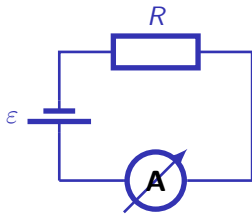


D.C. Circuits

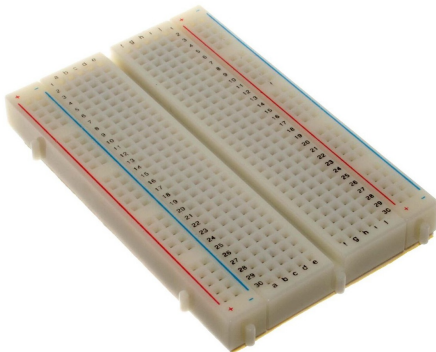
AS Physics ■ Topic 10

A-Level Physics



What we will cover

- 1 e.m.f. and p.d.
- 2 Internal resistance
- 3 Kirchhoff's laws
- 4 Combining resistors
- 5 Potential dividers
- 6 Recap



1

e.m.f. and p.d.

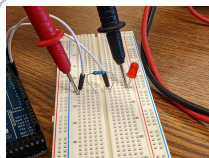
e.m.f. and p.d.

Both in volts: the **potential difference** 电势差 is the energy each unit of charge gives up *inside* a component.

e.m.f. 电动势 ϵ
electromotive force 电动势:
energy **into** the circuit per unit charge

p.d. V
energy **out** (resistor, lamp, motor)

Build and test on a **breadboard** 面包板; measure with a **multimeter** 万用表.



Internal resistance

A real source – its **electrolyte** 电解质 has resistance – carries an **internal resistance** 内阻 r .

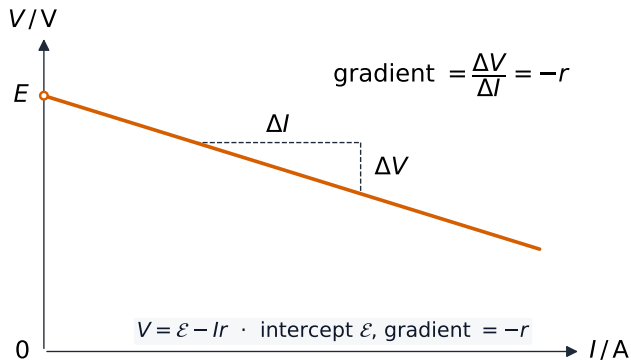
$$V_{\text{terminal}} = \varepsilon - Ir.$$

The load gets $P_{\text{ext}} = (\varepsilon - Ir)I$; the cell wastes $P_{\text{int}} = I^2 r$; the cell supplies εI in total. A **short circuit** 短路 ($R \rightarrow 0$) gives $I = \varepsilon/r$ – the largest current the cell can ever deliver.

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

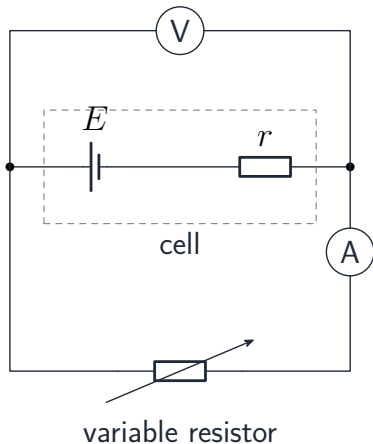
$$I = \frac{1.5}{3.0} = 0.50 \text{ A}, V = 1.25 \text{ V}$$

Internal resistance, in detail



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

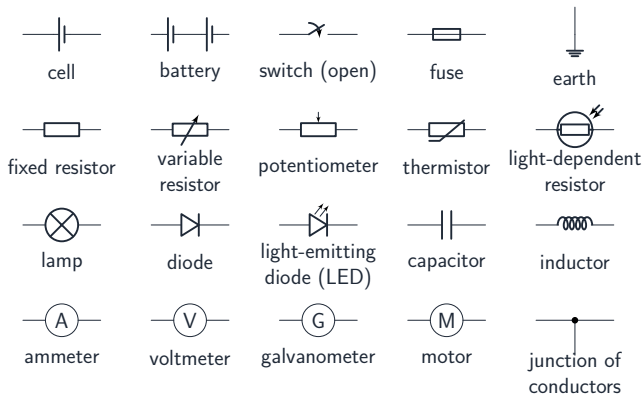
The cell drawn with its own resistance



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

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

Circuit symbols



Ideal **ammeter** 电流表:
zero R , in **series**.

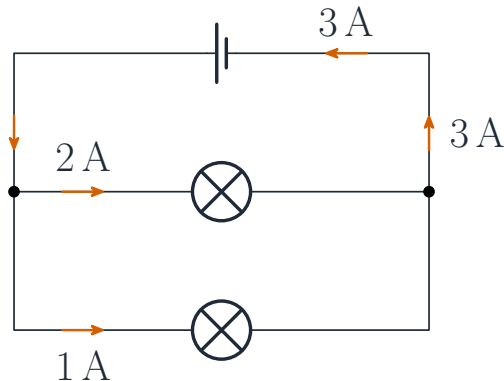
Ideal **voltmeter** 电压表:
infinite R , in **parallel**.

Also on the sheet: the **fuse** 保险丝, the **capacitor** 电容器, the variable resistor or **rheostat** 变阻器, and the **light-dependent resistor** 光敏电阻.

2

Kirchhoff's laws

Kirchhoff's two laws



at each junction: $3\text{ A} = 2\text{ A} + 1\text{ A}$

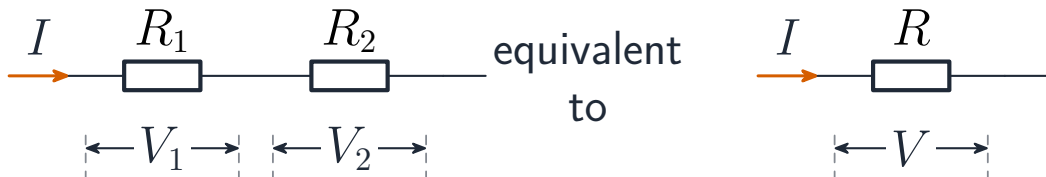
- **First law** (junction): current in = current out (**charge conserved** 电荷守恒)
- **Second law** (loop): around **any closed loop** 任意闭合回路, $\sum \varepsilon = \sum V$ – this is **conservation of energy** 能量守恒

Resistors in series

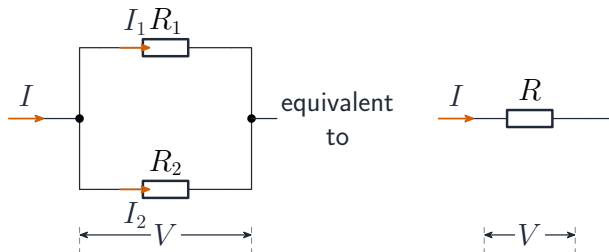
Same **current** 电流; p.d.s add:

$$R_{\text{series}} = R_1 + R_2 + \dots$$

Always **larger** than any single **resistor** 电阻器.



Resistors in parallel



Same p.d.; currents add:

$$\frac{1}{R_{\text{par}}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$$

4.0 Ω and 12 Ω in parallel

$$\frac{1}{R} = \frac{1}{4} + \frac{1}{12} = \frac{1}{3} \Rightarrow R = 3.0 \Omega$$

Two resistors in parallel and their single equivalent resistor

Solving a circuit

1 label every current
& direction

2 junction rule at each node

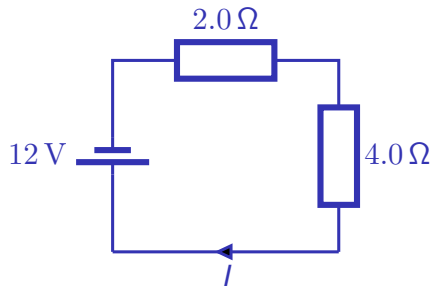
3 loop rule around each loop

4 $V = IR$ for each resistor

5. solve the equations together

In a **symmetric** network, spot branches carrying equal currents – and remember the branch with the most current dissipates the most **power** 功率, since $P = I^2 R$.

Worked example: one loop



Find I and each p.d.

loop rule: $12 = 2.0 I + 4.0 I = 6.0 I$

$I = 2.0 \text{ A}$; $V_1 = 4.0 \text{ V}$, $V_2 = 8.0 \text{ V}$

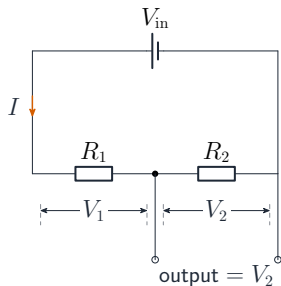
Check with the loop: $4.0 + 8.0 = 12 \text{ V}$

✓ – the p.d.s use up the e.m.f.

3

Potential dividers

Potential dividers



Two series resistors split the p.d. in proportion:

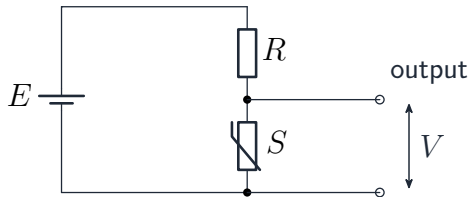
$$V_2 = V_{in} \cdot \frac{R_2}{R_1 + R_2}.$$

6.0 V, 2.0 & 4.0 k Ω

$$V_2 = 6.0 \times \frac{4.0}{6.0} = 4.0 \text{ V}$$

A potential divider – the p.d. splits between R_1 and R_2 in proportion to their resistances

Sensor dividers

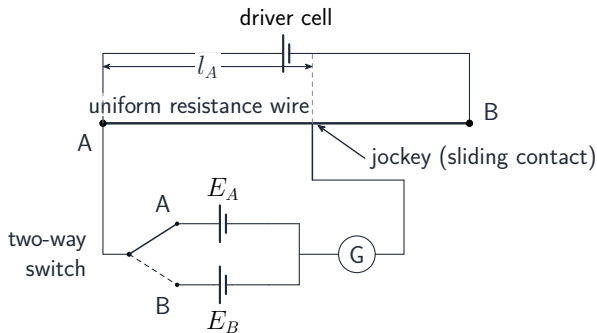


Swap one resistor for a **sensor** 传感器:

- **thermistor** 热敏电阻: output changes with temperature
- **LDR** 光敏电阻: output changes with light

Feed the output to a **transistor** 晶体管 base or a **comparator** 比较器 to switch a load when the temperature or **light intensity** 光强 passes a **threshold** 阈值.

Potentiometer – the null method



Slide the contact until the **galvanometer** 检流计 reads **zero**:

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{l_1}{l_2}.$$

At balance no current flows, so the cell's internal resistance does not matter.

Exam tips

- Apply **Kirchhoff's laws**: current into a junction = current out (charge conserved); $\sum \text{e.m.f.} = \sum \text{p.d. round a loop}$ (energy conserved).
- Combine resistors: **series** $R = R_1 + R_2$; parallel $1/R = 1/R_1 + 1/R_2$.
- A **potential divider** splits voltage in the ratio of the resistances.
- Include **internal resistance**: $\text{e.m.f.} = I(R + r)$ – the “lost volts” are Ir .

4

Recap

Topic 10 – key takeaways

1

Internal resistance

$$V_{\text{term}} = \varepsilon - Ir$$

2

Kirchhoff

junction: charge; loop: energy

3

Resistors

series add; parallel $1/R = \sum 1/R_i$

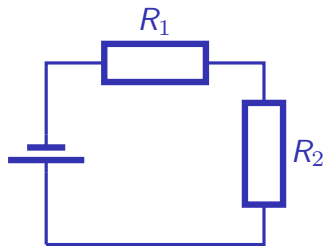
4

Dividers

$$V_2 = V_{\text{in}} R_2 / (R_1 + R_2)$$

Check yourself

- 1 Terminal p.d. of a cell on open circuit?
- 2 Two $6\ \Omega$ resistors in parallel – combined R ?
- 3 Which law comes from conservation of charge?
- 4 Why use the null method to compare e.m.f.s?



Answers 1. equals the e.m.f. ($I = 0$) 2. $3\ \Omega$ 3. the junction (first) law 4. internal resistance has no effect at balance