ATAR
Notes

QCE Physics Units 1&2
Complete Course Notes

2023–2025

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We acknowledge the Wurundjeri people of the Kulin nation as the traditional owners of the land on which this text was created. We pay our respects to Elders past, present, and future and acknowledge that this land we work on is, and always will be, Wurundjeri land.

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Preface

Hi everyone! My name is Elysia, and welcome to the 1&2 Physics Notes. Physics was one of my favourite subjects in Year 12 because it was so interesting, so I'm excited to take you through it!

In these Notes I explain everything in the simplest terms, because it took me *forever* to understand some of these concepts, so I know the pain! I also go through all of my tips for studying efficiently and staying motivated which you can take with you into Year 12. I'll also go through how to fulfil all of the QCAA criteria for your two assignments and how to study effectively for your data test and end-of-year exam.

But most importantly, my best advice, over any memorisation techniques or note-taking methods, is to **relax and believe in yourself.** And trust me, I am cringing as I write this but it's so true! I truly believe that what allowed me to do so well in Senior was that I believed so heavily in my ability to handle whatever came at me, which meant that I never had a negative association with school, didn't procrastinate, and didn't get stressed. Fit in practice questions and study where you can, have fun with it, and remember to look after yourself and enjoy life with your friends.

Good luck!

— Elysia

Contents

Part I

Unit 1: Thermal, nuclear, and electrical physics

Topic 1

Heating processes

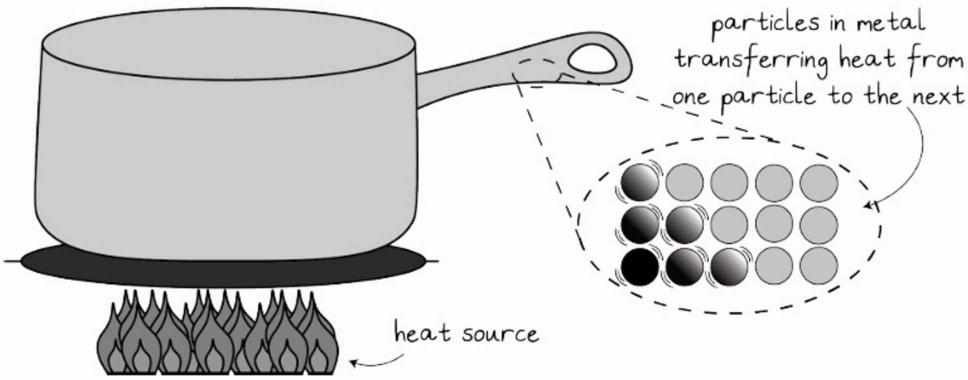
1.1 The kinetic particle model

Before we jump into concepts of heating, let's look at some key terms you'll need to be familiar with for this topic.

- **Kinetic energy** is the energy of moving particles. Anything that moves possesses kinetic energy.
- **Thermal energy** is the **total** kinetic energy in an object.
- **Internal energy** is the total energy in a system, including both kinetic and potential energy.
  - So, whilst thermal energy is the total *kinetic* energy in a system, internal energy includes *both* **kinetic** *and* **potential** energy in a system.
- **Temperature** is the **average** kinetic energy of the atoms making up an object.
- **Heat** is the transfer of kinetic energy between two systems of different temperatures. You commonly experience heat as a *feeling* – if you put your hand on a hotplate, the feeling you get is the kinetic energy being transferred from the hotter system (the hotplate) to the colder system (your hand). The hotplate *itself* does not have heat, despite its high temperature, because heat is a *process*. The hotplate has heat because it is near other objects which it transfers kinetic energy to such as your hand, the surrounding parts of the stove, and the air.
- **The kinetic particle model of matter** states that all matter is made up of tiny particles which are constantly moving.

1.1.1 Conduction

Conduction is the **heat transfer between objects** which are **touching each other.** Particles in the hotter object have more kinetic energy, and this kinetic energy is transferred to particles in the colder object.

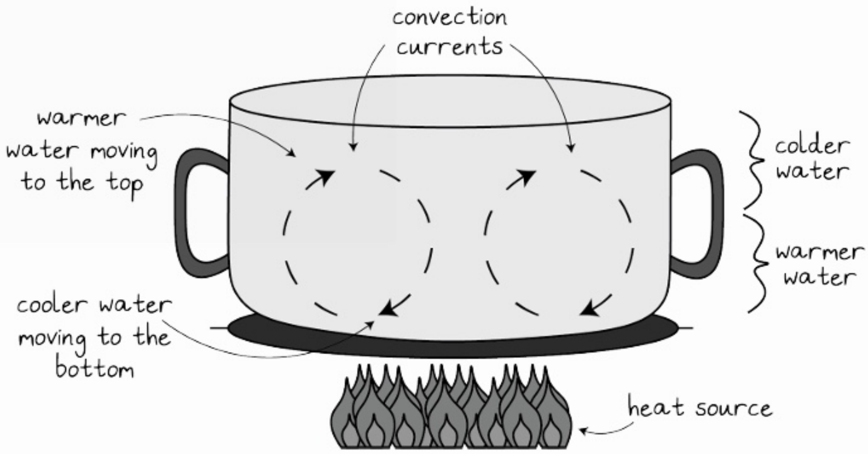


An example of this would be stirring a hot cup of tea with a cold spoon. The tea will heat the spoon up and the spoon will cool the tea down until both are the same temperature.

1.1.2 Convection

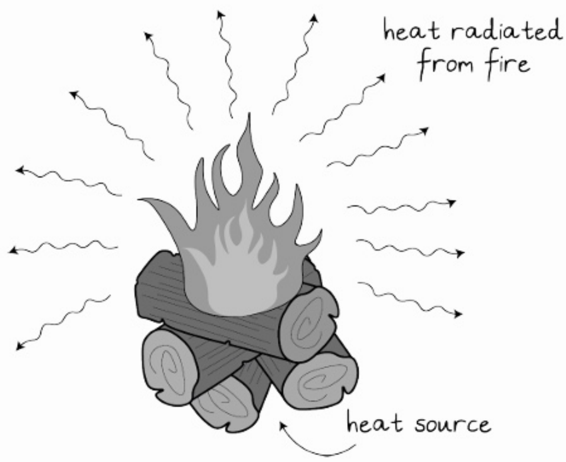
Convection is the **heat transfer via fluids** within a system. *Fluids* include any substance where particles are free to move around, so both **liquids** and **gases** but not solids. In everyday life we usually use *liquids* and *fluids* interchangeably, so I know this can get really confusing to include gases!

Convection occurs due to differences in density. Warmer fluids have a lower density. This is because particles in the warmer fluid have more kinetic energy, allowing them to overcome attraction to one another and move further away from one another (this is why materials increase in size when hot!). Less dense fluids rise up and denser fluids fall to the bottom. This is why hot air rises and water at the bottom of a pool is way colder than the surface.

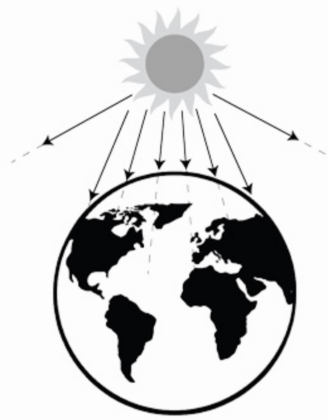


1.1.3 Radiation

Radiation is the **transfer of heat between objects that aren't directly touching.** This is done through **electromagnetic waves.** Since electromagnetic waves don't need a medium, neither does radiation. This means that radiation occurs in a **vacuum.**



For example, heat from the sun is transferred to your body via radiation. It travels through the vacuum of space via electromagnetic waves (visible light and infrared) into Earth's atmosphere and to the surface where it is either reflected or absorbed.
If you would like to understand more about electromagnetic waves, have a look at Unit 2 Topic 2 on page 35, where we go further into waves.



1.2 Understanding temperature

If you recall from the previous section, temperature is a measure of the average kinetic energy of a substance. This means that the more the particles are moving about, the higher the temperature. Therefore, if the **average kinetic energy** in a system changes, so will the temperature.

Temperature is sometimes measured in units called Kelvin. You can use the following formula to convert between Celsius and Kelvin.

$$T_K = T_C + 273$$

1.2.1 Specific heat capacity

Specific heat capacity is the amount of energy required to increase 1 kg of a substance by 1° C.

As an example, water has a specific heat capacity of 4,184 joules. This means that to heat up 1 kg of water by 1° C, you would need to use 4,184 joules of energy. This also means that if 1 kg of water decreases temperature by 1° C, then 4,184 joules would be released.

Key Point :
An important nuance of specific heat capacity is that it **does not apply during phase changes.** This is because during a phase change, energy added or removed does not change the temperature of the substance.

The following formula describes the energy used to change the temperature of a substance:

$$Q = mc\Delta T$$

where

Q	is energy (joules)
m	is mass (kg)
c	is specific heat capacity (joules)
ΔT	is change in temperature

This symbol Δ (called delta) means change. So you can't just use the temperature of a substance, you need to use the *change* in temperature! A typical way to do this is as follows.

$$\Delta T = T_{\text{final}} - T_{\text{initial}}$$

Key Point :
Since specific heat capacity does not apply during phase changes, you cannot use this formula if a phase change occurs.

1.2.2 Proportionality in specific heat capacity

The energy that is absorbed or released by a substance will be **proportional** to the change in temperature. You can see this by looking at the formula $Q = mc\Delta T$.

Suppose that you have a set mass of a particular substance. If you wanted to use the formula to make Q greater, you would need to increase ΔT.

Example 1.1
250 g of milk is heated up from 20° C to 27° C and 6,947.5 J of energy is used. What is the specific heat capacity of milk?

Here, we are given 250 g of milk; however, we need this value in kg. We need to convert this value so that our answer is correct.

$$\begin{aligned}
m &= 0.25\,\text{kg} \\
\Delta T &= T_{\text{final}} - T_{\text{initial}} \\
&= 27 - 20 \\
&= 7^{\circ}\text{C} \\
c &= ? \\
Q &= 6,947.5\,\text{J}
\end{aligned}$$

Then we can put our values into the formula:

$$\begin{aligned}
Q &= mc\Delta T \\
6,947.5 &= 0.25 \times c \times 7 \\
c &= \frac{6,947.5}{0.25 \times 7} \\
&= 3,970\ \text{J}
\end{aligned}$$

So, the specific heat capacity of milk 3,970 J.

Key Point :
Make sure you checked that the units were correct! The exams can sometimes include tricky content where you are given non-standard units. In this case you might forget to convert those units when you're under pressure during an exam.

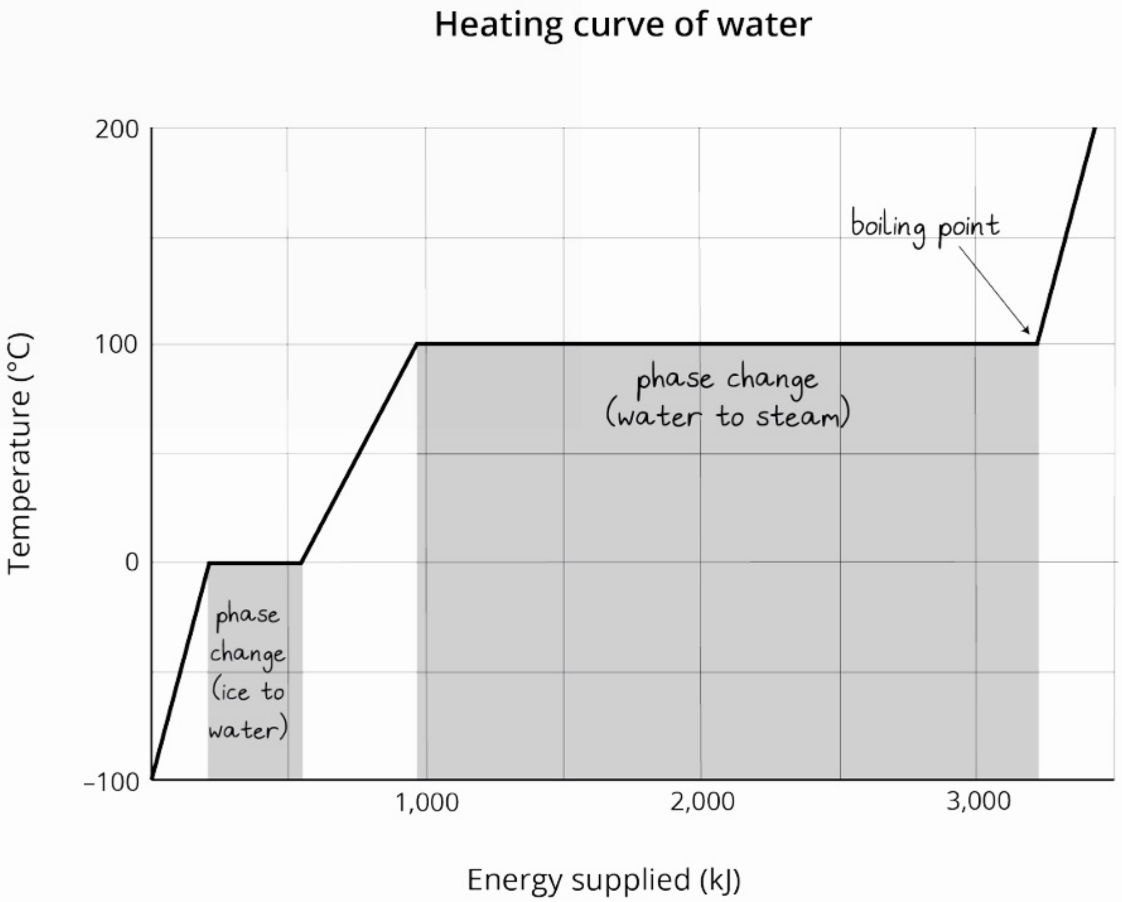
1.3 Phase changes

When there is a phase change, how the particles are held in the substance changes. For example, when a substance is melted from a solid to a liquid, the particles which were previously held in place by strong bonds become free to move about as those bonds are broken. Similarly, when a liquid is vaporised, the bonds holding the particles together are broken altogether, allowing particles to float about freely. If a substance is heated, bonds are broken. If a substance is cooled, bonds are snapped into place between particles.

The very act of changing these bonds actually requires energy. So the *internal energy* of the substance will be changing; however, the ***temperature* is not changing** because all of the added energy is going towards changing the bonds between particles.

1.3.1 Heating curve of water

Where the gradient is positive, there is no phase change occurring. This is because the temperature of the substance is *increasing* with the energy added, so the trendline goes *up*. However, when the **gradient is zero** or the curve is *flat*, there is a **phase change occurring.** This is because even though energy is being added, the temperature isn't changing.



Key Point :
It is very likely that you will see this graph on an exam or practice exam. So make sure that you practise questions on it!

1.3.2 Specific latent heat

Specific latent heat is the energy necessary to change the state of 1 kg of a substance *without* changing the temperature. This means that specific latent heat is used during phase changes, because phase changes occur when energy is added but the temperature doesn't increase.

There are two types of specific latent heat – latent heat of fusion and latent heat of vaporisation.

- **Latent heat of fusion** occurs when a substance changes between being a solid and a liquid.
- **Latent heat of vaporisation** occurs when a substance changes between being a liquid and a gas.

This is the equation you need to be able to use for specific latent heat.

$$Q = mL$$

where

Q	is energy (joules)
m	is mass (kg)
L	is specific latent heat

KEY POINT :
A typical complex exam question involves both formulas $Q = mc\Delta T$ and $Q = mL$. In this type of question you will be asked about the energy released or used when a substance undergoes heating between phase changes. For example, a question might ask the amount of energy released when 30° C water is changed into ice at 0° C.

Example 1.2
850 mL of water is at 90°C. How much energy is required for the water to become a gas at a temperature of 100°C?

Here, the water has been heated then undergone a phase change from a liquid to a gas. Remember how specific heat capacity only applies *in between* phase changes, whereas specific latent heat only applies *during* phase changes? We will therefore need to apply both.

First, we find how much energy is required to heat the water to 100°C. You will need to have a look at your QCAA formula sheet to find the specific heat capacity of water.

$$\begin{aligned} m &= 0.85 \text{ kg} \\ \Delta T &= T_{\text{final}} - T_{\text{initial}} \\ &= 100 - 90 \\ &= 10^\circ \text{ C} \\ c &= 4.18 \times 10^3 \end{aligned}$$

$$\begin{aligned} Q &= mc\Delta T \\ Q_1 &= 0.85 \times 4.18 \times 10^3 \times 10 \\ &= 35,530 \text{ J} \end{aligned}$$

Now we know how much energy is required to heat the water to 100°C, we need to find out how much energy is needed to change this water into a gas.

For this we will need to use the specific latent heat of vaporisation of water, which is on your QCAA formula sheet: $L = 2.26 \times 10^6$ J/kg.

$$\begin{aligned} Q &= mL \\ Q_2 &= 0.85 \times 2.26 \times 10^6 \\ &= 1.92 \times 10^6 \text{ J} \end{aligned}$$

The total energy needed is going to be the sum of our two values.

$$\begin{aligned} Q_{\text{total}} &= Q_1 + Q_2 \\ &= 35,530 + 1.92 \times 10^6 \\ &= 1.96 \times 10^6 \text{ J} \end{aligned}$$

So, we will need 1.96×10^6 J to heat our water and transform it into a gas.

KEY POINT :
Your QCAA formula sheet has the specific heat capacity of ice, water, and gas, and the latent heat for fusion and vaporisation for water. If you are asked a question involving water without being given these values, don't panic! You can just find them in your formula book.

1.3.3 Energy conservation

The **zeroth law of thermodynamics** states that if there are two systems of different temperatures in contact, energy will be transferred from the hotter substance to the colder substance until they both have the same temperature. This achieves **thermal equilibrium**, where two systems have the same temperature and therefore the same average kinetic energy.

Imagine putting a cold spoon in a hot cup of coffee. The particles of the coffee have a lot of kinetic energy and so will move around quickly and freely, bumping into the spoon particles and transferring kinetic energy. Particles in the spoon will start vibrating with more kinetic energy, which is transferred gradually to other particles in the spoon. Eventually, the handle of the spoon (which isn't in the coffee) will even be the same temperature! At this point, the coffee and spoon will be in thermal equilibrium.

Example 1.3
A 350 g metal cube is 50°C and placed into 500 mL of water at 20°C. The specific heat capacity of the metal is 400 J/kg/K. What will be the final temperature of the system? Explain why your answer is reasonable.

We know that the metal and water will come into thermal equilibrium.

Our final temperature will be T_f.

$$\begin{aligned} Q &= mc\Delta T \\ Q_{\text{metal}} &= 0.350 \times 400 \times (50 - T_f) \\ &= 140(50 - T_f) \end{aligned}$$

To find the energy lost for the water, find the specific heat capacity of water in your QCAA formula sheet. Because the water is going to heat up because the metal cube is hotter, $\Delta T = T_f - 20$ so that the change in temperature is positive.

$$\begin{aligned} Q_{\text{water}} &= 0.5 \times 4,180 \times (T_f - 20) \\ &= 2,090 \times (T_f - 20) \end{aligned}$$

We know from the law of conservation of energy, that the energy lost by the metal is going to be equal to the energy gained by the water.

$$\begin{aligned} Q_{\text{water}} &= Q_{\text{metal}} \\ 140\,(50 - T_f) &= 2,090 \times (T_f - 20) \\ 7,000 - 140T_f &= 2,090T_f - 41,800 \\ 7,000 + 41,800 &= 2,090T_f + 140T_f \\ T_f &= \frac{48,800}{2,230} \\ &= 21.88^\circ\,\text{C} \end{aligned}$$

This final temperature is not that high above the initial temperature of the water. This is because the metal has a far smaller specific heat capacity than water, so it didn't hold that much energy compared to the water. The metal also had a smaller mass than the water.

1.4 Energy in systems

1.4.1 Mechanical work

A system with thermal energy has the capacity to do mechanical work. Remember that thermal energy is the total kinetic energy of a system. So, the kinetic energy can be channelled into doing mechanical work.

The **first law of thermodynamics** states that the change in the internal energy of a system is equal to the sum of the change in energy from heating and the work done on or by a system. This means that energy cannot be created or destroyed – only transferred or altered in form. Mathematically, this means that the change in internal energy in a system (ΔU) is equal to the sum of the heat transfer (Q) and the work done on or by the system (W). This is expressed by the equation below:This is expressed by the equation below:

$$\Delta U = Q + W$$

where

ΔU	is the *change* in internal energy (J)
Q	is energy added or removed by heating (J)
W	is work (J)

The first law of thermodynamics is true due to the **law of conservation of energy.** This means that the change in internal energy of a system has to come from somewhere, and the energy from heat and work has to go somewhere. Therefore, the change in energy has to be equal to the energy added to the system!

1.4.2 Efficiency in heat transfers

Energy transfers and transformations in mechanical systems *always* result in a little bit of heat loss. This loss occurs due to heat being transferred to the surrounding environment, such as the container holding the system. As a result, some of the energy is not usable.

The **efficiency** of a heat transfer is the ratio of *useful* work to the energy expended. To determine the efficiency of a heat transfer, you will need to use the formula below, where η is the efficiency.

$$\eta = \frac{\text{energy output}}{\text{energy input}} \times 100\%$$

Example 1.4
You place a pot of soup on the stove. 721 J of energy is transferred from the stove and 536 J is transferred from the pot to the soup. What is the efficiency of the transfer? What happened to the remaining energy?

$$\begin{aligned}\eta &= \frac{\text{energy output}}{\text{energy input}} \times 100\% \\ &= \frac{536}{721} \times 100 \\ &= 74.34\%\end{aligned}$$

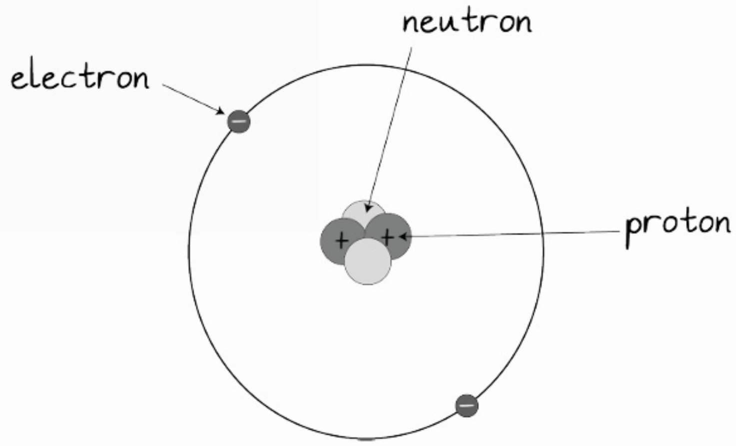
The energy transfer is 74.34% efficient. The remaining energy was lost to the surrounding air and to the pot itself.

Topic 2

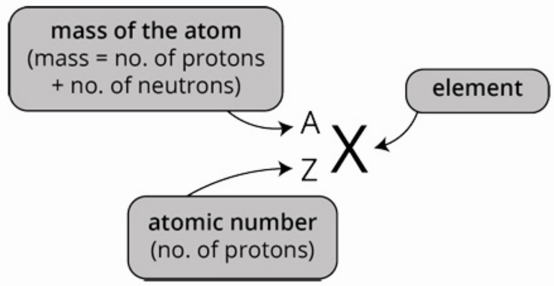
Ionising radiation and nuclear reactions

2.1 The nuclear model of the atom

The nuclear model of the atom is characterised by a small nucleus made of protons and neutrons, surrounded by orbiting electrons.



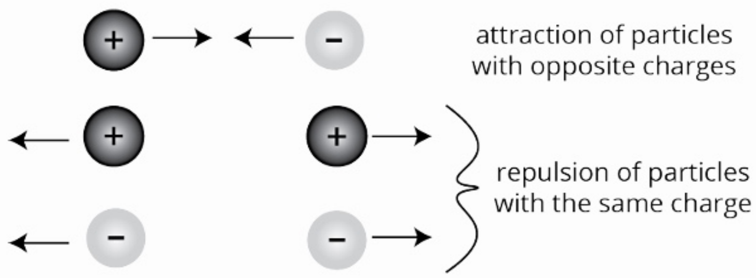
We represent an atom using this format:



The **mass of the atom** is the **sum of the number of protons and neutrons** because each of these have approximately one atomic mass unit (1 amu). You might wonder why electrons aren't included in the calculation of the mass – this is because they have a very small mass which is not worth counting for an approximate measure.

2.1.1 Strong nuclear force

You might have heard that opposites attract. This is true in physics too – opposite charges attract, and like charges repel. This is known as **electrostatic repulsion.**



The protons in the nucleus have a positive charge, meaning that they repel one another.

So, how does the nucleus stay together then? The answer is that the neutrally-charged neutrons are attracted to the protons due to the **strong nuclear force.**

The **strong nuclear force** is a force that attracts protons and neutrons. It acts only when the protons and neutrons are very close to one another, so it doesn't act over distances, but works well in the nucleus.

2.1.2 The stability of the nucleus

The stability of the nucleus depends on a few different factors. The strong nuclear force works to keep the protons and neutrons together, overwhelming the repulsive forces between protons as a result of electrostatic repulsion. This is why it's important to have a similar number of protons and neutrons to have a stable nucleus.

If, for example, the number of protons significantly outnumber that of neutrons, then the protons repelling will overwhelm their attraction to the neutrons.

When a nucleus is unstable, it will undergo **spontaneous decay** to revert to a more stable state.

2.1.3 Spontaneous decay

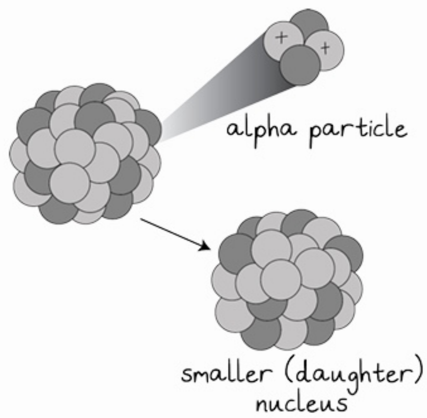
Natural radioactive decay occurs when the nucleus is unstable. The nucleus will often decay into smaller **daughter nuclei** and, sometimes, release a form of radiation. There are four types of radiation that can occur:

- Alpha decay
- Positive beta decay
- Negative beta decay
- Gamma decay

Alpha decay

In alpha decay, a nucleus will emit an **alpha particle.** This particle is made of two protons and two neutrons bound together, and is often represented as ${}^{4}_{2}\alpha$. Since an alpha particle is also a helium nucleus, it can also be represented as ${}^{4}_{2}He$ or He^{2+}. It has a positive charge and an atomic weight of 4 amu.

They are slow and heavy compared to some of the other forms of radiation we'll go through, and as such can be stopped by a mere sheet of paper.

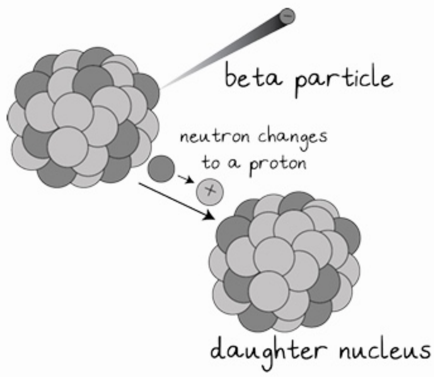


Beta decay

In beta decay, a nucleus emits a **beta particle.**

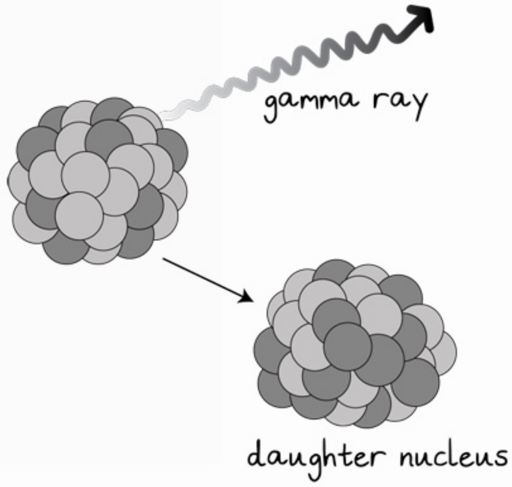
- **Beta positive decay** (β^{+}) occurs when a proton in a nucleus spontaneously becomes a neutron, causing a positron and a neutrino to be emitted. This is represented by ${}^{0}_{+1}\beta$.
- **Beta negative decay** (β^{-}) occurs when an electron is emitted from the nucleus when a neutron spontaneously becomes a proton, an electron, and an antineutrino. This is represented by ${}^{0}_{-1}\beta$.

Beta particles would require a sheet of aluminium to stop them.



Gamma decay

Gamma decay occurs when electromagnetic radiation is released from a decaying nucleus. This releases a **gamma ray** which travels at the speed of light, is neutrally charged, and has an atomic mass of 0. It is represented by ${}^0_0\gamma$ but is often written as just γ. It would take a slab of concrete to stop a gamma ray.



2.1.4 Equalising nuclear equations

Equalising nuclear equations is a process we use to express the reactants and the products of a reaction. The total atomic mass on the left-hand side (LHS) should be equal to the total atomic mass on the right-hand side (RHS). Similarly, the total number of protons on the LHS should be equal to that of the RHS.

$$^{238}_{92}\text{U} \longrightarrow {}^{234}_{90}\text{Th} + {}^{4}_{2}\text{He}^{2+} + \gamma$$

In this reaction, uranium decays into a daughter nucleus, an alpha particle, and a gamma ray. The number of protons on the LHS is equal to that of the RHS. Remember from the previous section that gamma radiation does not have atomic mass or protons, so will have a value of 0 below.

$$92 = 90 + 2 + 0$$

The same goes for the atomic mass:

$$238 = 234 + 4 + 0$$

We often use these equations for a few different purposes – to determine the products of a reaction, to determine the reactants knowing what the products are, and to determine if a particular reaction is possible.

Determining the products of a reaction

To determine the products of a reaction you can follow these steps:

1. Form equations equalising the atomic weight on both sides, and the atomic number on both sides.
2. Find what atomic number and atomic weight the product needs to have.
3. Look at the periodic table in your formula sheet, or remember the different types of decay, and match this to the atomic number.

KEY POINT :
If you are instead given the products of the reaction and asked to find the reactants, you can follow very similar steps.

Example 2.1
What is the product of the following reaction?

$$\mathrm{Pu}_{94}^{239} \longrightarrow X_Z^A + \mathrm{He}_2^4$$

First, equalise the LHS and RHS of the atomic weight and numbers:

$$\begin{aligned} 239 &= A + 4 \\ 94 &= Z + 2 \end{aligned}$$

Solve for the atomic weight and number of our unknown product:

$$\begin{aligned} A &= 235 \\ Z &= 92 \end{aligned}$$

Now we need to look at the periodic table to find a particle with the atomic number 92. This happens to be uranium. Therefore, ${}^{235}_{92}\mathrm{U}$ is our product.

2.1.5 Half-life

Half-life is the amount of **time it takes for an element to decay to half of its original amount.** So if half-life is smaller, it means that the element is very unstable, because it is decaying faster. This follows an exponential decay model, meaning that a lot of nuclei will decay in the beginning, but the rate of decay will decrease with time. The formula for half-life decay is:

$$N = N_0\left(\frac{1}{2}\right)^n$$

where

N	is the amount of substance remaining
N_0	is the initial amount of the substance
n	is the number of half-lives that have passed

Example 2.2
You find 8 uranium-238 atoms and are told that two half-lives have passed. How many atoms were there initially?

$$\begin{aligned} N &= N_0\left(\frac{1}{2}\right)^n \\ 8 &= N_0 \times \left(\frac{1}{2}\right)^2 \\ N_0 &= \frac{8}{\left(\frac{1}{2}\right)^2} = 32 \end{aligned}$$

There were 32 uranium-238 atoms initially.

Key Point :
For radioactive decay problems, you will likely never be asked to find *how many* half-lives have passed given the initial and final amount of a substance. This is because to do so requires the use of logarithms, which is a type of maths taught in Mathematical Methods but not General Mathematics.

2.2 Nuclear energy and mass defect

When studying nuclear energy, we generally use the unit electron volts. **Electron volts** are a unit of energy which is equivalent the amount of charge on an electron. The conversion is given in your QCAA formula book as:

$$1\ \text{eV} = 1.6 \times 10^{-19}\text{J}$$

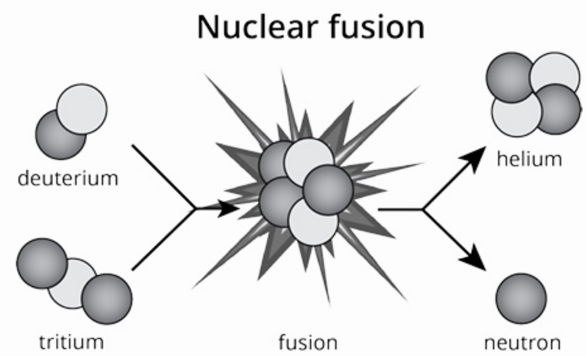
2.2.1 Artificial transmutation

Artificial transmutation is the process of **firing a particle at an isotope** to change the isotope into a different element.

Artificial transmutation is distinct from natural radioactive decay, which was discussed in the last section. The change from one element to another is not due to the instability of the nuclei, but due to the intentional bombardment with a smaller particle.

2.2.2 Nuclear fission and fusion

Nuclear fusion is when multiple nuclei collide and mash into one bigger particle, sometimes releasing subatomic particles and energy in the process.

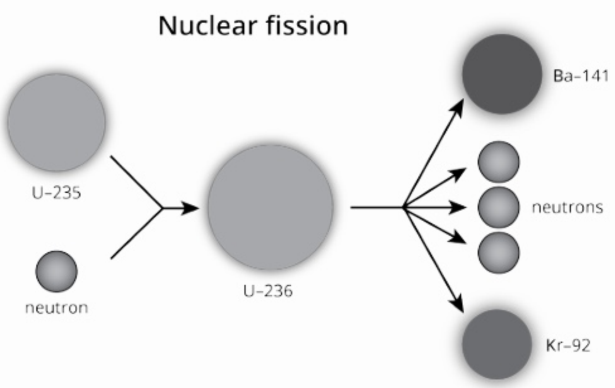


You should also be able to represent fusion reactions in equation form.
For example, for this reaction:

$${}^{2}_{1}\text{H} + {}^{3}_{1}\text{H} \longrightarrow {}^{4}_{2}\text{He} + {}^{1}_{0}n + \text{energy}$$

Nuclear fission is when a large unstable particle splits apart into multiple smaller and more stable particles, sometimes releasing subatomic particles and energy.

Fission can occur spontaneously due to the instability of the nucleus. It can also occur as a result of the collision of a nucleus and a neutron, as the neutron causes the nuclei to become unstable and split. The second scenario is shown here.



To represent the above reaction, the following equation would be used:

$${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \longrightarrow {}^{141}_{56}\text{Ba} + {}^{92}_{36}\text{Kr} + 3{}^{1}_{0}\text{n} + \text{energy}$$

Fission chain reactions occur when the products of a fission reaction cause *another* fission. This might happen if neutrons produced by a fission collide with other nuclei in the surrounding area, causing them to become unstable and thus split.

2.2.3 Mass and energy

Mass defect is the difference in the mass of a nucleus. This difference comes from looking at what the mass *should be* when adding the mass of the protons and neutrons compared to the actual mass. Therefore, the actual mass is less than what we would predict it to be. So where did this mass go?

Binding energy is the energy used to bind a nucleus together. When a nucleus is formed, some of the mass of the nuclides is converted into binding energy – accounting for the mass defect!

The **energy–mass equivalence** formula tells us how to convert the mass defect to binding energy.

$$\Delta E = mc^2$$

where

ΔE	is change in energy (J)
m	is mass (kg)
c	is the speed of light (3×10^8 m/s)

> **KEY POINT :**
> In the equation for energy–mass equivalence, mass needs to be in kg. If a question gives you mass in amu, the conversion is 1 amu = 1.66×10^{-27} kg. This is also given on your QCAA formula sheet.

To find the binding energy of an atom, we need to determine the mass defect and plug this into our energy–mass equivalence formula. This will tell us the amount of energy that mass is equivalent to.

$$\text{Mass defect} = m_{\text{predicted}} - m_{\text{actual}}$$

If you aren't given the predicted mass in the question, you can calculate it like this:

$$m_{\text{predicted}} = \text{no. protons} \times m_p + \text{no. neutrons} \times m_n$$

- mass of a proton: $m_p = 1.6726219 \times 10^{-27}$ kg
- mass of a neutron: $m_n = 1.6749275 \times 10^{-27}$ kg

These values for the mass of a proton and the mass of a neutron are provided on your formula sheet, so don't stress about remembering them!

Topic 3

Electrical circuits

3.1 Current, potential difference, and energy flow

3.1.1 Electric charge

Electric charge can be positive or negative. An electron has one negative charge and a proton has one positive charge.

This charge only comes in 'discrete' packages. This means that charge comes only in whole packages – you will never get half of a positive charge, or 1.5 of a negative charge. You will only ever get one positive or one negative charge.

Charge cannot be created nor destroyed, only transferred. This is known as the **law of conservation of electric charge.** Charge is conserved at all points in an electrical circuit because there is no way for electric charge to be used or diminished in the same way as values such as current or power. Rather, current is a property inherent to the electrons.

3.1.2 Electrical circuits

Variable	Symbol	Units	Definition	Formula
Charge	Q	Coulombs (written as C)	A property inherent to subatomic particles which causes them to be affected by electric fields.	–
Current	I	Amperes (written as A)	The amount of charge that passes a point per second.	$I = \frac{q}{t}$
Potential difference or voltage	V	Volts (written as V)	The amount of energy that a charge carries.	$V = \frac{W}{q}$
Power	P	Watts (written as W)	The amount of work done over a period of time.	$P = \frac{W}{t} = VI$

Current is a measure of how many electrons are passing through a point (i.e. how much *charge*). A high current implies that there is a massive sea of electrons passing through a point in a wire, or that the electrons are moving very fast past a point. However, current does *not* imply the amount of energy that each of these electrons carries.

What does measure this is the **voltage** or **potential difference.** Think of potential difference similarly to gravity – the higher an object is above the ground, the greater potential difference it has. It has a greater ability to do work, or it will generate more energy when it falls. So an electron with a high potential difference can generate more energy.

It is important here to note that electric charge and potential difference are *not the same thing.* **Electric charge** is a **property inherent to electrons** and protons, but **potential difference** is the amount of ***work* that an electron can do.** You can have two massive pools of electrons, one with low potential difference and one with high potential difference. Since both pools have the same number of electrons, they both have the same charge. However the pool with greater potential difference will power a lightbulb for far longer than the other pool.

Power is the amount of work done per second. This is why $P = VI$ (or power = voltage × current). If there is a high current (a lot of electrons passing per second) and a high voltage (each of these electrons carry a lot of energy) then a lot of work will be done in a short period of time.

> **KEY POINT :**
> You can think about these variables like a water tank. Charge is the volume of water in the tank, voltage is the water pressure, and current is the water flow.

Example 3.1

10 J of energy is carried by 2 C of charge. The current is 5 A. What is the power?

We know that $P = VI$, and we are given current, so we need to find voltage before we can calculate power.

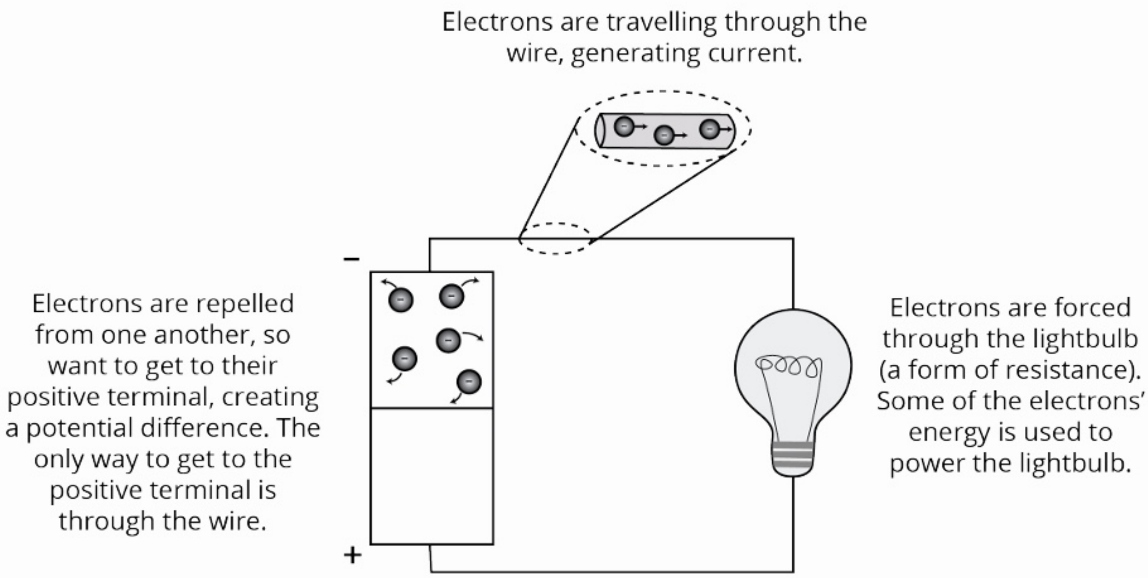
$$\begin{aligned} V &= \frac{W}{q} \\ V &= \frac{10}{2} \\ &= 5\text{ V} \end{aligned}$$

Now we need to find power.

$$\begin{aligned} P &= VI \\ &= 5 \times 5 \\ &= 25\text{ W} \end{aligned}$$

3.1.3 Electric potential difference in batteries

Electric charge separation is where there is a concentration of electrons in one place and a lack of electrons in another. A good example of this is a battery. The negative terminal has a lot of electrons and the positive terminal has an absence of electrons. You might have heard that opposites attract. For electric charge, opposites attract and charges that are the same repel. This is referred to as **electrostatic repulsion.** Where there is separation of electric charge, the electrons are attracted to the place with an absence of electrons, and the electrons are repelled from one another. Hence, in a battery, the electrons will move to get to the positive terminal and to get away from each other.



The diagram here shows how these values are incorporated in a battery. Note that **this is not how you will be asked to represent circuits,** the visuals used are merely to help you understand what's happening. We will discuss how you need to represent circuits later on.

3.1.4 Kirchhoff's voltage law

Kirchhoff's voltage law states that the sum of all voltages across the circuit must equal the sum of all the voltages across other components.

Example 3.2

If 120 C of charge passes through a point in an electrical circuit in one minute, what is the current at that point?

Here we need to apply our basic formula given in the previous table.

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

Remember that charge is measured in coulombs and time is measured in seconds, so we may need to adjust our given information accordingly. In this case, we need to adjust our time into seconds.

$$\begin{aligned} I &= \frac{120}{60} \\ &= 2\text{ A} \end{aligned}$$

So the current is 2 amperes at this point.

3.2 Resistance

Resistance in an electrical circuit is how much voltage is applied per charge.

To calculate resistance, we use **Ohm's law**:

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

where

V	voltage (V)
I	current (A)
R	resistance (Ω)

The units for resistance are Ohms, which are written as Ω.

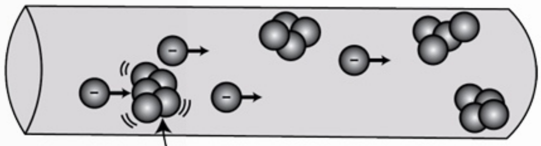
Example 3.3

5 C of charge runs through a resistor of 2 Ω. What is the voltage across the resistor?

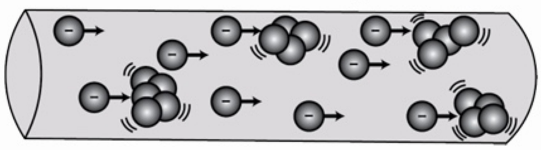
$$\begin{aligned} V &= IR \\ &= 5 \times 2 \\ &= 10\text{ V} \end{aligned}$$

3.2.1 What causes resistance?

Resistance through transmission occurs because the electrons bump into the atoms in the conductor, losing kinetic energy. The atoms in the conductor now have more kinetic energy – this is why conducting wires get hot!



If current is increased, so will resistance, because there are so many electrons stuffed into the conductor that they will bump into the atoms more.



3.2.2 Ohmic and non-Ohmic resistors

Ohmic resistors are resistors that follow Ohm's law. **Non-ohmic resistors** are resistors that don't follow Ohm's law. You can tell if a resistor follows Ohm's law or not from a graph of voltage and current.

Since Ohm's law predicts a *positive linear relationship* between voltage and current, an Ohmic resistor will show a straight line with a positive gradient. However a curved graph shows a non-Ohmic resistor.

3.2.3 Voltage–current graphs

You need to know how to interpret a graph of voltage and current to determine the resistance:

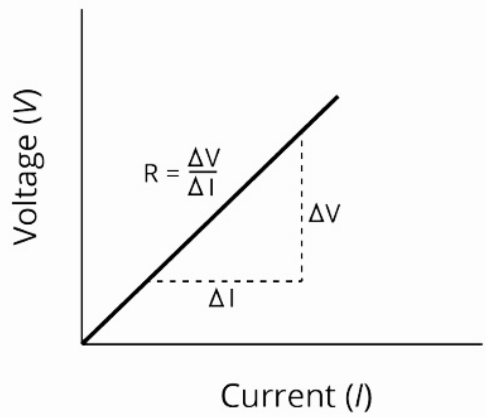
$$m = \frac{\Delta y}{\Delta x}$$

V is on the y-axis and I is on the x-axis, so this means that the gradient of this line is given as:

$$m = \frac{\Delta V}{\Delta I}$$

Ohm's law is:

$$\begin{aligned} R &= \frac{V}{I} \\ \therefore m &= R \end{aligned}$$



KEY POINT :
The gradient of a voltage–current graph is the resistance.

If anything about gradient feels unfamiliar to you, have a look at the tips on page 47 to go more in depth into analysing graphs in general.

3.3 Circuit analysis

Power dissipation is the rate at which the power of a transmission is reduced across a circuit due to resistors. It can be calculated by

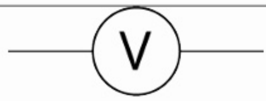
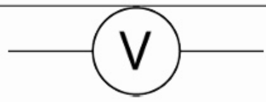
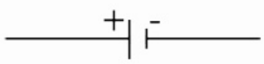
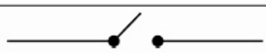
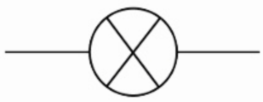
$$P_{\text{lost}} = I^2 R$$

where

P_{lost}	is power dissipation
R	is resistance (Ω)
I	is current (A)

3.3.1 Circuit diagrams

Circuits are represented in diagrams with symbols for each element. These are depicted in the following table.

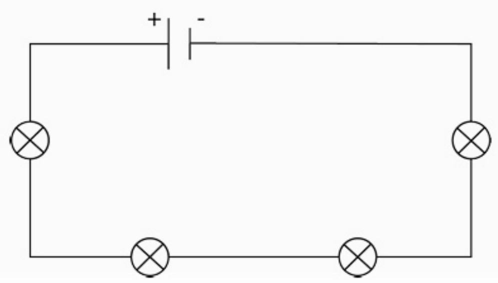
Element	Symbol
Resistor	
Voltmeter	
Ammeter	
Cell	
Battery	
Switch	
Bulb	

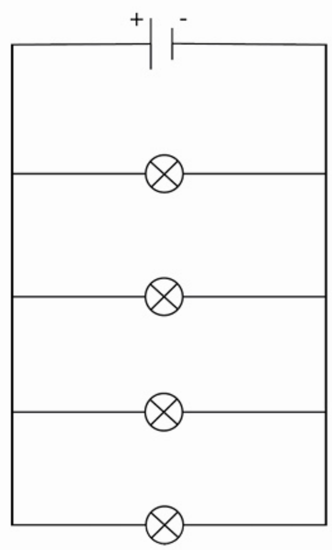
3.3.2 Series and parallel circuits

Series circuits are components placed **one after the other,** so that current must **flow through *all* of the components** to complete the circuit.

Parallel components are components placed **next to one another,** so that the current **splits evenly to go through one or the other component.**

Series	Parallel





3.3.3 Solving problems involving parallel and series circuits

The following equations are used to determine the total voltage, resistance, and current over a circuit.

	Series circuit	Parallel circuit
Total voltage	$V_t = V_1 + V_2 + \cdots + V_n$	$V_1 = V_2 = V_n$
Current	$I_1 = I_2 = I_n$	$I_t = I_1 + I_2 + \cdots + I_n$
Resistance	$R_t = R_1 + R_2 + \cdots + R_n$	$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$

Example 3.4
Two resistors are connected in series, with respective resistances of 2 Ω and 3 Ω. The potential difference of the circuit is 30 V. What is the current across the circuit? What is the voltage across each of the separate resistors? What is the current across each separate resistor?

Remember that with series circuits, the resistance is added. So, our total resistance across the circuit will be:

$$R_t = R_1 + R_2 + \cdots + R_n$$

$$R_t = 3 + 2 = 6$$

We need to find current, so think of an equation which involves current, and the two values we were given: resistance and potential difference. This is Ohm's law!

$$\begin{aligned} V &= IR \\ &= \frac{V}{R} \\ &= \frac{30}{5} \\ &= 6 \text{ A} \end{aligned}$$

Therefore, the current across the circuit is 6 A.

Now we need to find the voltage across each separate resistor, we need to apply Ohm's law again, but with the resistance of each resistor.

Resistor 1:

$$V = IR = 6 \times 2 = 12 \text{ V}$$

Resistor 2:

$$V = IR = 6 \times 3 = 18 \text{ V}$$

You might notice that the voltage across each resistor adds to the total voltage around the circuit! This is because $V_t = V_1 + V_2 + \cdots + V_n$.

To determine the current across each resistor, recall the equation describing current across series circuits.

$$I_1 = I_2 = I_n$$

So, the current across each resistor will be 6 A.

Example 3.5

Two resistors are parallel in a circuit, with resistances of 5Ω and 8 Ω respectively. If the total current across the circuit is 20 A, what is the potential difference across each of the individual resistors?

Here we know that we can find the total resistance using the formula for resistance in a parallel circuit.

$$\begin{aligned} \frac{1}{R_t} &= \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}\frac{1}{R_t} \\ &= \frac{1}{5} + \frac{1}{8}\frac{1}{R_t} \\ R_t &= \frac{1}{0.325} \\ &\approx 3.08\ \Omega \end{aligned}$$

Now that we have the total resistance, we can use this to find the potential difference. Remember that in a parallel circuit, the voltage is split evenly across each component:

$$V_1 = V_2 = V_n$$

So, we will use Ohm's law to find voltage.

$$\begin{aligned} V &= IR \\ &= 3.08 \times 20 \\ &= 61.6 \text{ V} \end{aligned}$$

The voltage across both resistors is going to be 61.6 V.

Part II

Unit 2: Linear motion and waves

Topic 1

Linear motion and force

1.1 Vectors

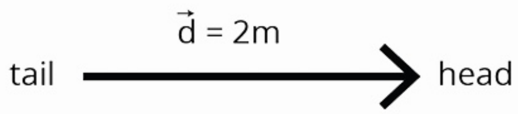
1.1.1 Understanding vectors

Scalar quantities are values with **magnitude only**, whereas **vector quantities** have **magnitude *and* direction.**

Scalar quantities	Vector quantities
Speed, such as 5 ms^{-1}	Velocity, such as 5 ms^{-1} north
Distance, such as 3 m	Displacement, such as 3 m at 30° to the horizontal
Mass, such as 2 kg	Weight, such as 2 N downwards
Rate of change of speed, such as 5 ms^{-2}	Acceleration, such as 5 ms^{-2} upwards
Voltage	Force

Key Point :
When doing calculations, please remember to give direction for scalar quantities! To know if a quantity is scalar or vector, you can use this rule. If you multiply or divide two scalar quantities, you will have a resulting scalar quantity. However, if you multiply or divide a scalar and vector quantity, or two vector quantities, you will be left with a vector quantity.

Vectors can be represented through either a line with an arrow, or with accents. For example, a force vector could be represented as $\tilde{F}$ or $\overrightarrow{F}$.



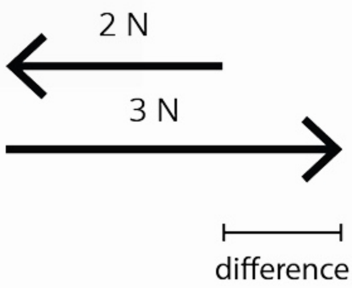
For the vector shown above, the actual *length* of the line represents the magnitude and the angle represents the direction. So this vector represents *2 m to the right.* The arrow is called the ***head*** of the vector and the other end is called the ***tail.***

1.1.2 Using vectors

To add two vectors, you need to place them *head to tail* and add the magnitudes. To subtract two vectors, you need to place them head to tail and subtract the magnitudes.

Example 1.1
Subtract the following force vectors.

Here we need to place them head to tail and subtract the magnitudes, remembering to leave the resulting direction correctly.



$$\text{magnitude} = 3 - 2 = 1$$

So our resulting vector is 1 N to the right.

> **KEY POINT :**
> The vector addition and subtraction we do here will get more complex in Year 12 when you learn about electromagnetism. Practise finding the magnitude of a resulting vector, then conceptualising the direction in your head.

1.2 Linear motion

1.2.1 Basic concepts of linear motion

Displacement is the net difference between an initial and final position. So if you walk around an oval, starting and finishing in the same place, your displacement will be 0 *even though* your distance travelled could be 200 m. Your *net position* hasn't changed!

Velocity is the rate of change of displacement, or in other words, the speed of travel in a particular direction.

Acceleration is the rate of change of velocity. So accelerating means that you are speeding up. It also means that if your acceleration is zero, you could still be moving very fast, but just at a constant velocity.

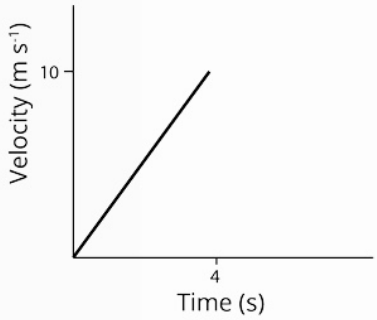
Instantaneous velocity is the velocity at a *particular moment.*

Average velocity is the average velocity over a period of time, often described by the following equation.

$$v_{\text{average}} = \frac{\text{displacement}}{\text{time}}$$

> **KEY POINT :**
> The area underneath a velocity–time graph will give us the displacement.

Example 1.2
A ball rolls down an inclined plane. Its velocity is modelled on the graph below. Determine the distance travelled over the 4 seconds and then find the acceleration of the ball.



The distance is going to be the area underneath the graph. See how the function forms a triangle with the horizontal axis? We can therefore find the area of a triangle, where the base is 4 and the height is 10.

$$\begin{aligned} A &= \frac{1}{2}bh \\ &= \frac{1}{2} \times 4 \times 10 \\ &= 20 \text{ m} \end{aligned}$$

The acceleration is the gradient of the curve, since $a = \frac{v}{t}$.

To find the gradient of the curve, we need to use the gradient equation.

$$\begin{aligned} m &= \frac{\Delta y}{\Delta x} \\ &= \frac{10}{4} \\ &= 2.5 \text{ m s}^{-2} \end{aligned}$$

1.2.2 Solving linear motion problems

When solving linear motion problems, you have multiple equations available to you and it can often be hard to know which equation to use. It's helpful to write out all the information you're given and the value you need to find, especially when you need to combine the use of multiple equations. These equations are given below:

$$\begin{aligned} v &= u + at \\ s &= ut + \frac{1}{2}at^2 \\ v^2 &= u^2 + 2as \end{aligned}$$

where

v	is final velocity (m/s)
u	is initial velocity (m/s)
s	is displacement (m)
a	is acceleration (m/s/s)
t	is time (s)

Example 1.3

A ball is dropped from a cliff. When the ball hits the ground, it has a velocity of 17 m/s. How high is the cliff?

We can assume that the initial velocity is 0, because the ball is "dropped". We know that the acceleration acting on the ball is acceleration due to gravity.

Let's write out the information we know and the value we need to find.

$$\begin{aligned} 17u &= 0 \text{ m/s} \\ v &= 17 \text{ m/s} \\ a &= -9.8 \text{ m/s} \\ s &= ? \end{aligned}$$

The following equation uses all the values we were given:

$$\begin{aligned} v^2 &= u^2 + 2as \\ 17^2 &= 0^2 + 2 \times -9.8 \times s \\ s &= -14.74 \text{ m} \end{aligned}$$

This tells us that the ball's displacement is –14.74 m, so it has fallen this far. However the height of the cliff is 14.74 m, because height is a scalar quantity.

1.3 Newton's laws of motion

1. **Newton's first law:** a body will remain in its state unless acted on by an external, unbalanced force.
2. **Newton's second law:** if a force is applied to an object, the object will accelerate in the same direction, proportionately to its mass. This is expressed by the formula:

$$F = ma$$

   where

   F is force (N)

   m is mass (kg)

   a is acceleration (m/s/s)

3. **Newton's third law:** every action has an equal and opposite reaction.
   Let's consider a scenario to help us understand these laws. When floating around in space, astronauts are often tethered to their spaceship. When they attempt to enter back into their spaceship, they come across a problem. Every time they touch the spaceship, they bounce off. So if forces occur in equal and opposite pairs, why does the astronaut bounce off so dramatically but nothing happens to the spaceship?
   The spaceship will apply an equal and opposite force back onto the astronaut. When the astronaut applies force to the spaceship, it only moves away a *tiny* bit because it has so much mass. However, the astronaut has a lot less mass than the spaceship, meaning it requires far less force to move. So even though the force applied to the spaceship and the force applied to the astronaut are equal, the astronaut has a far greater consequence because he is much smaller.

Example 1.4

A force of 30 N is experienced by a magnet in a magnetic field. It moves with an acceleration of 2.5 ms^{-2}. *What is the mass of the magnet?*

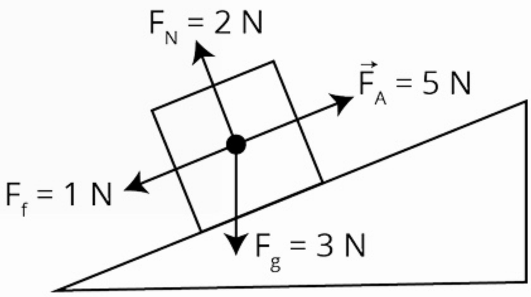
$$\begin{aligned} F &= ma \\ 30 &= m \times 2.5 \\ m &= 12 \text{ kg} \end{aligned}$$

1.3.1 Free body diagrams

In a free body diagram:

- Forces are represented as **vectors,** drawn from the centre of a box.
- **Friction forces** (F_f) always act in the direction exactly ***opposite* to** that of an applied force (F_A).
- **Normal force** (F_N) always acts **perpendicular** to the surface that an object is on. *Perpendicular* means *at a right angle to.*
- **Force due to gravity** (F_g) always acts directly **downwards,** regardless of the orientation of the surface which the object lies on.

The diagram below is a free body diagram of a box being pulled up a ramp.



Have a think about what's happening here. The applied force is greater than the friction. This means that the box will be moving up the ramp because the forces aren't balanced. The normal force is perpendicular to the surface that the object is on, and the force of gravity is acting directly downwards, meaning the box stays on the surface of the ramp.

1.3.2 Momentum

Momentum is mass in motion. You can think about this as how hard it is to stop an object from moving.

$$\rho = mv$$

where

ρ	is momentum (N s)
m	is mass (kg)
v	is velocity (m/s)

Impulse is the change in momentum of an object.

$$\Delta\rho = Ft$$

where

$\Delta\rho$	is impulse (N s)
F	is force (N)
t	is elapsed time (s)

Key Point :
The area underneath a graph of force over time will tell us the impulse over that time!

Example 1.5

A 1 tonne car crashes into a wall with a velocity of 20 m/s. What is the impulse?

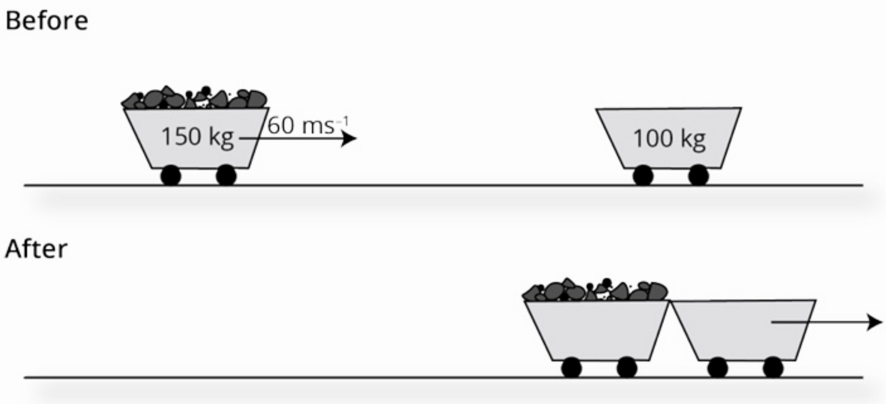
$$\begin{aligned} \rho &= mv \\ &= 1,000 \times 20 \\ &= 20,000 \text{ N s} \end{aligned}$$

Conservation of momentum

In a closed system, the momentum before a collision between objects is equal to the momentum afterwards.

$$\sum mv_{before} = \sum mv_{after}$$

In the formula, $\sum$ represents the *sum of.* So the sum of the momentum of all the objects before a collision will be equal to that of afterwards.



The momentum of the system is conserved because the cart initially in motion *transfers* energy to the stationary cart.

Example 1.6

Ball A is 2 kg and travels at 5 m/s. It hits Ball B, which was stationary before the collision. The resulting velocities of the two balls are 3 m/s. What is the mass of Ball B?

Here we need to use the law of conservation of momentum, because we're given information about before and after a collision.

$$\sum mv_{before} = \sum mv_{after}$$

We'll make this into something more useful by including the momentum of both Ball A and Ball B, and the initial velocity u and final velocity v for each.

$$\begin{aligned} m_A u_A + m_B u_B &= m_A v_A + m_B v_B \\ 2 \times 5 + m_B \times 0 &= 2 \times 3 + m_B \times 3 \\ 3m_B &= 4 \\ m_B &= 1.3 \text{ kg} \end{aligned}$$

1.4 Energy

Mechanical work is the application of force using energy. When you push a box along a table, you apply force using energy to move it.

To calculate the work done on an object, we can determine the change in energy (e.g. kinetic energy) or the displacement multiplied by the force component acting parallel to the displacement.

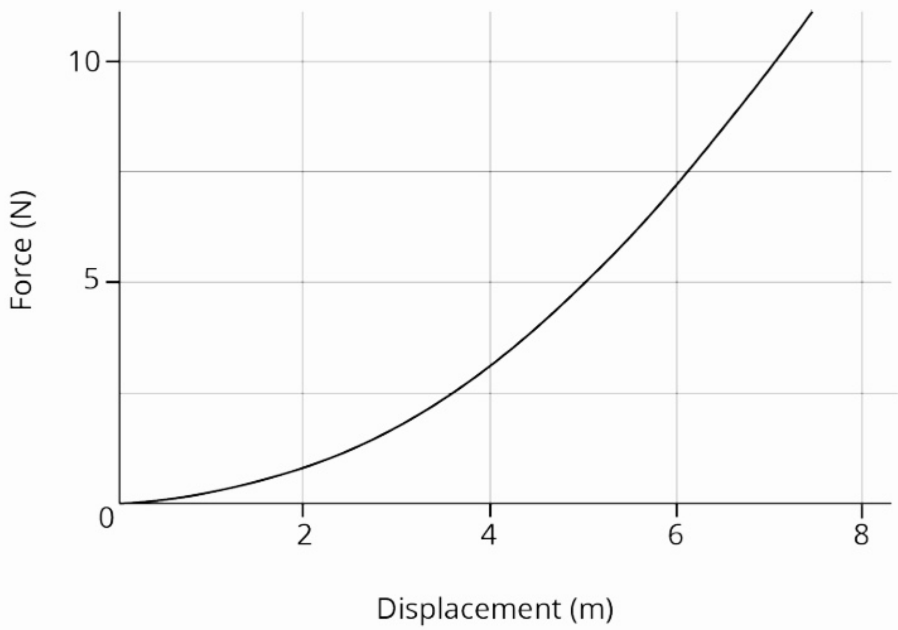
$$W = \Delta E$$
$$W = Fs$$

where

W	is work (J)
ΔE	is change in energy (J)
F	is force (N)
s	is displacement (m)

If the force is non-constant, then the work done is found by estimating the area under a **force–time graph.**

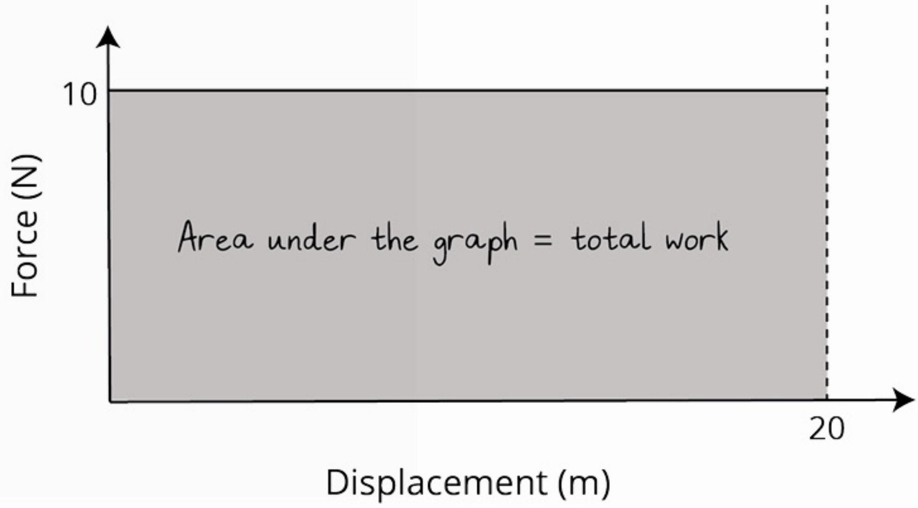
Work is known as the product of force and distance, where the force vector in the formula is being applied in the same direction as the displacement of the object. However, it is crucial to understand that work is also the area under a force–displacement graph. Force is usually on the y-axis, measured in Newtons, and distance is on the x-axis, measured in metres. The units have to be Newtons and metres. If not, then you have to convert them yourself.



1.4.1 Using graphs to determine work

Graphs can also be used to find the total work done by an object or energy transformation since work is the change in energy of an object. The graph must be a force–distance graph. No matter the kind of force, its units have to be in Newtons (N) and the distance has to be in metres (m). When looking at one of these graphs we can use the area under the curve to find the total work in joules.

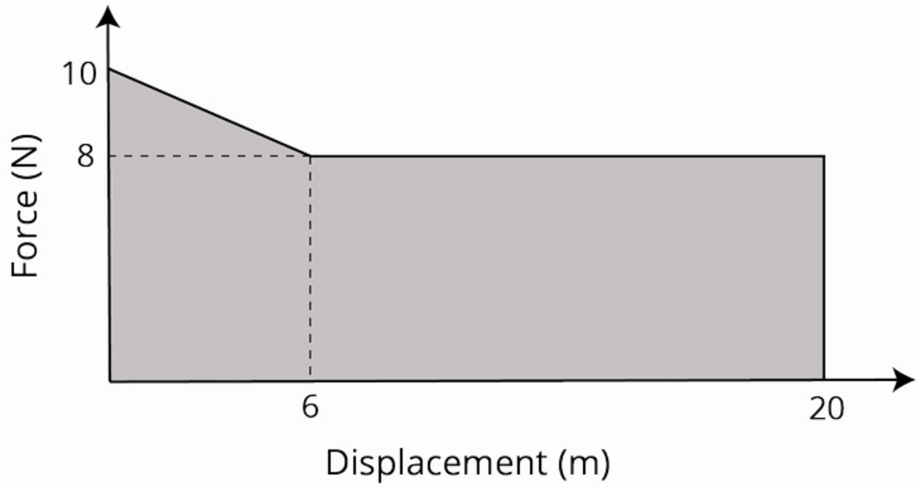
The following graph shows a very simple force–displacement graph where something is being displaced to 20 m with a constant force of 10 N. Since work is the force applied over a certain distance, we can see how the area under a force–distance graph would give us the total work done.



Calculating the work done in the above graph would be fairly simple, however there are two different ways you can calculate area for harder graphs in Physics.

Using shapes

You may find it easiest to choose to separate the graph into different geometric shapes and use the respective formulas to find the area of each shape. Then simply add these together to find the total area. Let's consider the following force–distance graph:



There are two ways you could find the area under this graph: you could calculate the area of the trapezium and the rectangle and add them together. Or, if you've forgotten the formula for a trapezium, you could calculate the area of the triangle and the rectangle to the get the total area. Either way would provide the correct answer.

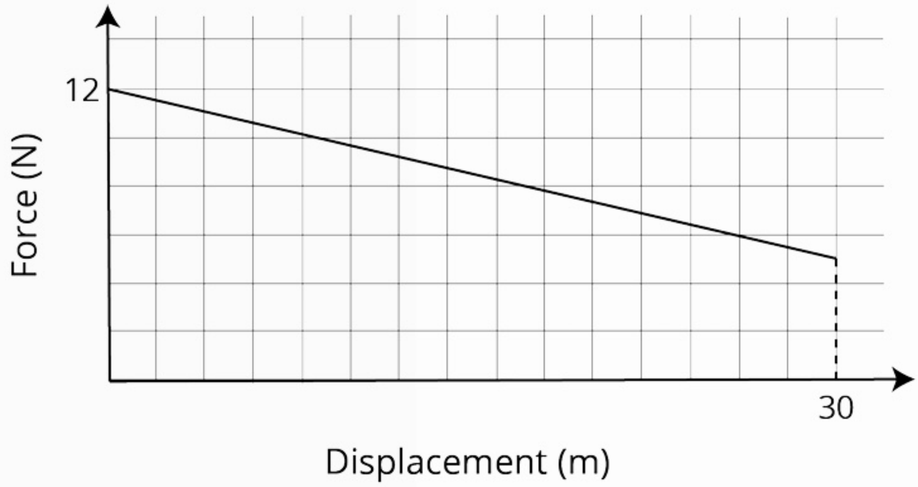
So, for the above graph we could do:

- $\left(\frac{1}{2}h(a+b)\right) + (lh) = \left(\frac{1}{2} \times 6(8+10)\right) + (14 \times 8) = 166$
- $\left(\frac{1}{2}bh\right) + (lh) = \left(\frac{1}{2} \times 2 \times 6\right) + (20 \times 8) = 166$

So, the total work done is 166 joules.

Counting squares

Alternatively, you can choose to calculate the number of squares within the shaded region of the graph and multiply by the area of one square. Consider the following graph:



One square on this graph is equivalent to four, so we can just calculate the number of squares to equal the area then times by four to arrive at the correct answer. Using the counting squares method, you should find the area to be approximately 252. However, using the shapes method the area is exactly 255.

This method is certainly more likely to produce error than if you chose to calculate work by adding the areas of shapes, so be wary when using it. The reason this method is more likely to produce error is that you might have to approximate some numbers when squares are cut by the graph, which can lead to inconsistencies. However, this can be a good method if the shapes are too complex, or you simply can't remember the area formulas because of exam pressure. Remember to check the question: if it uses the word **approximation** then this is a great method to choose to make your life easier. However, if it asks for exact values, it's better to use the method of calculating the areas of shapes to get the correct answer.

1.4.2 Types of energy

Kinetic energy is the energy of an object in motion.

$$E_k = \frac{1}{2}mv^2$$

where

E_k	is kinetic energy (J)
m	is mass (kg)
v	is velocity (m/s)

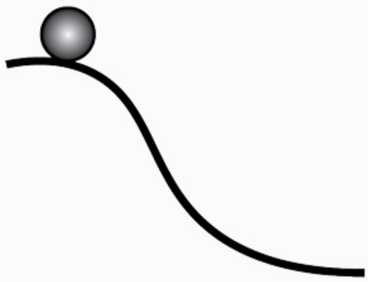
Gravitational potential energy is the energy stored by an object when raised at a height.

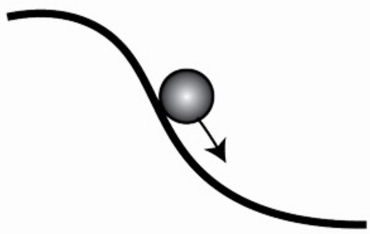
$$E_p = mg\Delta h$$

where

E_p	is gravitational potential energy (J)
m	is mass (kg)
g	is acceleration due to gravity = 9.8 ms^{-2}
Δh	is height (m)

You can think about the relationship between kinetic energy and gravitational potential energy like this:





Here the ball has the *potential* to roll down the hill but hasn't rolled anywhere yet, so it has high gravitational potential energy and no kinetic energy.

Now the ball has rolled down half of the hill and so has kinetic energy. It still has half of the hill to roll down, so it still has half of the potential energy it had to begin with.

Example 1.7

A crate is held 10 m above the ground and has a mass of 15 kg. What is its potential energy? After the box is dropped, what will its velocity be, and what will its kinetic energy be? What can you say about the relationship between potential and kinetic energy after doing these calculations? What role does mass have to play?

$$\begin{aligned} E_p &= mg\Delta h \\ &= 15 \times 9.8 \times 10 \\ &= 1,470 \text{ J} \end{aligned}$$

To find the velocity, we will need to use our motion equations.

$$\begin{aligned} v^2 &= u^2 + 2as \\ v^2 &= 0^2 + 2 \times 9.8 \times 10 \\ v &= 14 \text{ m/s} \end{aligned}$$

Now we can find the kinetic energy at exactly the point where the ball reaches the ground.

$$\begin{aligned} E_k &= \frac{1}{2}mv^2 \\ &= \frac{1}{2} \times 15 \times 14^2 \\ &= 1,470 \text{ J} \end{aligned}$$

As you can see, our potential and kinetic energy are exactly the same! This is because they are inversely proportional. When the ball is held above the ground, it has a potential energy of 1,470 J and a kinetic energy of 0 J, because it's not moving. When it hits the ground, all of that potential energy has been converted into kinetic energy.

Now that we know this, we can say that:

$$\begin{aligned} E_k &= E_p \\ \frac{1}{2}mv^2 &= mg\Delta h \end{aligned}$$

What do you notice about this? Mass can be cancelled out! This tells us that mass does not determine the velocity of the object. This is why mass is not in any of our equations of linear motion!

1.4.3 Elastic and inelastic collisions

An **elastic collision** occurs when the kinetic energy in a system is **the same before and after** a collision. So the amount of movement before and after is the same. For example, think of two bouncy balls rolling towards one another, then colliding and bouncing off in opposite directions.

A perfectly elastic collision does not occur in everyday objects, as there is always going to be at least *some* energy lost in a collision.

An **inelastic collision** occurs when the kinetic energy is **different before and after** a collision. This means that there is less movement after the collision. The kinetic energy is transformed into a different type of energy, such as thermal or sound energy. The most common example you might be familiar with is when the kinetic energy is transferred to deforming the objects which collided.

For example, think of a ball of dough being dropped onto the ground – it will lose kinetic energy to sound (the *slap* on the concrete), and to changing the shape of the dough (it will now be more flat against the ground).

Solving problems involving elastic and inelastic collisions

We know that whether a collision is elastic or inelastic depends on if kinetic energy is conserved. So we can use the formula for kinetic energy to determine if a collision is elastic or inelastic.

$$E_k = \frac{1}{2}mv^2$$

Example 1.8

Car A, which weighs 1 ton, is driving towards Car B at a constant velocity of 20m/s. *Car B is stationary and weighs 1 ton. After colliding, Car A bounces off with a velocity of* 2 m/s *and Car B now moves at a velocity of* 3 m/s. *Explain whether this collision was elastic or inelastic and determine how much energy was lost in the system.*

To determine if the collision was elastic, we need to see whether the kinetic energy before and after the collision is the same or different.

$$\begin{aligned} E_{k \text{ before}} &= \frac{1}{2} \times 1,000 \times 20^2 + \frac{1}{2} \times 1,000 \times 0^2 \\ &= 200,000 \text{ J} \end{aligned}$$

$$\begin{aligned} E_{k \text{ after}} &= \frac{1}{2} \times 1,000 \times 2^2 + \frac{1}{2} \times 1,000 \times 3^2 \\ &= 12,500 \text{ J} \end{aligned}$$

The kinetic energy before and after is very different, so this collision was inelastic.

To find how much energy was lost, we need to find the difference between the kinetic energy before and after the collision.

$$\begin{aligned} E_{\text{lost}} &= 200,000 - 12,500 \\ &= 187,500 \text{ J} \end{aligned}$$

This energy was most likely transformed into energy which changed the shape of the two cars. Both of the cars likely crumpled a lot.

Topic 2

Waves

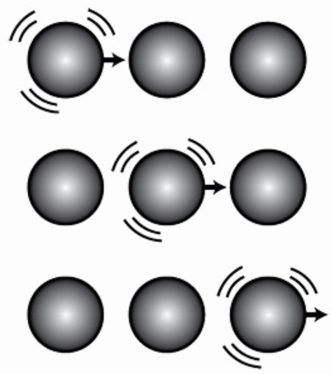
2.1 Wave properties

Waves transfer energy. In more technical terms, we can define a wave as a propagation of a disturbance from one place to another.

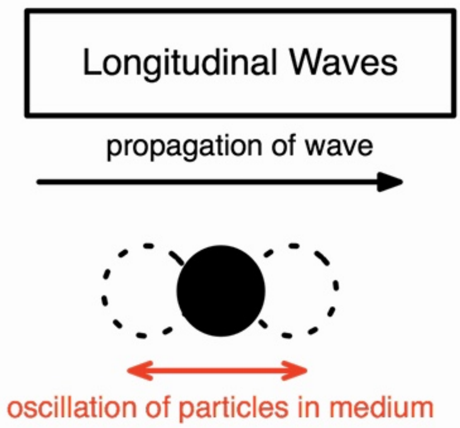
Mechanical waves are waves that need a medium. **Sound waves** travel through air, **water waves** travel through water, and a Mexican wave travels through people.

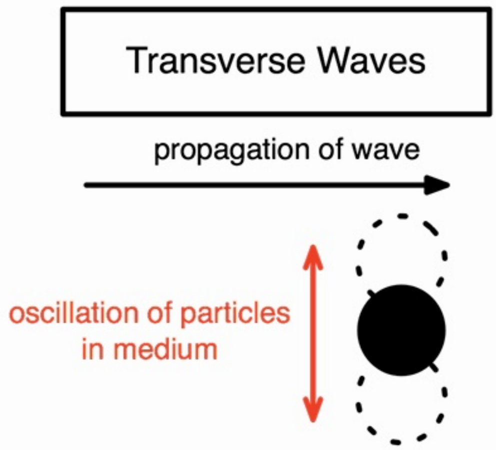
In mechanical waves, particles will have **no net displacement** even though energy is transferred. A particle will receive energy from a particle behind it, causing it to move forward and bump into another particle, transferring energy. It will then revert back to its original position.

A particle with energy moves into the next one. After energy is transferred, the particles go back to their original position (i.e. there is *no net displacement.*)



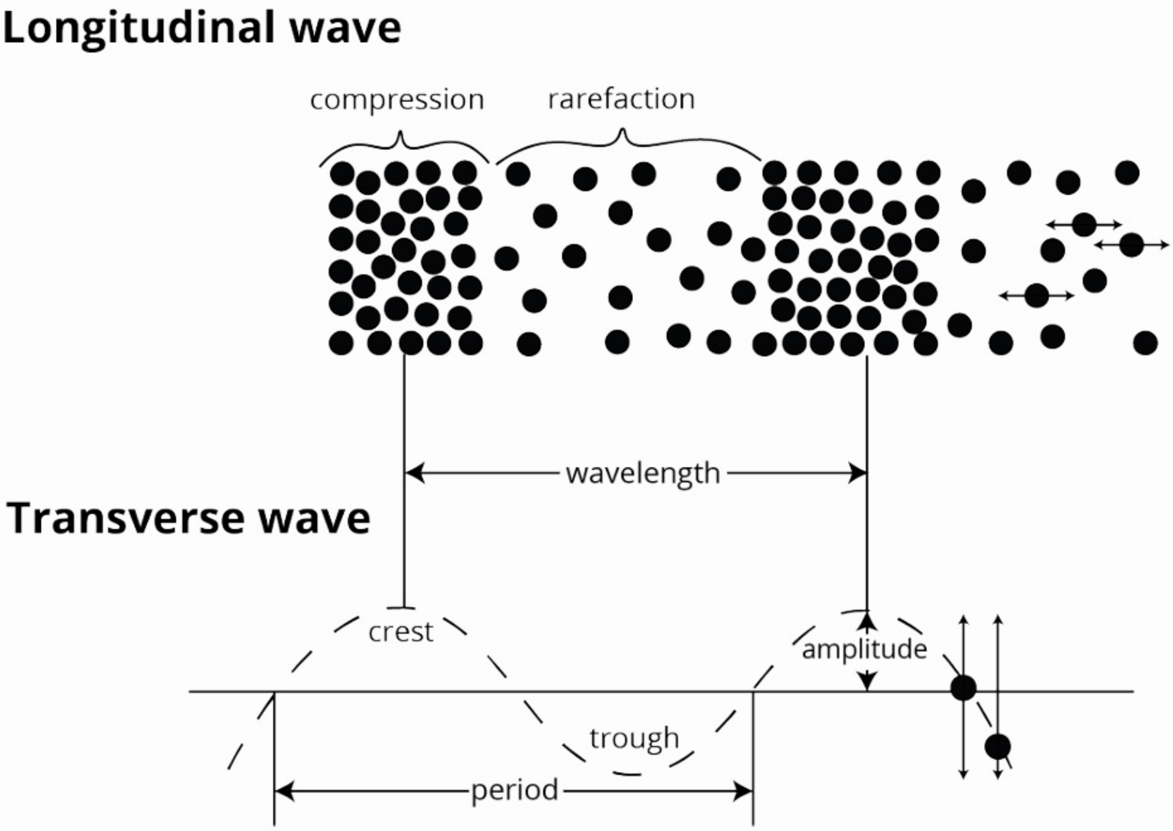
- **Longitudinal waves:** particles oscillate in the same direction as the propagation of the wave.
- **Transverse waves:** particles oscillate perpendicular to the direction of propagation of the wave.





Before we look at how waves are represented visually, we first need to understand some of the major characteristics of waves. The first four, outlined in the following table, are especially important to remember as they will come into play in calculations regarding waves.

Characteristic	Symbol (if applicable)	Explanation
Amplitude	A	The maximum displacement of a particle from its mean position (equilibrium position).
Wavelength	λ	The distance between two points which are in the same phase.
Period	T	The time it takes for one full wave cycle to form.
Frequency	f	The number of waves formed per second. We can calculate this by finding 1 divided by the period: $f = \frac{1}{T}$.
Crest		The highest point of a transverse wave, which is analogous to the compression on a longitudinal wave.
Trough		The lowest point of a transverse wave, which is analogous to the rarefactions on a longitudinal wave.



Key Point :
The following table, which outlines all the important concepts to understand about the different types of waves, will be handy to memorise if you find you get tripped up when answering questions about the differences between mechanical and electromagnetic waves.

Waves	
Mechanical	**Electromagnetic**
Slower	Faster (travel at speed of light)
Transverse or longitudinal	Transverse only
Require a medium to travel	Do not require a medium to travel (can travel in a vacuum)
E.g. sound, seismic, water waves	E.g. visible light, UV, gamma rays

2.1.1 Calculations involving waves

There are two basic equations you need to know to find velocity and frequency of any waves.

Key Point :
Make sure you apply these equations if you come across a complex question and don't know where to go next! It's often easy to forget them otherwise, but they are very important.

The first is the equation to find velocity:

$$v = f\lambda$$

where

v is velocity (m/s)

f is frequency (Hz)

λ is wavelength (nm)

The second is the equation to find frequency:

$$f = \frac{1}{T}$$

where

f is frequency (Hz)

T is period (s)

As the frequency goes up, the period goes down. This is because frequency is the measure of how many waves pass per second, while period is the measure of how long each wave takes to pass. So if the waves are really quick (T is low), then a lot of them will be able to go through each second (f is high).

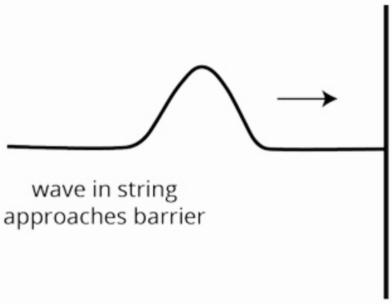
Example 2.1
The period of a wave at the beach is 5 seconds. Its velocity is 10 m/s. What is the wavelength?

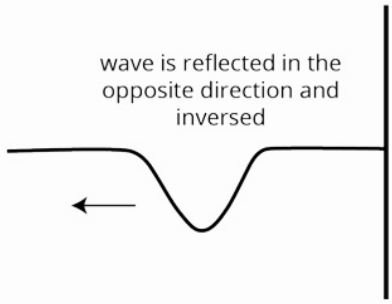
$$\begin{aligned} f &= \frac{1}{T} \\ &= \frac{1}{5}\ \text{Hz} \end{aligned}$$

$$\begin{aligned} v &= f\lambda \\ 10 &= \frac{1}{5}\lambda \\ \lambda &= 10 \times 5 \\ &= 50\ \text{nm} \end{aligned}$$

2.1.2 Interactions of waves with surfaces and mediums

- **Reflection** occurs when a wave hits a surface and is reflected back, changing directions. If a wave is reflected, it will be inverted.





- **Refraction** occurs when a wave changes from one medium to another and thus changes speed and wavelength.
- **Diffraction** occurs when a wave travels around a barrier or through an opening, bending in the process.

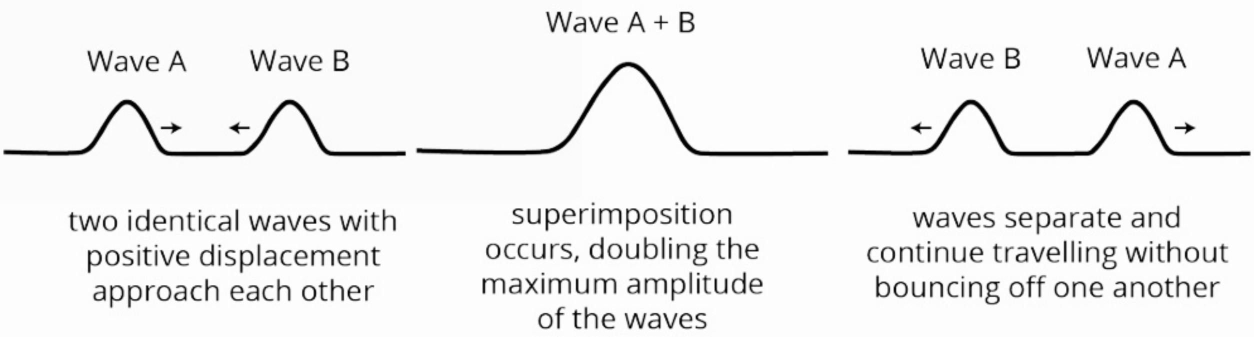
2.1.3 Superposition

Superposition occurs when two waves **of any amplitude and wavelength** collide with one another, and the **total displacement** of the resultant wave is equal to the **sum of the displacements of each wave.**

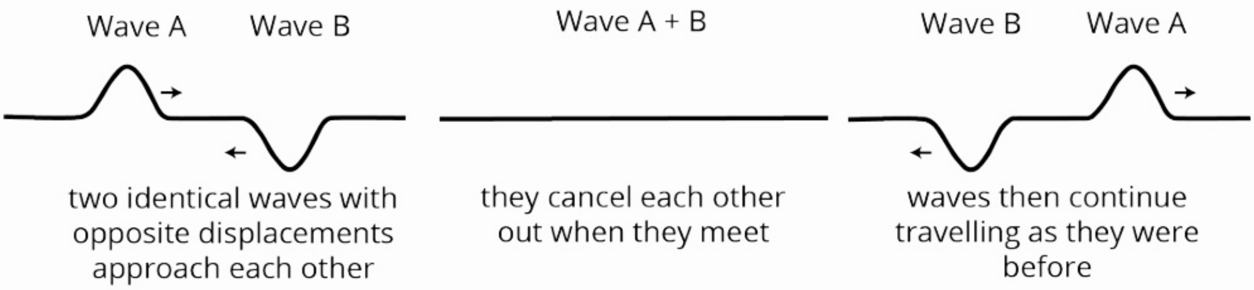
So to find the **resultant amplitude** of a superposition, you need to add the amplitude of the two waves at that point.

There are two types of superposition you need to know: constructive and destructive interference.

Constructive interference occurs when **two identical waves superimpose.** They travel towards one another and collide at the point where they have displacement in the **same direction,** leading to the creation of a larger overall displacement.



Destructive interference occurs when **two identical waves** superimpose when one has positive displacement and one has negative displacement. You can think of this like the waves cancelling each other out.

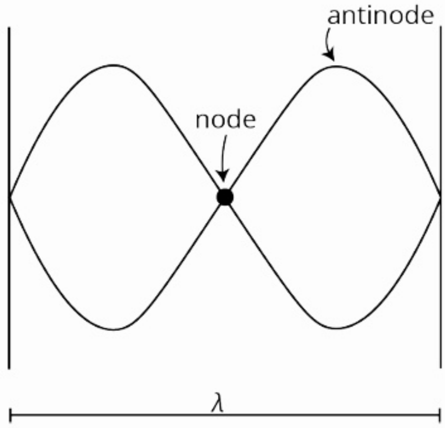


2.1.4 Standing waves

Standing waves are special waves which appear to not move, rather they look like they just vibrate and stand in place. **Standing waves** form when two identical waves approach each other in opposite directions and superpose. The waves experience **constructive and destructive interference alternately** along the medium. So instead of two single crest or single trough waves superimposing momentarily, which we considered before, for standing waves to occur the superimposition is happening **constantly.**

The two waves need to collide at exactly the right point, so that they cancel out at certain points to create **nodes.** Even though the waves are constantly travelling in opposite directions, the quarter of one wave will always meet the quarter of the other wave, cancelling out perfectly. As the waves continue moving, the crest and trough of the two waves meet, cancelling out perfectly. The point is that the waves are perfectly timed so that at the nodes, they will *always cancel each other out.* So at the node, there is destructive interference. This is a really hard concept to grasp, so don't stress if you don't get it straight away!

The following diagram shows a standing wave. You can see the node where destructive interference is occurring. At the nodes, the medium is not moving, meaning there is no net displacement. This is why at either end of the wave, there must be a node; the medium cannot move there. A similar concept applies for the **antinodes,** or the tops of the loops. At these points, the two waves are constantly colliding so as to constructively interfere.



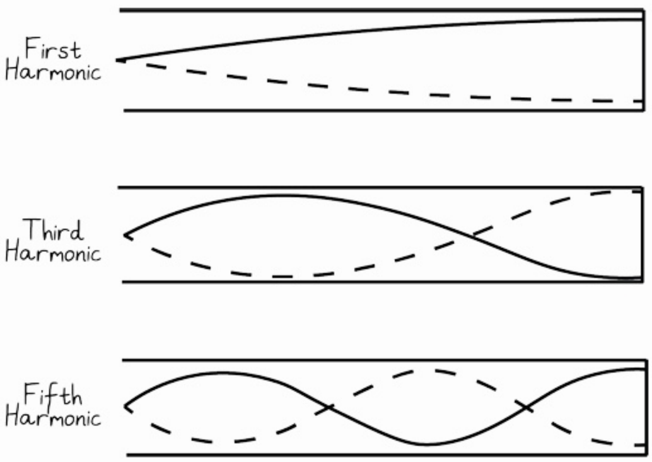
2.2 Sound

2.2.1 Standing waves in instruments

In this section we'll focus on how standing waves can be observed in pipe and string instruments.

Sound is created in pipes through resonance. **Resonance** occurs when sound is amplified due to the vibrations of the system at its **natural frequency.** Resonance increases the efficiency of energy transfer because the vibrations continue on further vibrations. The natural frequency is the frequency at which an object will naturally vibrate at. This will depend on the size, shape, and material of the object.

Objects can vibrate at **multiples** of the natural frequency. These are known as **harmonics.** The first harmonic is a half of a wavelength, and each additional harmonic adds one more half wavelength.



We can calculate the number of harmonics from the length of the wave using the following equations.

$$L = n\frac{\lambda}{2}$$

$$L = (2n-1)\frac{\lambda}{4}$$

where

L is the length of wave (m)

n is the n^{th} harmonic

For pipe instruments, there needs to be an antinode at an open end, and a node at a closed end. For a string instrument where there is string stretched between two points, there needs to be a node at each end.

Example 2.2

A single string on a guitar has a length of 65 cm. The first harmonic standing wave has a frequency of 10 Hz. What length would the guitar string need to be in order to create the 3rd harmonic standing wave at 15 Hz?

First, we need to find the velocity of the wave, since that will be constant for both scenarios. To do that we need to find the wavelength.

$$\begin{aligned} L &= n \times \frac{\lambda}{2} \\ 0.65 &= 1 \times \frac{\lambda}{2} \\ \lambda &= 0.65 \times 2 \\ &= 1.3 \text{ nm} \end{aligned}$$

Now we can substitute this into our formula from the previous section to find velocity.

$$\begin{aligned} v &= f\lambda \\ &= 10 \times 1.3 \\ &= 13 \text{ m/s} \end{aligned}$$

Now we know the velocity, we can substitute this into our formula to determine the wavelength of our wave:

$$\begin{aligned} v &= f\lambda \\ 13 &= 15 \times \lambda \\ \lambda &= \frac{13}{15} \\ &\approx 0.87 \text{ nm} \end{aligned}$$

Now substitute this into our equation for length:

$$\begin{aligned} L &= n \times \frac{\lambda}{2} \\ &= 3 \times \frac{0.87}{2} \\ &= 1.3 \text{ m} \end{aligned}$$

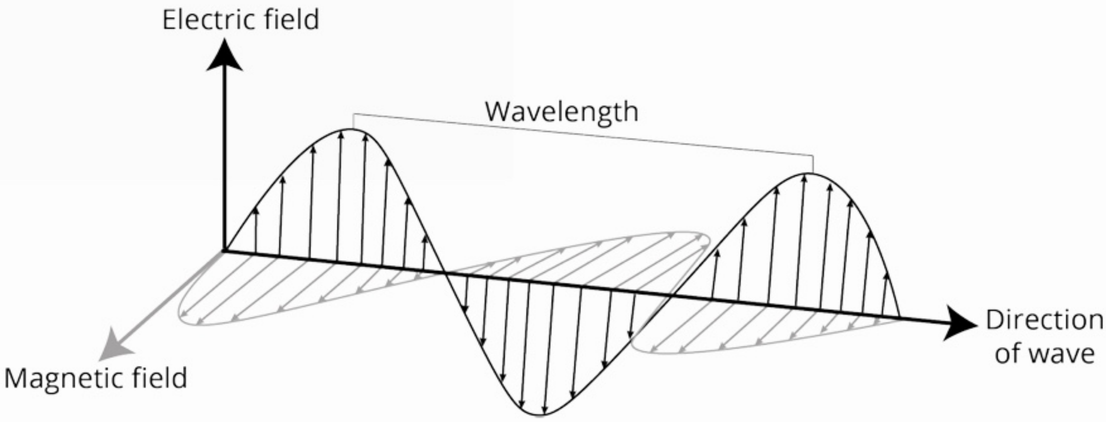
2.3 Light

2.3.1 Light as a wave

Light is an **electromagnetic wave** rather than a mechanical one. This means that **it doesn't need a medium.** This is why light is able to travel through the vacuum of space, where sound wouldn't be able to travel, because sound is a mechanical wave.

Light in a vacuum travels at $c = 3 \times 10^8$ ms^{-1}. It travels slower in mediums because the light keeps on bumping into all of the particles. However in a vacuum, there is nothing to get in the light's way.

Light is a transverse wave because the electric and magnetic fields oscillate perpendicularly to the direction of propagation.



Light travels a lot faster than mechanical waves. This is why you always see the lightning before you hear the thunder. The speed of light is faster than sound for two main reasons:

- Electromagnetic waves can travel by themselves. But mechanical waves *need particles to move,* and particles move a lot slower than light!
- Mechanical waves are subject to variances in speed because there are variances in mediums, such as density and kinetic energy. Sound can travel faster through a solid, for example, because all of the particles are right next to each other. But in a gas, the particles are so spread out that it is much slower.

There are many conceptions of *what* light actually is; however, the model of light as a wave explains much of the phenomena that we can observe about light, and hence is what we will cover here. These phenomena include reflection, refraction, dispersion, diffraction, interference, and total internal reflection.

2.3.2 Refraction and Snell's law

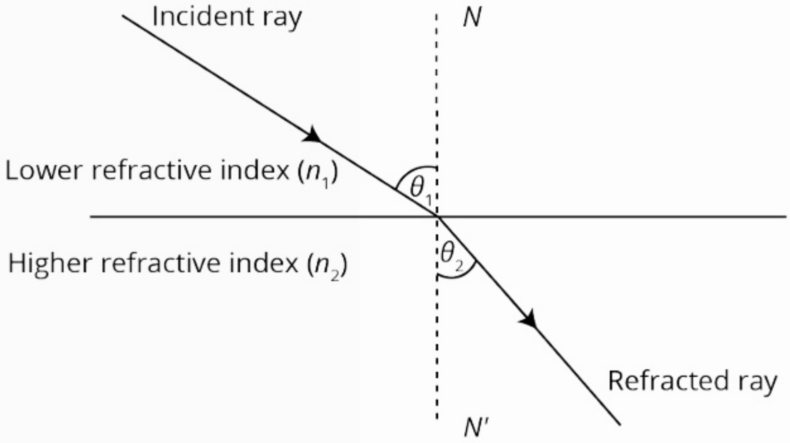
We can use Snell's law to describe the refraction of light. This tells us how the velocity and wavelength of light change when it travels between one medium and another.

$$\frac{\sin(i)}{\sin(r)} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}$$

where

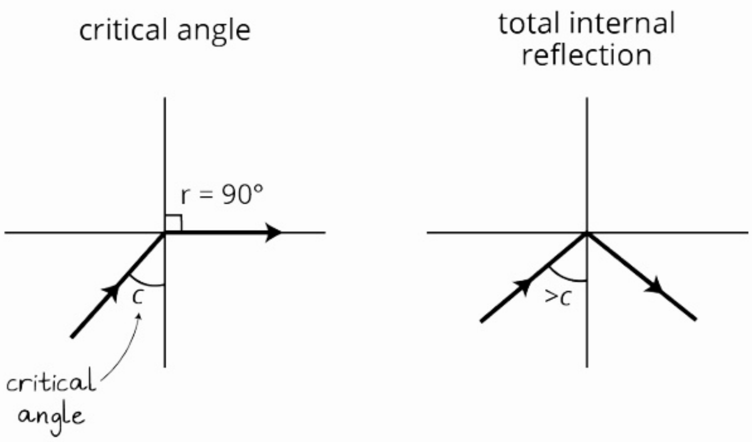
n	is refractive index of the medium
i	is incident angle in degrees
r	is refractive angle in degrees

The refractive angle is measured from a normal to the surface (a line perpendicular to the surface as shown in the diagram below). If the medium that the light is shone into is denser than the initial one, then the angle at which it is refracted will be closer to the normal.



The **critical angle,** c, is the angle at which the refracted ray is 90°. This is going to be different depending on how dense the two mediums are.

- ***i* < *c*:** if the incident ray is less than the critical angle, the light will be refracted (as above).
- ***i* > *c*:** if the incident angle is greater than the critical angle, the light will be totally reflected – no light will pass into the next medium!
- ***i* = *c*:** if the incident angle is the critical angle, then the ray will be refracted parallel to the line separating the two mediums.



Example 2.3

A beam of light from a torch is shone onto the surface of a pool. The incident angle is 30°. The velocity of the light in the air is 3×10^8 *m/s and the velocity in water is* 2.25×10^8 *m/s. What is the refracted angle, and what is the ratio of refractive indexes?*

For questions involving the refraction of light at the boundary between two mediums, we need to use Snell's law.

$$\frac{\sin(i)}{\sin(r)} = \frac{v_1}{v_2}$$

$$\frac{\sin(30)}{\sin(r)} = \frac{3 \times 10^8}{2.25 \times 10^8}$$

Topic 2 – Waves

Now we can cancel out the 10^8 and isolate $\sin r$.

$$\begin{aligned}
\frac{\sin(30)}{\left(\frac{3}{2.25}\right)} &= \sin(r) \\
0.375 &= \sin(r) \\
\sin^{-1}(0.375) &= r \\
r &= 22.02^\circ
\end{aligned}$$

So, our refracted angle is 22.02°. To find the ratio of refractive indexes, we need to find $\frac{n_2}{n_1}$. What we know from Snell's law is that:

$$\frac{\sin(i)}{\sin(r)} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

We can then use our velocities to find our ratio:

$$\begin{aligned}
\frac{3 \times 10^8}{2.25 \times 10^8} &= \frac{n_2}{n_1} \\
\frac{n_2}{n_1} &= 1.3
\end{aligned}$$

This tells us that the water is 1.3 times denser than air.

2.3.3 Concave and convex lenses

You need to be able to draw diagrams and describe the images of light shone through singular convex or concave lenses. When light is shone through lenses, it is travelling to a different medium and therefore refracted, changing its direction.

When light is shone through a lens, there will be a **focal point.** The focal point is basically where all of the lines on the refracted rays intercept or join together.

Concave lenses are shaped inwards, like a cave, and they will diverge light that is shone at them. The image generated by these lenses will be all of the following:

- Virtual
- Erect
- Diminished

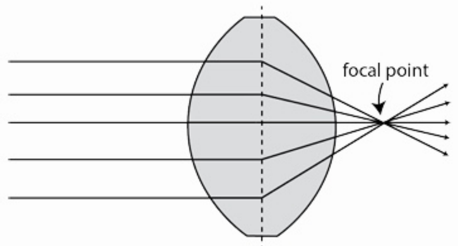
The **focal point will be negative,** which means that it will be **before the actual lens.** This is because the only place where all of the refracted rays would converge is before the lens.

Convex lenses are shaped outwards, and will converge light shone at them. Images created by them will be all of the following:

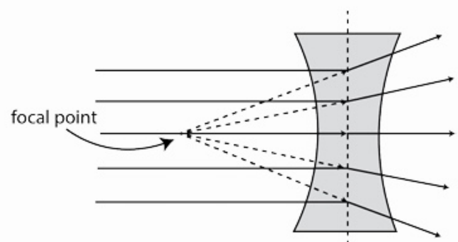
- Real
- Inverted

The **focal point will be positive,** which means that it will be **after the actual lens.**

Convex lens: converging rays

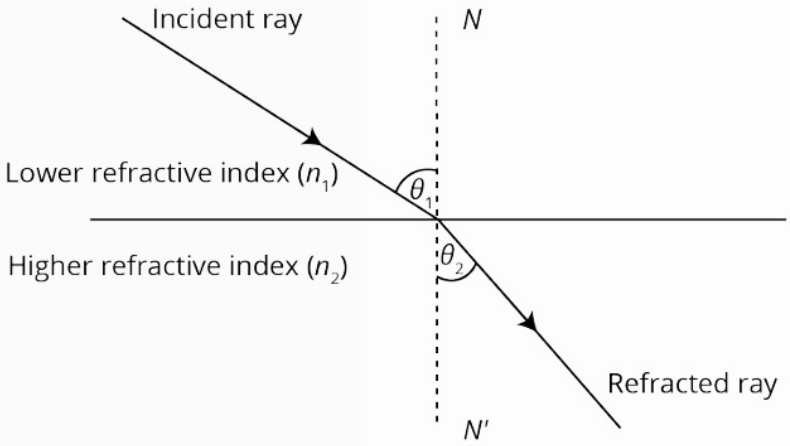


Convex lens: diverging rays



So why does this happen? Think about the thickness of the lenses and refraction. A thicker part of glass will *refract the light* ***more.*** A thicker part will also change the direction of the light more.

The refractive angle is measured from a normal to the surface (a line perpendicular to the surface as shown in the diagram below). If the medium that the light is shone into is denser than the initial one, then the angle at which it is refracted will be closer to the normal.



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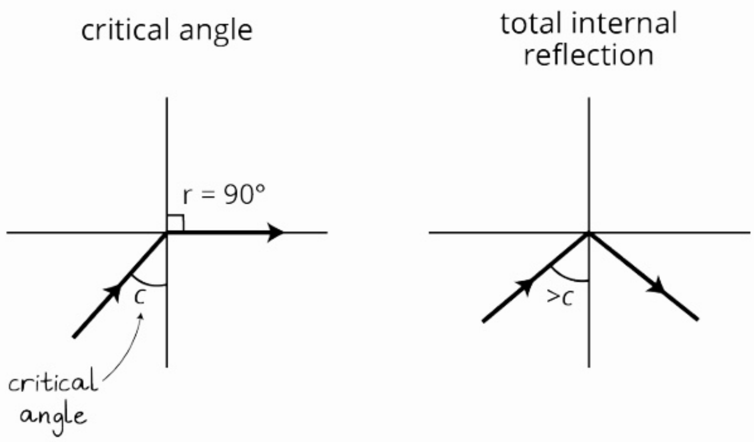

Example 2.3

A beam of light from a torch is shone onto the surface of a pool. The incident angle is 30°. The velocity of the light in the air is 3×10^8 *m/s and the velocity in water is* 2.25×10^8 *m/s. What is the refracted angle, and what is the ratio of refractive indexes?*

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$$\frac{\sin(i)}{\sin(r)} = \frac{v_1}{v_2}$$

$$\frac{\sin(30)}{\sin(r)} = \frac{3 \times 10^8}{2.25 \times 10^8}$$

Now we can cancel out the 10^8 and isolate $\sin r$.

$$\begin{aligned} \frac{\sin(30)}{\left(\frac{3}{2.25}\right)} &= \sin(r) \\ 0.375 &= \sin(r) \\ \sin^{-1}(0.375) &= r \\ r &= 22.02^\circ \end{aligned}$$

So, our refracted angle is 22.02°. To find the ratio of refractive indexes, we need to find $\frac{n_2}{n_1}$. What we know from Snell's law is that:

$$\frac{\sin(i)}{\sin(r)} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

We can then use our velocities to find our ratio:

$$\begin{aligned} \frac{3 \times 10^8}{2.25 \times 10^8} &= \frac{n_2}{n_1} \\ \frac{n_2}{n_1} &= 1.3 \end{aligned}$$

This tells us that the water is 1.3 times denser than air.

2.3.3 Concave and convex lenses

You need to be able to draw diagrams and describe the images of light shone through singular convex or concave lenses. When light is shone through lenses, it is travelling to a different medium and therefore refracted, changing its direction.

When light is shone through a lens, there will be a **focal point.** The focal point is basically where all of the lines on the refracted rays intercept or join together.

Concave lenses are shaped inwards, like a cave, and they will diverge light that is shone at them. The image generated by these lenses will be all of the following:

- Virtual
- Erect
- Diminished

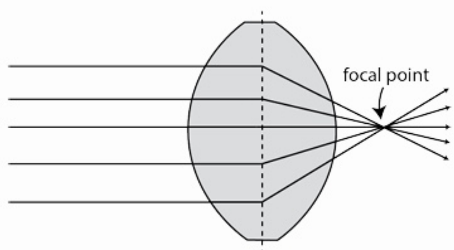
The **focal point will be negative,** which means that it will be **before the actual lens.** This is because the only place where all of the refracted rays would converge is before the lens.

Convex lenses are shaped outwards, and will converge light shone at them. Images created by them will be all of the following:

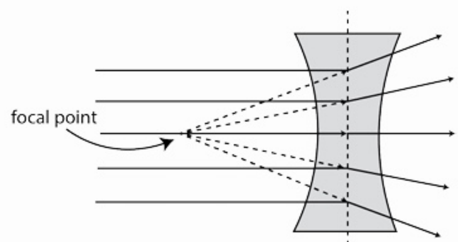
- Real
- Inverted

The **focal point will be positive,** which means that it will be **after the actual lens.**

Convex lens: converging rays



Convex lens: diverging rays



So why does this happen? Think about the thickness of the lenses and refraction. A thicker part of glass will *refract the light* ***more.*** A thicker part will also change the direction of the light more.

Topic 2 – Waves

2.3.4 Intensity

Intensity is basically just *brightness.* Technically, intensity is **how much energy is concentrated in one area** – so if there's more light energy in one area, you're going to see it as a lot brighter.

There are two mathematical relationships you need to know.

Intensity is proportional to the square of amplitude. This is written as:

$$I \propto A^2$$

> **KEY POINT :**
> What this basically means is that if the amplitude of the light is bigger, so is the intensity.

Intensity is inversely proportional to the radius from a source *r*. This is written as:

$$I \propto \frac{1}{r^2}$$

> **KEY POINT :**
> This basically means that as one increases, the other decreases. So, as you get further away from a light source, the intensity will decrease (which is why a light will get less bright the further you are away).

You might wonder why I'm using distance and radius interchangeably – this is because we think of intensity in a *sphere shape.* If you're further away from a light source in any direction, it will be less intense, regardless of if you're standing next to it, or above it, or below it.

Example 2.4

The intensity of light from a streetlight is 100 W/m² when 2 m away from it. What would the intensity be if you were 5 m away from the light?

We know that:

$$I \propto \frac{1}{r^2}$$

For solving these problems, we need to consider that the ratio of two values is going to be equal.

$$\begin{aligned}
\frac{I_A}{I_B} &= \frac{\left(\frac{1}{r_A^2}\right)}{\left(\frac{1}{r_B^2}\right)} = \frac{r_B^2}{r_A^2} \\
\frac{100}{I_B} &= \frac{5^2}{2^2} \\
I_B &= \frac{100}{\left(\frac{5^2}{2^2}\right)} \\
&= 16 \text{ W/m}^2
\end{aligned}$$

> **KEY POINT :**
> For solving problems where you are given the intensity of light at two different points away from the source, use the equation $\frac{I_A}{I_B} = \frac{r_B^2}{r_A^2}$.

Topic 2 – Waves

Part III

Learning Senior Physics

My tips for learning Physics

Understand the cognitive verbs used in the syllabus.

A cognitive verb is a verb used in a dot point in the syllabus. They are usually grey and underlined. QCAA provides definitions of these online.

Understanding the meaning of these is really important to how you study a specific topic. This is because cognitive verbs tell you exactly how much information you need to know about a topic and therefore help you study efficiently. For example, if a syllabus dot point provides that you need to "define thermal energy," all you need to know is the definition of thermal energy. In fact, most definitions you need to know are provided in the glossary at the end of the syllabus. However, if a syllabus dot point asks you to "explain heat transfers in terms of conduction, convection and radiation," you need to understand the concept and be able to write 2–4 sentences about it. In this way, you can fast track your exam preparation by studying only what an exam will ask you to do.

Understand concepts.

Understanding the concepts is one of the main elements of succeeding in Physics, especially because a lot of the concepts are really hard to get your head around! Sometimes it would take me literal *months* to fully understand a concept. When you're learning new content, make sure you put effort into understanding what's actually happening instead of just reciting a definition. This is the test I would give myself to see if I *actually* understood the concept: can I explain this concept to my five-year-old brother in words he would understand?

Here are some tips for understanding concepts:

- Watch videos online with different visuals.
- Talk through it to yourself or your friends.
- Have a look at the formulas related to the concept and ask yourself why these variables are included? What values are proportional or inversely proportional to each other?

Data test

Using graphs to calculate values

You will almost certainly be asked in your data test to calculate values using a graph of experimental data. You will either need to use the gradient or the area under the trendline.

Gradient

How to find the gradient

To find the gradient of a trendline, you need to pick two points on the trendline that you can accurately read the coordinates for. Such points will typically exactly line up to a number along an axis. Using these two coordinates, follow the formula:

$$m = \frac{\Delta y}{\Delta x} = \frac{y_1 - y_2}{x_1 - x_2}$$

A common mistake using this formula is mixing up your coordinates – make sure you write out which coordinate is (x_1, y_1) and which is (x_2, y_2)!

KEY POINT :
Remember that the direction of the gradient matters! If your trendline slopes downwards from left to right, make sure your value for the gradient has a negative sign out the front.

How to use the gradient

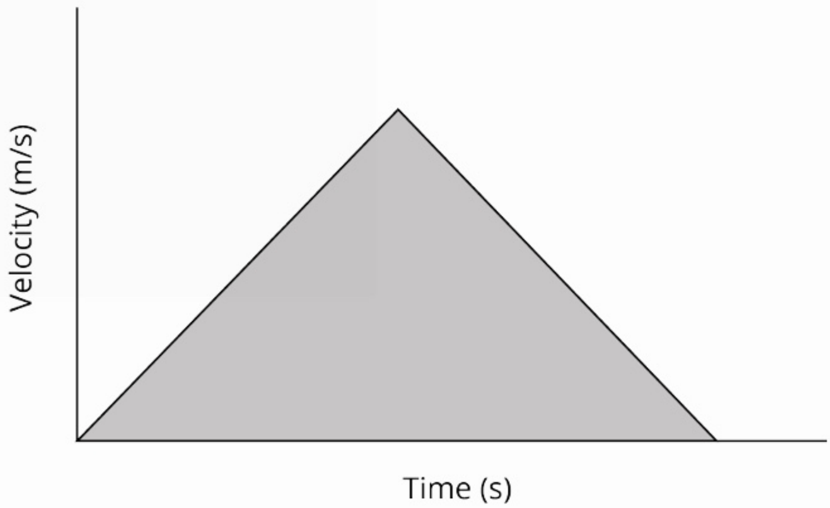
The gradient will be equal to the variable on the y-axis divided by the value on the x-axis. This means that you can substitute the gradient into a formula on your formula sheet to find another value.

Area underneath a trendline

How to find the area underneath a trendline

You may need to find the area *underneath* a trendline, which means the area formed by the trendline, the *y*-axis, and the *x*-axis. How you do this depends on the shape of the trendline. However, you will likely only ever be asked to find the area under a linear trendline in a data test, so it will never be too complex.

The most common example is a trendline that starts at the origin and slopes upwards, then downwards like shown below. You need to find the shaded area.



To find the area, recognise that this is a triangle. So determine the coordinate at the endpoint of the trendline; the *x* component of this coordinate will give you the base length, and the *y* component will give you the height length.

$$A_{\text{triangle}} = \frac{1}{2} \times \text{base} \times \text{height}$$

So how would you find the area underneath a trendline if the trendline doesn't intercept the origin? You need to split the area into a triangular section and a rectangular section.

Counting squares is another method you can use to calculate the area. This is where you count the squares underneath the trendline and add them together.

> **KEY POINT :**
> The area underneath a trendline tells you the variable on the *y*-axis multiplied by the variable on the *x*-axis.

Student experiment and research investigation

Marking criteria

Here I will go through the most important marking criteria and how to satisfy it. Some of these will apply only to your student experiment (SE) and not your research investigation (RI); however, the criteria is largely the same for both.

Research question

This must be specific and relevant.

- SE: make sure that your question is detailed by including all of the variables you're changing and which ones you're keeping constant. An example of this is might *'what is the relationship between variable x and variable y when values a, b, and c are kept constant?'* Make sure you include as much detail as possible about variable *x* and *y*.
  - Your research question must also be relevant to your rationale and the rest of the experiment. Essentially, it should be about the **two variables that you're investigating.**
- RI: your claim will be very vague and open ended, so in your research question you need to narrow this down a lot to make it very specific. There isn't a clear structure for this that will apply for all topics, but a good strategy is to go through each word in your claim and identify how you can make this more specific.

Considered rationale

Your rationale must basically show that you put a lot of thought into your research question by thoroughly justifying it. So go through each element of your research question and explain why you put it there! In the process of this, you will need to explain the theory behind your question. If you have an expected relationship (for your SE), put this in your rationale.

For your RI, you need to justify all of the things that you made more specific in your research question. You will need to use your knowledge on the topic to do this. Explain why one area of the claim will be better to investigate than others, or why limitations of evidence available make it such that you need to investigate a particular area.

Justified modifications (SE)

Make sure that you explain *why* you made the modifications that you did to the original experiment and be very specific about *what* exactly you changed. Include detail about how you conducted the experiment if it is relevant to your modification. This needs to go in your rationale.

Justified conclusions

You need to come to conclusions throughout your report using evidence from your data. You can include your error calculations, the coefficient of determination from your linearised graph, uncertainty values, and any visual observations from your graph.

Don't just say that your experiment was successful if it wasn't – come to conclusions that actually make sense based on your evidence, and whether the value or relationship you calculated was close to the actual one!

Your conclusions also need to be relevant to the research question. So, make sure that you explicitly answer your research question and that your statements are backed up by your evidence.

Reliability and validity (SE)

You need to have a detailed discussion about the reliability and validity of your results. **Reliability** is when your results are **precise.** Your data is **valid** if the results are **accurate** – if they are close to your expected value or relationship.

You need to back up your discussion using **evidence about percentage uncertainty** and the **expected value.** Identify which issues are systematic and which are random.

- **Systematic errors** are errors which are **repeated throughout the experiment** at a constant amount (such as a thermometer that always measures the result 10 degrees higher than it actually is) and is suggested by a y-intercept other than 0 in your linearised graph.
- **Random error** is something which **varies throughout the experiment,** such as human error.

Give some suggestions about what your systematic and random error could have been caused by, but don't say that one thing was 'definitely' the cause if you don't know that.

Suggested improvements and extensions.

Your suggested improvements and extensions need to be linked to your analysis. So if in your analysis you identify an issue with how you measured your data (perhaps you used a stopwatch to time, but this resulted in a lot of random error), you should make suggestions on how to improve the method of measurement.

For your RI, your improvements and extensions need to be relevant to your claim.

Final exam

- **Find a way to *not hate* studying.** Make sure you're not doing questions that are too hard for you and making you feel defeated. Try only doing one question at a time, so you don't feel forced to sit down for hours and study heaps. Have fun with your notes – draw little diagrams or highlight things in nice colours.
- **Practise complex questions.** You learn the most efficiently when you devote the most thinking power to something. If you feel like your brain is *just* on the brink of exploding, that's a good place to be. You won't be able to study for as long when you're consistently challenging yourself, and this is the point. You will study for less time, but learn more. Here are some places I found harder questions in Year 12.
  - Different brands of textbooks. You might have some at your library, or you could buy second-hand books.
  - Workbooks or revision books.
  - Online resources designed for high school students. You can often find these just by searching them up online.
  - Have you and your friend write difficult questions for one another.
- **Take notes on the mistakes you commonly make.** Following from this, make sure you check your answers. Then in your exam, go through the mistakes you commonly make in your head and make sure you haven't made any of them.
- **Take notes in your own words.** Explain concepts back to yourself in the most basic words, and eventually you will be able to explain them in an exam in complex ones! If you make it a little story, it will be far easier to remember too. Here's an example of an explanation I wrote for myself in Year 11 for how batteries and circuits work:
  - *The electrons in the negative terminal hate each other because they all have the same charge. They want to get to the positive terminal. So they all travel through the conducting wire, but they bump into atoms on the way and the atoms steal their energy.*
- **Change your environment.** I often find that studying at home is distracting – I want a snack, or want to talk to my roommate, or want to clean something. If you can, try studying at your local library. Something about the florescent lights and absence of other things to do really helps me to focus.
- **Do a tiny bit of study consistently.** Memorise one definition, do one question, or write one dot point in your notes every day. You will feel happy with yourself for doing that one small thing, so after time your attitude will change (which sounds cliché, I know).
- **Don't force yourself to study for long periods of time.** Go for a walk every hour, get something to eat and have something to drink. If you don't, not only will you be less productive, but you'll grow to resent the work you're doing.
- **Don't put too much pressure on yourself.** If you do, every time you get a question wrong it will feel like a failure – we don't want that! Just take things slowly and have faith in yourself!