

4.2 Electrical quantities

Name: _____ Class: _____ Date: _____

Total: 45 marks

KEY WORDS resistance • current • potential difference • conductor • kilowatt-hour
 • current • resistance • volt • electrical power • electrical quantities

Objective

Build the skills to answer exam questions on **electrical quantities** : charge, current, e.m.f. and p.d., resistance, and electrical power and energy.

You must be able to:

- describe **charging by friction** and test whether an object is charged
- tell conductors from insulators, and explain the difference using electrons
- use $I = \frac{Q}{t}$, and choose the right range on an ammeter or a voltmeter
- define e.m.f. and p.d. and use $E = \frac{W}{Q}$ and $V = \frac{W}{Q}$
- measure resistance, use $R = \frac{V}{I}$, 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

1 Key knowledge and worked examples

■ Charges, conductors and current

Rub a plastic rod with a cloth: **electrons** move from the cloth onto the rod. For this assumed electron transfer, the rod becomes negative and the cloth positive. The ions remain in the solid. Like charges **repel** and unlike charges **attract**. To test whether a rod is charged, hang it on a thread and bring another charged rod near it: **repulsion** is the only sure sign, because attraction also happens with an uncharged object.

A **conductor** (a metal) has free electrons that can move, so charge flows through it. An **insulator** (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.

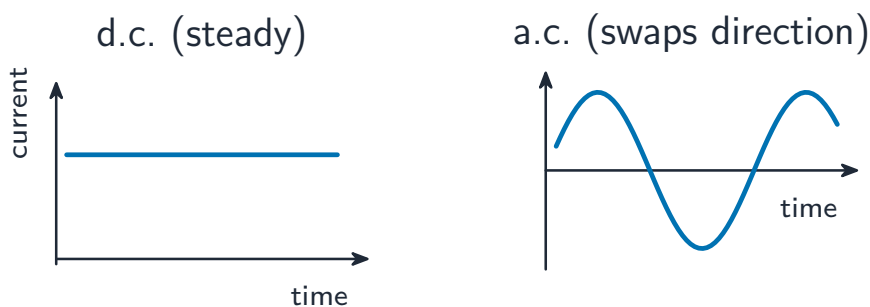
Current is the charge passing a point each second, measured in amperes (A):

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

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

Rearrange $I = Q/t$ to give $Q = It$, then substitute: $Q = 3.0 \times 20 = 60 \text{ C}$.

Conventional current flows from + to – round the circuit; the electrons drift the other way. A **direct current** (d.c.) always flows one way; an **alternating current** (a.c.) keeps reversing.



d.c. flows one way; a.c. keeps reversing

■ Meters and their ranges

An **ammeter** goes in series; a **voltmeter** goes in parallel, across the component. Both may be **analogue** (a needle on a scale) or **digital** (a number on a screen). Choose a **range** that includes the expected reading with useful resolution: about 0.4 A fits the 0–1 A range. Start high if the current is unknown, then reduce safely. A finer scale improves reading resolution, not necessarily calibration accuracy.

■ E.m.f. and p.d.

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

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

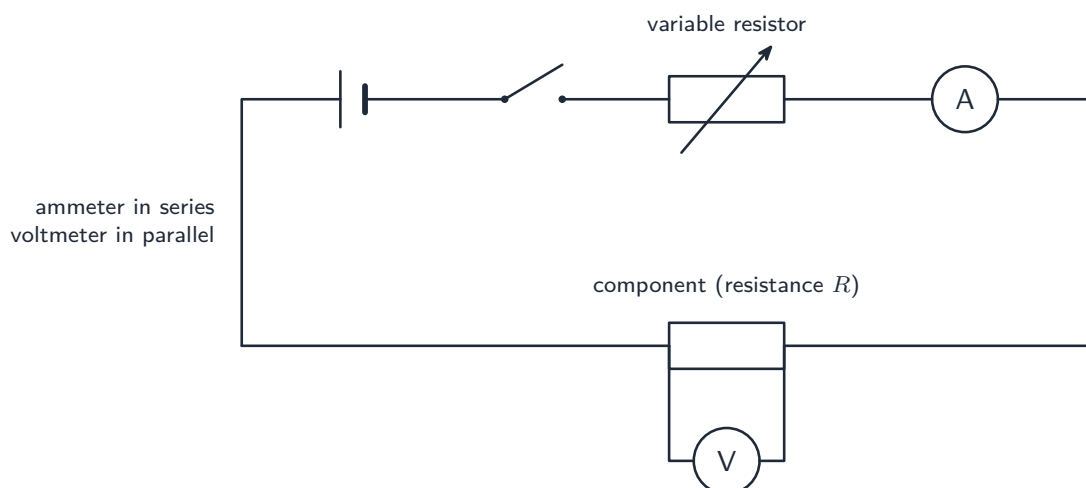
Worked example 2. A battery does 180 J of work moving 30 C of charge round a circuit. Find its e.m.f.

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

■ Measuring resistance

Resistance measures how hard it is for current to flow:

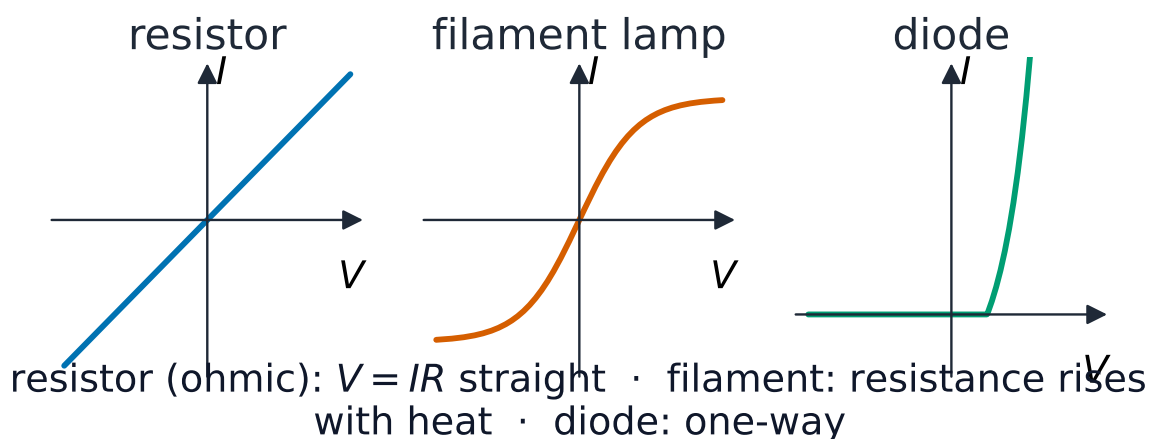
$$R = \frac{V}{I}$$



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.

$R = \frac{V}{I} = \frac{4.8}{0.20} = 24 \, \Omega$. At approximately constant temperature, obtain several V, I pairs. For an ohmic component, plot V against I : its straight-line gradient is R . Do not assume a filament lamp has constant resistance as it heats.

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

■ Power, energy and the kilowatt-hour

$$P = IV \quad E = IVt$$

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: $P = IV = 8.0 \times 230 = 1840 \, \text{W}$.

2. Time in seconds: $t = 3.0 \times 60 = 180 \text{ s}$.
3. Energy: $E = Pt = 1840 \times 180 = 331\,200 \text{ J} \approx 3.3 \times 10^5 \text{ J}$.

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

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

Worked example 5. A 2.0 kW heater runs for 2.5 hours. Electricity costs 0.60 yuan per kWh. Find the cost.

$E = 2.0 \times 2.5 = 5.0 \text{ kWh}$, so the cost is $5.0 \times 0.60 = 3.0 \text{ yuan}$.

2 Practice

2.1 A current of 2.0 A flows for 15 s. Find the charge that passes. [2]

2.2 A charge of 240 C passes through a motor in 4.0 minutes. Find the current. (Hint: change the time into seconds first.) [3]

2.3 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. [2]

2.4 A cell does 27 J of work moving 18 C of charge round a circuit. Find its e.m.f. [2]

2.5 A p.d. of 12 V across a heater drives a current of 0.50 A through it. Find its resistance. [2]

2.6 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. [2]

2.7 A 12 V motor draws a current of 2.5 A . Find its power, and the energy it transfers in 40 s . [3]

2.8 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. [3]

3 Exam-style questions

3.1 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? [1]

- ☐ **A** $R/4$
B R
C $2R$
D $4R$

3.2 A charged rod is brought near a small ball hanging on a thread. The ball moves towards the rod. Which statement is correct? [1]

- ☐ **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.

3.3 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. [1]

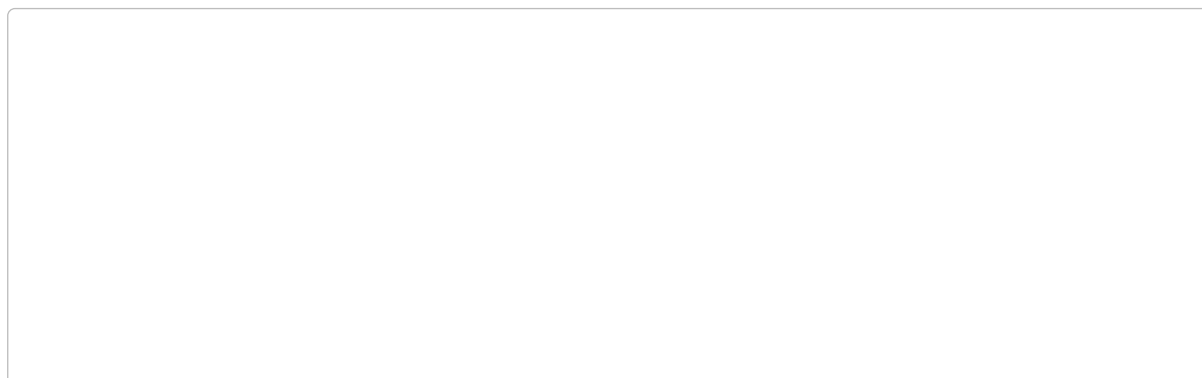
(b) Calculate the charge that flows into the phone in the 30 minutes. [3]

(c) Calculate the energy transferred to the phone in this time. [2]

(d) The case of the charger is made of plastic. Explain, in terms of electrons, why the plastic case does not conduct. [2]

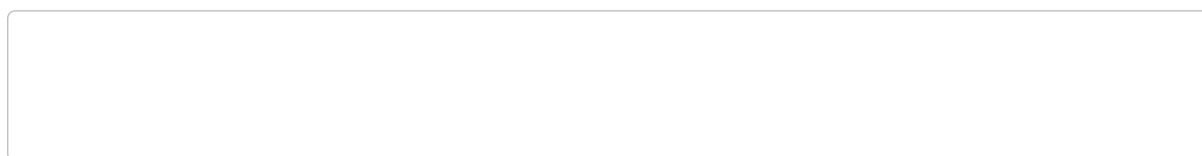
3.4 A student is given a length of resistance wire, a cell, a switch, an ammeter, a voltmeter and a variable resistor.

- (a) Draw a labelled circuit diagram she could use to find the resistance of the wire. [3]



- (b) Describe how she uses the circuit to obtain a reliable value for the resistance. [3]

- (c) Her readings are $V = 3.0 \text{ V}$ and $I = 0.60 \text{ A}$. Calculate the resistance of the wire. [2]



- (d) She replaces the wire with a filament lamp and increases the current. State and explain how the resistance of the lamp changes. [2]

3.5 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. [2]

(b) Calculate how many times longer the lamp would have to be on to use the same energy as the kettle. [2]

(c) The kettle is connected to the 230 V mains. Calculate the current in the kettle. [2]

Solutions

Each answer shows the steps, then the **result**.

2.1

- $Q = It$

$$Q = It = (2.0 \text{ A})(15 \text{ s}) = \mathbf{30 \text{ C}}$$

2.2

- $t = 4.0 \times 60 \text{ s} = 240 \text{ s}$
- $I = Q/t$

$$I = \frac{Q}{t} = \frac{240 \text{ C}}{240 \text{ s}} = \mathbf{1.0 \text{ A}}$$

2.3

- the 0–1 A range
- it is the smallest range above 0.25 A, so the needle moves well up the scale; the 0–100 mA range would be overloaded and the 0–10 A range would read only coarsely

2.4

- $E = W/Q$

$$E = \frac{W}{Q} = \frac{27 \text{ J}}{18 \text{ C}} = \mathbf{1.5 \text{ V}}$$

2.5

- $R = V/I$

$$R = \frac{V}{I} = \frac{12 \text{ V}}{0.50 \text{ A}} = \mathbf{24 \text{ } \Omega}$$

2.6

- Q: twice the length, so **12 Ω**
- S: twice the area, so **3.0 Ω**

2.7

- $P = IV$

$$P = IV = (2.5 \text{ A})(12 \text{ V}) = \mathbf{30 \text{ W}}$$

$$E = Pt = (30 \text{ W})(40 \text{ s}) = \mathbf{1200 \text{ J}}$$

2.8

- $E = Pt$ in kWh

$$E = nPt = (3.0 \text{ kW})(1.5 \text{ h}) \times 10 = \mathbf{45 \text{ kWh}}$$

- $\text{cost} = 45 \times 0.55 = 24.75 \approx \mathbf{25 \text{ yuan}}$

3.1 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; **C** counts only the length

3.2 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

3.3

(a) the work done by a unit charge (one coulomb) passing through the phone

(b) $t = 30 \times 60 \text{ s} = 1800 \text{ s}$

- $Q = It$

$$Q = It = (2.0 \text{ A})(1800 \text{ s}) = \mathbf{3600 \text{ C}}$$

(c) $E = IVt$

$$E = IVt = (2.0 \text{ A})(5.0 \text{ V})(1800 \text{ s}) = \mathbf{18\,000 \text{ J}}$$

(d) plastic has no free electrons

- its electrons are held in their atoms, so charge cannot flow through it

3.4

(a) cell, switch, variable resistor and ammeter in series with the wire

- voltmeter in parallel across the wire
- correct symbols in a complete loop

(b) close the switch and read the ammeter and the voltmeter

- adjust the variable resistor to obtain several pairs of readings
- calculate $R = V/I$ for each pair and take the average, or plot V against I and use the gradient

(c) $R = V/I$

$$R = \frac{V}{I} = \frac{3.0 \text{ V}}{0.60 \text{ A}} = \mathbf{5.0 \, \Omega}$$

(d) the resistance increases

- because the filament gets hotter as the current rises

3.5

(a) $E = Pt$

$$E = (1.5 \text{ kW}) \times \frac{20}{60} \text{ h} = \mathbf{0.50 \text{ kWh}}$$

(b) the lamp uses 0.10 kW, so it needs $0.50/0.10 = 5.0 \text{ h}$

- $5.0 \text{ h} \div 20 \text{ min} = \mathbf{15}$ times longer

(c) $I = P/V$

$$I = \frac{P}{V} = \frac{1500 \text{ W}}{230 \text{ V}} = \mathbf{6.5 \text{ A}}$$