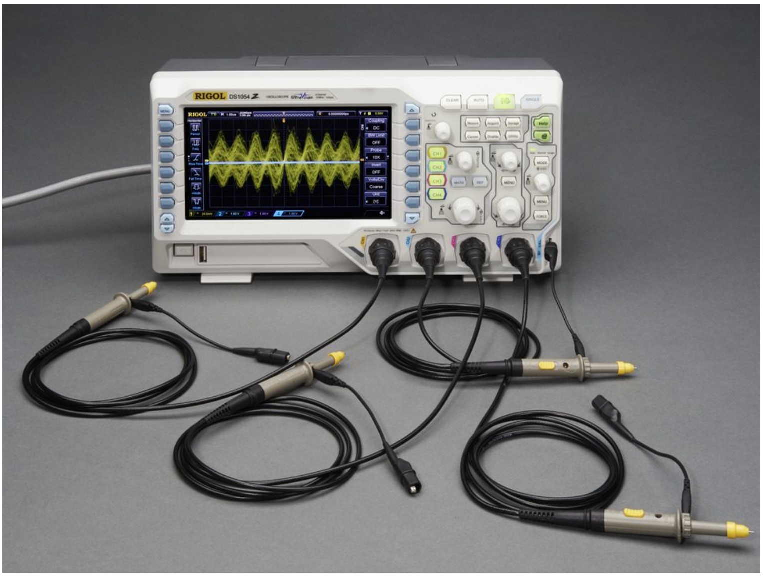
# Electric Circuits

AP Physics 2

## Electric Current

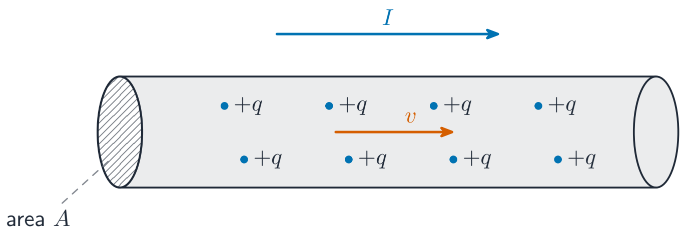


*An oscilloscope: circuit behaviour over time is measured as voltage against time*

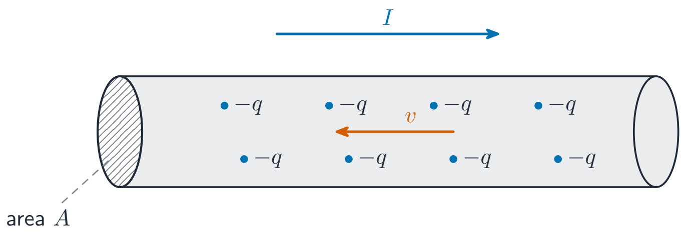
**Electric current** 电流 is the rate at which charge flows past a point, measured in **amperes** 安培 (A):

$$I = \frac{\Delta q}{\Delta t}.$$

By convention, current points the way **positive** charge would move (opposite to the electrons in a wire). A steady current needs a complete loop and an energy source (a battery's **electromotive force**, or emf).




(a) positive carriers drift with $I$

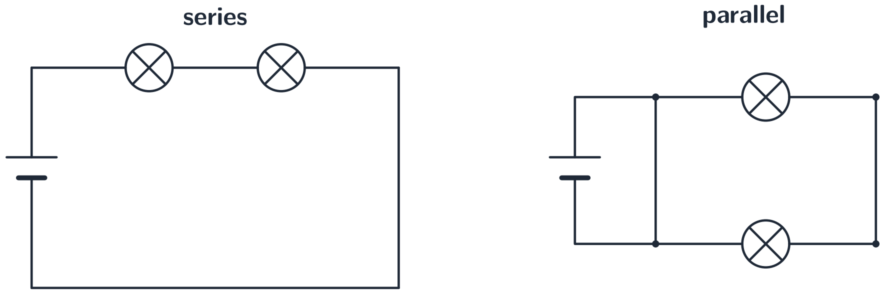



(b) electrons drift against $I$

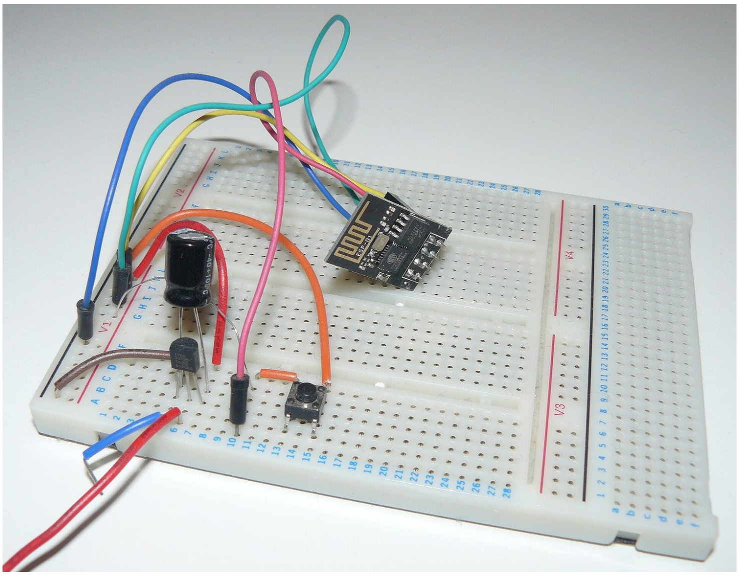
*Charge carriers drift slowly through a conductor to make a current*

# Simple Circuits

A **circuit** is a closed loop of conductors, a source (battery), and components. In a **series** 串联 path the same current flows through each element; in a **parallel** 并联 path the same voltage is across each branch. A **circuit diagram** uses standard symbols; reading it correctly is the first step of any circuit problem.




*Components can be joined in series or in parallel*



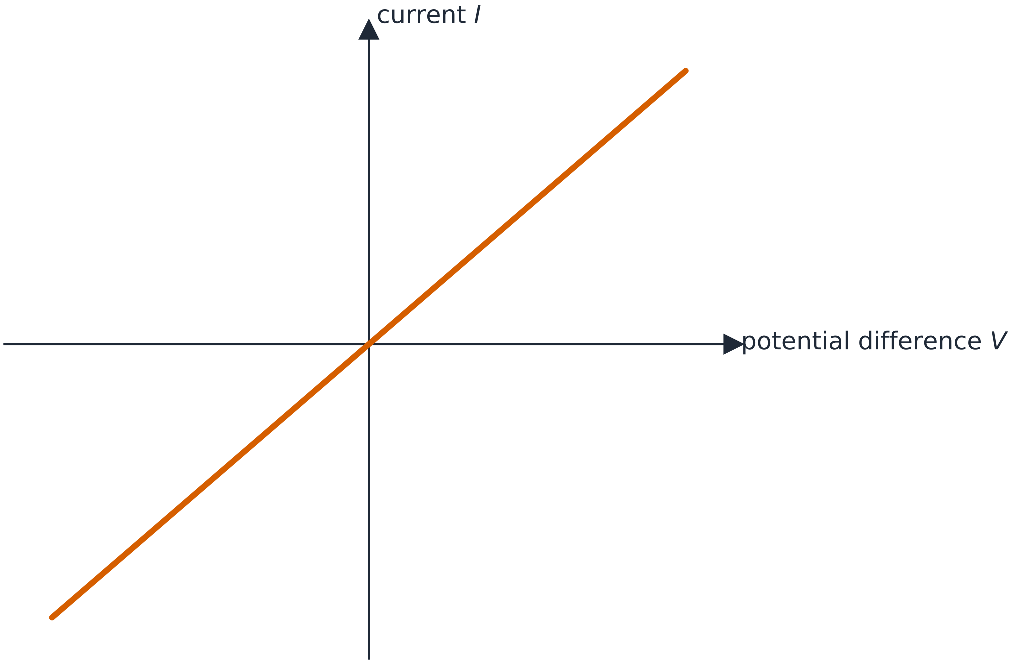
*A real circuit: components pushed into a breadboard and joined by wires so current has a complete path*

# Resistance, Resistivity, and Ohm's Law

**Resistance** 电阻 $R$ opposes current, measured in ohms. **Ohm's law** 欧姆定律 links the three key quantities:

$$V = IR.$$

A component's resistance depends on the material's **resistivity** 电阻率 $\rho$, its length, and its cross-sectional area: $R = \dfrac{\rho L}{A}$ – longer and thinner means more resistance.




*The I-V line of an ohmic conductor is straight through the origin*

**Worked example.** A 2.0 A current flows through a 6.0 Ω resistor. The voltage across it is $V = IR = 2.0 \times 6.0 = 12$ V.

# Electric Power

**Electric power** 电功率 is the rate a component converts electrical energy (to heat, light, motion):

$$P = IV = I^2R = \frac{V^2}{R}.$$

Pick the form that uses the quantities you know. A resistor's power all becomes heat.

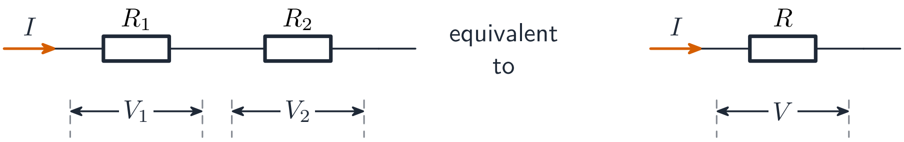
**Worked example.** The 6.0 Ω resistor above, carrying 2.0 A, dissipates $P = I^2R = 2.0^2 \times 6.0 = 24$ W – equivalently $P = IV = 2.0 \times 12 = 24$ W.

A **light bulb** 灯泡 is just a resistor that glows, and its **brightness** 亮度 rises with the **power** it dissipates. So to rank bulbs, compare their power. In a series string every bulb carries the same current, so by $P = I^2R$ the bulb with the **largest** resistance is brightest; wired in parallel every bulb gets the full battery voltage, so by $P = V^2/R$ the bulb with the **smallest** resistance is brightest.

*High-voltage power lines: electrical power is transmitted as high voltage so current (and $I^2R$ loss) stays low*

# Compound DC Circuits

Combine resistors to find an **equivalent resistance** 等效电阻:




*Resistors in series add to a single equivalent resistance*

- **Series:** $R_{eq} = R_1 + R_2 + \cdots$ (resistances add).
- **Parallel:** $\dfrac{1}{R_{eq}} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \cdots$ (the total is **less** than the smallest).

Reduce the network step by step to find the total current from the battery, then work back to each element.

**Worked example.** A 12 V battery drives a 4.0 Ω and a 12 Ω resistor in **parallel**. First combine them: $\dfrac{1}{R_{\text{eq}}} = \dfrac{1}{4} + \dfrac{1}{12} = \dfrac{4}{12} \Rightarrow R_{\text{eq}} = 3.0\ \Omega$. The total current from the battery is $I = \dfrac{V}{R_{\text{eq}}} = \dfrac{12}{3.0} = 4.0$ A, which splits so that the smaller resistor carries the larger share (3.0 A through the 4 Ω, 1.0 A through the 12 Ω).

# Measuring Current and Voltage

Two meters read a circuit. An **ammeter** 电流表 measures the current at a point, so it must be wired **in series** – the current you want to measure has to flow *through* it. A **voltmeter** 电压表 measures the potential difference between two points, so it is wired **in parallel**, bridging across the component whose voltage you want.

For a meter to read the true value it must barely disturb the circuit:

- an **ideal ammeter** has **zero resistance**, so putting it in series does not reduce the current it reads;
- an **ideal voltmeter** has **infinite resistance**, so almost no current is diverted through it.

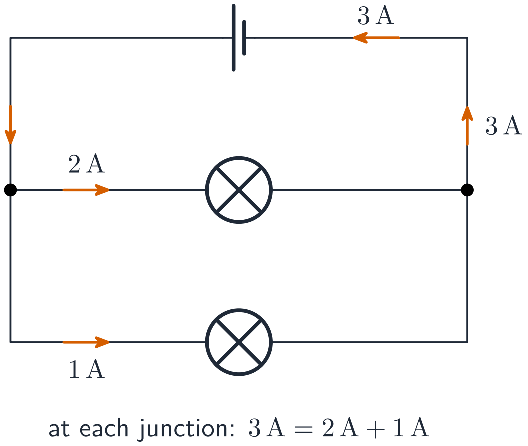
A real, **nonideal** 非理想 meter is imperfect: a real ammeter has a small resistance (it slightly lowers the current), and a real voltmeter lets a little current leak through (it slightly lowers the voltage it reads). So connecting any meter changes, a little, the very quantity it is measuring.

# Kirchhoff’s Loop Rule

**Kirchhoff’s loop rule** 基尔霍夫电压定律 (energy conservation): around any closed loop, the voltage gains and drops sum to **zero**. Add the battery’s emf and subtract each $IR$ drop as you go around. This gives one equation per independent loop.

# Kirchhoff's Junction Rule

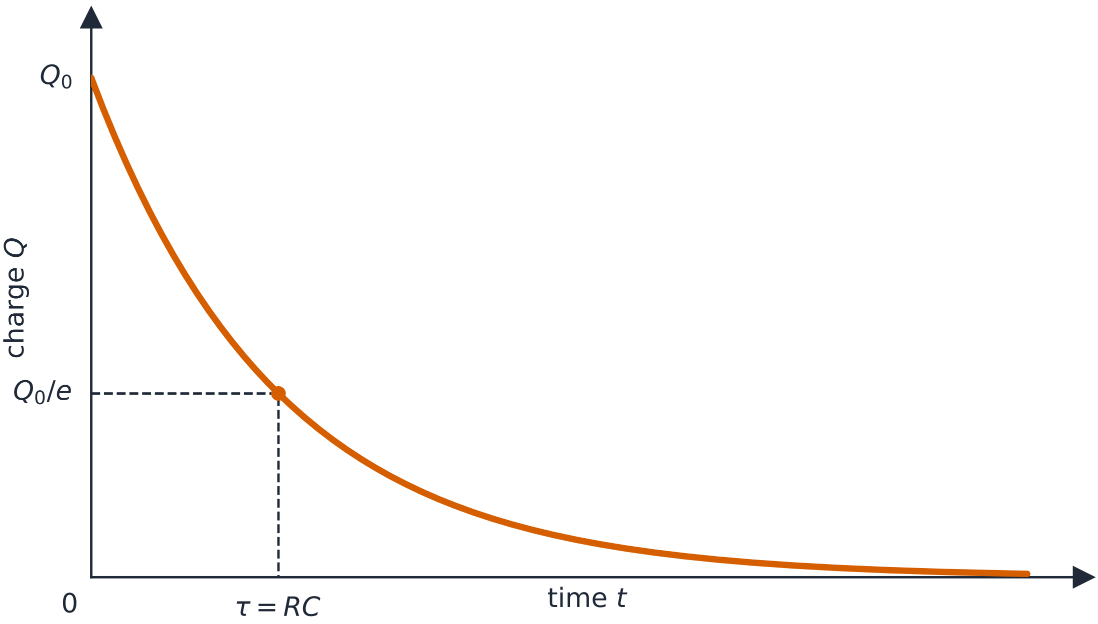
**Kirchhoff's junction rule** 基尔霍夫电流定律 (charge conservation): the total current **into** any junction equals the total current **out**. Together with the loop rule, it lets you solve any multi-loop circuit for its unknown currents.




*Current divides at a junction: what flows in equals what flows out*

# RC Circuits

An **RC circuit** RC 电路 contains a resistor and a capacitor. When charging, the capacitor's voltage rises and the current falls, both **exponentially**, over a characteristic time $\tau = RC$. Key limits: at the first instant the uncharged capacitor acts like a plain wire (maximum current); after a long time it is fully charged and blocks current (acts like a break).




*The charge on a capacitor decays exponentially as it discharges*

**Worked example.** For $R = 10$ kΩ and $C = 100$ $\mu$F, the time constant is $\tau = RC = (10 \times 10^3)(100 \times 10^{-6}) = 1.0$ s. After one time constant the capacitor reaches about 63% of the supply voltage; after about $5\tau$ it is essentially fully charged.

# Exam tips

- In **series** the current is the same throughout; in **parallel** the voltage is the same across each branch — never mix these up.
- Combine resistors: series **add**; parallel $1/R_{\text{eq}} = \sum 1/R_i$ (the total is **less** than the smallest).
- Apply **Kirchhoff's rules**: junction (current in = current out, charge conserved) and loop (voltages sum to zero, energy conserved).
- Pick the power form that fits your knowns: $P = IV = I^2R = V^2/R$.
- An **ammeter** goes in **series** (ideal: zero resistance); a **voltmeter** goes in **parallel**

(ideal: infinite resistance). A real meter slightly disturbs the circuit it measures.

- A bulb is brighter when it dissipates more **power** – in series the biggest resistance ($I^2R$) glows brightest; in parallel the smallest ($V^2/R$) does.
- In an **RC circuit** the capacitor acts like a plain wire the instant it starts charging and like a break once fully charged.