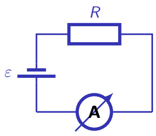
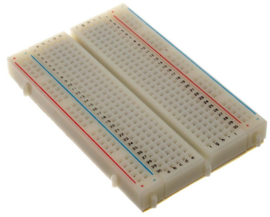
D.C. Circuits

AS Physics ▪ Topic 10

A-Level Physics



What we will cover



1 e.m.f. and p.d.

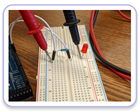
e.m.f. and p.d.

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:

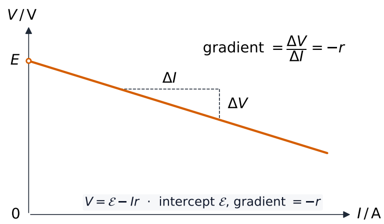
$$V_{\text{terminal}} = \varepsilon - Ir.$$

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 $(R \to 0)$ gives $I = \varepsilon / r$ – the largest current the cell can ever deliver.

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

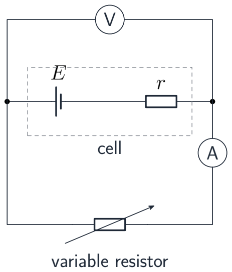
$$I = \frac{1.5}{3.0} = 0.50\,\mathrm{A},\ V = 1.25\,\mathrm{V}$$

Internal resistance, in detail



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

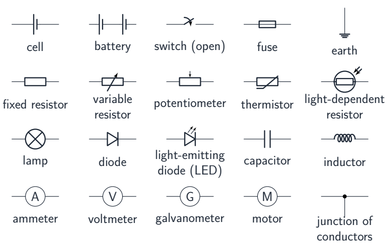
The cell drawn with its own resistance



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

> 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



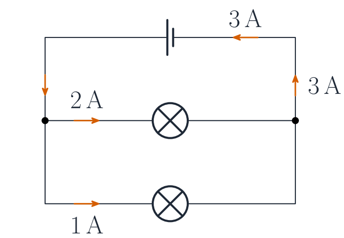
> Ideal **ammeter** 电流表: zero R, in series.

> 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: $3\,\mathrm{A} = 2\,\mathrm{A} + 1\,\mathrm{A}$

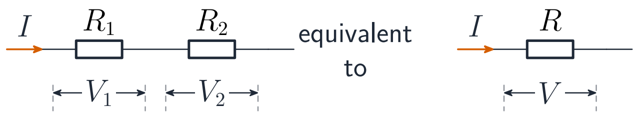
- First law (junction): current in = current out (**charge conserved** 电荷守恒)
- Second law (loop): around **any closed loop** 任意闭合回路, $\sum \varepsilon = \sum V$ – this is **conservation of energy** 能量守恒

Resistors in series

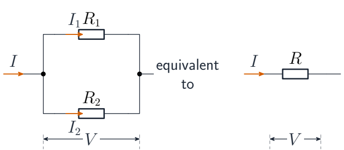
Same **current** 电流; p.d.s add:

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

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



Resistors in parallel



Same p.d.; currents add:

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

$4.0\,\Omega$ and $12\,\Omega$ in parallel

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

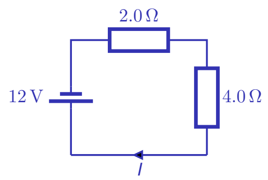
> Two resistors in parallel and their single equivalent resistor

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 $P = I^2R$.

Worked example: one loop



Find I and each p.d.

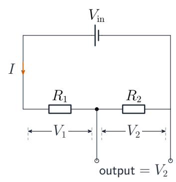
loop rule: $12 = 2.0\,I + 4.0\,I = 6.0\,I$

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

Check with the loop: $4.0 + 8.0 = 12\,\mathrm{V}$
✓ – the p.d.s use up the e.m.f.

3 Potential dividers

Potential dividers



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

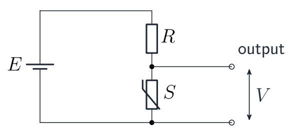
$$V_2 = V_{in} \cdot \frac{R_2}{R_1 + R_2}.$$

6.0 V, 2.0 & 4.0 k

$$V_2 = 6.0 \times \frac{4.0}{6.0} = 4.0\,\mathrm{V}$$

A potential divider – the p.d. splits between R1 and R2 in proportion to their resistances

Sensor dividers

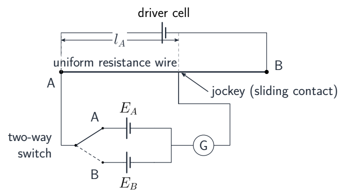


Swap one resistor for a **sensor** 传感器:

- **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); $\sum$ e.m.f. = $\sum$ 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**: 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

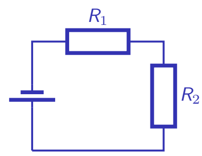
series add; parallel $1/R = \sum 1/R_i$

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