an ammeter to measure the current from the battery and a voltmeter to measure the terminal p.d. [2]

(b) Calculate the total resistance of the external circuit. [2]

(c) Calculate the current delivered by the battery. [2]

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]

(b) Use the first and last pairs of readings to calculate the internal resistance of the source. [3]

(c) Calculate the e.m.f. of the source. [2]

(d) Calculate the power dissipated inside the source when the current is 1.20 A. [2]

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