St Ninian's HS



National 5 Physics

Energy
and
Electricity

Pupil Notes

Unit 3: Energy and Electricity

Topics:

- [3.1 Energy]
- [3.2 Electrical Charge Carriers]
- **3.3 Voltage, Ohm's Law & Circuit Rules**
  - [3.3.1 Practical electrical and electronic circuits]
  - [3.3.2 Potential dividers and Transistors]
- [3.4 Electrical Power and Energy]
- [3.5 Specific heat Capacity and Specific Latent Heat]
- [3.6 Gas Laws and the Kinetic Model]

SQA Course Specifications N5

Energy

- ☐ Explanation of energy conservation and of energy conversion and transfer.
- ☐ Use of an appropriate relationship to solve problems involving work done, unbalanced force and distance/displacement.
- ☐ Definition of gravitational potential energy.
- ☐ Use of an appropriate relationship to solve problems involving gravitational potential energy, mass, gravitational field strength and height
- ☐ Definition of kinetic energy.
- ☐ Use of an appropriate relationship to solve problems involving kinetic energy, mass and speed.
- ☐ Use of appropriate relationships to solve problems involving conservation of energy.

Energy

When a force causes movement, some energy is changed from one form to another (it is transformed) and we say that work is done. Work is a form of energy, other examples include:



Chemical



Heat



Sound

All forms of energy are measured in Joules (J).

Word Done

The work done is a measure of the energy transformed. It is equal to the force multiplied by the distance the object moves.

The work done can be calculate using the formula:

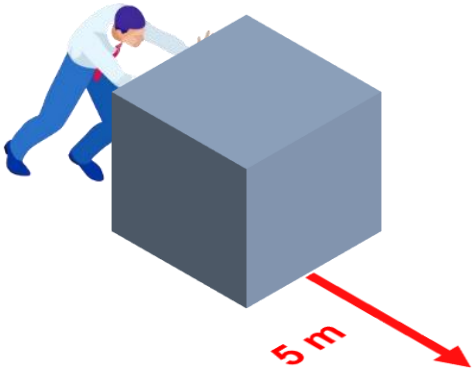
$$E_w = F\,d$$

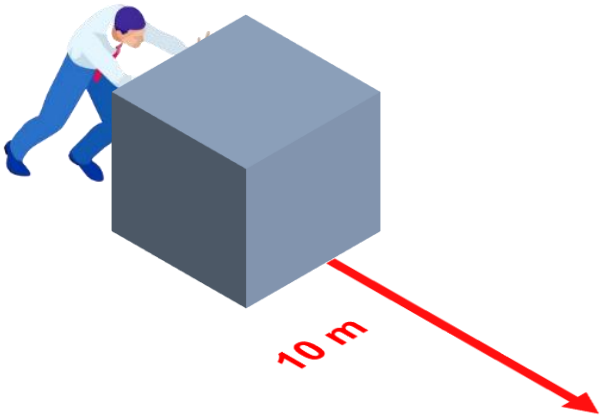
Energy [work] (J) → E_w

distance (m) → d

Force (N) → F

Pushing the same force over a larger distance will take more energy:





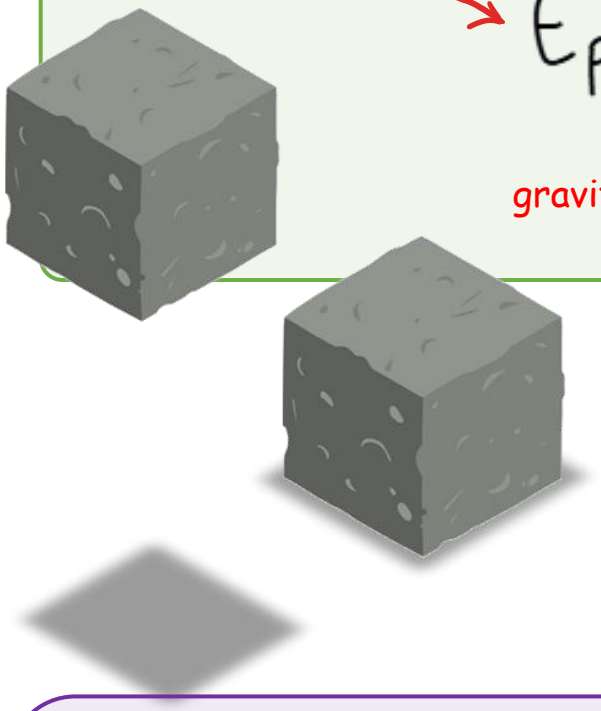
Gravitational Potential Energy

An object which is raised up to a high position is said to have gravitational potential energy.

Gravitational potential energy: the work done against gravity to raise an object.

The potential energy can be calculate using the formula:

Energy [potential] (J) ← $E_p = m\ g\ h$ → mass (kg), height (m), gravitational field strength (N/kg)



This means it takes more energy when lifting an object in the air if either the mass, height or gravitational field strength are increased.

Worked Example:

A chairlift raises a skier of mass 50 kg to a height of 250 m. **Calculate** how much potential energy the skier gains.

$E_p = ?$

$m = 50$ kg

$g = 9.8\ Nkg^{-1}$

$h = 250$ m

$E_p = m\ g\ h$

$E_p = 50 \times 9.8 \times 250$

$E_p = 122500\ J$

Kinetic Energy

Kinetic energy: is the energy associated with a moving object.

The kinetic energy that an object can be calculated using the formula:

$$E_k = \frac{1}{2} m v^2$$

Energy [kinetic] (J) ← E_k

m ← mass (kg)

v ← speed (ms^{-1})

Worked Example:

Calculate how much kinetic energy a car of mass 1000 kg has when it is travelling at 20 m/s.



$$E_k = \frac{1}{2} m v^2$$

$$E_k = \frac{1}{2} \times 1000 \times 20^2$$

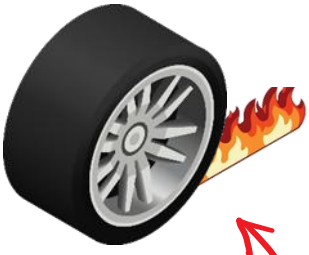
$$E_k = 200000 \text{ J}$$

Conservation of Energy

The law of conservation of energy states:

"Energy cannot be created or destroyed, but can be changed from one form into another."

For example:



Kinetic energy being transformed into heat energy due to friction.



Potential energy being transformed into kinetic energy.

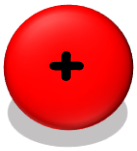
SQA Course Specifications N5

Electrical Charge Carriers

- ☐ Definition of electrical current as the electric charge transferred per unit time.
- ☐ Use of an appropriate relationship to solve problems involving charge, current and time.
- ☐ Knowledge of the difference between alternating and direct current.
- ☐ Identification of a source (as a.c. or d.c.) based on oscilloscope trace or image from data logging software.
- ☐ Knowledge that a charged particle experiences a force in an electric field.
- ☐ Knowledge of the path a charged particle follows: between two oppositely charged parallel plates; near a single point charge; between two oppositely charged points; between two like charged points.

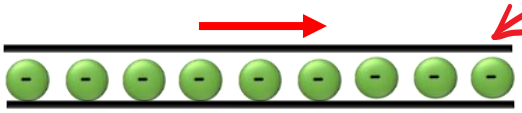
Electrical Charge Carriers

There are two types of electrical charge:

Positive: 

Negative: 

Electric current is the amount of charge per second.



Electricity is the flow of tiny charges called electrons

The formula that relates these quantities is given as:

$$Q = I\,t$$

Charge (C) → Q

t ← time (s)

I ↑ Current (A)

Worked Example:

A Van De Graaff produces 3 C of charge every minute.

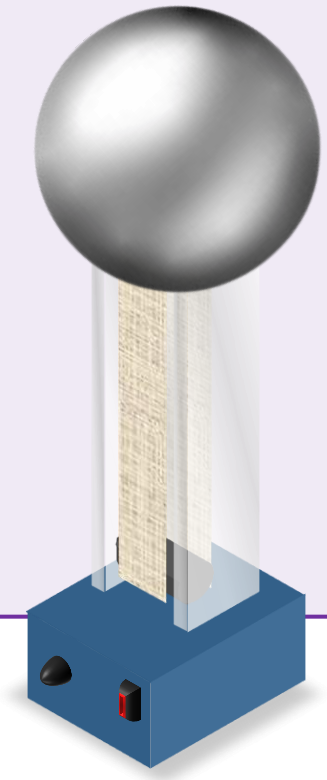
Calculate the electric current during this time.

$Q = I \times t$ ← 60 seconds in 1 minute

$3 = I \times 60$ | ÷ 60

$I = \frac{3}{60}$

$I = 0.05$ A



A.C. and D.C.

All power supplies can be grouped into one of two categories depending on the way that they supply energy to the charges in a circuit.

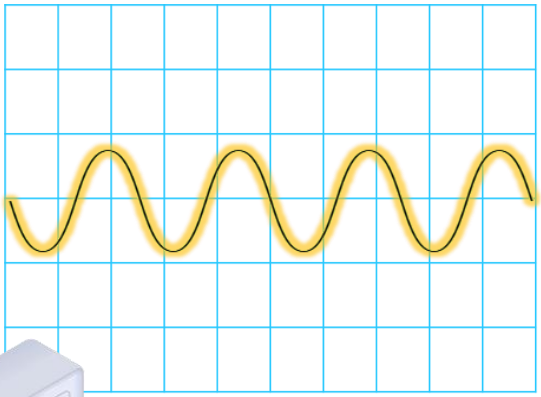


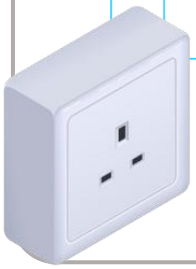
Oscilloscopes graphically display voltage signal over time. They can be used to see the difference between A.C. and D.C.

Alternating Circuit:

An a.c. supply produces a flow of charge which regularly reverses its direction through a circuit:

Oscilloscope trace:



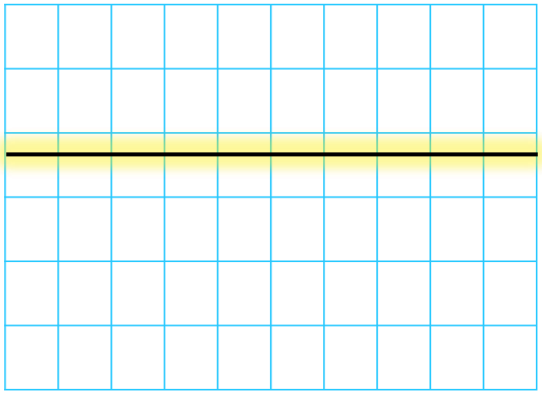


Mains supply is A.C.

Direct Circuit:

A d.c. supply produces a flow of charge through a circuit in one direction only.

Oscilloscope trace:





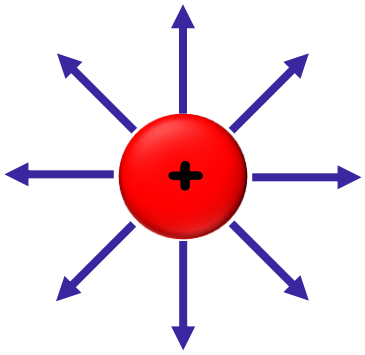
Batteries are D.C.

Electric Fields

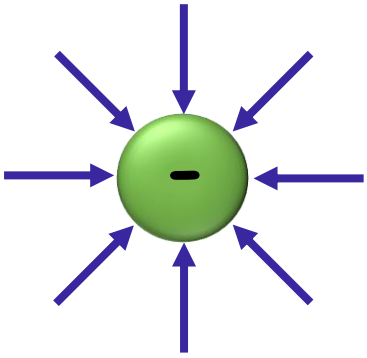
In Physics, a field means a region where an object experiences a force without being touched.

In an electric field, a charged particle will experience a force. We use lines of force to show the strength and direction of the force. The closer the field lines the stronger the force. Field lines are continuous; they start on a positive and finish on a negative charge.

Positive point charge:



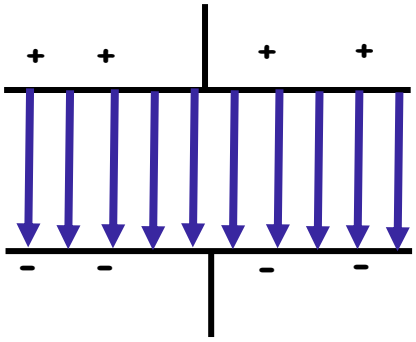
Negative point charge:



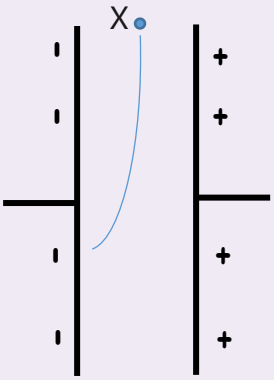
The direction is taken as the same as the force on a positive,  "test" charge placed in the field.

I.e the positive test charge would be **attracted** to positive point charge and **repelled** from the opposite negative point charge (opposites attract and like charges repel).

Charged Plates



Worked Example:



Identify the charge of particle X.
You **must justify** your answer

X is positively charged.

This is because it is attracted towards the negatively charged plate (opposites attract)

Potential Difference (voltage)

An electrical current is a flow of charges. The charges require energy in order to move.

The **voltage (or potential difference)** of the supply is a measure of the energy given to the charges in a circuit.

SQA Course Specifications N5

Voltage, Ohm's Law & Circuit Rules

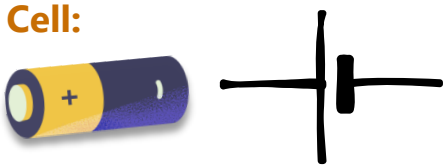
(Practical electrical and electronic circuits)

- ☐ Knowledge of the circuit symbol, function and application of standard electrical and electronic components.
- ☐ Application of the rules for current and potential difference (voltage) in series and parallel circuits.
- ☐ Knowledge that the potential difference (voltage) of the supply is a measure of the energy given to the charge carriers in a circuit.
- ☐ Calculation of the gradient of the line of best fit on a V-I graph to determine resistance.
- ☐ Measurement of current, potential difference (voltage) and resistance, using appropriate meters in simple and complex circuits.
- ☐ Use of appropriate relationships to solve problems involving potential difference (voltage), current and resistance.
- ☐ Description of an experiment to verify Ohm's law.
- ☐ Knowledge of the effect on the total resistance of a circuit of adding further resistance in series or in parallel.
- ☐ Use of appropriate relationships to solve problems involving the total resistance of resistors in series and in parallel circuits, and in circuits with a combination of series and parallel resistors.
- ☐ Knowledge of the qualitative relationship between the temperature and resistance of a conductor.

Practical electrical and electronic circuits

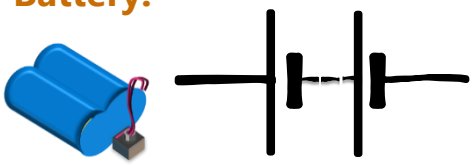
Circuit symbols:

Cell:



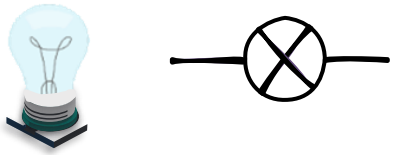
Provides Voltage

Battery:



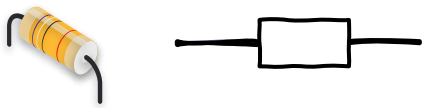
Provides Voltage

Lamp:



Electrical energy -> Light Energy

Resistor:



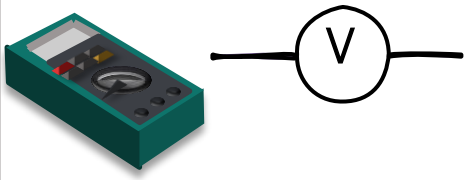
Opposes current

Switch:



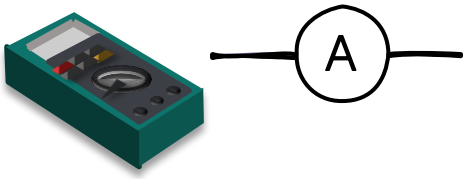
Connects/disconnects circuit

Voltmeter:



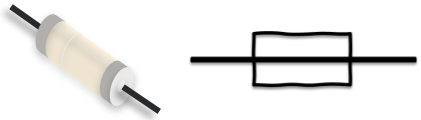
Measures voltage

Ammeter:



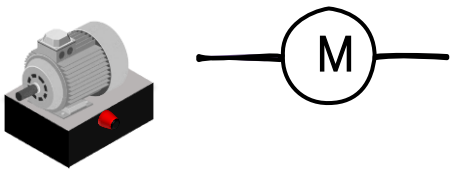
Measures current

Fuse:



Blows if too much current goes through.

Motor:



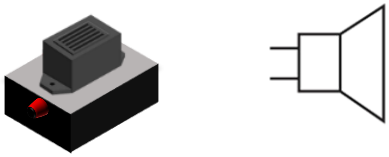
Electric energy -> Kinetic Energy

Microphone:



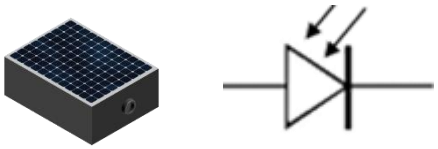
Sound energy -> Electric Energy

Loudspeaker:



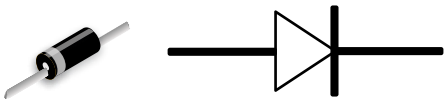
Electric energy -> Sound Energy

Photovoltaic Cell:



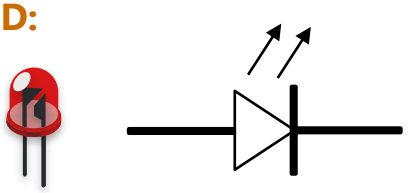
Light energy -> Electrical Energy

Diode:



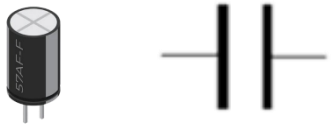
Allows current to flow through in one direction

LED:



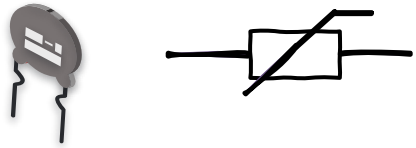
Allows current to flow through in one direction and emits light.

Capacitor:



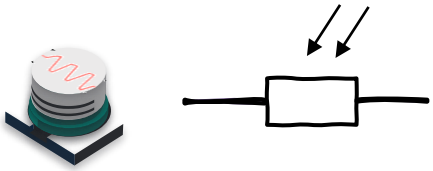
Stores and release electrical energy.

Thermistor:



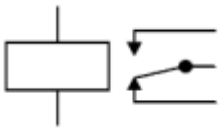
Temperature dependent resistor

LDR:



Light dependent resistor

Relay:

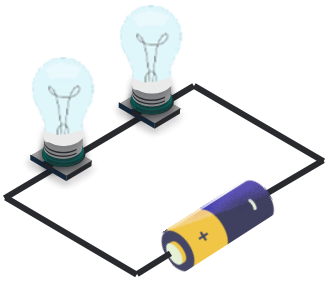


Switch that links two circuits

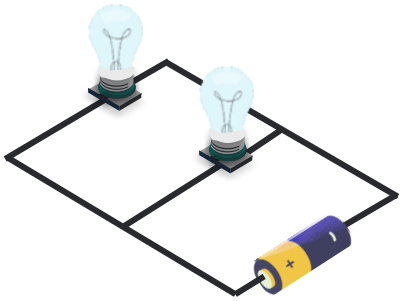
Series and Parallel Circuits

Circuits can be categorised as either series or parallel:

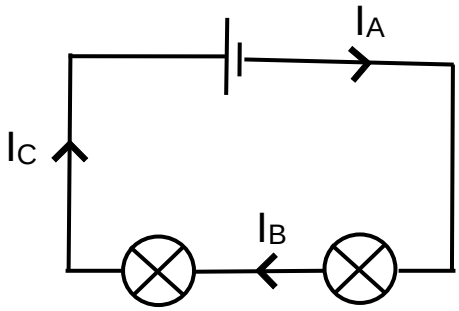
In a **series** circuit there is only one path for the current to flow.



In a **parallel** circuit there is more than one path for the current to follow.



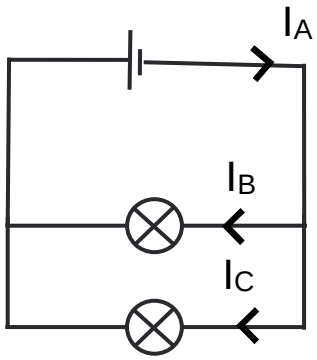
Current in a Series Circuit:



Current is the same at all points in a series circuit:

$$I_A = I_B = I_C$$

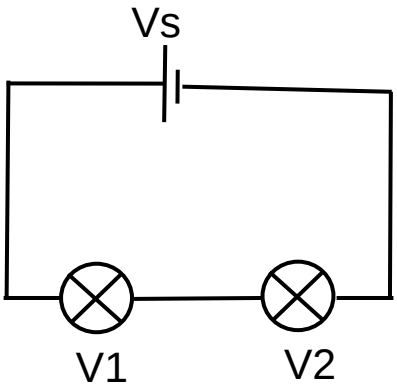
Current in a Parallel Circuit:



Current is split in a parallel circuit:

$$I_A = I_B + I_C$$

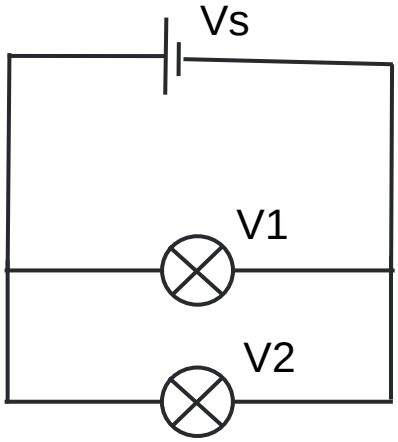
Potential Difference in a Series Circuit:



The sum of the potential difference across the components in a series circuit is equal to the voltage of the supply:

$$V_s = V_1 + V_2$$

Potential Difference in a Parallel Circuit:

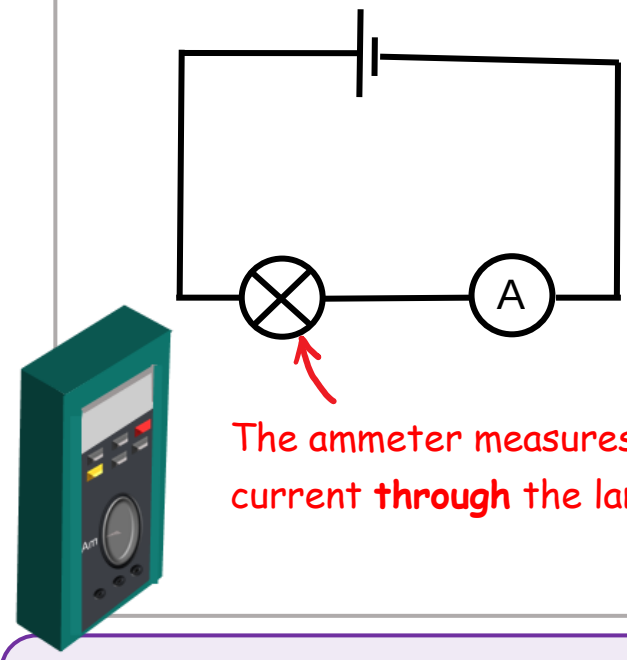


The potential difference across each branch of a parallel circuit is the same as the supply voltage:

$$V_s = V_1 = V_2$$

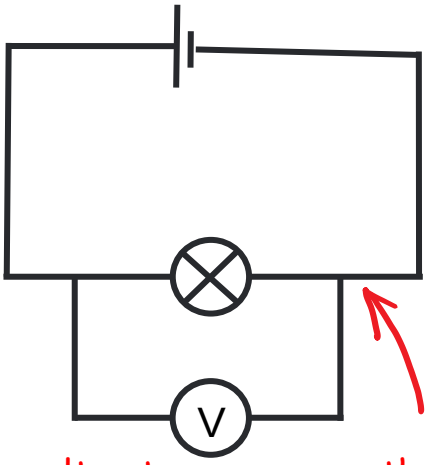
Placing meters

Electric current is measured using an ammeter which is connected in **series** with the component:



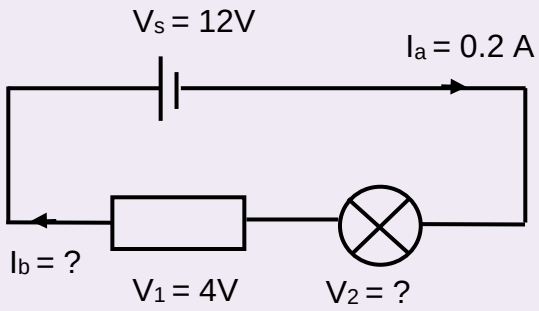
The ammeter measures the current **through** the lamp.

Potential difference (p.d.), or voltage, is measured using a voltmeter which is connected in parallel with a component:



The voltmeter measures the voltage (p.d.) **across** the lamp.

Worked Example: (series circuit)



For the circuit above.

a) **State** the value of V_2.

$V_S = V_1 + V_2$

$12 = 4 + V_2$

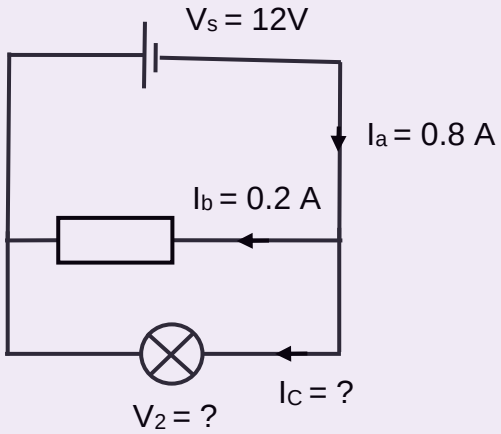
$V_2 = 8V$

b) **State** the value of I_b.

$I_A = I_B$

$I_B = 0.2\ A$

Worked Example: (parallel circuit)



For the circuit above.

a) **State** the value of V_2.

$V_2 = 12V$

b) **State** the value of I_b.

$I_A = I_B + I_C$

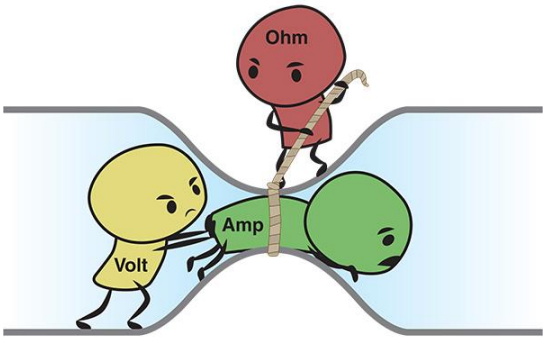
$0.8 = 0.2 + Ic$

$Ic = 0.6\ A$

Ohm's Law

Ohm's Law is a formula that tells us the relationship between, voltage current and resistance.

All components have some resistance.-When a resistor is kept at a constant temperature, its resistance will remain unchanged.



Resistance is a measure of the opposition of a circuit component to the current through that component.

Ohm's Law can be written as:

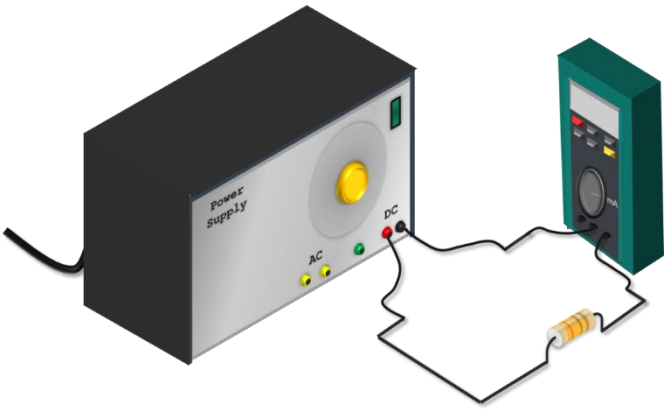
Current (A)

Voltage (V) $V = IR$ Resistance (Ω)

We can confirm this experimentally by completing the following steps:

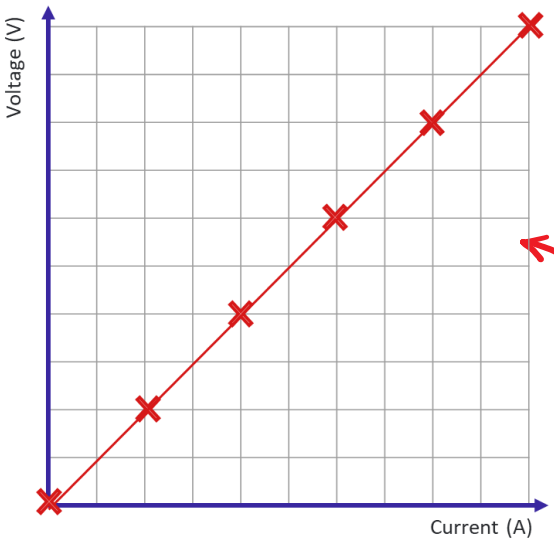
1. Connect a resistor in series with a power supply

2. Measure the current going through the resistor with an ammeter.



3. Repeat your measurement as you increase the voltage across the resistor by adjusting the power supply.

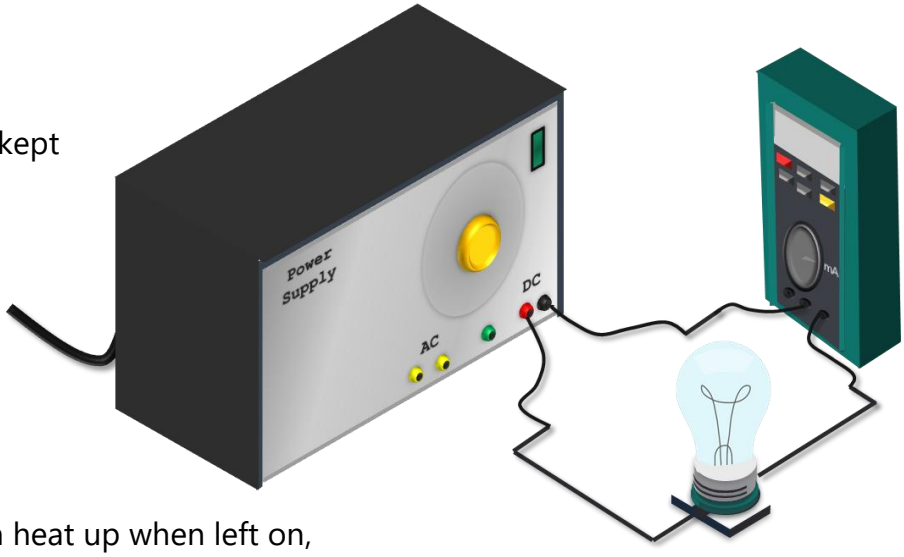
4 Plot a graph of voltage against current.



Produces a straight-line graph that passes through the origin. This means voltage and current are directly proportional.

Resistance and Temperature

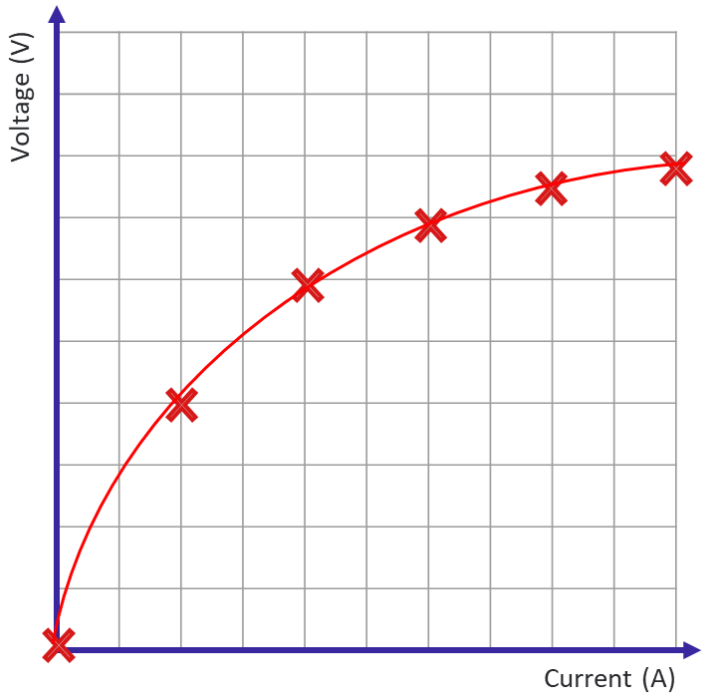
Ohm's law is true if temperature is kept constant.



In reality, an increase in temperature will increase the resistance of a component.

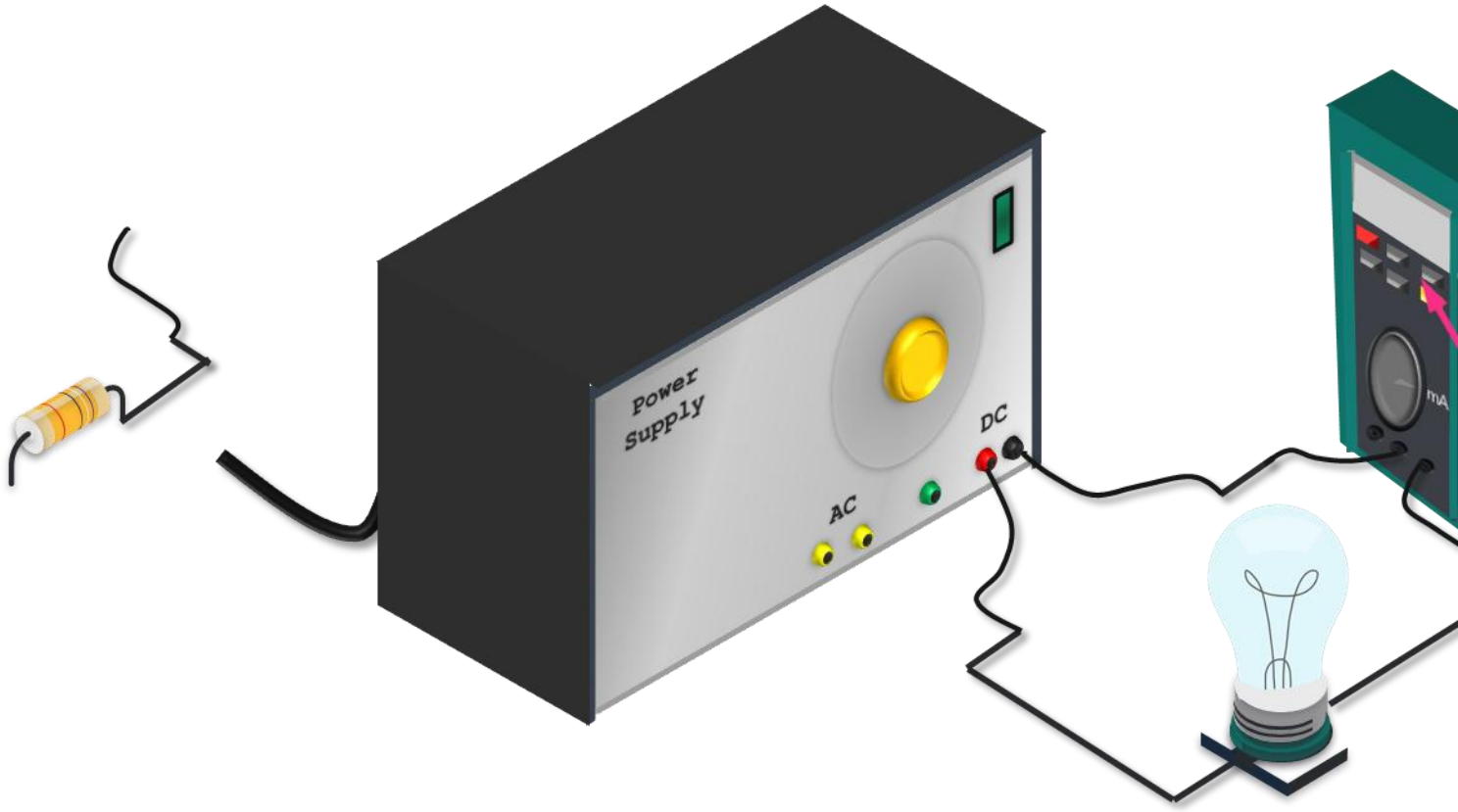
This is true for lightbulbs that often heat up when left on, components like this are non as non-ohmic conductors.

Plotting a graph of voltage against current for a non-ohmic conductor will produce a graph like this:



Current and voltage are no longer directly proportional.

Instead, we know that as current increases, the resistance decreases.



Combined Resistance

When finding the combined resistance of multiple resistors series and parallel circuits must be treated differently:

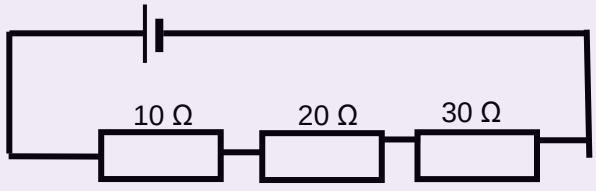
Series:

Total resitence in series circuits is determined with the following relationship:

$$R_T = R_1 + R_2 + \dots$$

Worked Example:

Determine the total resistance of the circuit below:



$$R_T = R_1 + R_2 + R_3$$

$$R_T = 10 + 20 + 30$$

$$R_T = 60\,\Omega$$

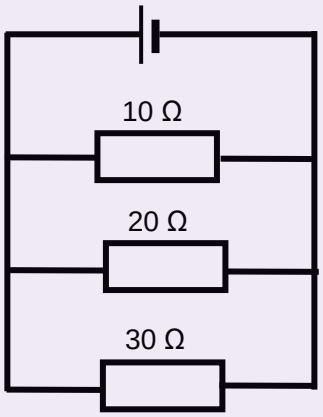
Parallel:

Total resitence in parallel circuits is determined with the following relationship:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$$

Worked Example:

Determine the total resistance of the circuit below:



$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R_T} = \frac{1}{10} + \frac{1}{20} + \frac{1}{30}$$

$$\frac{1}{R_T} = 0.183$$

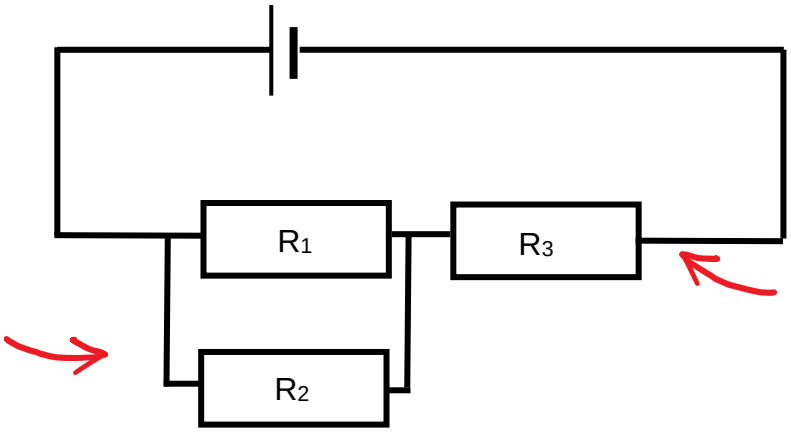
$$R_T = 5.5\ \Omega$$

Note: Combining resistors in parallel causes the total resistance to become smaller

Combination Circuits

Some circuits cannot fully be described as series or parallel. We call these combination circuits.

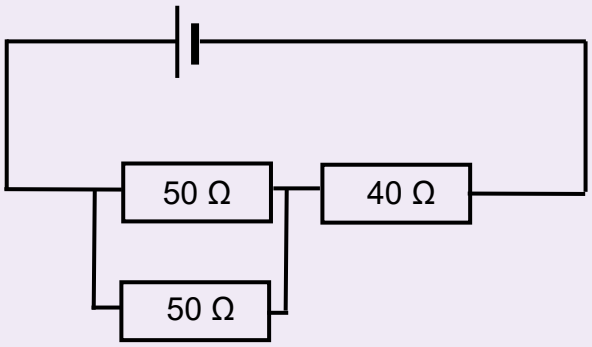
In this example R1 and R2 make up a parallel section.



R3 is in series with this parallel section.

Worked Example:

For the circuit below **calculate** the total resistance.



1: Calculate the resistance in the parallel section:

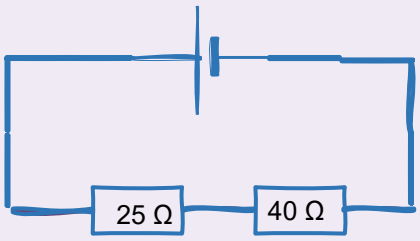
$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R_p} = \frac{1}{50} + \frac{1}{50}$$

$$\frac{1}{R_p} = \frac{1}{25}$$

$$R_p = 25$$

2: Simplify the circuit into an "equivalent circuit". In this example the two 50 Ω can be replaced with a 25 Ω resistor.



3: We now have a series circuit so can use the series circuit rule to find the total resistance.

$$R_T = R_1 + R_2$$

$$R_T = 25 + 40$$

$$R_T = 65\ \Omega$$

SQA Course Specifications N5

Voltage, Ohm's Law & Circuit Rules

(Potential dividers and Transistors)

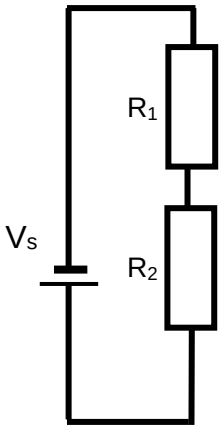
- ☐ Use of appropriate relationships to solve problems involving potential difference (voltage), current and resistance.

- ☐ For transistors, knowledge of the symbols for a npn transistor and an n-channel enhancement mode MOSFET.

- ☐ Explanation of their function as a switch in transistor switching circuits.

Potential Dividers

A potential divider is a device or a circuit that uses two (or more) resistors in series:



The voltage of the supply V_s is divided across the resistors in direct proportion to their individual resistances (i.e. the larger the resistance of a resistor the bigger a share of the voltage it will take.)

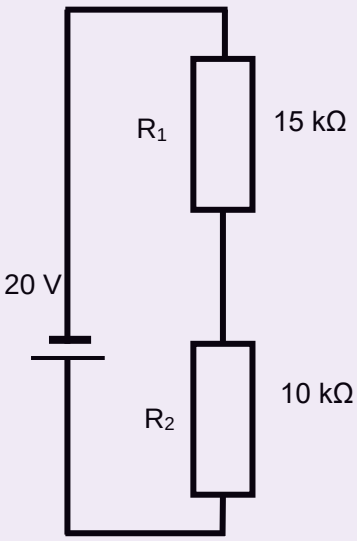
There are two formula that apply to potential dividers:

$$\frac{V_1}{V_2} = \frac{R_1}{R_2}$$

$$V_2 = \frac{R_2}{R_2 + R_1} V_S$$

Worked Example:

For the circuit seen below, **calculate** the voltage across the resistor R_2.



$V_2 = ?$
$V_s = 20\ V$
$R_1 = 15\ k\Omega$
$R_2 = 10\ k\Omega$

Useful step for deciding which of the two formulas to use and for keeping all your information the write way around.

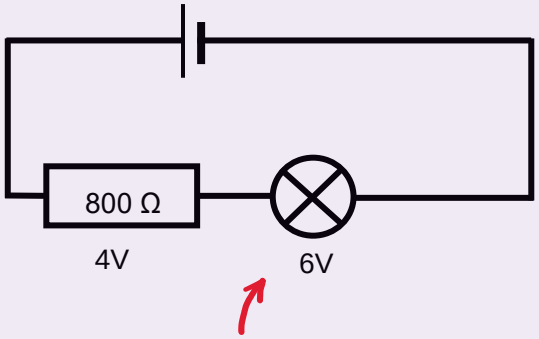
$$V_2 = \frac{R_2}{R_1 + R_2} V_s$$

$$V_2 = \frac{10}{15 + 10} 20$$

$$V_2 = 8V$$

Worked Example 2:

For the circuit below, **calculate** the resistance of the bulb.



$V_1 = 4$
$V_2 = 6$
$R_1 = 800$
$R_2 = ?$

$$\frac{V_1}{V_2} = \frac{R_1}{R_2}$$

$$\frac{4}{6} = \frac{800}{R_2}$$

$$R_2 = 1200\ \Omega$$

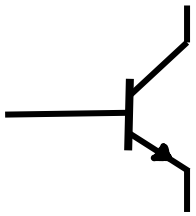
Potential divider formulas can be used any two components with resistance that are in series with one another such as this resistor and light bulb.

Transistors

A transistor is an electronic component which contains numerous parts. In this course, we will look at how a transistor can be used as an electronic switching device.

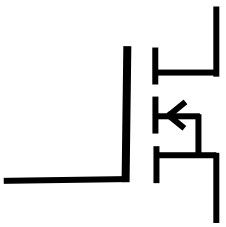
NPN Transistor





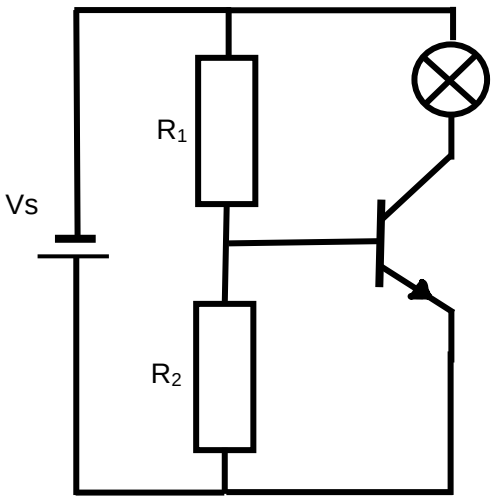
n-channel enactment mode MOSFET





Using transistors in circuits:

Transistors are usually connected to potential divider circuits as seen below:



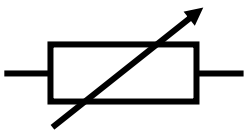
R_1 and R_2 make up a potential divider. Each of the two resistors will take a share of V_s , where the "larger" resistor will take more of the voltage.

If R_2 receives a certain "switch on" voltage, the transistor will conduct.

When the transistor conducts, the output device (here, a bulb) it is connected to will switch on.

The above circuit contains fixed resistors R_1 and R_2. Replacing either of these with one of the resistors below will mean the resistance (and thus the share of the voltage) can be controlled manually or as a result of the environment – therefore changing when the light bulb turns on:

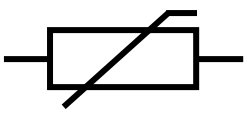
Variable Resistor



Resistance can be manually increased or decreased.

(used in a transistor circuit to manually vary the **[environmental condition**] at which the **[output device]** is switched on)

Thermistor



T - emperature

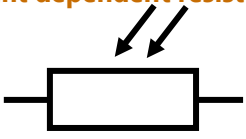
U -p

R - esistance

D - own

LDR

(light dependent resistor)



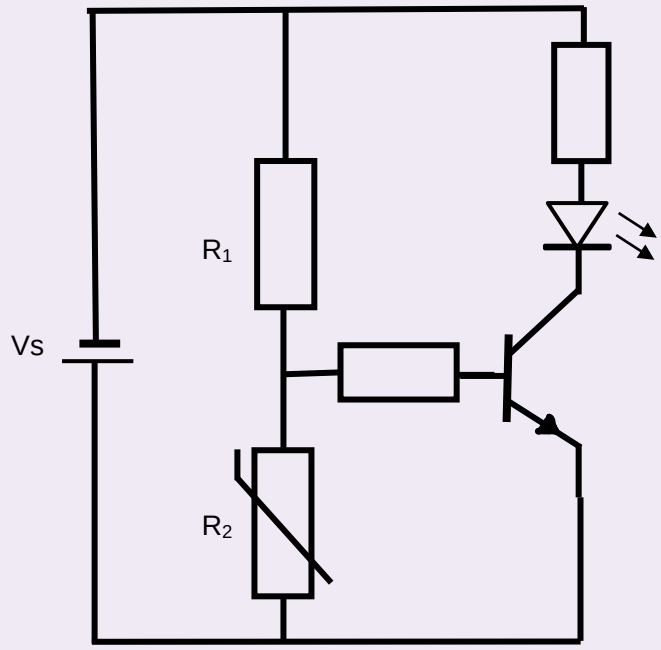
L - ight

U -p

R - esistance

D - own

Worked Example 1: **Explain** how the circuit operates to turn on the LED as the temperature decreases.



To answer these questions follow the 3 steps below:

1. How does the environment effect the component?

As temperature goes down the resistance of the ***thermistor R_2*** *goes up.*

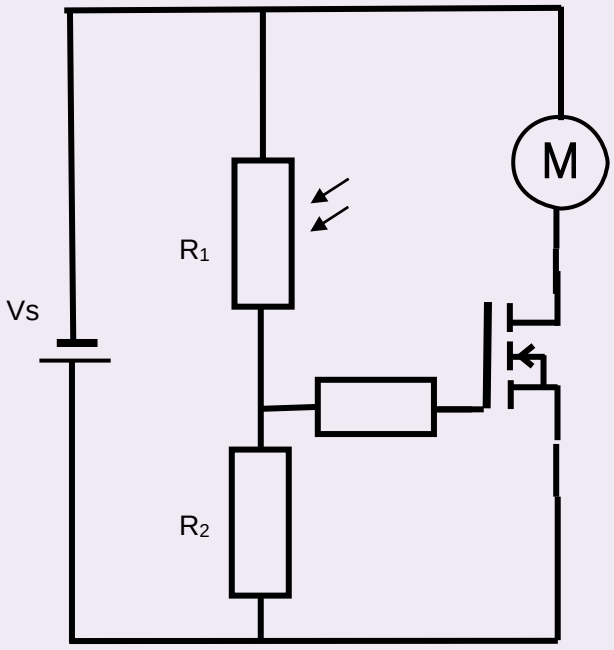
2. How does this effect the voltage of V_2?

The voltage across the thermistor R_2 goes up.

3. Will this cause the transistor to switch on (or off)?

If V_2 reaches the switch on voltage the transistor ***will conduct*** *and* ***switch on*** *the LED.*

Worked Example 2: **Explain** how the circuit operates to turn on the motor as the light level increases.



1. How does the environment effect the component?

As light level goes up the resistance of the ***LDR R_1*** *goes down.*

2. *How does this effect the voltage of V_2?*

The voltage across the LDR R_1 goes down. This means the voltage across R_2 goes up.

3. Will this cause the transistor to switch on (or off)?

If V_2 reaches the switch on voltage the transistor ***will conduct*** *and* ***switch on*** *the motor.*

SQA Course Specifications N5

Electrical Power and Energy

- ☐ Definition of electrical power in terms of electrical energy and time.
- ☐ Use of an appropriate relationship to solve problems involving energy, power and time.
- ☐ Knowledge of the effect of potential difference (voltage) and resistance on the current in and power developed across components in a circuit.
- ☐ Use of appropriate relationships to solve problems involving power, potential difference (voltage), current and resistance in electrical circuits.
- ☐ Selection of an appropriate fuse rating given the power rating of an electrical appliance.

Electrical Power

To compare different components it is often useful to compare the rate at which energy is transformed, that is the energy transformed each second (power).

Power is the (electrical) energy transformation each second.

The power of an appliance can be found using the following equation:

Power (W) → $P = \frac{E}{t}$ ← Energy (J), Time (s)

Worked Example:

The electric motor on a ceiling fan uses 207 kJ of electrical energy in 30 minutes.

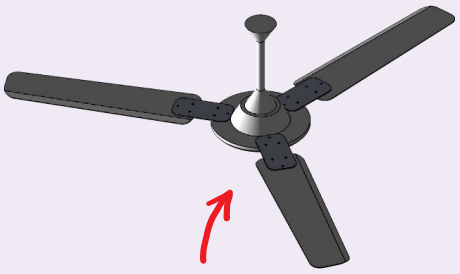
Calculate the power rating of the motor in the fan.

$E = 207\ kJ = 207000\ J$
$t = 30\ minutes = 1800\ seconds$
$P = ?$

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

$$P = \frac{207000}{1800}$$

$$P = 115\ W$$



Keeping it cool

Power, Current and Voltage

Electrical power is also dependent on the potential difference across the component and the current through it and the resistance.

The following formulas can be used:

$$P = I V$$

$$P = I^2 R$$

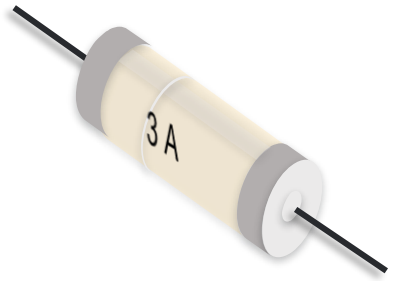
$$P = \frac{V^2}{R}$$

Where the symbols have their usual meaning.

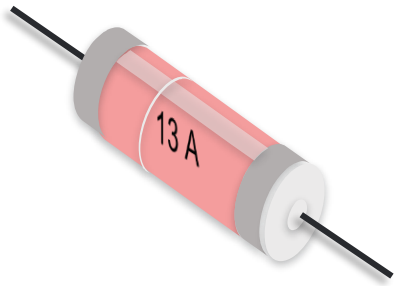
Fuses

Fuses are safety devices in circuits. They "blow" if too much current passes through them. By doing this the fuse breaks the circuit.

There are typically two types of fuse:



A 3 A fuse should be selected for most appliances rated **up to** 720 W



A 13 A fuse should be selected for appliances rated **over** 720 W

Worked Example:

A coffee machine operates at 230 V a.c. and has a resistance of 150 Ω.



a) **Show** that the power rating of the coffee machine is 350 W

$$P = \frac{V^2}{R}$$

$$P = \frac{230^2}{150}$$

$$P = 350 \text{ W}$$

b) **State** the fuse rating that should be used for this coffee machine.

A 3 A fuse should be used

350 Watts is less 720 Watts so a 3A fuse should be used.

SQA Course Specifications N5

Specific heat Capacity and Specific Latent Heat

- [ ] Knowledge that different materials require different quantities of heat to raise the temperature of unit mass by one degree Celsius.

- [ ] Use of an appropriate relationship to solve problems involving mass, heat energy, temperature change and specific heat capacity.

- [ ] Knowledge that the temperature of a substance is a measure of the mean kinetic energy of its particles.

- [ ] Use of the principle of conservation of energy to determine heat transfer.

- [ ] Knowledge that different materials require different quantities of heat to change the state of unit mass.

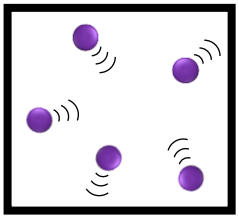
- [ ] Knowledge that the same material requires different quantities of heat to change the state of unit mass from solid to liquid (fusion) and to change the state of unit mass from liquid to gas (vaporisation).

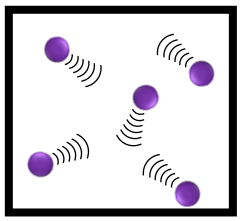
- [ ] Use of an appropriate relationship to solve problems involving mass, heat energy and specific latent heat.

Properties of Matter

Heat and Temperature

The **temperature** of a substance is a measure of the mean kinetic energy of its particles





Heat and temperature are related, but they are not the same. Heat energy is actually a type of kinetic energy. It increases as the movement of the individual particles of the material increases.

Specific Heat Capacity

The **specific heat capacity** of a substance is the amount of heat energy required to change the temperature of 1kg of a substance by 1°C.

Specific heat capacity can be calculated using the formula:

Energy [heat] (J)

mass (kg)

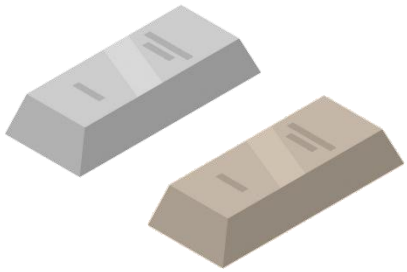
$$E_h = c\,m\,\Delta T$$

Change in temperature (°C)

Specific heat capacity ($Jkg^{-1}\,°C^{-1}$)

Specific heat capacity of materials

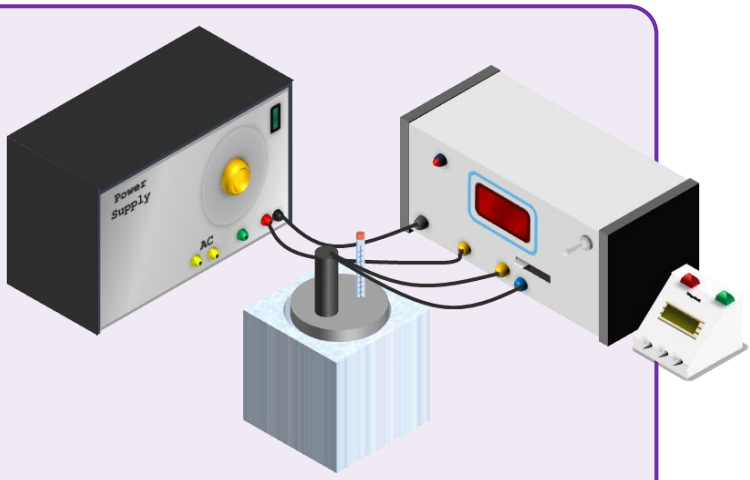
Material	*Specific heat capacity in* $Jkg^{-1}\,°C^{-1}$
Alcohol	2350
Aluminium	902
Copper	386
Glass	500
Ice	2100
Iron	480
Lead	128
Oil	2130
Water	4180



Different materials have different specific heat capacities

Worked Example:

The following experminet is completed to determine the specific heat capacity of alunium. 1kg of aluminium is connected to an imersion heater. It is found in the experiment that providing 37000J of energy causes the metal to go from 20°C to 60°C.



a) **Calculate** the specific heat capacity of aluminium obtainned from this experiment.

$$E_h = c\,m\,\Delta T$$

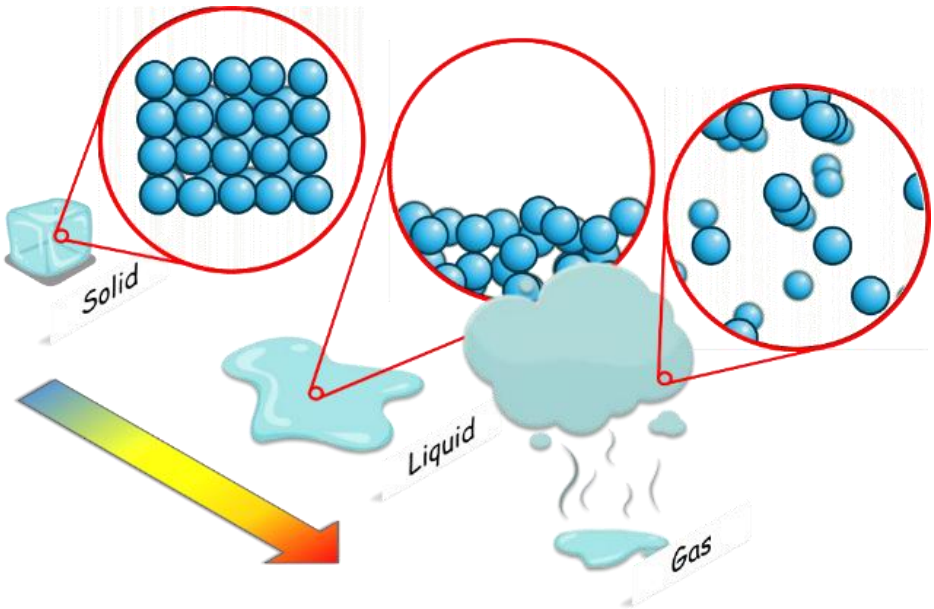
$$37000 = c \times 1 \times 40 \quad | \div (1 \times 40)$$

$$c = \frac{37000}{1 \times 40} = 925\ J\,kg^{-1}\,°C^{-1}$$

b) **Explain** why the value calculated in part a) is different from that on the data sheet.

Heat (energy) is lost to the surroundings/to air.

Providing a material with heat energy doesn't only have the effect of changing its temperature. It can also change its state:

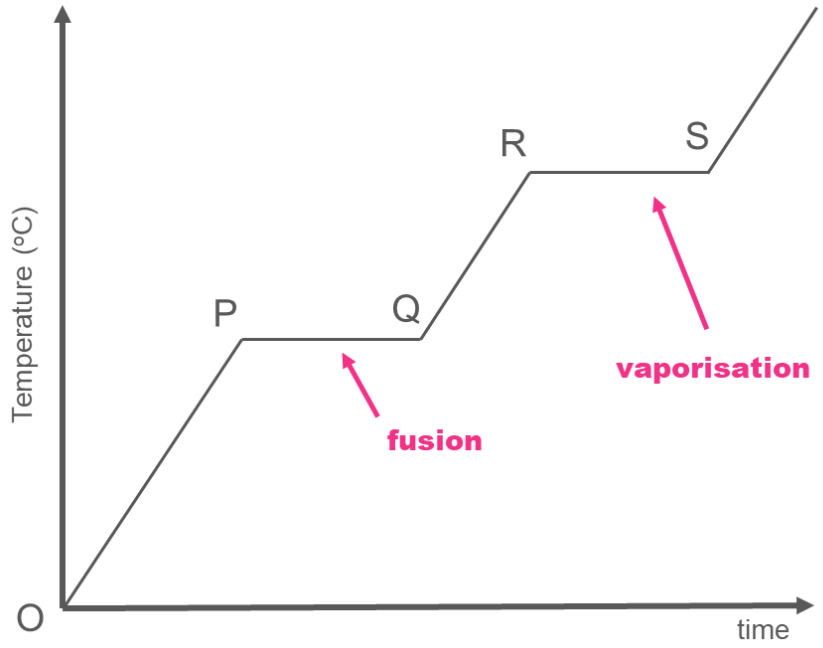


We call solids turning into liquids fusion.

We call liquids turning into gas vaporisation.

When a substance changes from one state to another, the temperature remains constant.

This process can be seen on the following graph:



O-P: A solid is increasing in temp.

P-Q: It is changing state from solid to a liquid.

Q-R: The liquid in increasing in temp.

R-S: The liquid is changing into a gas,

S-T: The gas is increasing in temp.

Specific Latent Heat

The specific latent heat of a substance is the energy involved in changing the state of 1 kg of the substance without any temperature change.

Specific latent heat of a substance can be calculated using the formula:

Energy [heat] (J) → $E_h = m l$ ← Specific latent heat (Jkg^{-1})

mass (kg) ↗

Specific latent heat of fusion of materials

Material	*Specific latent heat of fusion* in Jkg^{-1}
Alcohol	$0{\cdot}99 \times 10^5$
Aluminium	$3{\cdot}95 \times 10^5$
Carbon Dioxide	$1{\cdot}80 \times 10^5$
Copper	$2{\cdot}05 \times 10^5$
Iron	$2{\cdot}67 \times 10^5$
Lead	$0{\cdot}25 \times 10^5$
Water	$3{\cdot}34 \times 10^5$

Used when solids turn into liquids.

Specific latent heat of vaporisation of materials

Material	*Specific latent heat of vaporisation* in Jkg^{-1}
Alcohol	$11{\cdot}2 \times 10^5$
Carbon Dioxide	$3{\cdot}77 \times 10^5$
Glycerol	$8{\cdot}30 \times 10^5$
Turpentine	$2{\cdot}90 \times 10^5$
Water	$22{\cdot}6 \times 10^5$

Used when liquids turn into gases.

SQA Course Specifications N5

Gas Laws and the Kinetic Model

- ☐ Definition of pressure in terms of force and area.
- ☐ Use of an appropriate relationship to solve problems involving pressure, force and area.
- ☐ Description of how the kinetic model accounts for the pressure of a gas.
- ☐ Knowledge of the relationship between Kelvin and degrees Celsius and the absolute zero of temperature.
- ☐ Explanation of the pressure–volume, pressure–temperature and volume–temperature laws qualitatively in terms of a kinetic model.
- ☐ Use of appropriate relationships to solve problems involving the volume, pressure and temperature of a fixed mass of gas
- ☐ Description of experiments to verify the pressure–volume law (Boyle's law), the pressure–temperature

Pressure

Pressure on a surface is defined as the force acting normal (perpendicular) to the surface per unit area.

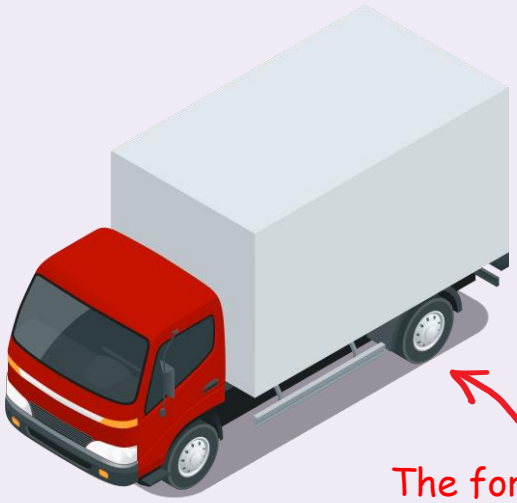
The formula is:

$$P = \frac{F}{A}$$

Pressure (Pa) — Force (N) — Area (m^2)

Worked Example:

Calculate the pressure exerted on the ground by a truck of mass 1600 kg if each wheel has an area of 0.02 m^2 in contact with the ground.



The truck has 4 wheels

Total area, $A = 4 \times 0.02 = 0.08\ m^2$

The force of the truck on the ground is given by the weight

Force = $W = mg$

$W = 1600 \times 9.8$

$W = 15680\ N$

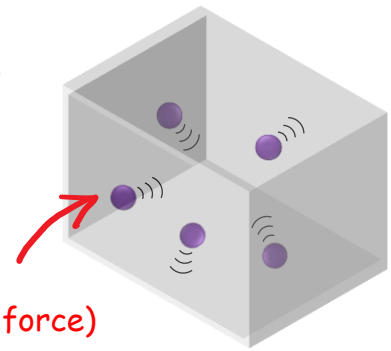
$$P = \frac{F}{A}$$

$$P = \frac{15680}{0.08}$$

$$P = 196000\ Pa$$

Gas Laws and Kinetic Theory of Gases

The kinetic model considers a gas to be composed of a large number of very small particles which are far apart and which move randomly at high speeds, colliding with the container.

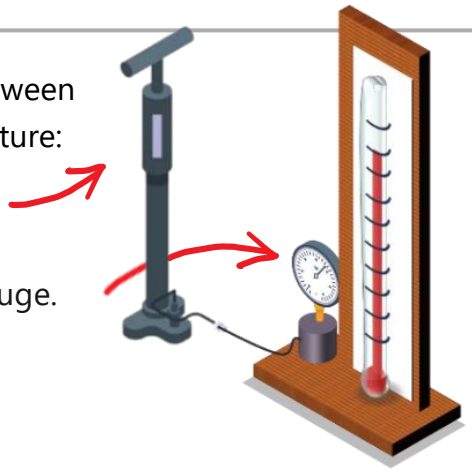


The gas laws describe how pressure, temperature and volume of a fixed mass of gas are related.

Pressure: Caused by the particles colliding (providing a force) to the container (more collisions = more pressure).

Pressure and Volume (Boyles Law)

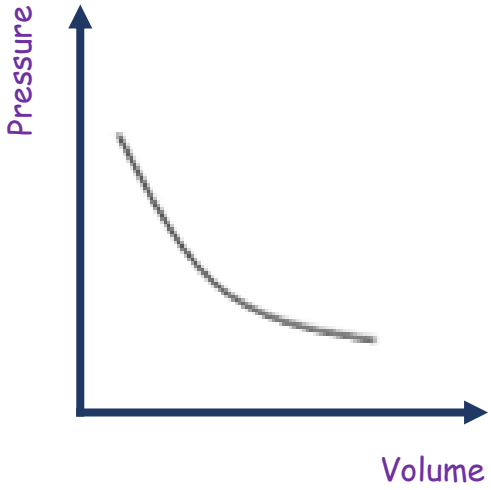
The following can be completed to determine the relationship between pressure and volume of a fixed mass of gas at a constant temperature:



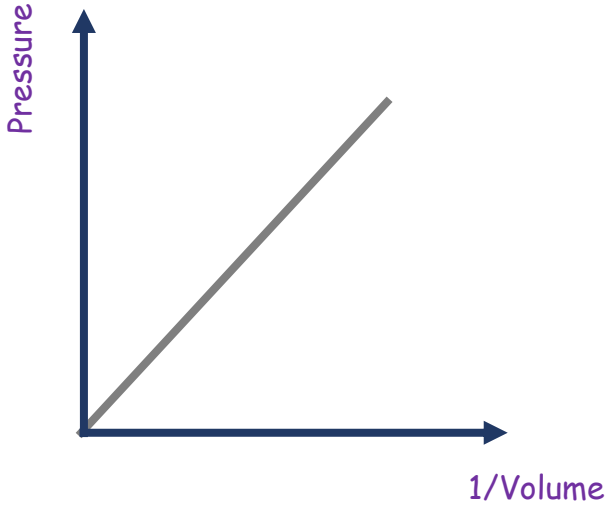
1. A Bike pump can be used to change the volume of a gas.

2. The change in pressure can be measured with the pressure gauge.

3. Plotting pressure against volume shows, as the volume increases the volume of the gas decreases:

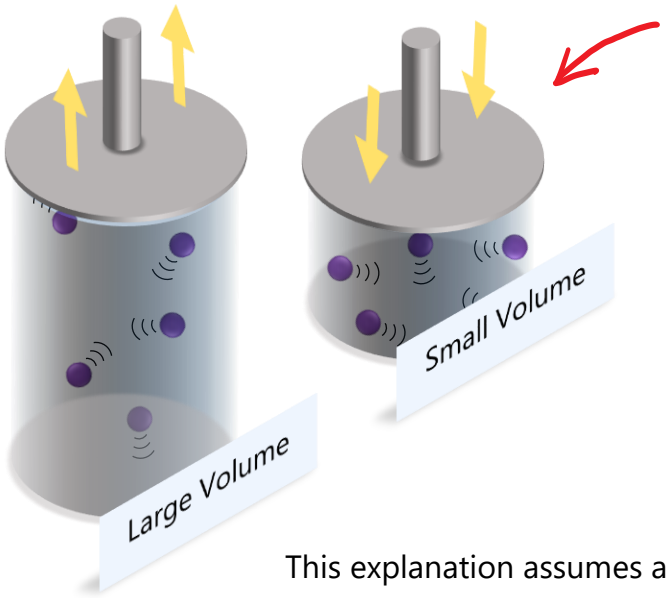


4. Plotting pressure against 1/volume shows, pressure is **inversely proportional** to volume:



From this experiment we can arrive at the following relationship:

$$P_1 V_1 = P_2 V_2$$



When volume is decreased, pressure is increased because particles will collide with the walls of the container more frequently.

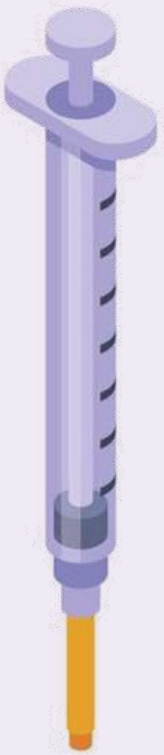
Every time a particle hits the container it exerts a force.

Because $P = \frac{F}{A}$ when the overall force on the area of the container goes up, the pressure increases.

This explanation assumes a **fixed mass of gas** and a **constant temperature**.

Worked Example:

The volume of a gas enclosed in a cylindrical syringe changes from 25 ml to 10 ml.



a) If there is no change in temperature and the initial pressure was 80 Pa, **calculate** the new pressure

$P_1 = 80\,Pa$
$P_2 = ?$
$V_1 = 25\,ml$
$V_2 = 10\,ml$

$P_1V_1 = P_2V_2$

$80 \times 25 = P_2 \times 10$ ÷10

$P_2 = \frac{80 \times 25}{10} = 200\,Pa$

b) Using the kinetic model **explain** why the pressure of the gas increases as the volume decreases.

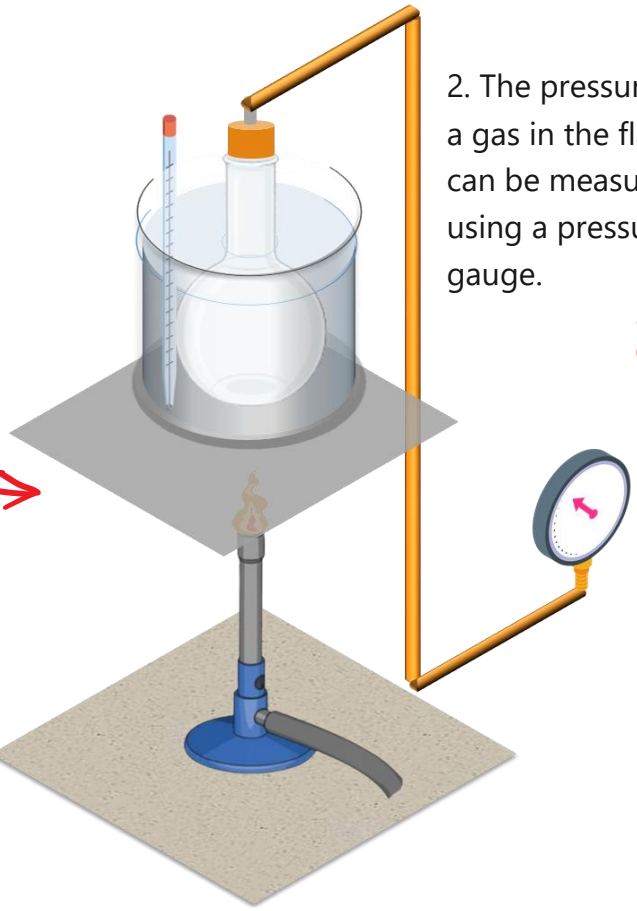
(individual) particles collide with container/walls more frequently (than before)

causing (overall) force (on walls) to be greater

therefore pressure increases

Pressure and Temperature

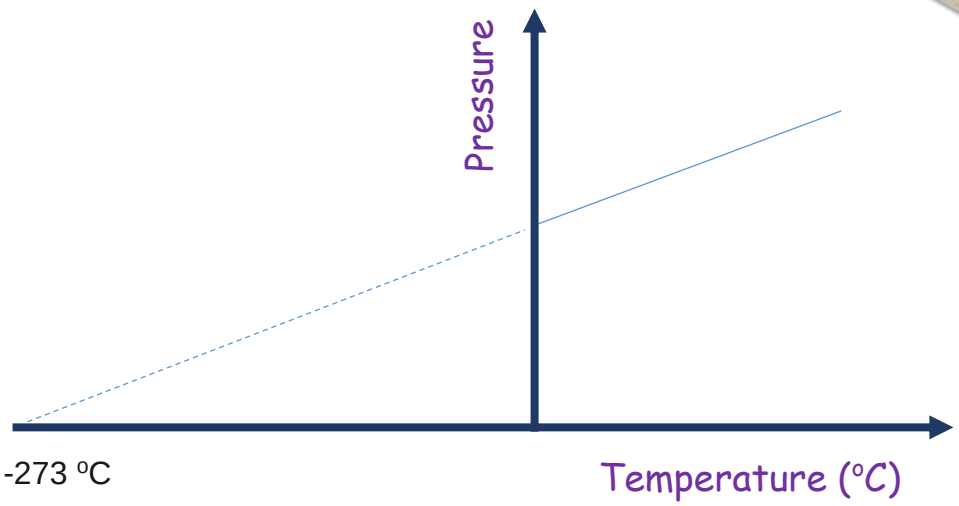
The following experiment can be completed to determine the relationship between pressure and temperature of a fixed mass of gas at a constant volume:



2. The pressure of a gas in the flask can be measured using a pressure gauge.

1. The temperature of the gas in the flask is increased and measured with a thermometer

3. Plot a graph of pressure against temperature:



The graph is a straight line which **does not** pass through the origin.

When the graph is extended until the pressure reaches zero, it crosses the temperature axis at –273°C.

Kelvin and Absolute Zero

-273°C is called absolute zero and is zero on the Kelvin temperature scale.

At a temperature of absolute zero, 0 K, all particle motion stops and this is therefore the lowest possible temperature.

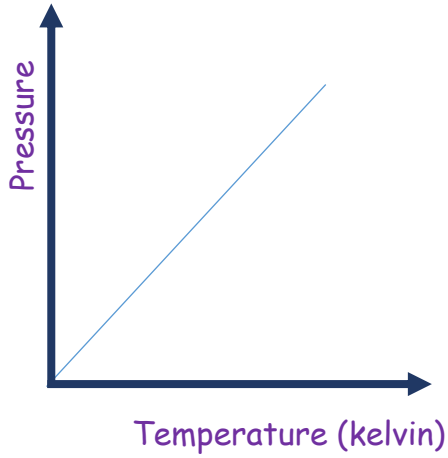
One division on the Kelvin temperature scale is the same size as one division on the Celsius temperature scale, i.e. temperature difference is the same in Kelvin as in degrees Celsius.

Kelvin to degrees Celsius

Converting °C into K	add 273
Converting K into °C	subtract 273

experiment description continued on next pg.

4. Convert the temperatures to Kelvin and replot the graph of pressure against temperature:



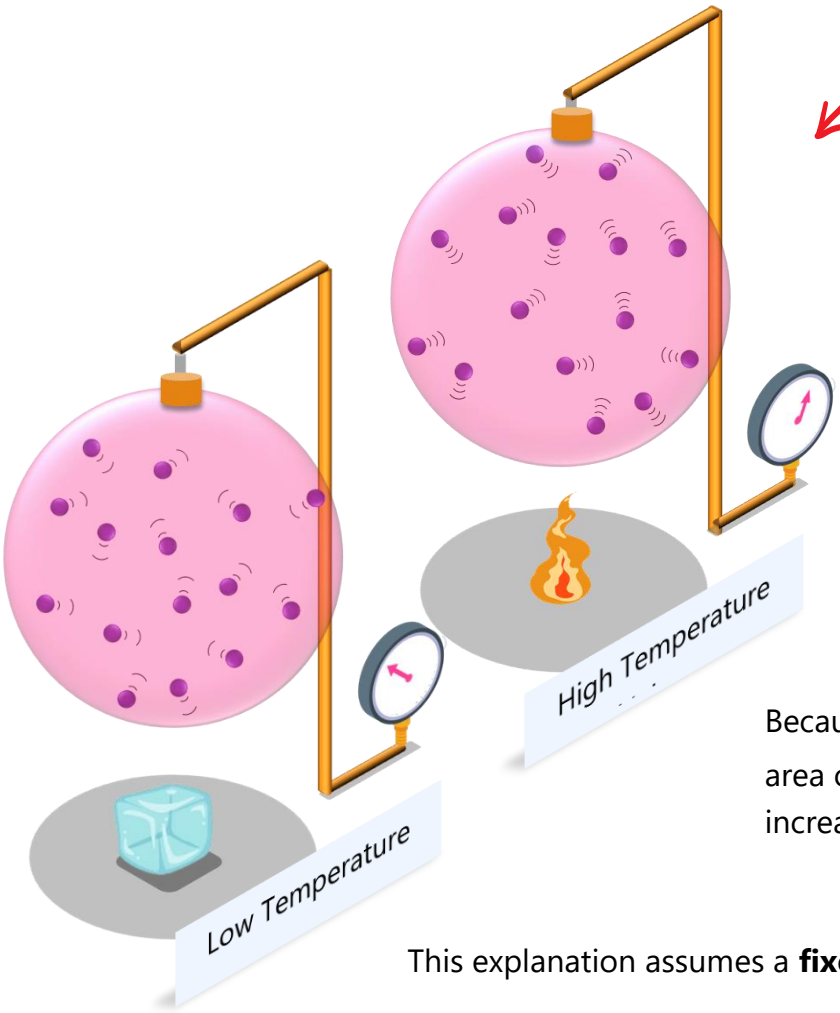
The graph is a straight line which **does** pass through the origin.

This shows that pressure and temperature (in kelvin) are **directly proportional.**

From this we can arrive at the relationship:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Where temperature **must** be in kelvin!



When temperature is increased, pressure increases.

This is because the particles gain more kinetic energy (meaning they move faster.

Meaning individual particles will hit the container more frequently.

Every time a particle hits the container it exerts a force.

Because $P = \frac{F}{A}$ when the overall force on the area of the container goes up, the pressure increases.

This explanation assumes a **fixed mass of gas** and a **constant volume**.

Worked Example:

A student sets up an experiment to investigate the relationship between the pressure and temperature of a fixed mass of gas.

The student heats the water and records the following readings of pressure and temperature:

Pressure (kPa)	101	107	116	122
Temperature (K)	293	313	333	353

a) Using **all** the data, establish the relationship between the pressure and the temperature.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

You know the relationship between pressure and temperature is this. This is what you are trying to prove.

Using all 4 sets of data

$$\frac{P_1}{T_1} = \frac{101}{293} = 345$$

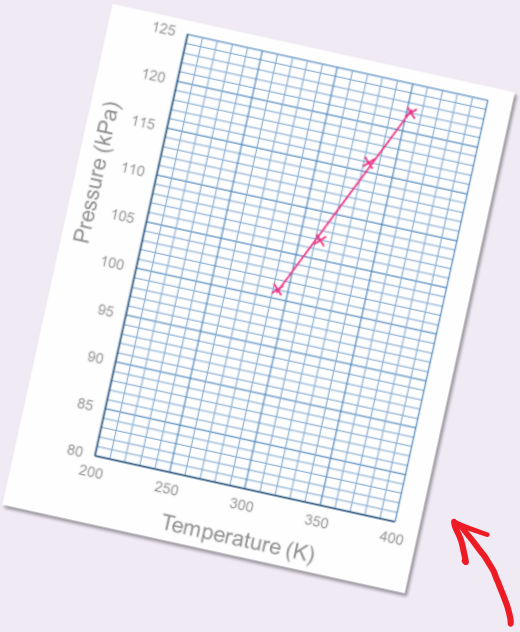
$$\frac{P_2}{T_2} = \frac{107}{313} = 342$$

$$\frac{P_3}{T_3} = \frac{116}{333} = 348$$

$$\frac{P_4}{T_4} = \frac{122}{353} = 346$$

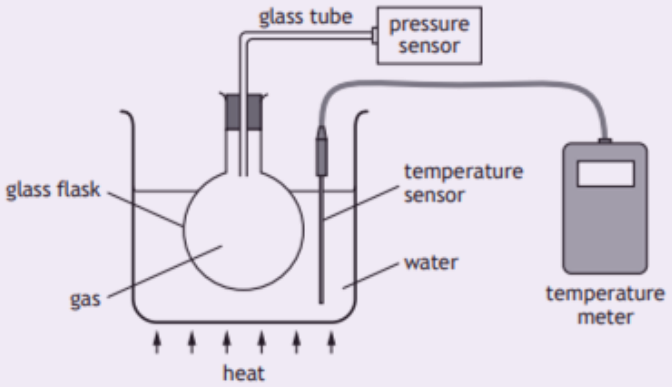
Because these values are all approximately equal one another you can say...

$$\frac{P}{T} = \text{constant}$$



Alternate method: a graph of the data can be plotted on graph paper, where you state the relationship, p is directly proportional to T .

b) **State** one way in which the set-up of the experiment (seen below) could be improved to give more reliable results. **Justify** your answer.



Have more of the flask under the water, so that the gas is at the same temperature.

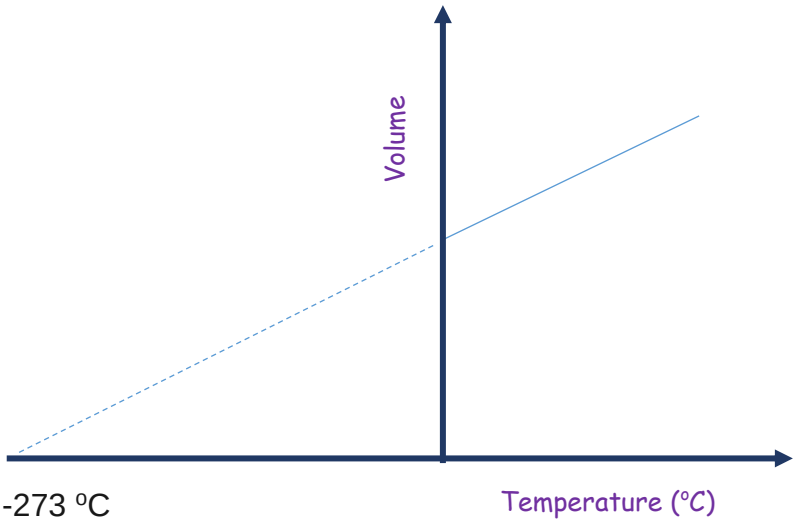
or

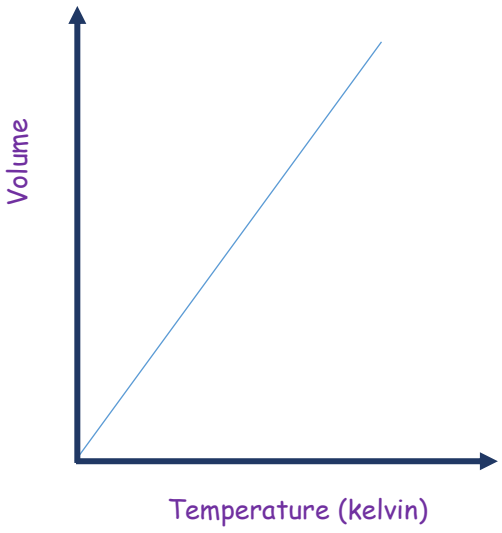
Place the temperature sensor in the flask so that the temperature of the gas is being measured

Volume and Temperature

If the temperature of a gas is increased, the kinetic energy and hence the speed of the particles of the gas increases. If the pressure is to remain constant, then the volume of the gas must increase to increase the area of the container walls that the increased force is acting on.

As the temperature increases the volume of the container increases:





If a graph is drawn of volume against temperature, in degrees Celsius, for a fixed mass of gas at a constant pressure, the graph is a straight line which **does not** pass through the origin.

When the graph is extended until the volume reaches zero, again it crosses the temperature axis at -273 °C.

If the graph of volume against temperature is drawn using the Kelvin temperature scale, the graph now goes through the origin.

This means, for a fixed mass of gas at a constant pressure, the volume of a gas is **directly proportional** to its temperature measured in Kelvin (K).

From this we can arrive at the relationship:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Where temperature **must** be in kelvin!

Ideal gas Law

So far we have the following three gas laws:

$$P_1 V_1 = P_2 V_2$$ - used if temperature is kept constant.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$ - used if volume is kept constant.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$ - used if pressure is kept constant.

In reality it is rare that pressure, temperature and volume can be kept constant.

In these situations, the combined gas law can be used.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Worked Example:

A balloon contains 1.5 m^3 of helium at a pressure of 100 kPa and a temperature of 27 °C. If the pressure is increased to 250 kPa at a temperature of 127 °C, **calculate** the new volume of the balloon.

$P_1 = 100\ kPa$

$V_1 = 1.5\ m^3$

$T_1 = 27\,°C = 300\ K$

$P_2 = 250\ kPa$

$V_2 = ?$

$T_2 = 127\,°C = 400\ K$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\frac{100 \times 1.5}{300} = \frac{250 \times V}{400}$$

$$V_2 = 0.8\ m^3$$