Exercise walk-through

Electrical quantities ▪ 4.2

eXercise

You must be able to

- describe **charging by friction 摩擦起电** and test whether an object is charged
- tell conductors from insulators, and explain the difference using electrons
- use $I = \dfrac{Q}{t}$, and choose the right range on an ammeter or a voltmeter
- define e.m.f. and p.d. and use $E = \dfrac{W}{Q}$ and $V = \dfrac{W}{Q}$
- measure resistance, use $R = \dfrac{V}{I}$, and say how length and thickness change it
- read current–voltage graphs for a resistor, a filament lamp and a diode
- use $P = IV$ and $E = IVt$, and work out a cost in kilowatt-hours

Method — Charges, conductors and current

Rub a plastic rod with a cloth: **electrons 电子** move from the cloth onto the rod. The rod is now negative and the cloth is positive. Only electrons move; the positive charge stays where it is. Like charges **repel 排斥** and unlike charges **attract 吸引**. To test whether a rod is charged, hang it on a thread and bring another charged rod near it: **repulsion 排斥力** is the only sure sign, because attraction also happens with an uncharged object.

A **conductor 导体** (a metal) has free electrons that can move, so charge flows through it. An **insulator 绝缘体** (plastic, rubber, glass) has no free electrons. To test a material, put it in a circuit with a cell and a lamp: the lamp lights only for a conductor.

Current 电流 is the charge passing a point each second, measured in amperes (A):

$$I = \frac{Q}{t}$$

Method — Charges, conductors and current

Worked example 1. A current of 3.0 A flows in a lamp for 20 s. Find the charge that passes.

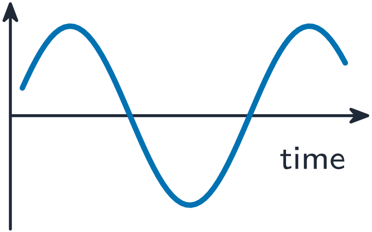
1. Write down what you know: $I = 3.0$ A and $t = 20$ s.
2. Rearrange $I = Q/t$ to give $Q = It$.
3. Substitute: $Q = 3.0 \times 20 = 60$ C.

Conventional current 常规电流 flows from $+$ to $-$ round the circuit; the electrons drift the other way. A **direct current 直流电** (d.c.) always flows one way; an **alternating current 交流电** (a.c.) keeps reversing.

Method — Charges, conductors and current

d.c. (steady)

a.c. (swaps direction)



Direct current is steady; alternating current keeps swapping direction

Method — Meters and their ranges

An **ammeter 电流表** goes in series; a **voltmeter 电压表** goes in parallel, across the component. Both may be **analogue 模拟** (a needle on a scale) or **digital 数字** (a number on a screen). Choose the **range 量程** just above the biggest reading you expect: for a current of about 0.4 A use the 0–1 A range, not the 0–10 A range, because the needle moves further and the reading is more accurate.

Method — E.m.f. and p.d.

The **e.m.f. 电动势** of a cell is the work it does driving one coulomb of charge round the whole circuit. The **p.d. 电势差** across a component is the work done by one coulomb passing through that component. Both are measured in volts (V):

$$E = \frac{W}{Q} \qquad V = \frac{W}{Q}$$

Worked example 2. A battery does 180 J of work moving 30 C of charge round a circuit. Find its e.m.f.

$E = \dfrac{W}{Q} = \dfrac{180}{30} = 6.0$ V.

Method — Measuring resistance

Resistance 电阻 measures how hard it is for current to flow:

$$R = \frac{V}{I}$$

The circuit for measuring resistance: the ammeter is in series, the voltmeter is across the component, and the variable resistor changes the current

Worked example 3. In this circuit the voltmeter reads 4.8 V and the ammeter reads 0.20 A. Find the resistance of the component.

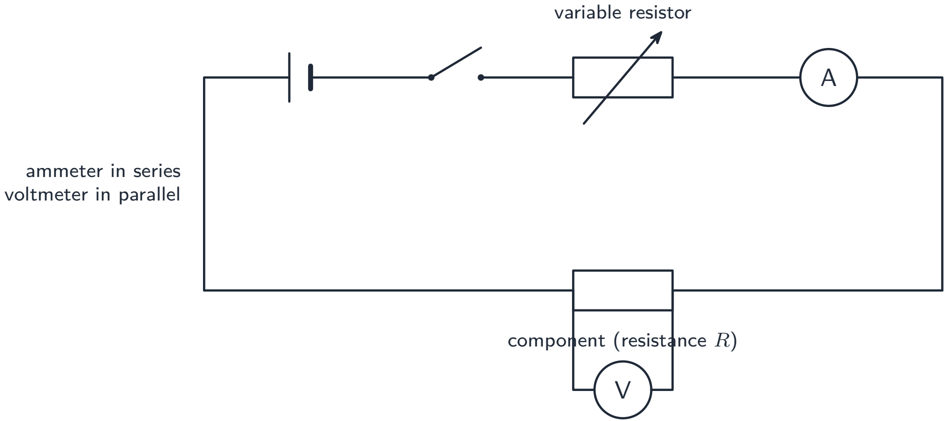
$R = \dfrac{V}{I} = \dfrac{4.8}{0.20} = 24\ \Omega$. In the experiment, change the variable resistor to get four or five pairs of readings. Then either find R for each pair and take the average, or plot V against I: the gradient of the straight line is R.

Method — Measuring resistance

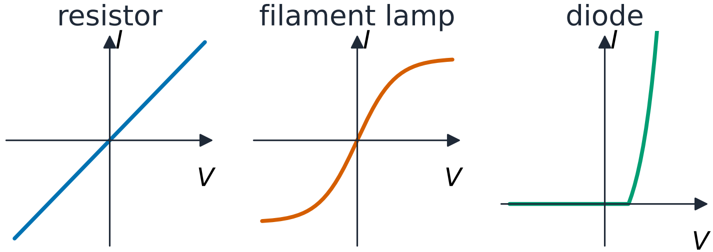
For a wire at constant temperature, a longer wire has more resistance ($R \propto l$) and a thicker wire has less ($R \propto 1/A$). Doubling the length doubles R; doubling the cross-sectional area halves it.

A resistor gives a straight line through the origin (constant R); a filament lamp curves as it heats up and its resistance rises; a diode conducts one way only

Method — Measuring resistance



Method — Measuring resistance



resistor (ohmic): $V = IR$ straight · filament: resistance rises with heat · diode: one-way

Current-voltage graphs define resistance

Method — Power, energy and the kilowatt-hour

$$P = IV \qquad E = IVt$$

Worked example 4. A 230 V kettle takes a current of 8.0 A for 3.0 minutes. Find its power and the energy it transfers.

1. Power: $P = IV = 8.0 \times 230 = 1840$ W.
2. Time in seconds: $t = 3.0 \times 60 = 180$ s.
3. Energy: $E = Pt = 1840 \times 180 = 331\,000$ J $\approx 3.3 \times 10^5$ J.

Method — Power, energy and the kilowatt-hour

Electricity bills use the **kilowatt-hour 千瓦时** (kWh), the energy a 1 kW appliance uses in 1 hour:

$$E\ (\text{kWh}) = P\ (\text{kW}) \times t\ (\text{h}) \qquad \text{cost} = E\ (\text{kWh}) \times \text{price per kWh}$$

Worked example 5. A 2.0 kW heater runs for 2.5 hours. Electricity costs 0.60 yuan per kWh. Find the cost.
$E = 2.0 \times 2.5 = 5.0$ kWh, so the cost is $5.0 \times 0.60 = 3.0$ yuan.

Practice 2.1 ▪ 2 marks

A current of 2.0 A flows for 15 s. Find the charge that passes.

Solution 2.1

Method: Charges, conductors and current

Worked steps

$Q = It = 2.0 \times 15 = 30$ C M1 A1.

Practice 2.2 ▪ 3 marks

A charge of 240 C passes through a motor in 4.0 minutes. Find the current. (Hint: change the time into seconds first.)

Solution 2.2

Worked steps

$t = 4.0 \times 60 = 240$ s **B1**; $I = \dfrac{Q}{t} = \dfrac{240}{240} = 1.0$ A **M1** **A1**.

Practice 2.3 ▪ 2 marks

A student wants to measure a current of about 0.25 A. Her ammeter has ranges of 0–100 mA, 0–1 A and 0–10 A. State which range she should use and explain why.

Solution 2.3

Method: Meters and their ranges

Worked steps

The 0–1 A range B1. It is the smallest range above 0.25 A, so the needle moves well up the scale and the reading is more accurate; the 0–100 mA range would be overloaded and the 0–10 A range would read only coarsely B1.

Practice 2.4 ▪ 2 marks

A cell does 27 J of work moving 18 C of charge round a circuit. Find its e.m.f.

Solution 2.4

Method: E.m.f. and p.d.

Worked steps

$$E = \frac{W}{Q} = \frac{27}{18} = 1.5\ \text{V} \quad \textbf{M1}\ \textbf{A1}.$$

Practice 2.5 ▪ 2 marks

A p.d. of 12 V across a heater drives a current of 0.50 A through it. Find its resistance.

Solution 2.5

Method: Measuring resistance

Worked steps

$$R = \frac{V}{I} = \frac{12}{0.50} = 24\ \Omega \quad \boxed{\textbf{M1}}\boxed{\textbf{A1}}.$$

Practice 2.6 ▪ 2 marks

Wire P has a resistance of $6.0\ \Omega$. Wire Q is made of the same metal and is the same thickness as P, but twice as long. Wire S is the same length as P but has twice the cross-sectional area. State the resistance of Q and of S.

Solution 2.6

Method: Measuring resistance

Worked steps

Q: twice the length, so $12\ \Omega$ **B1**. S: twice the area, so $3.0\ \Omega$ **B1**.

Practice 2.7 ▪ 3 marks

A 12 V motor draws a current of 2.5 A. Find its power, and the energy it transfers in 40 s.

Solution 2.7

Method: Power, energy and the kilowatt-hour

Worked steps

$P = IV = 2.5 \times 12 = 30$ W M1 A1; $E = Pt = 30 \times 40 = 1200$ J A1.

Practice 2.8 ▪ 3 marks

An electric oven is rated 3.0 kW. It is used for 1.5 hours each day for 10 days. Electricity costs 0.55 yuan per kWh. Find the cost.

Solution 2.8

Method: Power, energy and the kilowatt-hour

Worked steps

$E = 3.0 \times 1.5 \times 10 = 45$ kWh M1 A1; cost $= 45 \times 0.55 = 24.75 \approx 25$ yuan A1.

Exam-style 3.1 ▪ 1 mark

Two wires, X and Y, are made of the same metal at the same temperature. Y is twice as long as X and has half the cross-sectional area of X. The resistance of X is R. What is the resistance of Y?

A $R/4$

B R

C $2R$

D $4R$

Solution 3.1

Method: Measuring resistance

A $R/4$

B R

C $2R$

D $4R$ ✓

Worked steps

D. Twice the length doubles the resistance and half the area doubles it again, so $R_Y = 4R$. A takes both changes the wrong way, B assumes they cancel, and C counts only the length.

Exam-style 3.2 ▪ 1 mark

A charged rod is brought near a small ball hanging on a thread. The ball moves towards the rod. Which statement is correct?

A The ball must have the opposite charge to the rod.

B The ball must be a conductor.

C The ball may be uncharged.

D The ball must have the same charge as the rod.

Solution 3.2

Method: Charges, conductors and current

A The ball must have the opposite charge to the rod.

B The ball must be a conductor.

C The ball may be uncharged. ✓

D The ball must have the same charge as the rod.

Worked steps

C. A charged rod attracts an uncharged object as well as an oppositely charged one, so attraction proves nothing; only repulsion is a sure test.

Exam-style 3.3 ▪ 1 mark

A phone charger is connected to the 230 V mains. It supplies a current of 2.0 A at a p.d. of 5.0 V to the phone for 30 minutes.

(a) Define the potential difference across the phone.

(b) Calculate the charge that flows into the phone in the 30 minutes.

(c) Calculate the energy transferred to the phone in this time.

(d) The case of the charger is made of plastic. Explain, in terms of electrons, why the plastic case does not conduct.

Solution 3.3

Method: Charges, conductors and current

Worked steps

(a) The work done by a unit charge (one coulomb) passing through the phone **B1**.

(b) $t = 30 \times 60 = 1800$ s **B1**; $Q = It$ **M1** $= 2.0 \times 1800 = 3600$ C **A1**.

(c) $E = IVt = 2.0 \times 5.0 \times 1800 = 18\,000$ J **M1** **A1**.

(d) Plastic has no free electrons **B1**; its electrons are held in their atoms, so charge cannot flow through it **B1**.

Exam-style 3.4 ▪ 3 marks

A student is given a length of resistance wire, a cell, a switch, an ammeter, a voltmeter and a variable resistor.

(a) Draw a labelled circuit diagram she could use to find the resistance of the wire.

(b) Describe how she uses the circuit to obtain a reliable value for the resistance.

(c) Her readings are $V = 3.0$ V and $I = 0.60$ A. Calculate the resistance of the wire.

(d) She replaces the wire with a filament lamp and increases the current. State and explain how the resistance of the lamp changes.

Solution 3.4

Method: Measuring resistance

Worked steps

(a) Cell, switch, variable resistor and ammeter in series with the wire **B1**; voltmeter in parallel across the wire **B1**; correct symbols in a complete loop **B1**.
(b) Close the switch and read the ammeter and the voltmeter **B1**; adjust the variable resistor to obtain several pairs of readings **B1**; calculate $R = V/I$ for each pair and take the average, or plot V against I and use the gradient **B1**.
(c) $R = \dfrac{V}{I} = \dfrac{3.0}{0.60} = 5.0\ \Omega$ **M1** **A1**.
(d) The resistance increases **B1**, because the filament gets hotter as the current rises **B1**.

Exam-style 3.5 ▪ 2 marks

A 1.5 kW electric kettle and a 100 W lamp are each switched on for 20 minutes.

(a) Calculate the energy, in kWh, used by the kettle.

(b) Calculate how many times longer the lamp would have to be on to use the same energy as the kettle.

(c) The kettle is connected to the 230 V mains. Calculate the current in the kettle.

Solution 3.5

Method: Power, energy and the kilowatt-hour

Worked steps

(a) $E = 1.5 \times \dfrac{20}{60} = 0.50$ kWh **M1** **A1**.

(b) The lamp uses 0.10 kW, so it needs $\dfrac{0.50}{0.10} = 5.0$ h **M1**; 5.0 h $\div$ 20 min $=$ 15 times longer **A1**.

(c) $I = \dfrac{P}{V} = \dfrac{1500}{230} = 6.5$ A **M1** **A1**.