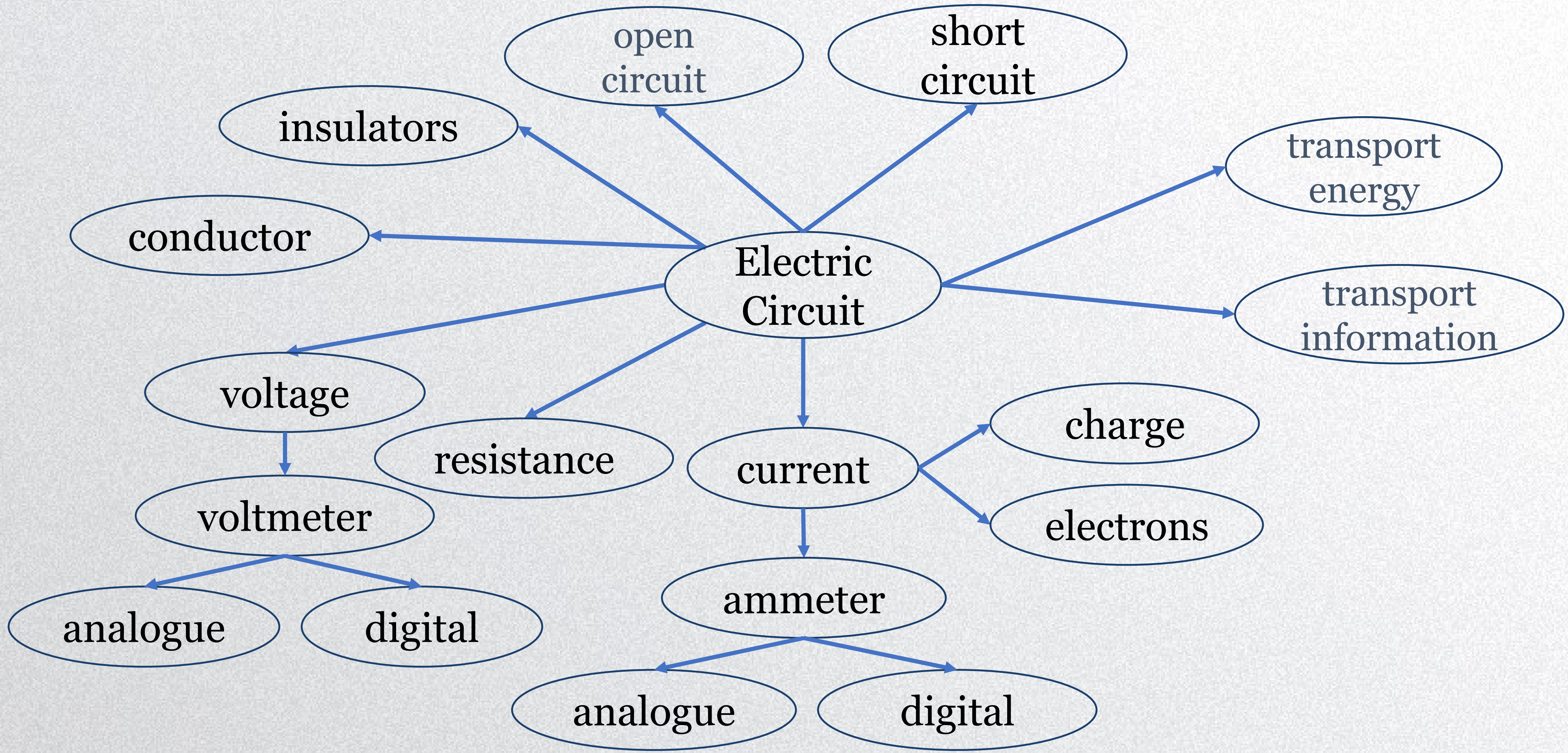
Section
4.3

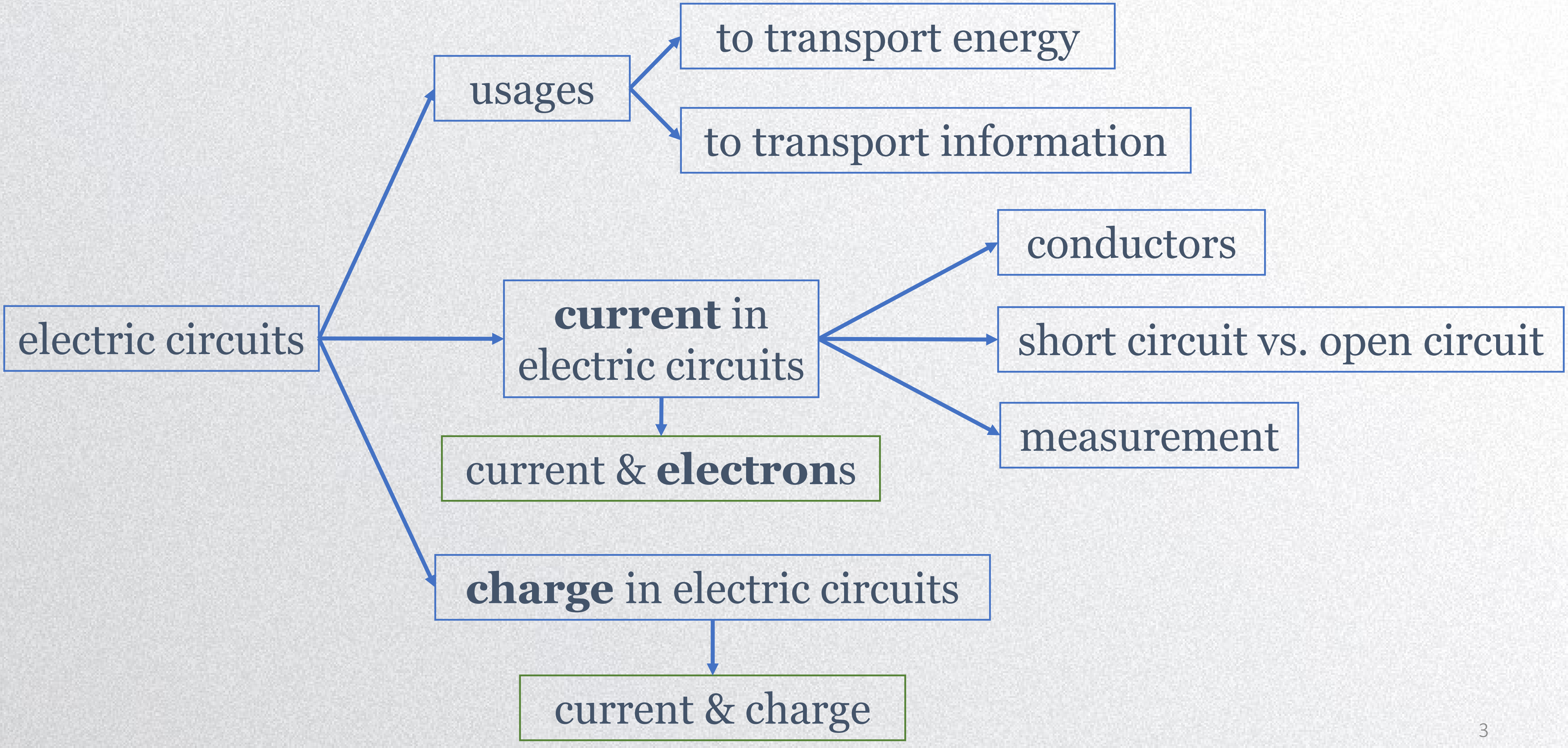
Electrical quantities

4.3.1 Current in electric circuits
4.3.2 Electrical resistance
4.3.3 More about electrical resistance
4.3.4 Electricity and energy

Brainstorming

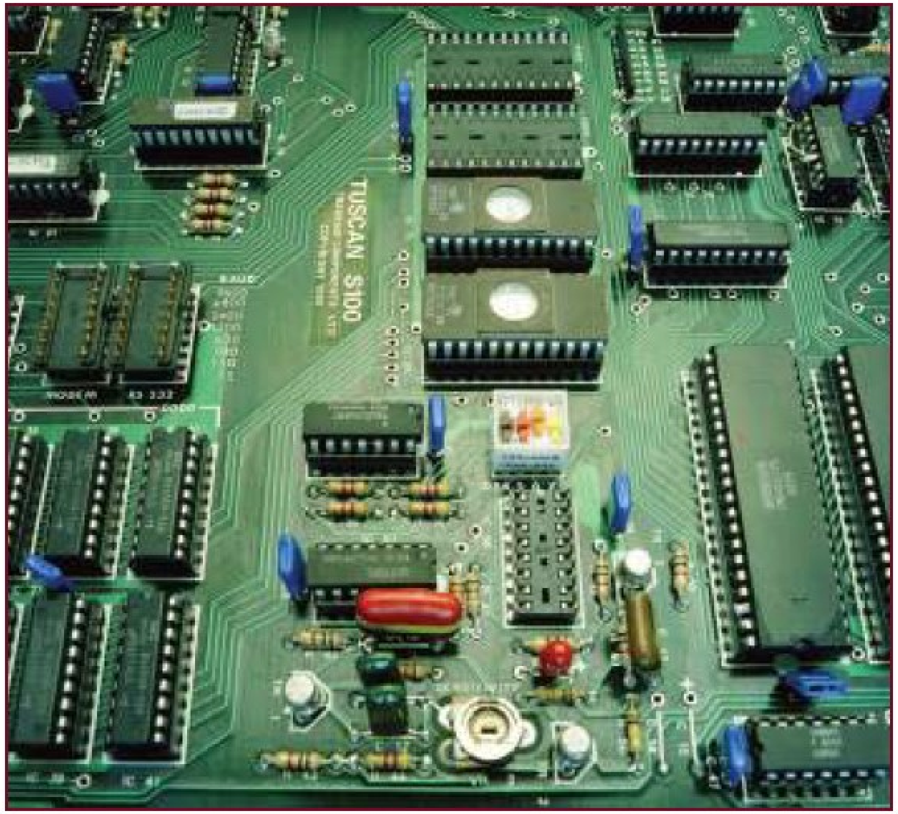


Learning objectives



Model circuits

The electric circuit that carries power from a generating station to places where it is used. These cables carry large electric currents.



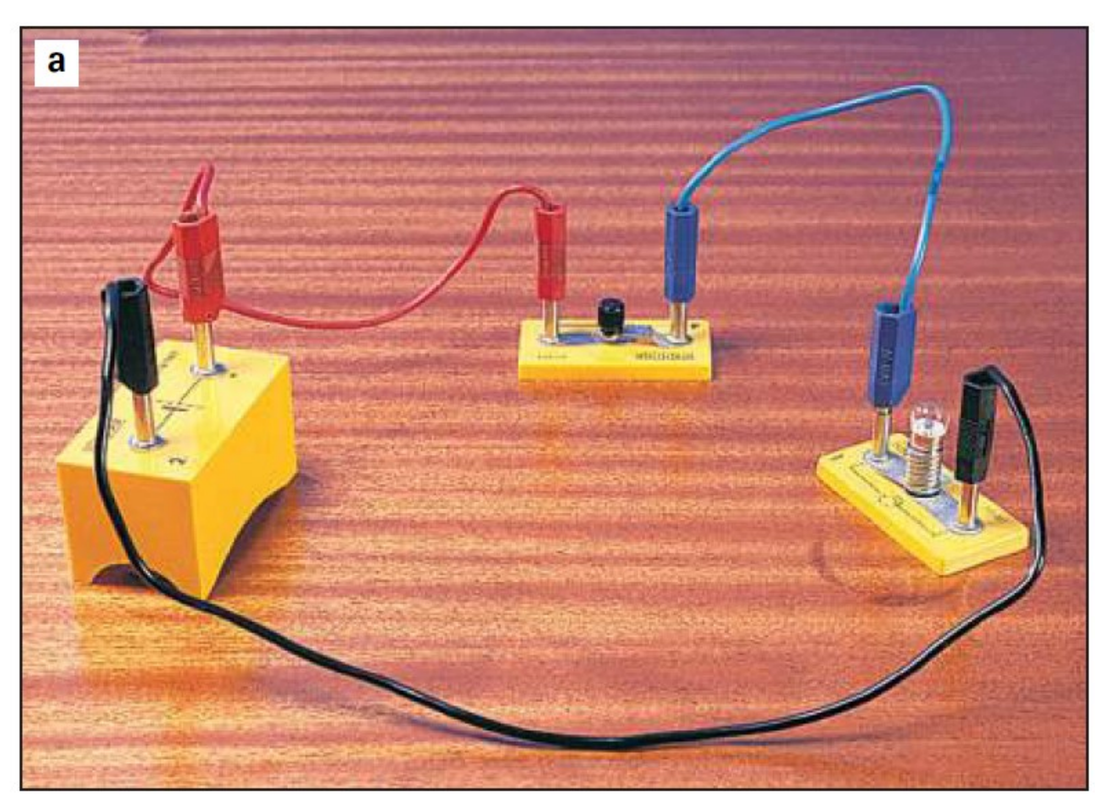
'Chips' (integrated circuits) in a computer, where electric current flows through silicon. The currents are very small.

Model circuits

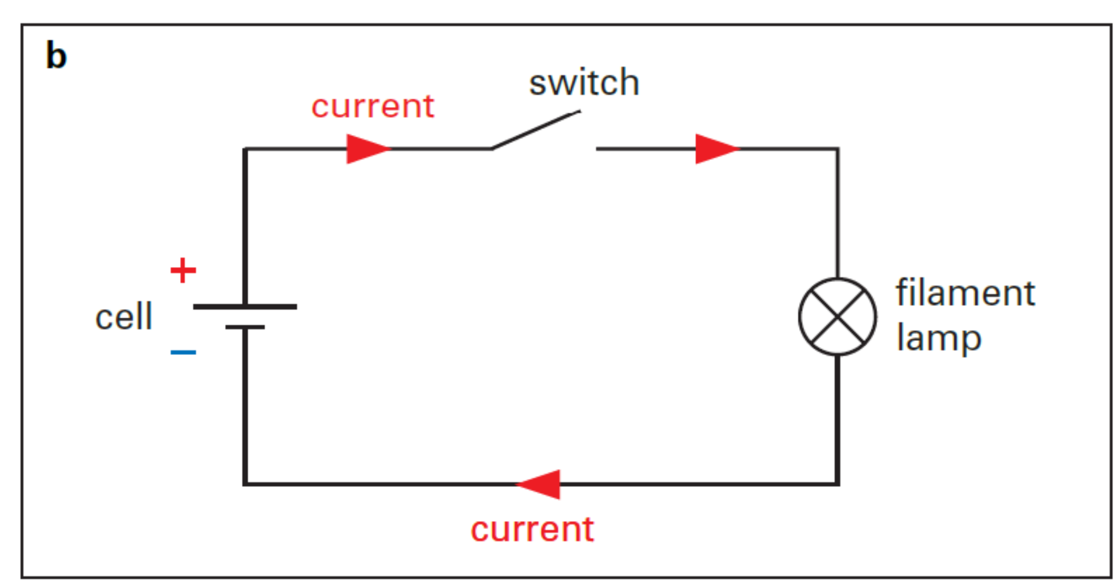
Two general uses for electric circuits:

- **Electricity can be used to transport energy**. The circuit contains devices for transforming energy. In a torch, energy is transferred electrically from the battery to the bulb, where it is transformed into light and heat.
- **Electricity can be used to transport information**. Computers manipulate digital information to produce pictures, sounds and new data. Our bodies have electric circuits – our brain and nerves handle information electrically.

Current in electric circuits



a. A simple **electric circuit**.



b. The same circuit represented as a **circuit diagram**.

Note: In the circuit symbol for a cell, the* ***longer* *line represents the* ***positive*** *terminal.*

Current in electric circuits

For an electric current to flow, two things are needed:

- a **complete circuit** for current to flow around. In most familiar circuits, metals such as **copper** or **steel** provide the circuit for the current to flow around.
- something to push current around the circuit. The 'push' might be provided by a **cell, battery or power supply**. A **battery** is simply two or more **cells** connected end-to-end.

Current flows **from the positive terminal** of the battery (or cell), then **back to the negative terminal** of the battery. Such a current that flows **in the same direction** all the time is called **direct current (d.c.)**.

Conductors

- The wires to connect up circuits are made of **metal** because metals are good conductors of electric current. The metal is usually surrounded by **plastic**, so that, if two wires touch, the electric current cannot pass directly from one to another (a short circuit). Plastics (polymers) are good electrical insulators.
  - ✓ Good **conductors**: most metals, including copper, silver, gold, steel.
  - ✓ Good **insulators**: polymers (such as Perspex or polythene), minerals, glass.

- In between, there are many materials that do conduct electricity, but not very well. For example, liquids may conduct, but they are generally poor conductors.

- People can conduct electricity – that is what happens when you get an electric shock. Our bodies conduct because the water in our tissues is quite a good electrical conductor.

Short circuit

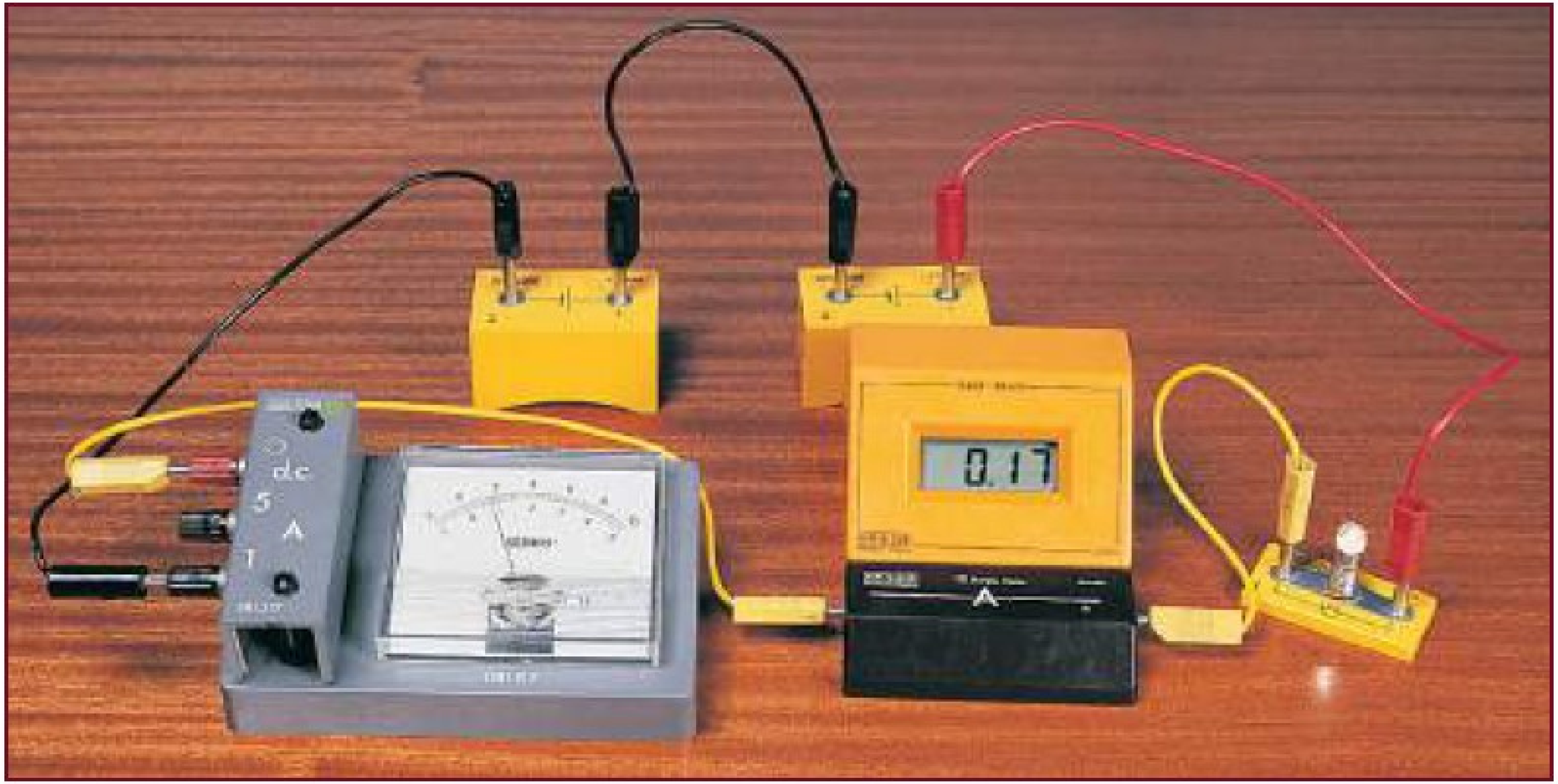
A **short circuit** is an electrical circuit that allows a current to travel along an unintended path with **no or very low electrical impedance**. This results in an excessive current flowing through the circuit.

The opposite of a short circuit is an "**open circuit**", which is an **infinite resistance** between two nodes.

Electric current

- When a circuit is complete, an electric current flows. Current flows **from the <u>positive</u> terminal** of the supply, around the circuit, and **back to the <u>negative</u> terminal**.
- The **battery or power supply** in a circuit provides the push needed to make the current flow. This ‘push’ is the same **force** that causes electric charges to attract or repel one another.
- A **current** is **a flow of electric charge**. In a metal, the current is **a flow of <u>electrons</u>**.

Measuring electric current



Ammeters measure electric current, in **amps (A)**.

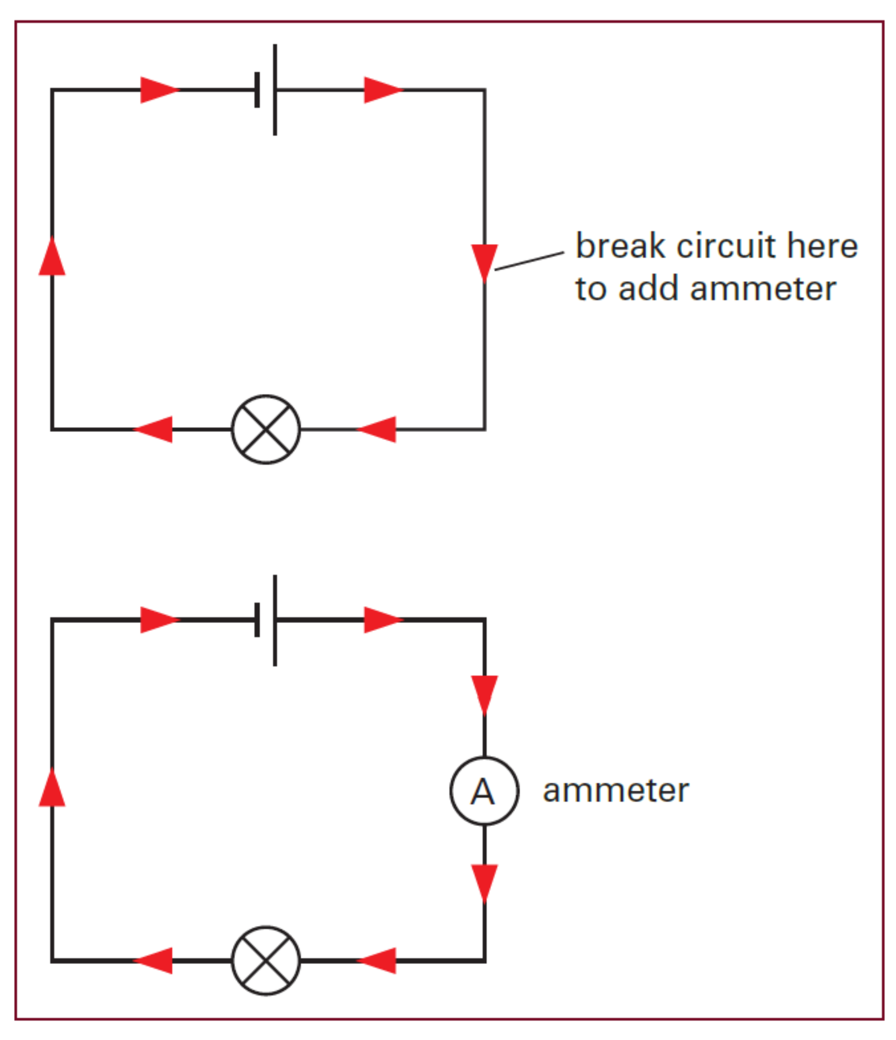
There are two types: **analogue** (on the left) and **digital** (on the right).

Measuring electric current

To measure electric current, we use an **ammeter**. There are two types:

- An **analogue meter** has a needle, which moves across a scale. You have to make a judgement of the position of the needle against the scale.
- A **digital meter** gives a direct read-out in figures. There is no judgement involved in taking a reading.

Measuring electric current



Adding an ammeter to a circuit. The ammeter is connected **in series**, so that the current can flow through it.

Measuring electric current

- The current **flows in** through one terminal (**red**, **positive**) and **out** through the other (**black**, **negative**). If the ammeter is connected the wrong way round, it will give negative readings.
- In a simple series circuit, it does not matter where the ammeter is added, since the current is the same all the way round the circuit.
- The reading on an ammeter is in **amps (A)**. The ampere (shortened to amp) is the SI unit of current.
- Smaller currents may be measured in **milliamps (mA)** or **microamps (μA)**:

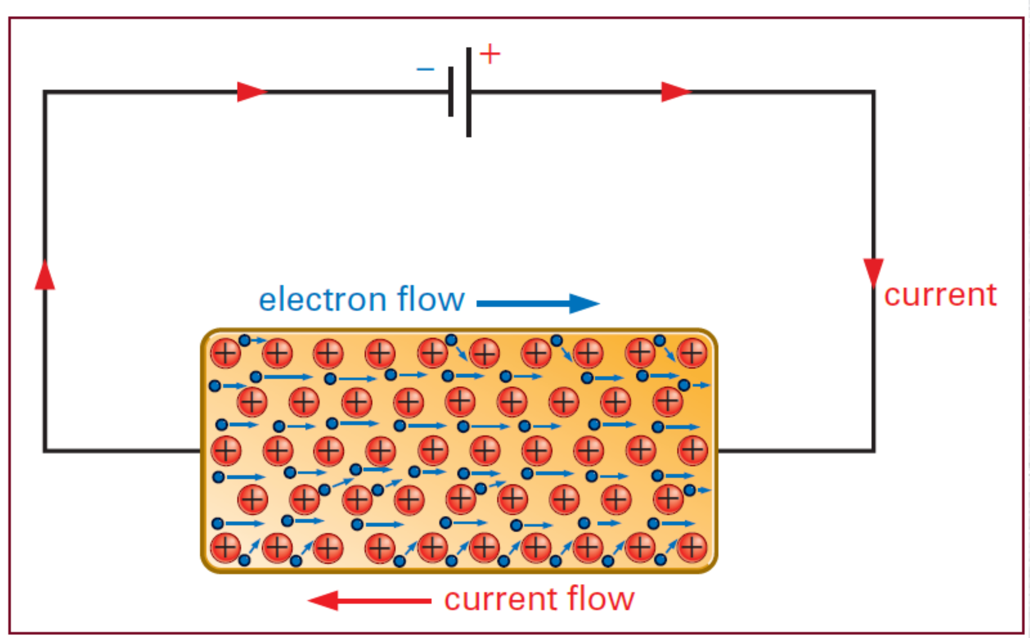
$$1 \text{ milliamp} = 1 \text{ mA} = 0.001 \text{ A} = 10^{-3} \text{ A}$$

$$1 \text{ microamp} = 1\ \mu\text{A} = 0.000\,001 \text{ A} = 10^{-6} \text{ A}$$

Current and electrons

- **Metals** are good electrical conductors because they contain ***electrons that can move about freely***. The idea is that, in a bad conductor such as most polymers, all of the electrons in the material are tightly bound within the atoms or molecules, so that they cannot move. Metals are different.
- A **voltage**, such as that provided by a battery or power supply, can start these **conduction electrons** moving in one direction through the metal, and an electric current flows.
- Since electrons have a negative electric charge, they are attracted to the positive terminal of the battery.

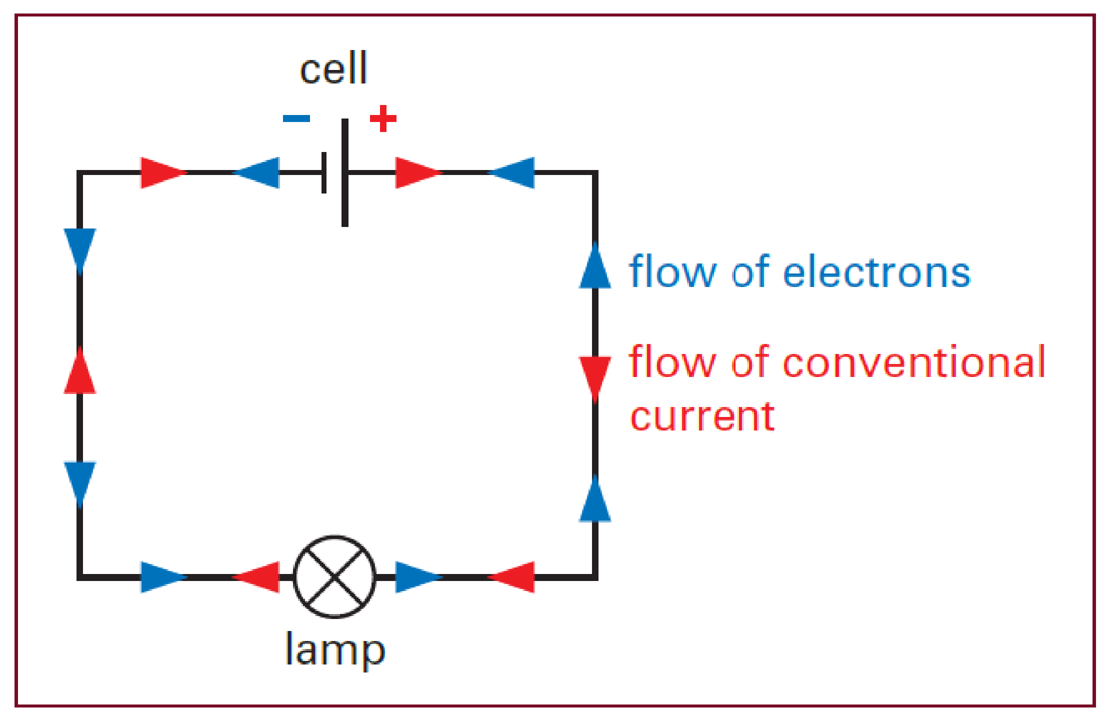
Current and electrons



A microscopic model (a small-scale model) to show the electron flow and current flow.

- In a metal, some electrons are free to move about. These are known as **conduction electrons.**
- In copper, there is one conduction electron for each atom of the metal. The atoms, having lost an electron, are positively charged ions.
- A battery pushes the conduction electrons through the metal. The force is the attraction between unlike charges.

Current and electrons



The conventional current picture is a macroscopic model (a large-scale model).

Two ways of picturing what happens in an electric circuit:

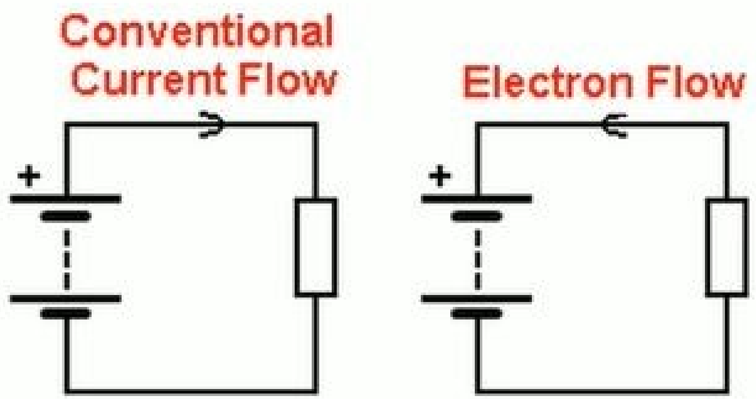
- **conventional current flows from <u>positive</u> to <u>negative</u>**;
- **electrons flow from <u>negative</u> to <u>positive</u>.**

Current and electrons

- **Conventional current** is a flow of positive charge, moving **from positive to negative**.
  - ✓ Positive charge flowing out of the positive terminal, around the circuit and back into the cell at the negative terminal.
- Alternatively, **electron flow**, a movement of conduction electrons, **from negative to positive**.
  - ✓ In a metal, it is the negatively charged electrons that move. They leave the negative terminal of the cell, and flow around to the positive terminal.

*Note: ***conventional current and electron flow are in opposite directions*** around a circuit.

Current and electrons



Electrons flow from the negative to positive terminal.
Conventional current flows from the positive to negative terminal.

Charge in Circuits

- **Charge** can be positive (+) or negative (-), when charge flows it is called **current**. It is measured in **coulombs**, **c**.
- **Current** is **the rate of flow of electrical charge (in amperes, A) around a circuit**.
- In solid metal conductors (e.g. copper wire), current is due to the flow of electrons.
- An ammeter measures the rate at which electric charge flows past a point in a circuit – in other words, **the amount of charge that passes per second**.

Current and charge

- The relationship between current and charge as an equation:

$$\text{Current} = \frac{\text{Charge}}{\text{Time}}$$

$$\mathrm{I}(amperes, A) = \frac{\mathrm{Q}\ (coulombs, C)}{\mathrm{t}\ (\text{seconds, s})}$$

- When current (I) flows past a point in a circuit for a length of time (t) then the charge (Q) that has passed is given by :

$$\text{Charge} = \text{Current} \times \text{Time}$$

$$\boldsymbol{Q}(coulombs, C) = \boldsymbol{I}\ (amperes, A) \times \mathbf{t}\ (\text{seconds, s})$$

Current and charge

Quantity	Symbol for quantity	Unit	Symbol for unit
current	I	amps	A
charge	Q	coulombs	C
time	t	seconds	s

Symbols and units for some electrical quantities

Study question #1

A current of 150 mA flows around a circuit for one minute. How much electric charge flows around the circuit in this time?

Study question #1

A current of 150 mA flows around a circuit for one minute. How much electric charge flows around the circuit in this time?

Step 1: Write down all givens with units.

$I = 150\ mA = 0.15\ A$ (or $150 \times 10^{-3}\ A$)

$t = 1$ minute $= 60\ s$

Find: $Q = ?$

Step 2: Write down an appropriate form of the equation relating Q, I and t.

Substitute values and calculate the answer.

$Q = I*t = 0.15\ A \times 60\ s = 9\ C$

Study question #2

There is a current of 0.29 A in an electrical circuit.

Calculate the time taken for a charge of 15 C to flow through the electrical circuit.

time = ... [3]

[Total: 3]

Study question #2

There is a current of 0.29 A in an electrical circuit.

Calculate the time taken for a charge of 15 C to flow through the electrical circuit.

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

$$t = \frac{Q}{I} = \frac{15}{0.29} = 52\ s$$

time = ...$52s$.... [3]

[Total: 3]

Study question #3

There is a current of 3.0 A in a copper wire. Calculate how many electrons pass through the copper wire every 60 s. The charge on an electron is 1.6×10^{-19} C.

number of electrons = ... [3]

[Total: 3]

Study question #3

There is a current of 3.0 A in a copper wire. Calculate how many electrons pass through the copper wire every 60 s. The charge on an electron is 1.6×10^{-19} C.

$$Q = I * t = 3 * 60 = 180\ C$$

$$\frac{180}{1.6 * 10^{-19}} = 1.1 * 10^{21}$$

number of electrons = ... $1.1 * 10^{21}$ .... [3]

[Total: 3]

Study question #4

A battery charge passes a current of 2.5 A through a cell over a period of 4 hours. How much charge does the charger transfer to the cell altogether?

Study question #4

A battery charge passes a current of 2.5 A through a cell over a period of 4 hours. How much charge does the charger transfer to the cell altogether?

$$Q = I \times t = 2.5 \times (4 \times 60 \times 60) = 36000\ C\ (36\ kC)$$

THANK YOU

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Electrical quantities

4.3.1 Current in electric circuits

4.3.2 Electrical resistance

4.3.3 More about electrical resistance

4.3.4 Electricity and energy

Background

- The current flowing in a circuit can be controlled by adding components with **electrical resistance** to the circuit. The greater the resistance, the smaller the current that will flow.
- The **cell** provides the voltage needed to push the current through the resistor. 'Voltage' is a rather loose term, and we should say that there is a **p.d. (potential difference)** across the resistor.
- **Potential difference (p.d.)** is measured in **volts (V)** using a **voltmeter** (like an ammeter, can be either analogue or digital). It indicates that there is **a difference in electrical potential across the resistor**.

Background

- There is a special name for the **p.d.** across a cell. It is called the **e.m.f.** of the cell, and is also measured **in volts**.
- The letters e.m.f. stand for **electro-motive force**, but this can be misleading since **e.m.f. is a voltage**, **not a force**.
- Any component that pushes a current around a circuit is said to have an e.m.f. – cells, batteries, power supplies, dynamos and so on.

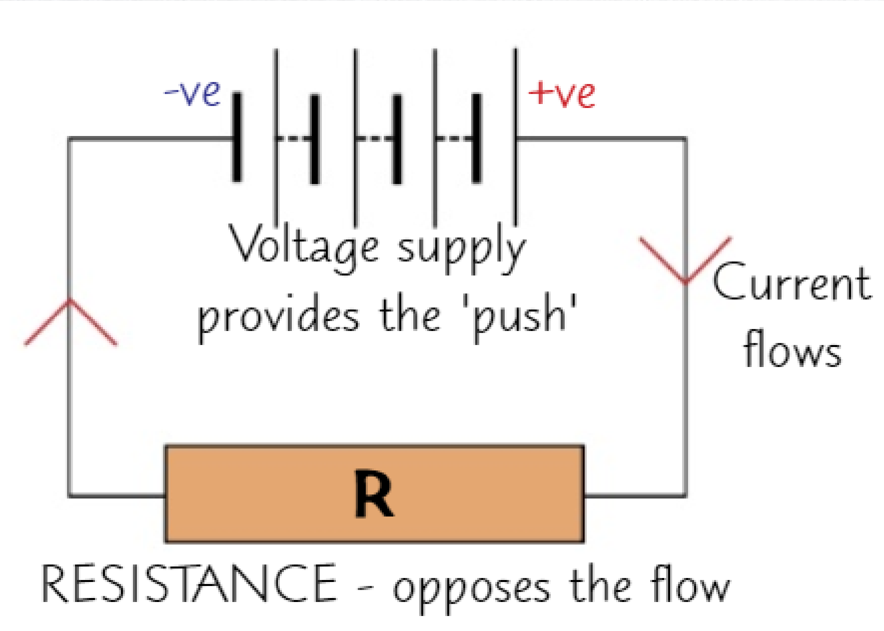
Potential Difference (p.d.)

- The reading on a voltmeter is in volts (V).
- Smaller 'voltages' may be measured in **millivolts (mV)** or **microvolts (μV)**.
- Take care not to confuse (italic) *V*, used as the symbol for an unknown **potential difference or voltage;** with (upright) V, used as the symbol for **the unit, volts**.

Voltmeter

- A voltmeter is always connected across the relevant component, because it is measuring the potential difference between the two ends of the component.
- Ammeters are connected in series, so that the current can flow through them.
- Voltmeters are connected <u>in parallel</u> across a component.

Resistance



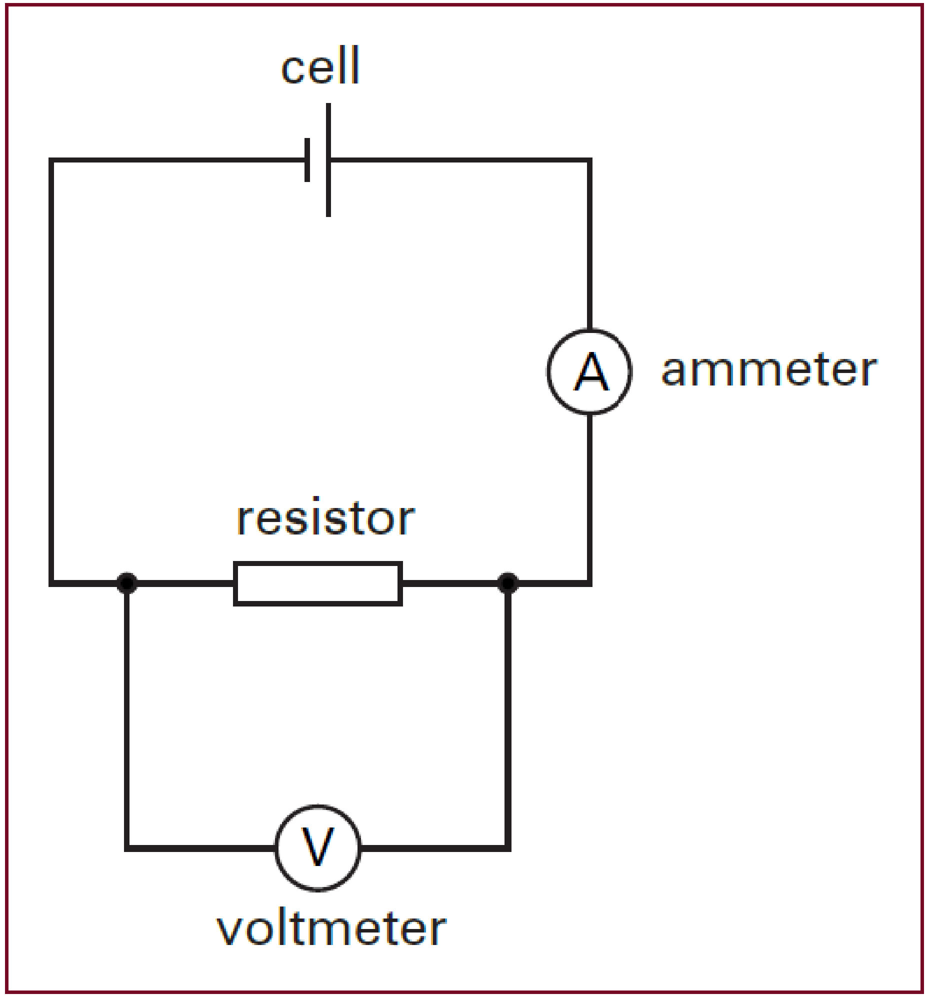
- The electrical resistance of an object is a measure of its opposition to the flow of electric current
- The resistance of a component is measured in **ohms (Ω)**
- Resistance (in Ω) tells us **how many volts are needed to make 1 A flow through that resistor**. To put it another way: **one ohm is one volt per amp.**

$$1\,\Omega = 1\ V/A$$

- $Resistance\ (\Omega) = \frac{Potential\ difference\ (V)}{Current\ (A)}$

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

Resistance



The cell provides the p.d. needed to push the current around the circuit. The amount of current depends on the p.d. and the resistance of the resistor. The ammeter measures the current flowing through the resistor. The voltmeter measures the p.d. across it. This circuit can thus be used to find the resistance of the resistor.

Resistance

The resistance of wires of different shapes, R:

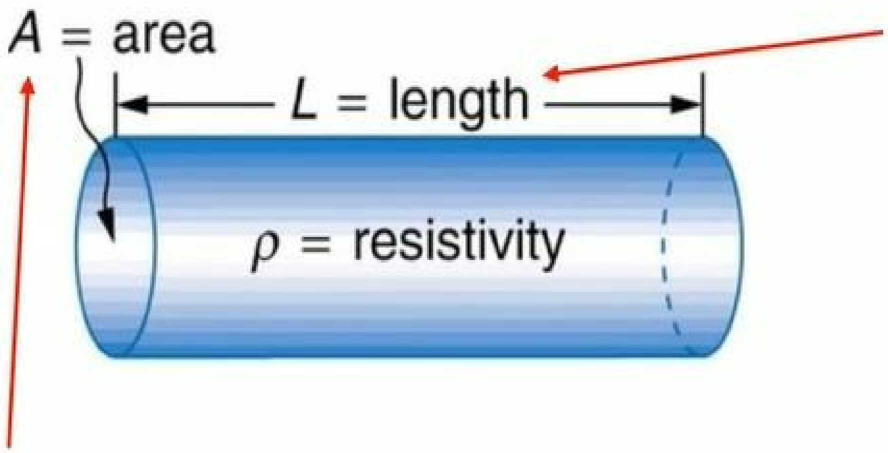
- length, l
- diameter, d
- cross-sectional area, A

$l \uparrow \quad R \uparrow$

$d \uparrow \quad R \downarrow$

$A \uparrow \quad R \downarrow$

Resistance of a wire



When the length of the wire is increased, the current must travel further in the wire and thus resistance increases

$$R = \frac{\rho L}{A}$$

where ρ is resistivity of the material

When the cross-sectional area of the wire is increased (i.e. larger wire diameter) the current has a greater area to travel through so the resistance decreases.

Resistance of a wire

- The resistance of a wire depends on two main things:
  - ✓ Length (of wire)
  - ✓ Cross-sectional area (of wire)
- Resistance of a metallic electrical conductor:
  - ✓ is **directly proportional** to length: the longer a wire, the greater is its resistance.
  - ✓ is **inversely proportional** to cross-sectional area: the greater the diameter of a wire, the less is its resistance.

Study question #1

A 12.0 Ω resistor and a 4.0 Ω resistor have wires of the same length and are made of the same alloy.

Calculate the ratio: $\dfrac{\text{cross-sectional area of } 12.0\ \Omega \text{ resistor}}{\text{cross-sectional area of } 4.0\ \Omega \text{ resistor}}$

ratio = ... [1]

[Total: 1]

Study question #1

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Calculate the ratio: $\dfrac{\text{cross-sectional area of } 12.0\ \Omega \text{ resistor}}{\text{cross-sectional area of } 4.0\ \Omega \text{ resistor}}$

$$R = \frac{\rho L}{A}$$

$$A = \frac{\rho L}{R}$$

$$\frac{A_{12}}{A_4} = \frac{\frac{1}{12}}{\frac{1}{4}} = \frac{1}{3}$$

ratio = ...$\frac{1}{3}$........................ [1]

[Total: 1]

$V = I \times R$

- The voltage across and current through a component are linked by resistance.

$$Voltag = \text{Current} \times Resistance$$

$$\mathbf{V = I \times R}$$

- The greater the resistance in the circuit, the smaller the current that flows.
- The greater the p.d. in a circuit (or across a component), the greater the current that flows.

Study question #2

A 4 Ω resistor in a circuit has a voltage of 6V across it. What is the current through the resistor?

Study question #2

A 4 Ω resistor in a circuit has a voltage of 6V across it. What is the current through the resistor?

Given: R = 4 Ω; V = 6v

Find: I

$$V = I \times R$$

I = V/R = 6/4 = 1.5 A

Study question #3

A 1.5 A current flows through a resistor when it is connected to a 9.0 V battery. Calculate the resistance of the resistor.

Study question #3

A 1.5 A current flows through a resistor when it is connected to a 9.0 V battery. Calculate the resistance of the resistor.

Given:
I = 1.5 A; V = 9.0 v
Find: R

$$R = V / I = 9.0 / 1.5 = 6.0\ \Omega$$

THANK YOU

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Electrical quantities

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How to measure resistance of a component?

The properties of a circuit

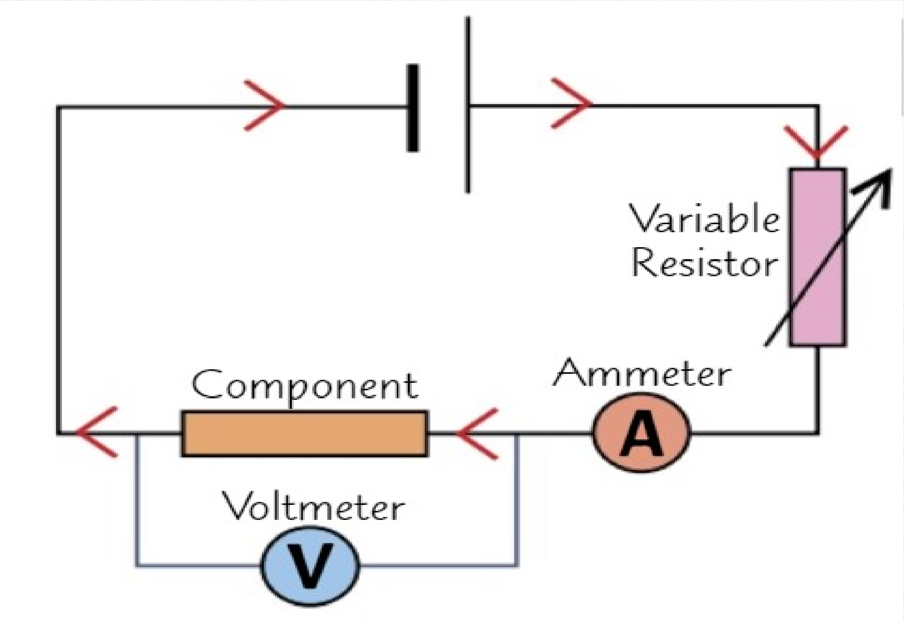
Current:

- The rate of flow of charge round the circuit.
- Electrons carry the charge – negatively charged particles
- Measured by **ammeter**s (analogue and digital) with different ranges
- Direct current (**d.c.**) vs. alternating current (**a.c.**)
- **Unit:** ampere (amp for short), A

Voltage:

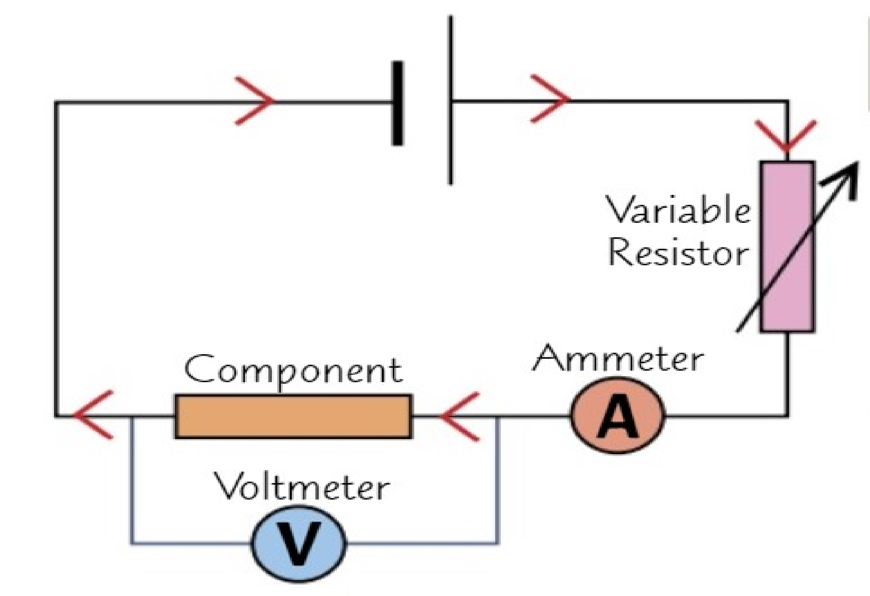
- also called *potential difference (p.d.)*
- is what drives the current round the circuit, like "electrical pressure"
- Measured by **voltmeter**s (analogue and digital) with different ranges
- **Unit:** volt, V

The standard test circuit



- The very basic circuit is used *for testing components*, and *for getting I-V graphs.*
- The *ammeter* and the *variable resistor* are all *in series*; the *voltmeter* can only be placed *in parallel* around the component under test.
- As the variable resistor varies, the current flowing through the circuit is altered.
- Pairs of readings from the ammeter and voltmeter.

Resistance of an unknow resistor



- This method can give us multiple measurements of voltage and current, which can help to obtain a more accurate result
- By changing the resistance of the variable resistor, the current and potential difference across the unknown resistor will change, too.
- You should end up with multiple and similar values for the resistance of the unknow resistor
- Average the results to get the final answer

The standard test circuit

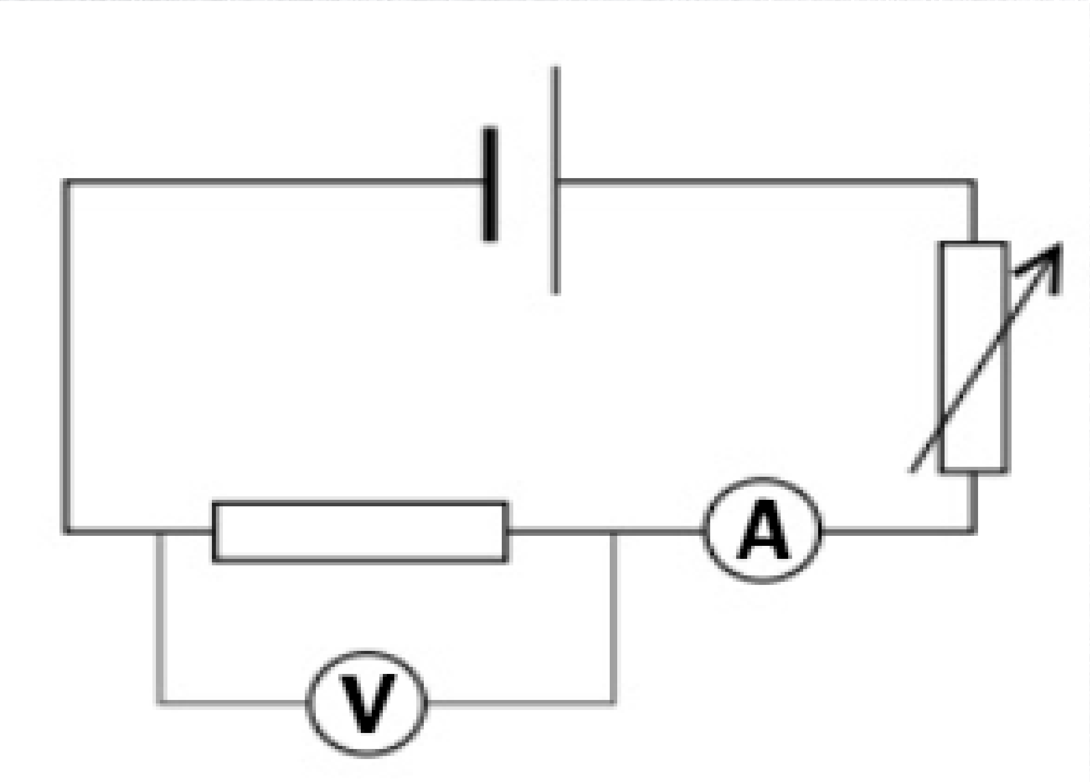
Practice:

Draw the standard test circuit.

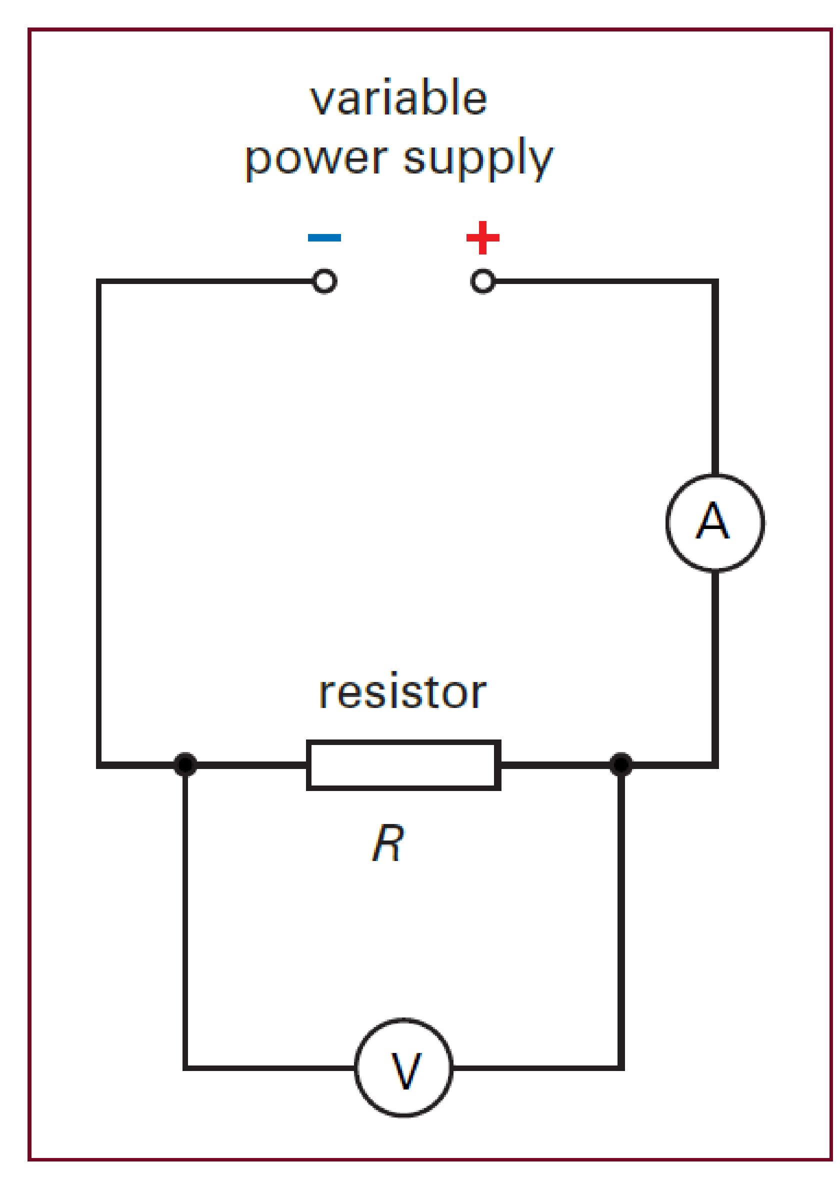
The standard test circuit

Practice:

Draw the standard test circuit.

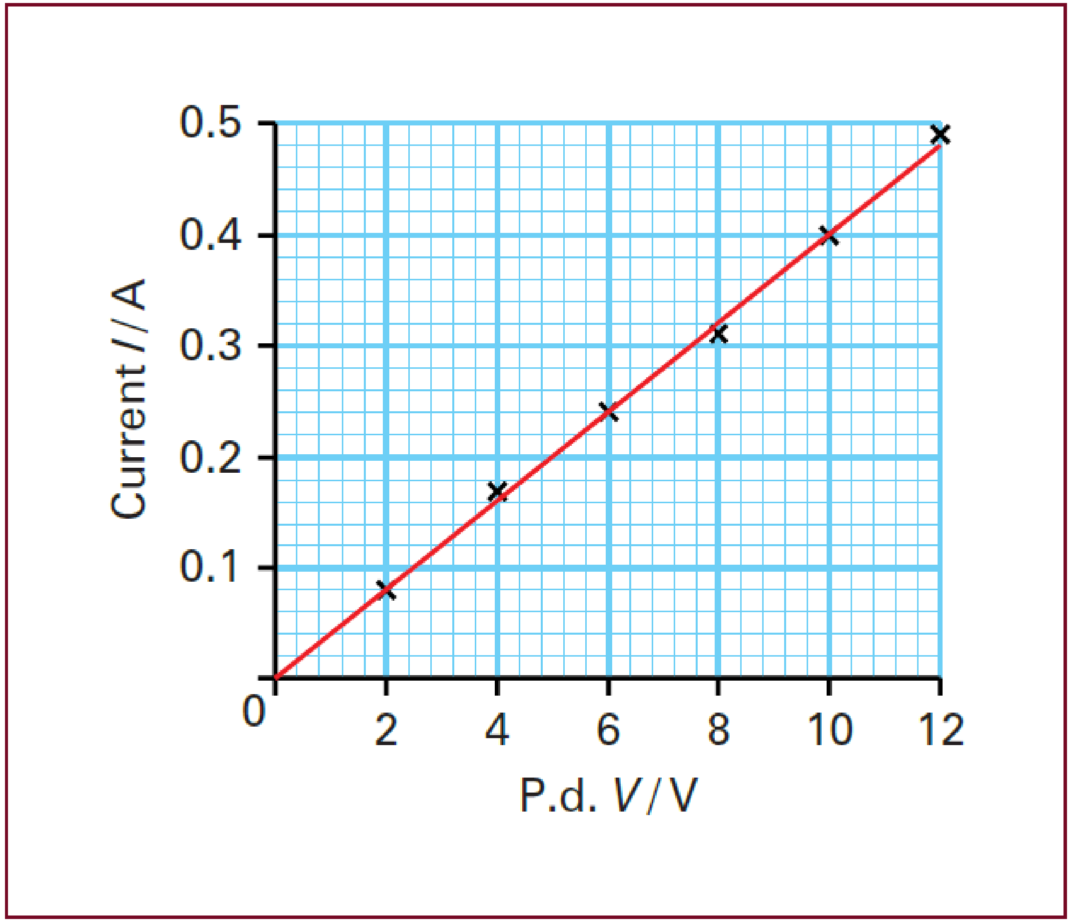


Measuring resistance



- A circuit for investigating how the current through a resistor changes as the voltage across it varies.
- The **power supply can be adjusted** to give a range of values of p.d. (typically from 0 V to 12 V).
- For each value of p.d., the **current** is recorded.
- Values for R is calculated by using **R = V/I**
- These can be **average**d to find the value of R.

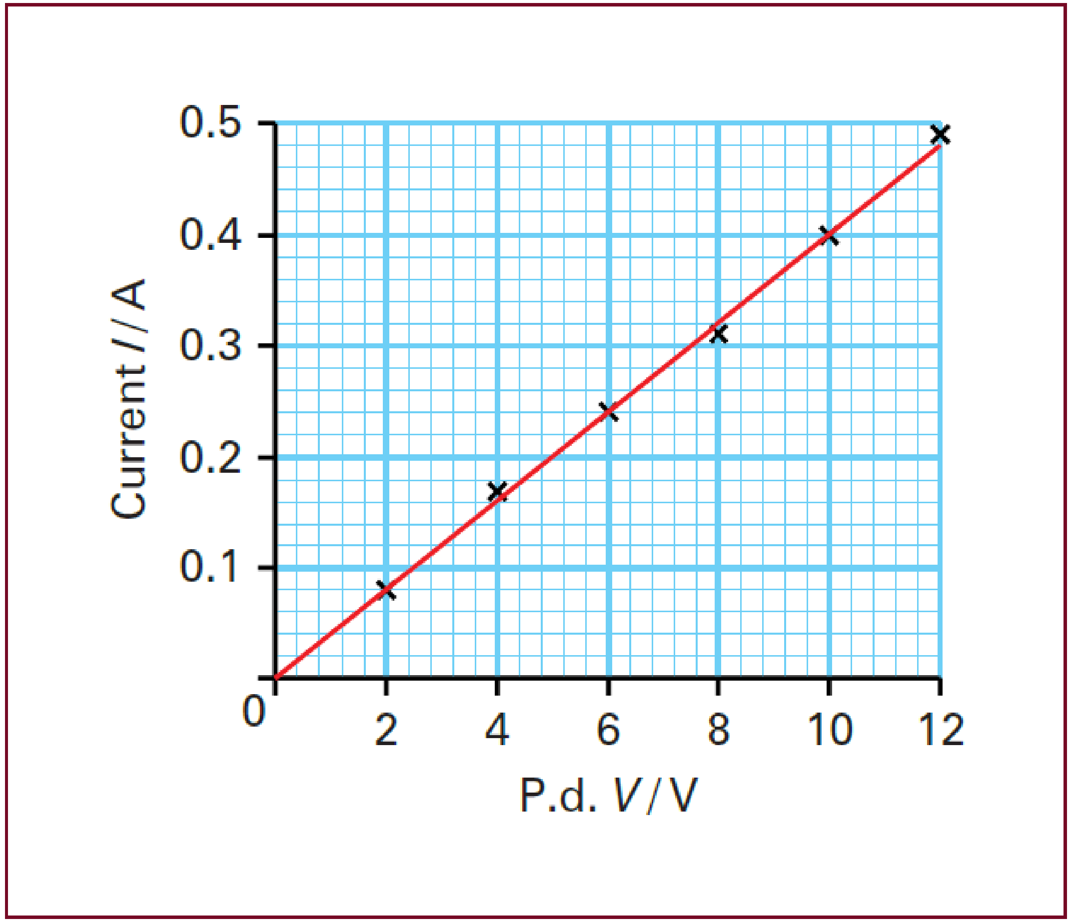
Current–voltage characteristics



To plot a graph of current against voltage for a resistor:

- The p.d. V is on the x-axis, because this is the quantity we vary.
- The current I is on the y-axis, because this is the quantity that varies as we change V.

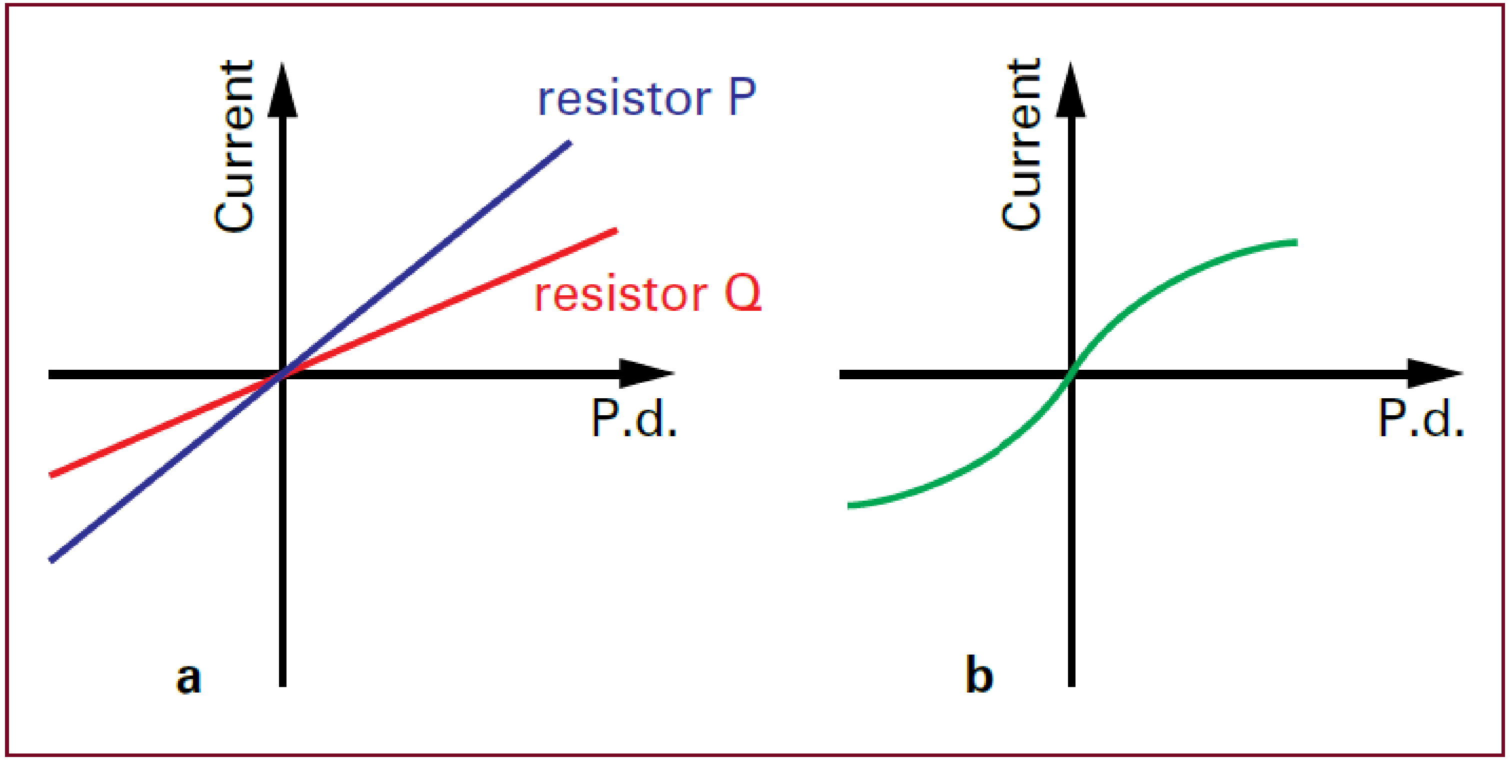
Current–voltage characteristics



In this case, the graph is a straight line that passes through the origin. This is what we expect because the equation I= V/R shows that the current *I* is proportional to the p.d. *V*.

A resistor whose current–voltage characteristic is like this is called an **ohmic resistor**.

Current–voltage characteristics

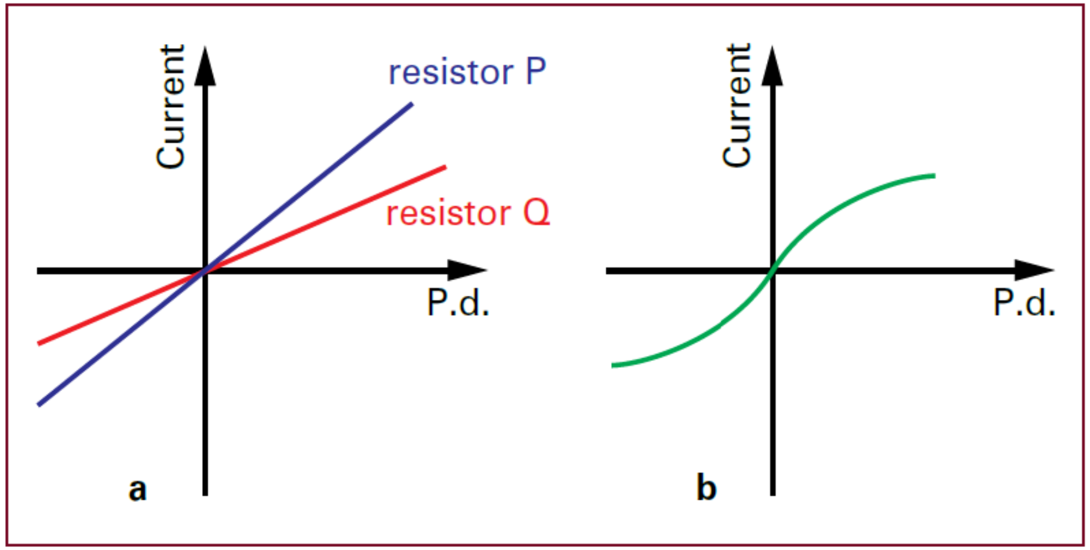


Typical current–voltage characteristics:

a. for two ohmic resistors (P has lower resistance than Q);

b. for a filament lamp

Current–voltage characteristics



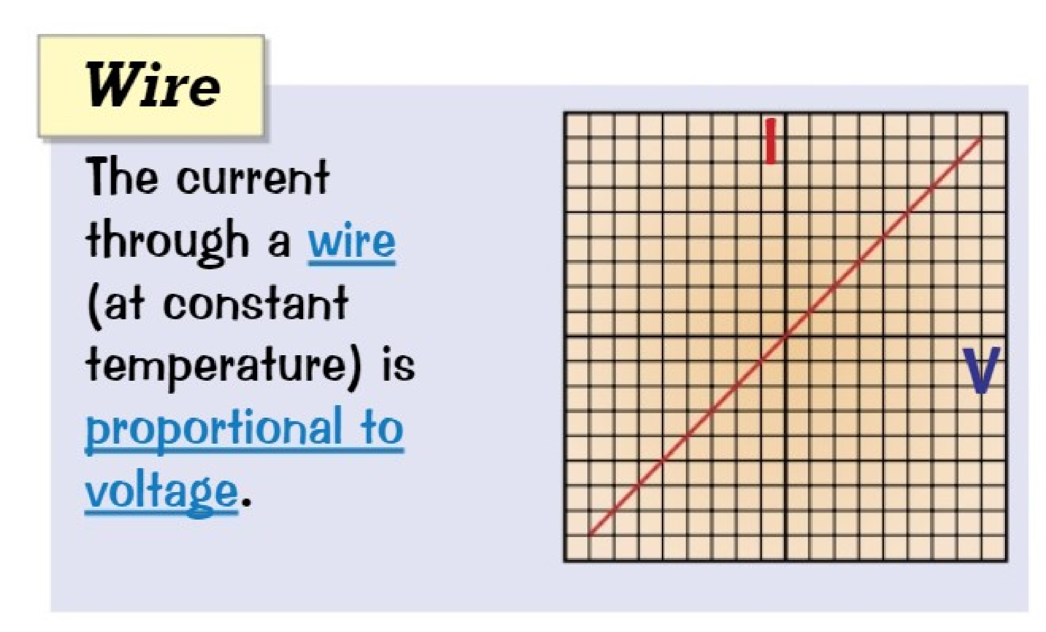
Notice that these graphs show both positive and negative voltages.

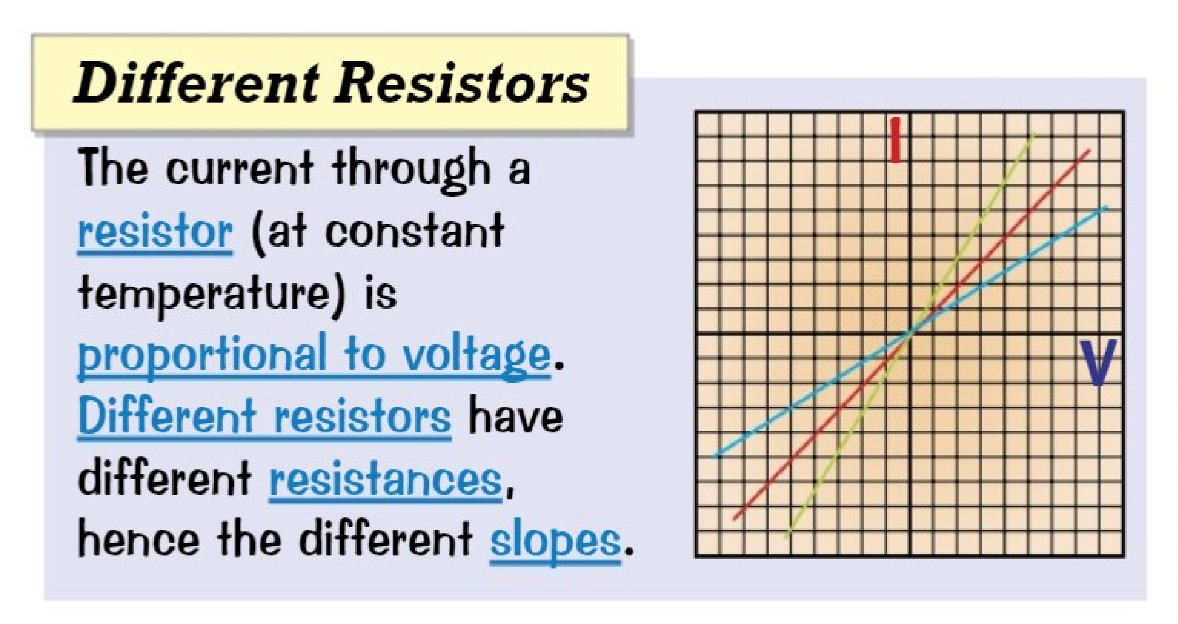
A negative current means one flowing in the opposite direction. This is achieved by connecting the voltage the other way round.

The graphs are symmetrical, showing that, whichever way round the components are connected, the current will be the same for a given voltage.

Current-Voltage (I-V) Graphs

- I-V graphs show how the current varies as you change the voltage.





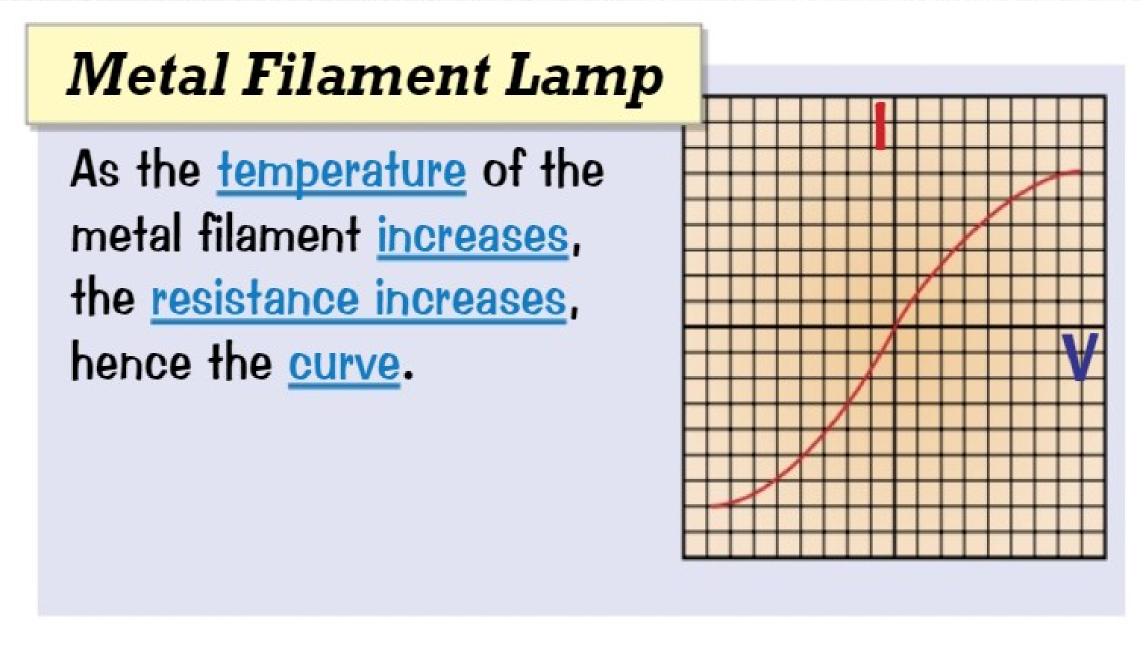
Current-Voltage (I-V) Graphs

The I-V characteristic for a **metallic conductor** is a **straight line**:

- At constant temperature, the current through a metallic conductor, e.g. a wire or a resistor, is *directly proportional* to the potential difference.
- The fact that the characteristic graph is a straight line through the origin tells that the *resistance* doesn't change – it's equal to 1/gradient.
- The shallower the gradient of the characteristic I-V graph, the *greater* the resistance of the conductor.
- Metallic conductors are *ohmic* – they have constant resistance provided their temperature doesn't change.

Current-Voltage (I-V) Graphs

- I-V graphs show how the current varies as you change the voltage.



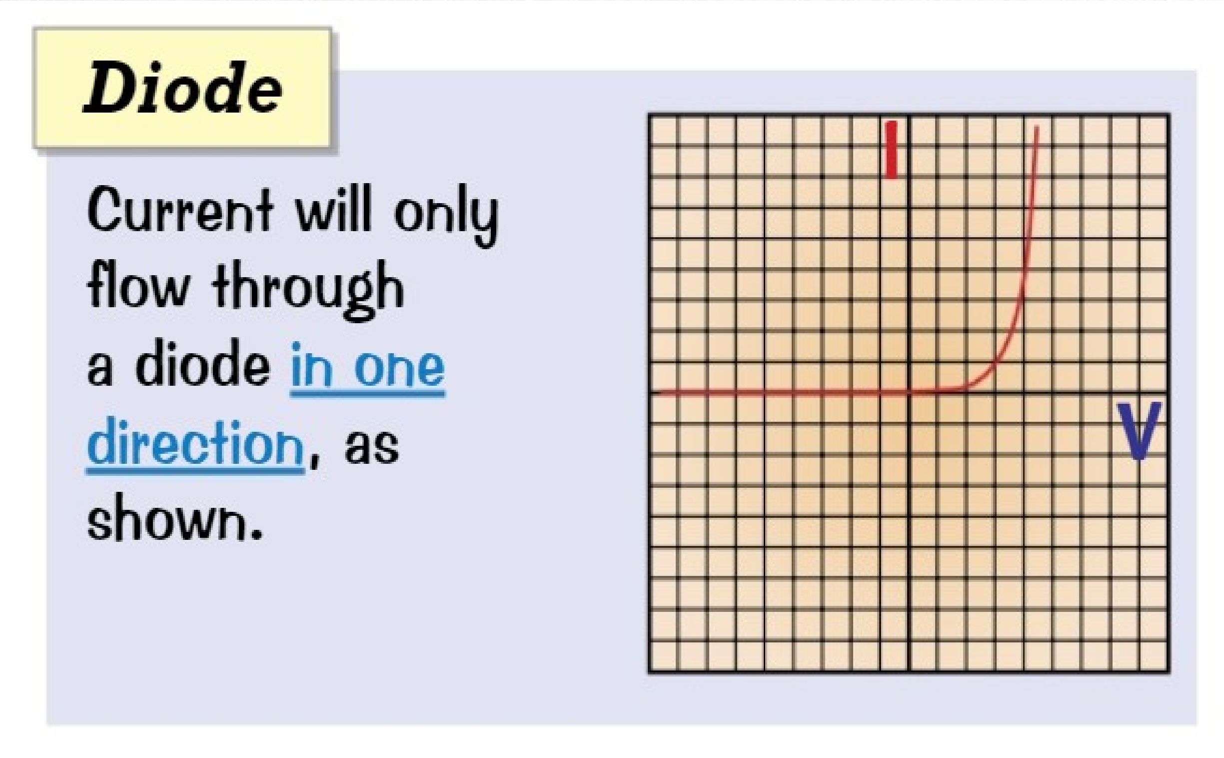
Current-Voltage (I-V) Graphs

The I-V characteristic for a **filament lamp** is curved:

- The characteristic graph for a filament lamp is a curve, which starts steep but gets shallower as the potential difference rises.
- The filament in a lamp is just a coiled up length of metal wire, however, current flowing through the lamp *increases* its temperature, so its resistance *increases*.

Current-Voltage (I-V) Graphs

- I-V graphs show how the current varies as you change the voltage.



Current-Voltage (I-V) Graphs

Diodes only let current flow in *one* direction:

- Diodes (including *light-emitting diodes or LEDs*) are designed to let current flow in one direction only.
- Forward bias is the direction in which the current is allowed to flow – it's the direction the triangle points in the circuit symbols.
- Most diodes require a threshold voltage of about 0.6 V in the forward direction before they will conduct.
- In reverse bias, the resistance of the diode is very high and the current that flows is very tiny.

Resistance & Temperature

How is temperature related to resistance?

The general rule is **resistivity increases with increasing temperature in conductors** and **decreases with increasing temperature in insulators**. For some materials, resistivity is a linear function of temperature.

THANK YOU

Section

4.3

Electrical quantities

4.3.1 Current in electric circuits

4.3.2 Electrical resistance

4.3.3 More about electrical resistance

4.3.4 Electricity and energy

What is the physical meaning of a volt?

Think in terms of energy.

Background

- Electricity is a good way of transferring energy from place to place.
- When you plug in an appliance to the mains supply, you are connecting to quite a high voltage – something like 110 V or 230 V, depending on where you live. This high voltage is the **e.m.f. of the supply**. Recall that e.m.f. is the name given to **the p.d. across a component** such as a cell or power supply that **pushes current around a circuit**.
- **Mains** electricity is **alternating current (a.c.)**.

Brainstorming

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

$$V = IR$$

$$E = QV = QIR$$

$$P = \frac{E}{t} = \frac{W}{t} = VI = I^2R = \frac{V^2}{R}$$

$$E = Pt = VIt$$

energy (E)

work done (W)

resistance (R)

charge (Q)

energy transferred (E)

voltage (V)

electrical power (P)

current (I)

time taken (t)

Electrical Working

$$\text{Power(Watt, W)} = \text{Potential difference (V)} \times \text{Current (A)}$$
$$\boldsymbol{P = V \times I}$$

$$\text{Energy } (\textbf{joules}, \textbf{J}) = \text{Power(Watts, W)} \times \text{Time(seconds, s)}$$
$$\boldsymbol{E = P \times t = V \times I \times t}$$

$$\text{Energy transferred} = \text{Charge} \times \text{Voltage}$$
$$\boldsymbol{E(joules, J) = Q \times V}$$

$$\text{Energy transferred} = \text{Charge} \times \text{Current} \times \text{Resistance}$$
$$\boldsymbol{E = Q \times I \times R}$$

Volt

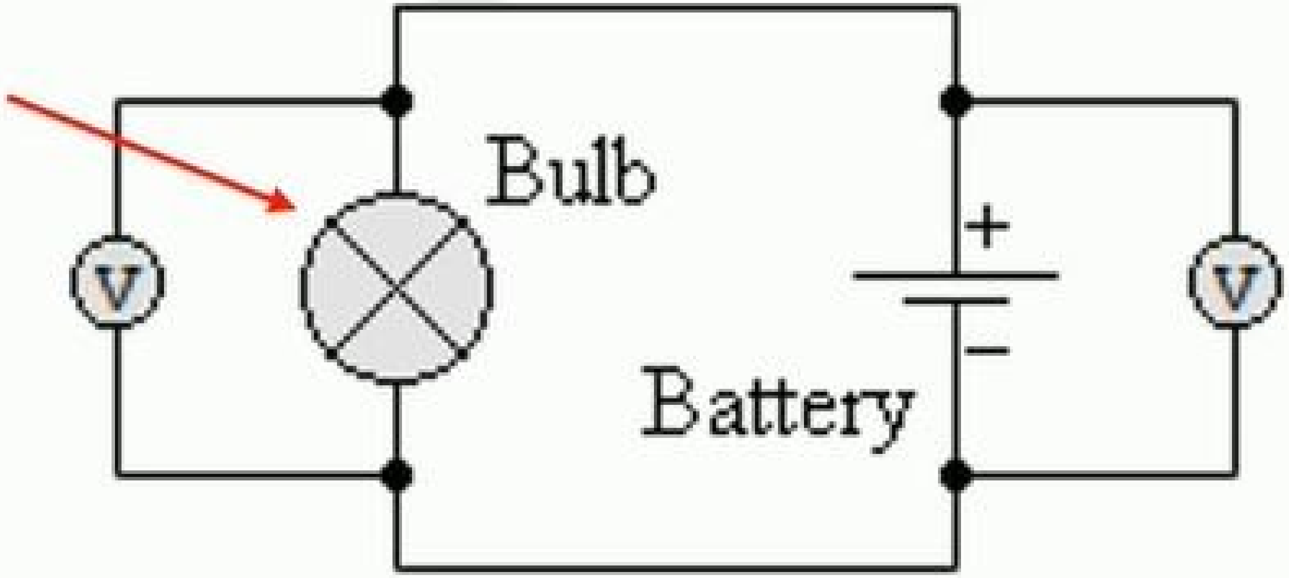
- A supply with a high e.m.f. gives a lot of energy to the charge that it pushes around the circuit.
- A **230 V** mains supply gives **230 J of energy to each coulomb of charge** that travels round the circuit.
- A supply with an e.m.f. of 1 volt gives 1 joule of energy to each coulomb of charge it pushes round a circuit. In other words, **a volt is a joule per coulomb**.
  - Volt (V) : the SI unit of potential difference (p.d.), equal to one joule per coulomb

$$\mathbf{1\ V = 1\ J/C}$$

- Ex.: a small lamp may have a p.d. of 1.5 V across it. This means that each coulomb of charge passing through the lamp will transfer 1.5 J of energy to the lamp.

Volt

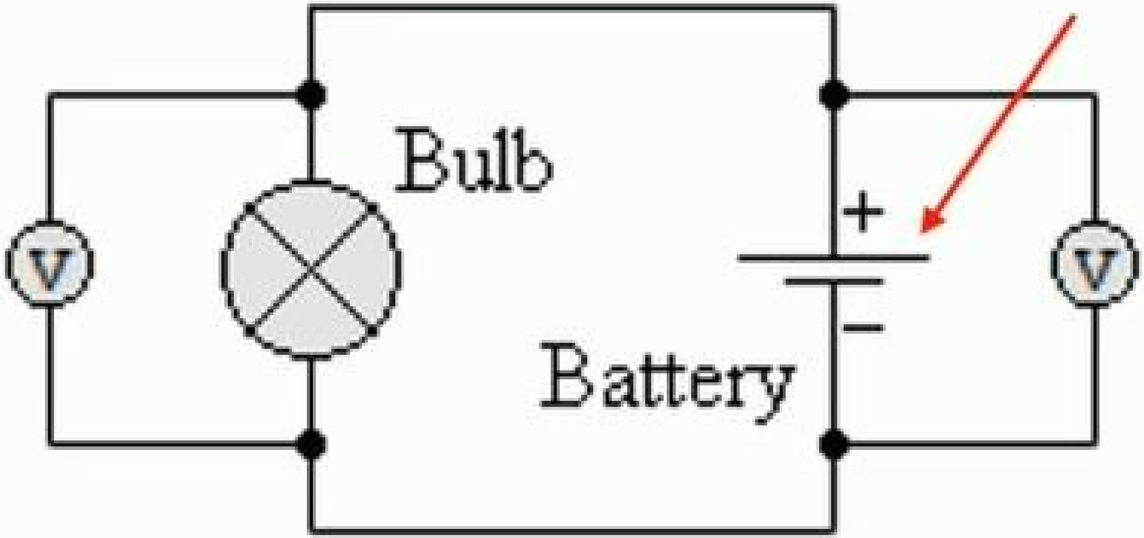
Bulb converts electrical energy into light energy



A 1V lamp converts 1J of electrical energy into light energy per coulomb of charge. It also means that 1J of energy per coulomb of charge is needed to drive current through the lamp.

Volt

Battery converts chemical energy into electrical energy which is supplied to the charge



9V battery supplies 9J of energy per coulomb of charge

Potential difference (p.d.)

- The **potential difference or voltage** across a component in a circuit is **the energy required per coulomb of charge** to drive the current through that component (e.x. a lamp)
- It is the amount of **electrical energy converted into** other forms (e.x. light) **per coulomb of charge**.
- It is the **work done by a unit charge** passing through a component.
- **Potential difference (p.d.)** is measured in **volts (V)**.

$$\boldsymbol{V = \frac{W}{Q}}$$

where

V = potential difference (volts, V)
W = work (J)
Q = charge (coulombs, c)

Electromotive force (e.m.f.)

- An electrical supply (a power pack, cell, or battery) **provides** electrical energy which drives charge around a complete circuit.
- The **electromotive force (e.m.f.)** is the electrical work done by a source in moving a unit charge around a complete circuit.
- The **electromotive force (e.m.f.)** of a supply is **the energy provided per coulomb of charge,** and is measured in **volts (V)** by a voltmeter connected **in parallel** across it.

$$\boldsymbol{E = \frac{W}{Q}}$$

where

E = e.m.f. (volts, V)

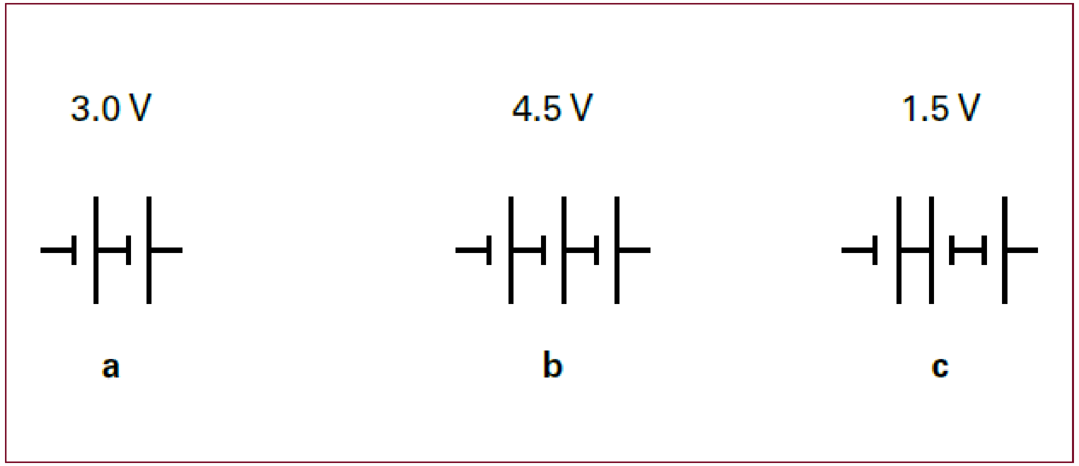
W = work (J)

Q = charge (coulombs, c)

Combining e.m.f.s

- Many battery-operated electrical appliances need more than one battery to make them work.
- In general, if cells with e.m.f.s E_1 and E_2 are **connected in series**, their combined e.m.f. E is given by: $E = E_1 + E_2$ (**added up**)
- For four 1.5 V cells in series, each coulomb of charge gains 1.5 J of energy as it passes. Through the first cell, it gains another 1.5 J of energy when it passes through the second cell, and so on. It gains a total of 6 J of energy from the four cells, so their combined e.m.f. must be 6 V.

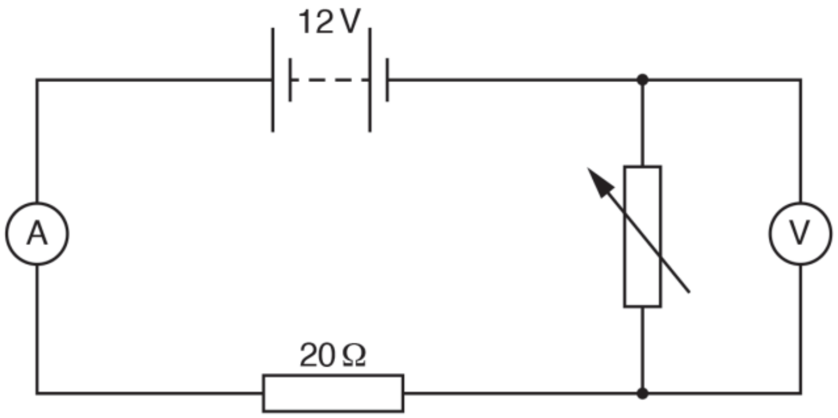
Combining e.m.f.s



- The e.m.f.s of cells or other supplies add up when they are connected in series.
- Each individual cell has an e.m.f. of 1.5 V
- a. & b.: more cells give a higher combined e.m.f.
- c.: If one cell is connected ‘the wrong way round’, the combined e.m.f. will be reduced.

Study question #1

The diagram shows a circuit that includes a battery of electromotive force (e.m.f.) 12 V.



The battery is formed from cells of electromotive force (e.m.f.) 1.5 V.

(a) Explain, in terms of electrical energy, what is meant by an *electromotiveforce(e.m.f.) of 1.5 V*.

....

.... [2]

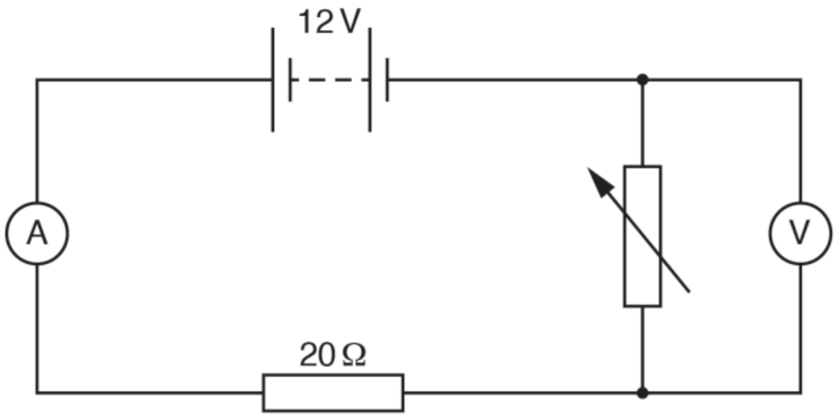
(b) State how many 1.5 V cells are connected in series to form the battery.

.... [1]

[Total: 3]

Study question #1

The diagram shows a circuit that includes a battery of electromotive force (e.m.f.) 12 V.



The battery is formed from cells of electromotive force (e.m.f.) 1.5 V.

(a) Explain, in terms of electrical energy, what is meant by an *electromotiveforce(e.m.f.) of 1.5 V*.

1.5 J of (electrical) energy supplied in driving charge around

the circuit / energy per unit charge OR per coulomb [2]

(b) State how many 1.5 V cells are connected in series to form the battery.

$12/1.5 = 8$ [1]

[Total: 3]

Electrical working

- Electric circuits transfer energy from a source of electrical energy, such as an electrical cell or mains supply, to the circuit components and then into the surroundings.
- The components will convert the electrical energy into other forms (i.e. a lamp will convert electrical energy into light energy).

Electrical power

- Most electrical appliances have a label that shows their **power rating**.
- Power ratings are indicated in **watts (W) or kilowatts (kW)**. The power rating of an appliance shows **the rate at which it transforms energy**, and indicates **the maximum power the appliance draws from the mains supply when it is operating at full power**.
- Power is the rate at which energy is transferred (from place to place) or transformed (from one form to another):

$$\text{Power (W)} = \frac{\text{energy transferred (J)}}{\text{time taken (s)}}$$

$$\boldsymbol{P = \frac{E}{t}}$$

Electrical power

Voltage & Energy

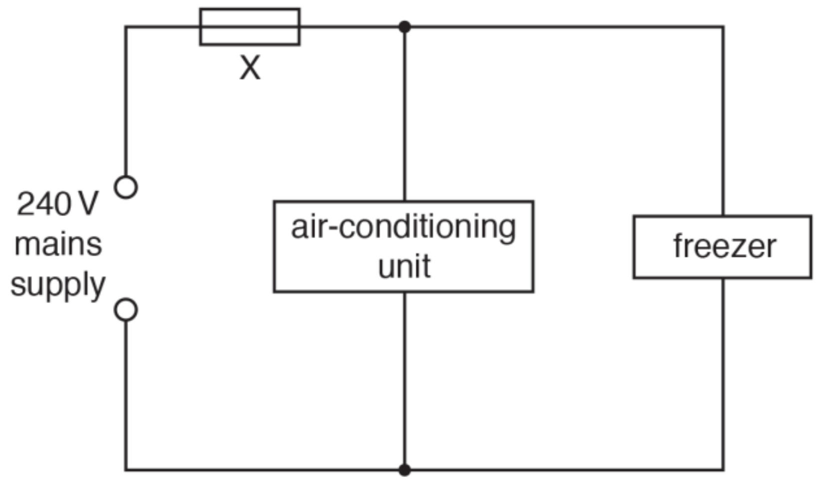
- We have seen that the e.m.f. (voltage) of a supply tells us about how much energy it transfers to charges flowing around the circuit.
- The greater the current flowing around the circuit, the faster that energy is transferred. Hence the rate at which energy is transferred in the circuit (the power P) depends on both **the e.m.f. *V* of the supply** and **the current *I* that it pushes round the circuit**.

$$\boldsymbol{Power(w) = current\ (A) \times p.d.(V)}$$

$$\boldsymbol{P = VI}$$

Study question #1

The circuit shows a 240 V mains supply connected to an air-conditioning unit and a freezer. A fuse X is placed in the circuit as shown.



The freezer has an operating power of 700 W.

Calculate the current in the freezer.

current = ... [2]

[Total: 2]

Study question #1

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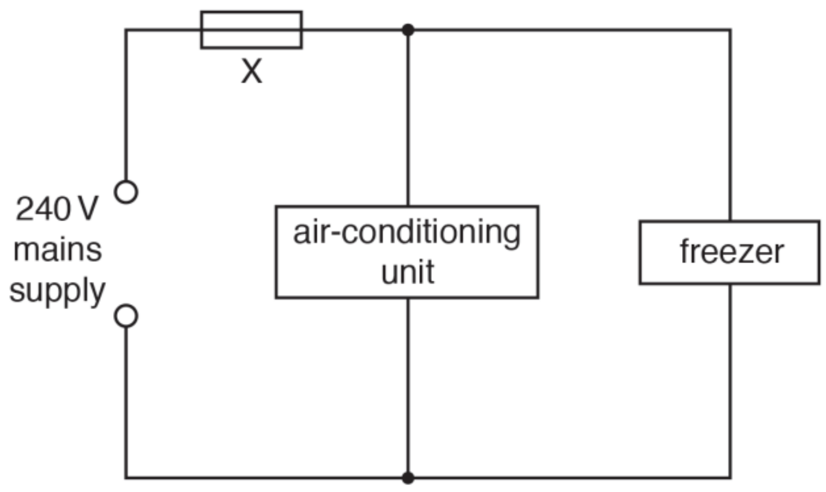

The freezer has an operating power of 700 W.

Calculate the current in the freezer.

$$I = \frac{P}{V} = \frac{700}{240} = 2.9\ A$$

current = ... $2.9\ A$ .... [2]

[Total: 2]

Study question #2

The power supply used in an electric vehicle contains 990 rechargeable cells each of electromotive force (e.m.f.) 1.2 V.

The cells are contained in packs in which all the cells are in series with each other. The e.m.f. of each pack is 54 V.

When in use, each pack supplies a current of 3.5 A.

Calculate the rate at which each cell is transferring chemical energy to electrical energy.

rate of energy transfer = ... [2]

[Total: 2]

Study question #2

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When in use, each pack supplies a current of 3.5 A.

Calculate the rate at which each cell is transferring chemical energy to electrical energy.

$$P_{actual} = IV = 3.5 \ * 1.2 = 4.2\frac{J}{s} = 4.2\ W$$

rate of energy transfer = $4.2\ J/s$ .... [2]

[Total: 2]

Study question #3

When fully charged, a 1.2 V rechargeable battery can deliver a current of 210 mA for 10 hours.

(a) Calculate the charge that can be delivered by the fully charged battery.

charge = ... [3]

(b) Calculate the energy stored in the battery when fully charged.

energy stored = ... [2]

[Total: 5]

Study question #3

When fully charged, a 1.2 V rechargeable battery can deliver a current of 210 mA for 10 hours.

(a) Calculate the charge that can be delivered by the fully charged battery.

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

$$Q = I * t = 0.21 * 10 * 60 * 60 = 7560\ C$$

charge = $7560\ C$ .... [3]

(b) Calculate the energy stored in the battery when fully charged.

$$E = V * \mathrm{Q} = 1.2 * 7560 = 9072\ J$$

OR

$$P = I * V = 0.21 * 1.2 = 0.252\ W$$

$$E = P * t = 0.252 * 10 * 60 * 60 = 9072\ J$$

energy stored = $9072\ J$ .... [2]

[Total: 5]

Study question #4

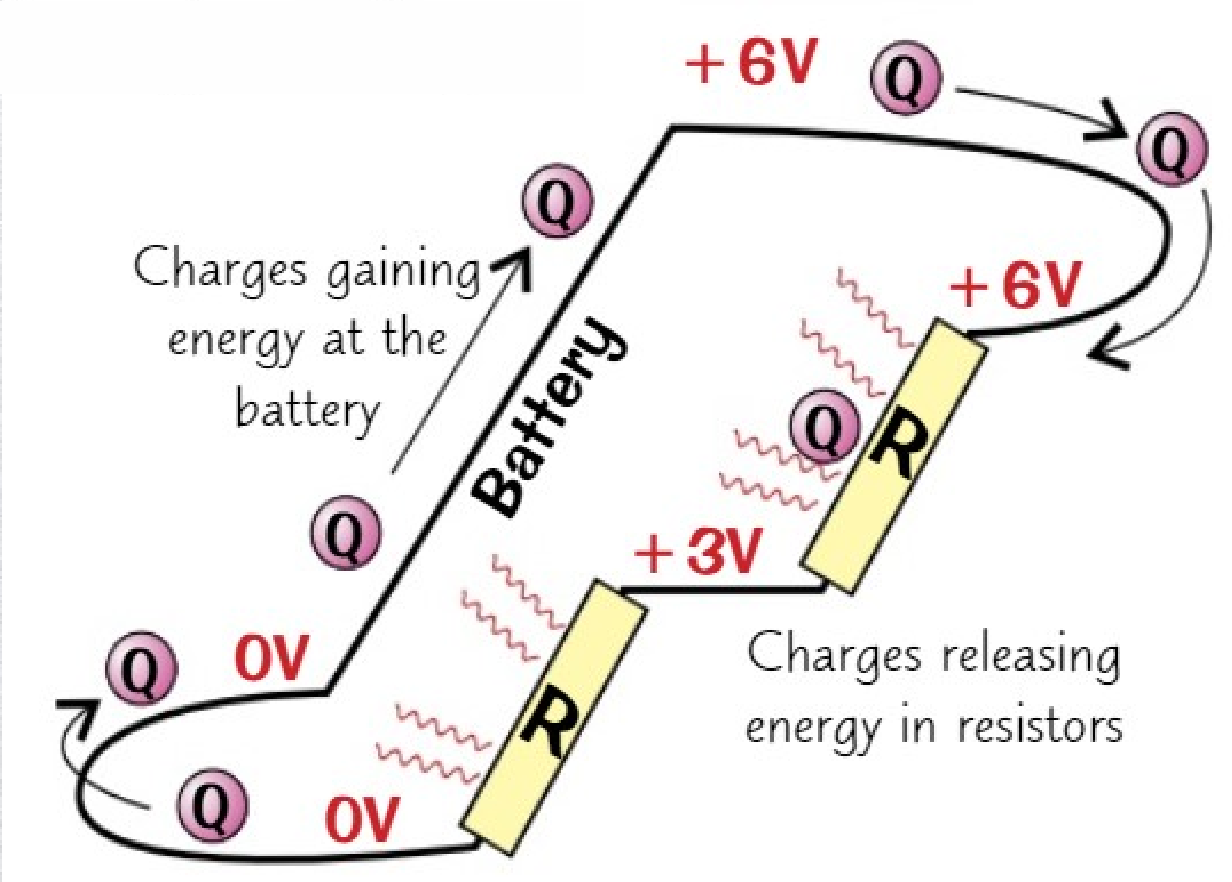
Calculate the energy transferred to 10000 C of charge as it passes through a 200 V source.

Study question #4

Calculate the energy transferred to 10000 C of charge as it passes through a 200 V source.

$$E = Q \times V = 10\,000 \times 200 = 2\,000\,000\ J$$

Voltage & Energy changes



Voltage & Energy changes

- When an electrical charge (Q) goes through a change in voltage (V), then energy (E) is transferred.
- Energy is supplied to the charge at the power source to ‘raise’ it through a voltage.
- The charge gives up this energy when it “falls” through any voltage drop in components elsewhere in the circuit.
- The bigger the change in voltage, the more energy is transferred for a given amount of charge passing through the circuit.
- A battery with a bigger voltage will supply more energy to the circuit for every coulomb of charge which flows round it.
- This is because the charge is raised up “higher” at the start, and more energy will be dissipated in the circuit, too.

Voltage & Energy changes

- Voltage is the energy transferred per unit charge passed.
- The unit for voltage, the volt, is defined as: **1 volt is 1 joule per coulomb**
- The energy transfer (in joules, J) to or from an amount of charge as it passes through a voltage can be calculated as **energy transferred = charge × voltage**
- Combing with V = I × R, the energy transferred by an amount of charge as it passes through a resistance can be calculated as: **energy transferred = charge × current × resistance**

Electrical Working

$$\text{Power(Watt, W)} = \text{Potential difference (V)} \times \text{Current (A)}$$
$$\boldsymbol{P = V \times I}$$

$$\text{Energy } (\textbf{joules}, \textbf{J}) = \text{Power(Watts, W)} \times \text{Time(seconds, s)}$$
$$\boldsymbol{E = P \times t = V \times I \times t}$$

$$\text{Energy transferred} = \text{Charge} \times \text{Voltage}$$
$$\boldsymbol{E(joules, J) = Q \times V}$$

$$\text{Energy transferred} = \text{Charge} \times \text{Current} \times \text{Resistance}$$
$$\boldsymbol{E = Q \times I \times R}$$

Calculating energy

- Since energy transformed = power × time, we can modify the equation P = I V to give an equation for energy transformed E:

$$\boldsymbol{E = current\ (A)\ \times\ p.d.\,(V)\ \times\ time\ (s)}$$

$$\boldsymbol{E = P \times t = V \times I \times t}$$

What is a kW and a kWh?

- A "watt" is the unit used to measure quantities of power and is named after the Scottish inventor and engineer James Watt (1736-1819).
  - ✓ A kilowatt, or kW, is equal to a thousand watts.
- The number of kW is the amount of power an electrical device uses in order to run, and a **kilowatt-hour (kWh)** is the **amount of energy** that an appliance uses every hour.
- For example, if your electric radiator is rated at 3 kW and is left on for an hour, it would use 3 kWh of electricity.

THANK YOU