The Student's Guide to

HSC Physics

Core Content

& Quanta to Quarks

2009 Edition

The next best thing to cheating

Romesh Abeysuriya

Illustrations by Michael Zhou

Reaction Studios

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About the Guide

The Student's Guide to HSC Physics is a brand new form of study guide, modelled on the way many students write their own study notes. Most books such as those published by Jacaranda, Excel and Macquarie are combinations of textbooks and questions. While they're fine for learning new ideas and concepts for the first time, they're often difficult to use when studying. This is because they don't follow the syllabus exactly, mixing and matching content, until it becomes difficult for you to decide what needs to be studied and what doesn't. The result is that you study irrelevant things, and may omit important things.

This guide is a revision aid, not a textbook. The Board of Studies publishes a syllabus for every course that tells you exactly what you need to know. The guide goes through each of those dotpoints clearly and comprehensively, so that you can revise exactly what you need to know to score highly in exams. Unlike a textbook, the Student's Guide to HSC Physics sticks to the syllabus. Under each dotpoint you will find only what you *need* to know to get *full* marks. By going through each of the dotpoints with this book, and by practicing answering questions, you will be prepared for any question in your HSC exam.

This book deals with the syllabus as comprehensively as possible. However, in the 3$^{\mathrm{rd}}$ column of the syllabus there are occasionally dot points dealing with the use of formulae. They are usually of the form "solve problems and analyse information using *a formula*". This book being about content, not questions, these dotpoints aren't included in the main document. However, the Formulae chapter is an all-inclusive formula guide that summarises *all* of the formulae encountered in HSC Physics, with some extras from the Preliminary course that are relevant to the HSC, along with detailed explanations and useful hints for using them. Make sure you get familiar with using the formulae by doing practice problems- although you don't need to memorise them, you *do* need to know how to apply them quickly in exam conditions.

Also in the 3$^{\mathrm{rd}}$ column are dotpoints concerning first-hand experiments that you performed in class. The answers in this guide are examples of experiments that can be performed. Only use them if you didn't perform the experiment or if your experiment didn't work, for whatever reason. If you performed a different experiment in class, it's better for you to write about that, because having done it you will know a great deal more and be able to write about it in far greater detail.

Finally, although this guide is designed to be simpler and more accessible than other guides in order to make it easier to study from, parts of it do get quite advanced. This is necessary to score full marks in *all* questions. However, the more complicated explanations are always there either so that you properly understand what is happening, or to provide depth of knowledge. Take time to understand everything fully- unlike other books, everything here is relevant and will help you in your exams

Romesh Abeysuriya

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Chapter 1

Space

"When you are courting a nice girl an hour seems like a second. When you sit on a red-hot cinder a second seems like an hour. That's relativity." -Albert Einstein

1.1 Gravity and Gravitational Fields

1.1.1 Define weight as the force on an object due to a gravitational field

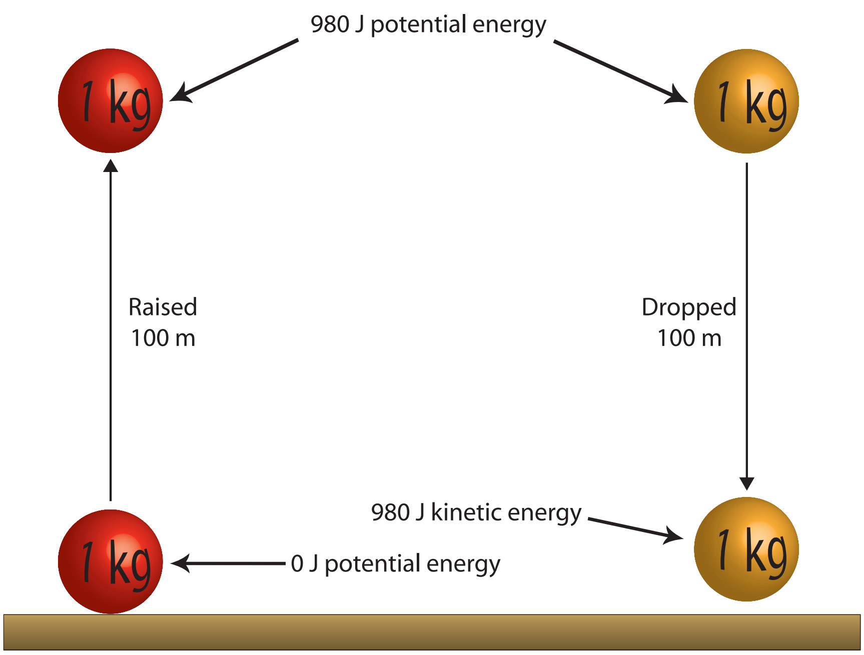
Weight is the force experienced by an object due to a gravitational field. It is directly related to the strength of the gravitational field at the point where the object is located, and is equal to the force which the field is exerting on the object.

Remember- Weight is the force on an object due to a gravitational field.

1.1.3 Explain that a change in gravitational potential energy is related to work done

This section will be hard to answer if you don't fully understand how potential energy works. If this here isn't enough, make sure you read through the various textbooks and look for other resources to make sure you understand potential energy properly.

Work done is the measure of how much energy was used to displace an object a specified distance. $W = Fs$ where s is displacement. When an object is moved away from a gravitational field, it gains energy. This is because by raising it up from the field's origin, work is done. If a 1kg stone was raised 100m, then work done would be 980J. However, conservation of energy states that this energy cannot be destroyed. The 980J is now 980J of gravitational potential energy, because if the stone was dropped from 100m then it would regain 980J in the form of kinetic energy due to the gravitational field. Gravitational potential energy is the potential to do work, and is related to work done.

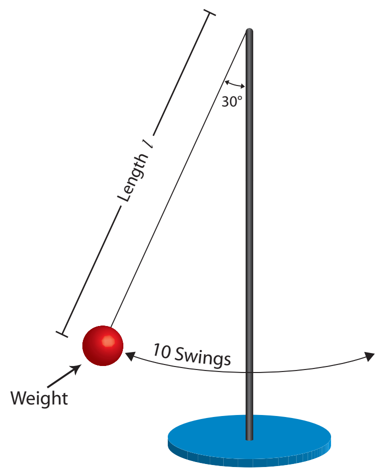


Remember- Potential energy is the work done to raise an object in a gravitational field.

1.1.4 Perform an investigation and gather information to determine a value for acceleration due to gravity using pendulum motion or computer-assisted technology and identify reasons for possible variations from the value $9.8\mathrm{m/s}^2$

This experiment will definitely give you a value that differs from $9.8m/s^2$, so make sure you know both experimental reasons for your error, as well as the factors affecting gravity itself.

In our investigation we used a pendulum consisting of a weight attached to a thick, non-elastic string that was tied to a clamp on a retort stand. We set the pendulum in motion by swinging it, being careful to ensure that the pendulum was deflected no more than 30° at maximum deflection, to minimise errors caused by tension in the string (because the string will lose tension at angles greater than 30°). We timed the pendulum over 10 complete cycles (time taken to return to its point of origin) in order to minimise timing errors and random factors affecting individual swings. We then used the formula $T = 2\pi\sqrt{\frac{l}{g}}$ where T is the period (time taken for one complete cycle), l is the length of the string (measured from the knot on the clamp to the centre of gravity of the weight) and g is gravitational acceleration, in order to calculate a value for g.



There are numerous factors affecting the strength of gravity on Earth (aside from experimental errors producing a result different to $9.8\mathrm{m/s}^2$).

Firstly, as the Earth spins it bulges at the equator, flattening at the poles. This causes the poles to be closer to the centre of the Earth than the equator. According to the formula for gravitational force, the force experienced depends on the distance from the centre of the field. This means that Earth's gravitational field is stronger at the poles than at the Equator. Refer to dotpoint 1.3.2 for more detail about this.

Secondly, the field of the Earth varies with the density of nearby geography. Places where the lithosphere is thick, or where there are dense mineral deposits or nearby mountains experience greater gravitational force compared to places over less dense rock or water. Refer to dotpoint 1.3.4 for a more detailed explanation of the variations in Earth's gravitational field.

Thirdly, as gravitational force depends on altitude, places with greater elevation such as mountain ranges experience less gravitational force, compared to areas at or below sea level.

Remember- Pendulum experiment, errors in the experiment, factors affecting the strength of Earth's gravity.

1.1.5 Gather secondary information to predict the value of acceleration due to gravity on other planets

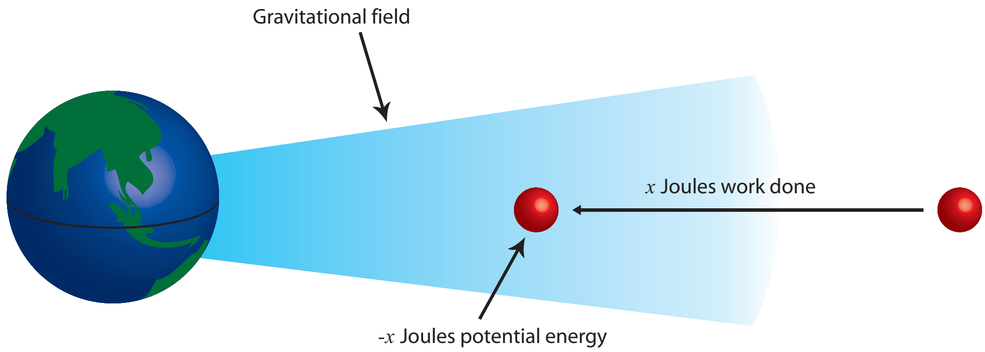
Just pick and choose a few values to memorise. If they give you a question in the exam regarding the different accelerations they'll most likely give you a table of values and ask you to do calculations with it. Don't spend long on this point. Also, Pluto is no longer officially a planet.

Planet	Gravitational Acceleration (m/s^2)
Mercury	4.07
Venus	8.90
Earth	9.80
Mars	3.84
Jupiter	24.83
Saturn	10.50
Uranus	8.45
Neptune	11.20

1.1.6 Define gravitational potential energy as the work done to move an object from a very large distance away to a point in a gravitational field

Again, you need to understand this section. A question may focus on why potential energy takes a negative value, and you need to be able to comprehensively explain and justify why. The reason the dotpoint is defined as a very large distance away is because this is equivalent to a point outside the field. Gravitational fields, like many fields, have no theoretical maximum range and theoretically exist at an infinite distance away from an object. In practice, because gravitational fields obey inverse square law and decrease in strength rapidly as distance increases, at large distances the field is for all intents and purposes nonexistent. Regardless, there is technically no point in the universe outside a gravitational field, hence a very large distance away is used.

Gravitational potential energy is defined as the work done to move an object from a point a very large distance to a specified point in the gravitational field. The work done is the energy input provided by the gravitational field to the object as it falls to that particular distance. $E_p = -\frac{Gm_1m_2}{r}$ is a more accurate definition because it takes into account the weakening of gravitational fields at a distance, and also results in objects far away out of the field having no energy, rather than the simpler definition $E_p = mgh$ where at an infinite distance, there is infinite potential energy.

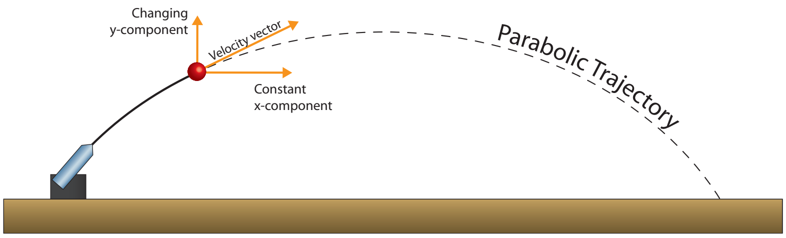


Remember- Potential energy is negative, and is the work done in moving an object from an infinite distance to a point within the field.

1.2 Rocket Launches and Orbital Motion

1.2.1 Describe the trajectory of an object undergoing projectile motion within the Earth's gravitational field in terms of horizontal and vertical components

The trajectory of an object in projectile motion on Earth is a parabola. The motion of an object can be derived through analysing the horizontal and vertical components of its motion and then adding the vectors to produce the resulting direction and magnitude of the object's velocity (the object's net velocity vector). In standard projectile motion on Earth, the horizontal component is constant, and is equal to the original horizontal component at the point of release. The vertical component is constantly changing, being affected by the gravitational field. The change occurs directly towards the centre of the field, and in the Earth's case, acts in this direction at 9.8m/s for every second in flight. At any given time, the vertical component is equal to the initial vertical component at the time of release, minus 9.8 times the time elapsed, where a negative value is downward motion.



Remember- An object in projectile motion travels in a parabola with a constant x-component and a changing y-component.

1.2.2 Describe Galileo's analysis of projectile motion

You'll need to memorise what Galileo said and how he devised his vector analysis. This is a history lesson, but it also tests whether you understand how the component system works so make sure you explain that too.

Galileo was the first to analyse projectile motion mathematically and have his work documented. Instead of considering the motion of the object as a whole, he divided the motion into a horizontal and a vertical component, which when added provide the total motion of the object. Galileo realised that during projectile motion, only the vertical component would change (excluding air resistance) while the horizontal component would remain constant. He also realised that the motion of projectiles is parabolic in nature due to the uniform acceleration vertically with constant horizontal motion.

Remember- Galileo was the first to break a projectile's motion into components.

1.2.4 Explain the concept of escape velocity in terms of the gravitational constant and the mass and radius of the planet

This dotpoint is essentially memorising the formula, and explaining the concept of what escape velocity is.

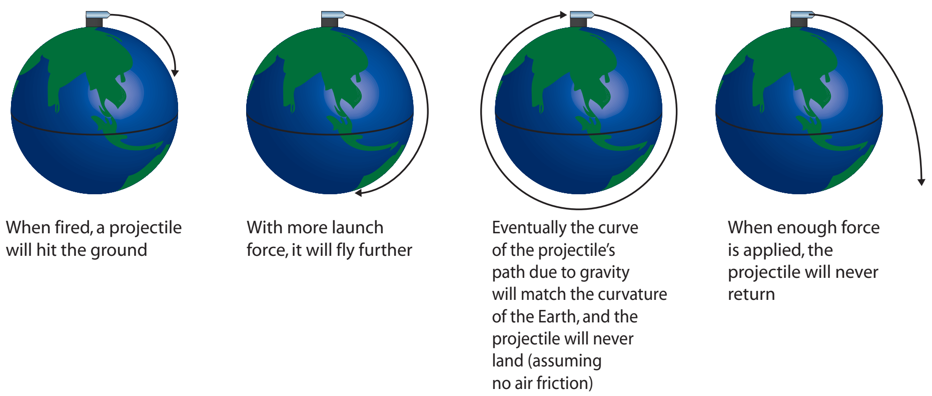
Escape velocity is the velocity required at a planet's surface to completely leave its gravitational field without further energy input. This means that it must have the same amount of kinetic energy as the absolute value of the gravitational potential energy it has at the point of takeoff. Assuming takeoff from the planet's surface, this means $\frac{1}{2}mv^2 = \frac{Gmm_p}{r_p}$ where m_p refers to the mass of the planet. Cancelling, $v^2 = \frac{2Gm_p}{r_p}$. This formula links escape velocity to the gravitational constant and the mass and radius of the planet. If at the surface of the planet v^2 is equal to the RHS, then the rocket will be able to escape the gravitational field. Thus the v value at this point is the escape velocity. Escape velocity increases as the mass of the planet increases, and decreases as the radius of the planet increases.

Remember- Escape velocity is the velocity needed at the surface to exit the gravitational field. More mass and a smaller radius make it bigger.

1.2.5 Outline Newton's concept of escape velocity

Make sure you can properly explain this, it has caused people trouble before. Memorise it.

Newton envisaged a cannon firing a projectile horizontally from the Earth's surface. Ignoring air resistance, the projectile would prescribe a parabola, eventually falling back to Earth. However, as the speed of the projectile is increased, the projectile will take progressively longer to hit the ground, because although gravity is pulling towards the centre of the field, the Earth's surface is falling away from the projectile at the same time due to its horizontal motion. Increase the speed enough, and the projectile will never hit the ground, instead travelling in a circle around the Earth. As the velocity increases even more, the circle becomes an ellipse, and if the speed is increased enough, the trajectory becomes hyperbolic. At this point, the projectile has enough velocity to leave the gravitational field. The velocity corresponding to the time when this first occurs is then the escape velocity.



Remember- Newton used a horizontal cannon to visualise orbits and escape velocity.

1.2.6 Identify why the term "g forces" is used to explain the forces acting on an astronaut during launch

This dotpoint is comparatively easy, but when considering G-forces take care to add the forces correctly. It may be easiest to visualise yourself in the scenario to get an idea as to how the forces interact.

'G-Forces' refers to the force experienced by an astronaut in terms of the Earth's gravitational field strength at the Earth's surface. 1G is equal to the force experienced by an astronaut on the surface of the Earth: $w = mg$ where $g = 9.8$. If a rocket is accelerating upwards at 9.8m/s^2, then the astronaut experiences a net force equal to 2Gs (twice the force they would experience due to Earth's gravity). If an astronaut is in freefall, they experience 0Gs. The term g forces is used because it is easy to relate to, and because it is eases calculations as to the forces which the human body can withstand during launch.

Remember- G-force measures acceleration in terms of Earth's gravity.

1.2.7 Perform a first-hand investigation, gather information and analyse data to calculate initial and final velocity, maximum height reached, range and time of flight of a projectile for a range of situations by using simulations, data loggers and computer analysis

In this experiment, we placed a grid against a wall and then threw a ball in a parabola in front of the grid. A video camera recorded the experiment so that we could see the ball travelling in front of the grid. Using the grid, we were able to calculate the position of the ball. Times were calculated based on each video frame representing $\frac{1}{25}^{\mathrm{th}}$ of a second. By analysing the movement of the ball between frames, we were able to use the standard motion equations in the X and Y axes to calculate the initial and final velocities, as well as the maximum height reached and the range of the projectiles, in this case, a tennis ball. There would have been errors caused by the ball not travelling in a straight line (i.e. It did not travel only vertically and horizontally, but laterally too) resulting in erroneous readings, and it is likely that the camera did not record frames at exactly $\frac{1}{25}^{\mathrm{th}}$ of a second intervals, producing further errors.

Remember- Grid on the wall, tennis ball, video camera, analyse changes between frames.

1.2.8 Analyse the changing acceleration of a rocket during launch in terms of the Law of Conservation of Momentum and the forces experienced by astronauts

The key part of this dotpoint is analysis in terms of Conservation of Momentum. To say that the thrust is constant and the weight decreases, so acceleration increases by $F = ma$ is incomplete. Make sure you deal with Conservation of Momentum as well.

The Law of Conservation of Momentum states that in a closed system, the sum of the momenta before a change is equal to the sum of momenta after the change. In a rocket, the change is the release of exhaust gas. The momentum of the exhaust gas is the same as the rocket's momentum, with a reversed direction, so that when added, they amount to 0. $P = mv$. This equation links velocity to mass and momentum. Because the sum of the momentum of the exhaust gas and the rocket is zero, $|m_{exhaust} \times v_{exhaust}| = |m_{rocket} \times v_{rocket}|$ (taking absolute values because one side of this equation will be negative, since the rocket and the exhaust travel in opposite directions). As the rocket travels into space, it burns fuel and so its mass decreases. But because the momentum of the exhaust is constant, this means the rocket's velocity must rise in order to balance the equation. This means that when the burn is completed, the rocket is travelling faster than if the rocket had maintained a constant mass (because v_{rocket} is now larger as m_{rocket} decreased while p_{rocket} and $p_{exhaust}$ remained constant). This in turn implies that the acceleration of the rocket has increased during the burn in order to fulfil conservation of energy. This can be seen through $F = ma$, where F is the thrust of the rocket motor. Because the rocket motor provides constant thrust, F is a constant. As the rocket burns fuel, its mass decreases, and so for ma to remain constant the rocket's acceleration must increase. This means that as the rocket takes off, its acceleration becomes progressively higher as it burns its fuel and becomes lighter. For the astronauts, this means an increasing force. So as the rocket lifts off, its thrust needs to be progressively reduced to protect its occupants.

Remember- As a rocket burns fuel, it accelerates faster.

1.2.9 Discuss the effect of the Earth's orbital motion and its rotational motion on the launch of a rocket

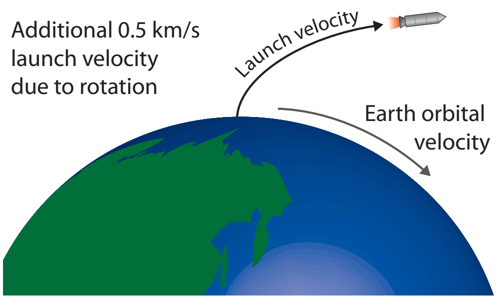
A question on this area will need a comprehensive answer, so make sure that you address the positives and negatives of both Earth's rotation and its orbital motion.

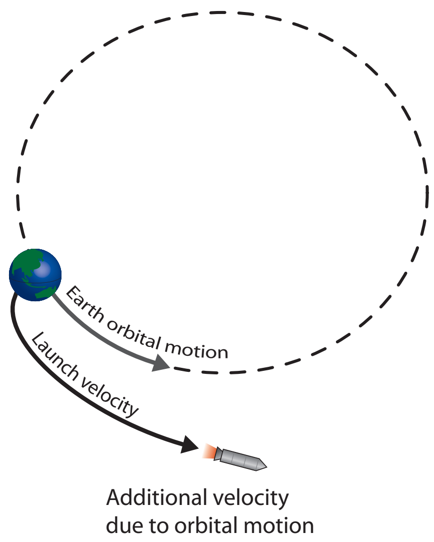
The orbital motion of the Earth and the rotational motion of the Earth both have related effects, the orbital motion affecting interplanetary travel and rotational motion affecting satellites orbiting the Earth. The effect arises because when a rocket is launched, its velocity is not simply that provided by the rocket motor, but also the velocity it has because of the Earth's movement through space.

In terms of orbital motion, space probes launched in the same direction as the Earth's orbit carry its orbital velocity, again reducing fuel requirements, resulting in greater payloads or cheaper missions.

For rotation, the Earth rotates constantly in an anticlockwise direction as viewed from above the North Pole. Rockets launched in an easterly direction therefore carry extra momentum with them, giving them around an additional 0.5km/s towards their velocity. This means that to achieve orbit, the rocket only needs to accelerate 7.5km/s, with the additional 0.5km/s resulting from the motion of the Earth. This means that less fuel is required, and/or a greater payload can be carried.

On the other hand, the orbital and rotational motion makes it hard to launch rockets in a direction against the motion. For example, to launch a rocket in a westerly direction into orbit would take an acceleration of 8.5km/s, significantly greater. Likewise, to launch a space probe against the motion of the Earth would result in far greater fuel requirements to achieve the same trajectory.



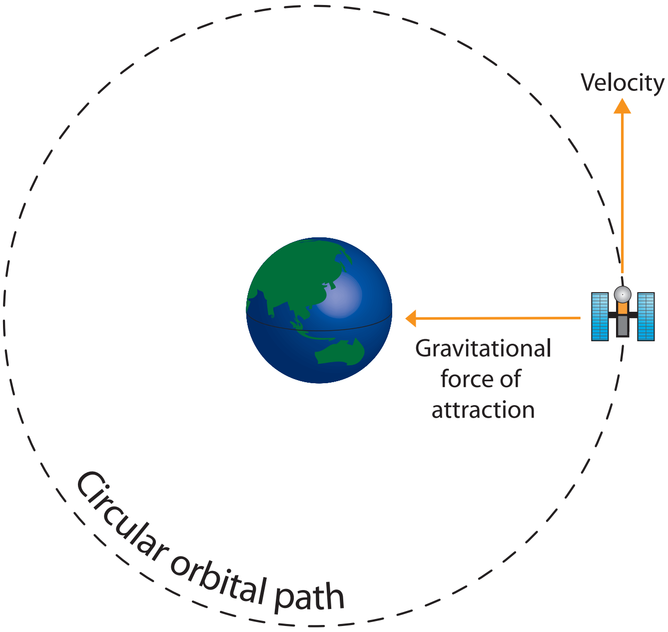


Remember- If you launch a satellite in the direction of the Earth's orbit or rotation, it effectively has more velocity, saving fuel.

1.2.10 Analyse the forces involved in uniform circular motion for a range of objects including satellites orbiting the Earth

The forces involved for uniform circular motion for satellites are the same as uniform circular motion in any situation. There will always be tangential velocity, and there will always be a centripetal force that causes the object to travel in a circular path. The only difference is the source of the forces. For an examination of the virtual force centrifugal force, see the Extra Content section at the end of the Guide.

Uniform circular motion refers to the motion of objects that prescribe a perfect circle as they move. The key force in uniform circular motion is centripetal force. Centripetal force is a centre-seeking force that always acts in a direction towards the centre of the circle in uniform circular motion. The formula for centripetal force is $F = \frac{mv^2}{r}$. The forces for uniform circular motion may be sourced differently, but all are centripetal in nature and all follow this formula. This is true of satellites in orbit around the Earth, cars as they turn, and a charged particle in a magnetic field.

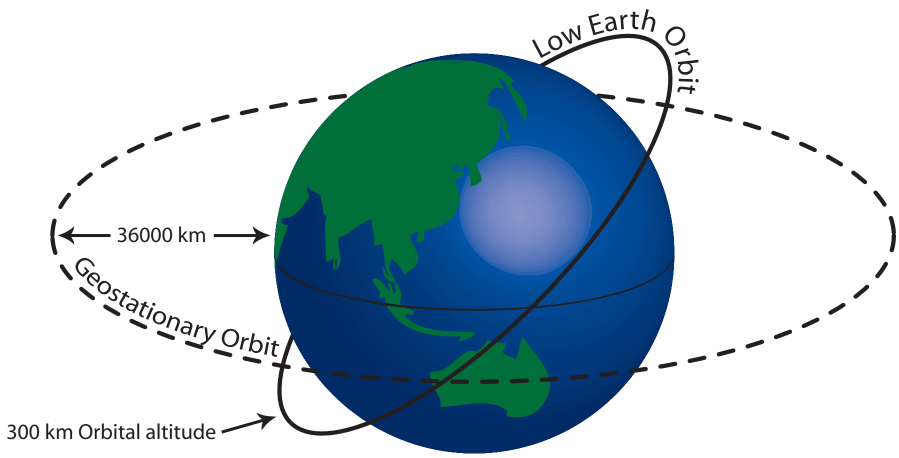


Remember- Uniform circular motion always requires centripetal force, which can come from a variety of sources.

1.2.12 Compare qualitatively low Earth and geo-stationary orbits

A low Earth orbit is one that is approximately 300km from the Earth's surface, although technically it refers to any satellite below 1500km in altitude. LEOs (Low Earth Orbit satellites) have an orbital period of around 90 minutes, with an orbital velocity of about 8km/s. Geostationary satellites remain above a fixed position on the Earth, because their orbital period is exactly 24 hours. They are far higher up than LEOs, at around 36000km in altitude, and have a lower orbital velocity (around 3km/s). A geo-stationary orbit is a special type of geo-synchronous orbit. A geo-synchronous orbit refers to any orbit with a period of 24 hours. However, not all geo-synchronous orbits are geo-stationary, because geo-stationary orbits must be equatorial, travelling directly above the equator. A polar orbit may be geo-synchronous, but it cannot be geo-stationary.

So essentially, compared to the low Earth orbit, a geostationary orbit is higher up, has a longer orbital period and a lower orbital velocity.



Remember- A low Earth orbit is low and fast with a short period, and geo-stationary is high and slow with a 24-hour period.

1.2.13 Identify data sources, gather, analyse and present information on the contribution of one of the following to the development of space exploration: Tsiolkovsky, Oberth, Goddard, Esnault-Pelterie, O'Neill or von Braun

Konstantin Tsiolkovsky (1857-1935), a Russian scientist, while not contributing directly to space travel during his lifetime, devised many new ideas that were almost prophetic and extremely important in space travel. The key ideas he had were firstly the principles behind rocket propulsion, secondly the use of liquid fuels, and finally multi-stage rockets. Tsiolkovsky showed how Newton's 3rd law and how conservation of momentum can be applied to rockets. This principle underlies the functioning of all rockets, and is vital to understanding their operation. Secondly, Tsiolkovsky proposed using liquid hydrogen and liquid oxygen as rocket fuels so that the thrust produced by a rocket could be varied. These same fuels were implemented in the Saturn V rocket that powered the Apollo missions to the moon, and the use of liquid fuels has proved vital in manned spaceflight because they allow g-forces experienced by astronauts to be controlled, unlike in solid fuel engines. Also, liquid fuels are used in satellites and space probes, where intermittent firing of rockets is desired rather than a continuous burn as provided by a solid rocket motor. Finally, Tsiolkovsky visualised a 20-stage rocket train that dropped stages as each stage ran out of fuel, to cut weight and improve efficiency. Although 20 stages was rather extreme, the multistage rocket proved vital in high-energy launches for manned space missions such as Apollo as well as missions with large payloads. So while Tsiolkovsky didn't directly impact space exploration during his lifetime, he devised many ideas that are vital to spaceflight today.

Remember- Tsiolkovsky devised concepts well before they could be practically implemented.

1.2.14 Define the term orbital velocity and the quantitative and qualitative relationship between orbital velocity, the gravitational constant, mass of the central body, mass of the satellite and the radius of the orbit using Kepler's Law of Periods

Although the dotpoint mentions the relationship between orbital velocity and the mass of the satellite, the mass of the satellite is irrelevant. Looking at the 2 equations provided here, the only 2 variables are the mass of the central body and the orbital radius. This means that there is no relationship between the mass of the satellite and orbital velocity, providing the satellite is significantly lighter than the central body (as otherwise more complicated effects would come into play).

Orbital velocity is simply the speed at which a satellite is travelling, calculated by dividing the distance it travels in its orbit (which is the circumference of the circle in a circular orbit) by its orbital period. Orbital velocity is linked to the gravitational constant, the mass of the central body and the radius of the orbit according to the formulae $\frac{r^3}{T^2} = \frac{Gm_c}{4\pi^2}$ and $v = \frac{2\pi r}{T}$. Essentially, orbital velocity increases when the mass of the central body increases, and decreases when the radius of the orbit is increased. The mass of the satellite has no bearing on the orbital velocity, as it cancels out when calculating orbital velocity.

1.2.16 Account for the orbital decay of satellites in low Earth orbit

LEOs continually lose orbital speed and require periodic rocket boosts in order to stay in orbit, preventing them from crashing. The reason LEOs lose velocity is because the Earth's atmosphere extends far into space. The boundary between the atmosphere and the vacuum of space isn't clearly defined, and there are still air particles high above the Earth's surface. As LEOs collide with these particles they slowly lose orbital velocity through friction, resulting in orbital decay. Orbital decay is where a satellite loses orbital velocity and therefore moves into a lower orbit closer to the Earth's surface. If orbital decay continues, the satellite will eventually crash.

Remember- LEOs crash because they collide with air particles.

1.2.17/1.2.18 Discuss issues associated with safe re-entry into the Earth's atmosphere and landing on the Earth's surface (including "Identify that there is an optimum angle for safe re-entry for a manned spacecraft into the Earth's atmosphere and the consequences of failing to achieve this angle")

Re-entry is a complex procedure due to the high velocities and temperatures encountered, as well as the fine balance of trajectory required to land safely. To land a space vehicle, the vehicle must firstly slow down, and secondly travel back down through the atmosphere. These are done simultaneously with atmospheric drag slowing the vehicle as it descends. The high velocity of the vehicle results in a great deal of friction, which heats the vehicle to up to 3000°C depending on airflow. This necessitates highly temperature resistant shielding, usually ceramic or carbon based, that can withstand the temperatures and protect the rest of the vehicle as it descends. Modern designs also feature blunt noses and have the spacecraft descend belly-first, which ensures the majority of the vehicle is shielded. Without appropriate shielding, the vehicle will be unable to return, as recently seen in the 2004 Columbia space shuttle accident in which its heat shielding was compromised. Secondly, the angle of re-entry is critical. If the angle is too steep, the descent rate will be too fast, and the vehicle will encounter the higher density atmosphere closer to the Earth's surface while it retains too much of its velocity. Higher density air provides more drag, which therefore decelerates the vehicle faster and leads to higher temperatures. This will result in at the very minimum excess g-forces for the crew, and at worst, the extra heating could destroy the entire vehicle. On the other hand, if the angle is too shallow, the spacecraft will retain too much of its velocity and exit the atmosphere by effectively skimming it, returning to space. The vehicle must have an angle between 5.2 and 7.2 degrees to make a safe re-entry. During re-entry, the high temperature of the spacecraft results in the air around it becoming ionised. This results in an ionisation blackout, with the ionised air blocking radio communication with the ground during re-entry. Although not a direct hazard, it can cause complications in the event of a safety issue arising during re-entry which could endanger the spacecraft. Finally, in order to land, the descent rate must be slowed dramatically. In the Apollo missions and with non-reusable space probes, parachutes are used to slow the descent to make a gentle landing. The space shuttle uses wings to generate lift, enabling it to glide to a gentle landing.

Remember- To re-enter, you need strong heat shielding and an approach with a specific angle of descent.

1.3 Gravitational Force and Planetary Motion

1.3.1 Describe a gravitational field in the region surrounding a massive object in terms of its effect on other masses in it

A gravitational field provides a force on objects within it that drags objects to the centre of the field. The strength of the field is related to the mass of the object that produces it, with larger masses resulting in stronger fields. A massive object will have a strong gravitational field that will attract other masses near it. If these masses have little or no tangential velocity, they will be dragged into the massive object. If they have some degree of tangential velocity, they will be pulled into orbit, or they will have their trajectory through space altered by the massive object with the force acting on the object pulling it towards the massive object.

Remember- A massive object has a gravitational field that drags other masses towards it.

1.3.2 Define Newton's Law of Universal Gravitation

Newton's Law of Universal Gravitation provides a formula by which the force exerted by gravity in a field can be calculated based on the masses involved and the distance between them. Gravitational force is equal to the multiple of the masses of the two objects, divided by the distance between them squared, then multiplied by the gravitational constant. $F = \frac{Gm_1m_2}{d^2}$. This formula serves to calculate the force experienced each of the bodies- however, the body with the larger mass will be less affected, because according to, $F = ma$ if F is constant and m is large, then acceleration must be small.

Remember- Universal gravitation calculates the force experienced by each of the objects, and is experienced by both of them equally.

1.3.4 Present information and use available evidence to discuss the factors affecting the strength of gravitational force

There are numerous factors affecting the strength of gravity on Earth. Firstly, as the Earth spins it bulges at the equator, flattening at the poles. This causes the poles to be closer to the centre of the Earth than the equator. According to the formula for gravitation force, the force experienced depends on the distance from the centre of the field. This means that Earth's gravitational field is stronger at the poles than at the Equator. Secondly, the field of the Earth varies with the density of nearby geography. Places where the lithosphere is thick, or where there are dense mineral deposits or nearby mountain experience greater gravitational force compared to places over less dense rock or water. Thirdly, as gravitational force depends on altitude, places with greater elevation such as mountain ranges experience less gravitational force, than areas at or below sea level. Finally, and more generally, gravitational force also depends on the mass of the central body, so that planets or bodies with less mass have weaker gravitational fields and therefore weaker gravitational force.

Remember- The Earth's gravitational field is changed by distance from the equator, altitude, and lithosphere composition.

1.3.5 Discuss the importance of Newton's Law of Universal Gravitation in understanding and calculating the motion of satellites

In order to launch a satellite, the orbital velocity required must be known. As outlined previously in 1.2.10, the centripetal force acting on a body in orbit must be equal to the force that gravity exerts in order to keep the body in orbit. This means

$$F_c = F_g$$

and therefore

$$\frac{Gm_pm}{r^2} = \frac{mv^2}{r}$$

where m_p is the mass of the planet, and m is the mass of the satellite. Simplifying this expression yields

$$v = \sqrt{\frac{Gm_p}{r}}$$

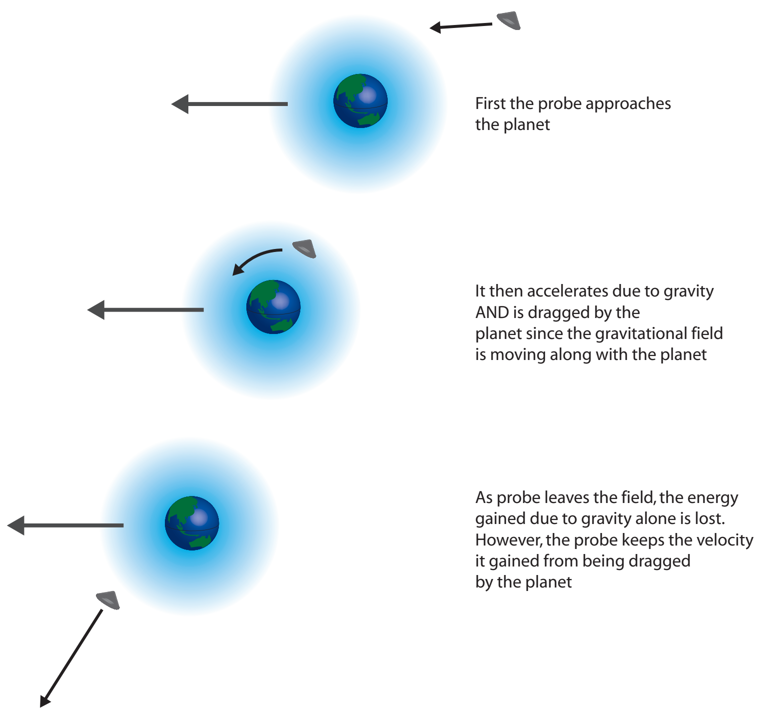
Since Newton's Law of Universal Gravitation is required to quantify the value of F_g in the derivation of orbital velocity (and indeed in any calculation involving gravitational field strength), it is therefore vital to understanding and calculating the motion of satellites. Further, Newton's Law can be used to derive Kepler's Law of Periods, an integral tool in understanding the motion of satellites in a given system. So although it is by no means a complete solution to understanding orbital motion, it is nonetheless an integral tool.

Remember- Newton's Law of Universal Gravitation is vital to mathematically modelling orbits, and was used to derive Kepler's Law of Periods.

1.3.6 Identify that a slingshot effect can be provided by planets for space probes

Note that some resources have the probe approaching the planet from the front, i.e. against the planet's orbital direction. This also provides the same slingshot effect, but it is harder to visualise and understand.

If trajectories are calculated carefully, space probes can use the motion of planets through space in order to increase the probe's velocity. In order to take advantage of the slingshot effect, the space probe approaches a planet in the same direction as the planet's orbital path i.e. it approaches the planet from behind. When the probe enters the field, the probe is accelerated. However, the field itself is moving at the same time, because the planet is moving. This additional momentum is also given to the probe, as the probe is effectively dragged by the planet. When the probe leaves the gravitational field, the momentum it gained simply by falling into the field is lost (since it is climbing up and out of the gravitational field). However, the momentum gained by the dragging effect is retained, boosting the velocity of the probe. This is the slingshot effect- using the motion of planets to accelerate space probes. Another application of the slingshot effect is the altering of trajectory. For a probe to travel to the outer planets, it must travel away from the sun. However, the energy required to leave the sun's gravitational field is immense. The probe's trajectory outwards is gradually curved into an orbital path by the sun's gravity. Using a variation of the slingshot effect, the probe can use a planet's gravitation field not to gain velocity, but to alter its trajectory away from the sun. Ordinarily this trajectory change would consume large amounts of fuel, but the harnessing of the motion of planets removes this need, as well as reducing the time taken for a probe to visit the outer planets.



Remember- The slingshot effect uses the movement of planets to change a space probe's speed or direction to help it reach outer planets.

1.4 Relativity and the Speed of Light

1.4.1 Outline the features of the aether model for the transmission of light

The concept that the aether is a stationary or absolute rest frame requires an understanding of frames of reference and relative motion. Scientists today agree that there is no absolute reference frame and the motion of objects can only be measured relative to other objects. In turn these other objects may be moving relative to still other objects. For example, a person on a train throws a ball. Relative to the train, the ball is travelling north at 5m/s. However, the train is travelling south at 20m/s, and so relative to a person on the Earth's surface next to the train the ball is travelling south at 15m/s. A person on an aircraft travelling north at 40m/s observes this same event, and sees that the ball is travelling south at 55m/s relative to him. An observer outside the solar system will see the ball's motion in light of the orbital motion of the Earth, and an observer outside the galaxy will see the ball's motion in light not only of the orbital motion of the Earth, but the motion of the Sun as it orbits around the centre of the galaxy. In this way it is impossible to "truly" determine an object's velocity in absolute terms- there is no one "correct" answer for the ball's velocity, and each of the observations made (in the train, outside the train, in the aircraft etc.) is equally valid. Previously, scientists thought that motion could be determined in absolute terms by measuring motion relative to the aether. Under such a model, the ball may be travelling west at 30m/s relative to the aether (an arbitrary figure) and this would be its true velocity. This is what is meant by the aether being a stationary frame, with all objects moving relative to it. This explanation is not part of the dotpoint and so is not necessary for an exam response. It exists only to clarify the meaning of "absolute rest frame".

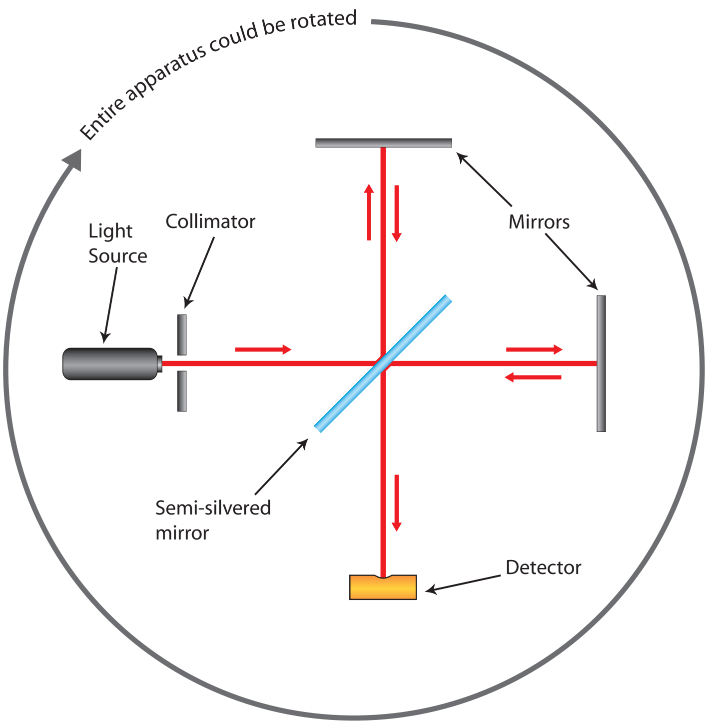
According to the aether model for transmission of light, light was a wave that propagated through a material called the "aether". According to the model, aether had no mass, could not be seen, heard or felt, and was distributed evenly throughout the universe residing between the particles that make up matter. Further, it was considered to be an absolute rest frame, meaning that the absolute motion of all objects in the universe could be measured relative to the aether.

Remember- The aether was invisible, without mass, existed at all points in the universe, is an absolute rest frame, and was the medium for light.

1.4.2 Describe and evaluate the Michelson-Morley attempt to measure the relative velocity through the aether

Be aware that the failure of the Michelson-Morley experiment to observe a changing interference pattern does not disprove the existence of the aether. All it does is question the theory and prove that either the theory or the experiment is flawed. Einstein subsequently interpreted this experiment as disproving the aether, but the experiment itself did not disprove the aether.

If the aether is stationary and the Earth is moving through the aether, then it follows that there is an aether "wind" that will affect the apparent speed of light to an observer on the Earth. The Michelson-Morley experiment was designed to analyse the aether wind, and thus calculate the velocity of Earth through space. A beam of light was split and sent into two directions at 90 degrees to each other horizontally by a half-silvered mirror. They were then reflected back and combined, such that both rays had travelled the same distance. This recombining process resulted in an interference pattern. The device was floated on liquid mercury, which enabled smooth rotation of the entire experiment. As the device was rotated, the aether wind was expected to cause the light to travel at different speeds in each direction, thus causing the interference pattern to change. The velocity of the Earth would be calculated by analysing the changing interference pattern. However, despite extensive testing, no change in the interference pattern was observed. This led to the conclusion that the aether model was flawed, which subsequently led to the conclusion that the aether did not exist. In terms of calculating the velocity of the Earth, the Michelson-Morley experiment was a failure, but its conclusion, based on results that were both valid and reliable changed scientific theory dramatically, making it one of history's most important experiments.



Remember- The Michelson-Morley experiment failed in its goal to determine the speed of the Earth through the aether.

1.4.3 Gather and process information to interpret the results of the Michelson-Morley experiment

The Michelson-Morley experiment was designed to calculate the velocity of the Earth through the aether, on the grounds that light would travel faster in certain directions and slower in others, due to the relative motion between the Earth and the aether. The Michelson-Morley experiment split a light beam, creating two beams at right-angles to each other, and after letting them travel for a short distance, recombined them. As the differences between the speed of light change when the device rotates, the interference pattern formed also changes as the phase difference between the two beams change. However, despite much repetition the experiment showed that light seemed to travel at the same speed in all directions, because the interference pattern formed never changed even when the orientation of the experiment was changed by rotating the apparatus. The experiment therefore provided a null result, neither disproving nor proving the existence of the aether. However, the results of the experiment could be taken in two ways- that the Earth wasn't moving through the aether, or that the aether model was flawed. Since the Earth was known to move, the Michelson-Morley experiment provided the final evidence that debunked the aether model for light transmission. Einstein interpreted the results of the experiment as confirming his theories as to the constancy of the speed of light, as well as the non-existence of the aether.

Remember- The Michelson-Morley experiment demonstrated that the speed of light on Earth was constant in all directions, significant evidence towards disproving the aether model.

1.4.4 Discuss the role of the Michelson-Morley experiments in making determinations about competing theories

The Michelson-Morley experiment produced startling results that in the end disproved the aether model for transmission of light and instead supported Einstein's model of light. At the time of the experiment there were two competing theories- the aether model in which light propagated through a stationary aether through which the Earth moved, and Einstein's model, part of which specifying that light travelled at a constant speed under all circumstances. The Michelson-Morley experiment showed that light travelled at a constant speed in all directions, and challenged the aether theory by showing that there was no aether wind. So the Michelson-Morley experiment provided pivotal evidence that determined the survival of competing theories as to the transmission of light.

Remember- The Michelson-Morley experiment helped prove Einstein's theory while debunking the aether theory.

1.4.5 Outline the nature of inertial frames of reference

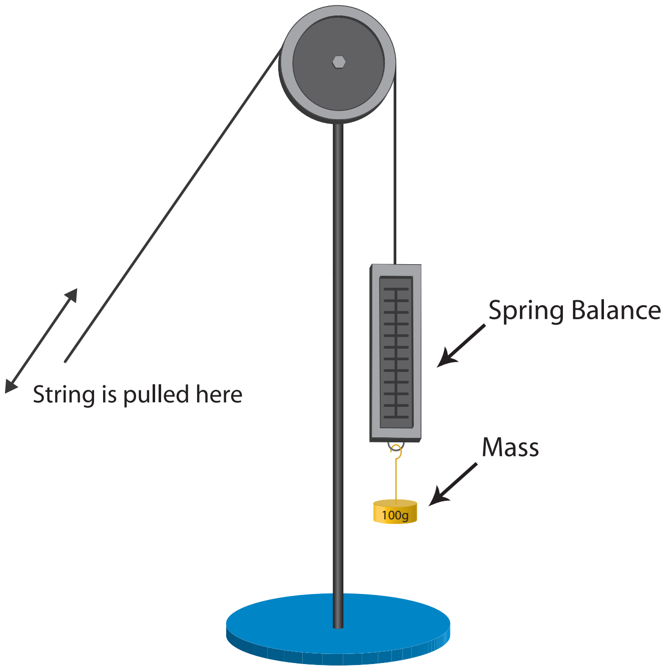
In terms of Newton's laws holding true, an inertial reference frame is one in which fictitious forces are not required to account for motion. For example, consider the rotating ride "Rotor" at Luna Park (Sydney), a ride where people are placed inside a rapidly spinning cylinder so that they are pinned to the sides of the cylinder. To an observer on the deck above, it is quite clear that the people inside the ride travel in a circular path because the walls of the ride exert centripetal force. However, an observer in the ride feels a force pressing them into the walls of the ride. To the person outside, this is simply their inertia pushing them against the wall. But to the observer inside, they may not even be moving- all the objects inside "Rotor" are stationary relative to them (as they are spinning along with the ride). Therefore, the fictitious force centrifugal force is pressing them against the wall of the ride. This force is fictitious because it does not exist as an "action" force in all inertial frames of reference- it exists in the frame inside Rotor but in the frame outside it is observed as a reaction force. Fictitious forces only exist in non-inertial reference frames, and so it can be concluded from this that the rotating cylinder in "Rotor" is non-inertial (which is true, as it is constantly accelerating because it rotates). Further, if the rider threw a ball straight into the middle of the ride, they would find that the ball would not travel in a straight line, disobeying Newton's laws, again showing that the laws only hold directly true in an inertial frame. This needn't be detailed in an answer- however, it is an important concept to understand. This answer has focussed on the use of the fictitious centrifugal force to show the difference between inertial and non-inertial frames of reference. For a more in-depth examination of centrifugal force itself, see the Extra Content chapter at the end of the Guide.

A frame of reference is essentially the environment from which measurements are taken by an observer. It can be a stationary room or a moving train. An inertial frame of reference is one in which no net force is acting, and in which all of Newton's laws hold true. No mechanical experiment or observation from within the frame can reveal if the frame is moving with constant velocity or at rest.

Remember- An inertial frame of reference is any frame that isn't accelerating.

1.4.6 Perform an investigation to help distinguish between non-inertial and inertial frames of reference

The experiment we carried out distinguished between non-inertial and inertial frames of reference by considering the definition of an inertial frame- one where all the laws of physics hold directly true and one which is indistinguishable from another inertial frame. In our experiment, we had a pulley with a string attached to a spring balance, holding a 100g weight. We took the apparatus as being an inertial reference frame when stationary- at that point the spring balance registered 100g. When we pulled the rope to cause the balance and weight to rise at a constant velocity, the spring balance still indicated 100g, showing that the constant-velocity frame was inertial. However, when we pulled the rope increasingly faster to cause the spring to accelerate upwards, it registered more than 100g, because according to $F = ma$, it was exerting extra force on the weight to cause it to accelerate upwards. Because this accelerating frame indicated a different value from the stationary 100g, we identified it as a non-inertial frame where the laws of physics do not directly hold true (in this case, because the 100g weight was indicated as weighing more by the spring balance while accelerating).



Remember- Spring balance with a pulley experiment, pulling the rope changed the reading on the balance.

1.4.7 Discuss the principle of relativity

Although some interpret this dotpoint as only covering classical Galilean relativity, it is useful at this point to consider Einstein's special relativity as well.

The classical principle of relativity was first explored by Galileo, and then developed upon by Newton, and states that no measurement made from within an inertial reference frame can be used to determine the velocity of that frame. This means that when within an inertial frame of reference, it is impossible to determine whether the frame is moving or not, unless measurements are taken involving observations outside the frame. For example, consider a train that is travelling at a constant velocity. From within the train, there is no observation that can be made to determine whether the train is stopped at a station (with a constant velocity of 0) or travelling at a constant velocity. This is because the train is an inertial frame of reference (so long as it is travelling at a constant velocity). The only way to determine the motion of the train is to make observations of other frames from within the train- for example, looking out of the window to the frame outside the train to see whether the train is moving or not. Effectively, this means that all inertial frames of reference are equal and equally correct- there is no such thing as an absolute rest frame against which all motion can be measured since all inertial reference frames are equal.

In 1905 Einstein devised his theory of special relativity. It was based on two key postulates- firstly, that the laws of physics are the same for all inertial reference frames (and by that it is meant that all inertial frames are equal and cannot be distinguished from another- there is no absolute rest frame) and secondly that the speed of light is constant for all observers. The idea that the speed of light is constant for all observers was extremely revolutionary because of its implications. Thought experiments, and subsequently physical experiments, showed that as observed velocity increases, time dilates, length contacts, and mass increases. Essentially, the principle of relativity states that nothing in the universe is constant except for the speed of light, and everything else is dependant on the relative movement between frames of reference. Although it was able to explain evidence (such as the Michelson-Morley experiment) and make predictions about the behaviour of light, this extremely revolutionary idea had little evidence to directly prove it when it was formulated. As a result, it took many years for the principle of relativity to become part of mainstream science.

Remember- No measurement from within an inertial reference frame can determine anything about the movement of that frame, all motion occurs relative to something else, and the speed of light is constant for all observers.

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1.4.8 Describe the significance of Einstein's assumption of the constancy of the speed of light

Einstein's key postulate was that the speed of light is constant for all observers. This means that whenever an observer takes measurements to determine the speed of light, the value calculated is always the same. However, in many cases Newtonian vector addition will increase the distance travelled by light as observed by a stationary observer. Under traditional vector addition, calculating the velocity by dividing distance by time would break Einstein's postulate resulting in a value greater than 3×10^8. The consequence and significance of the speed of light being constant is that mass, length and time change so that the speed of light can never be exceeded. This is extremely significant to predicting how objects behave at relativistic velocities.

Remember- The speed of light being constant is significant because it means mass, time and length all become variable.

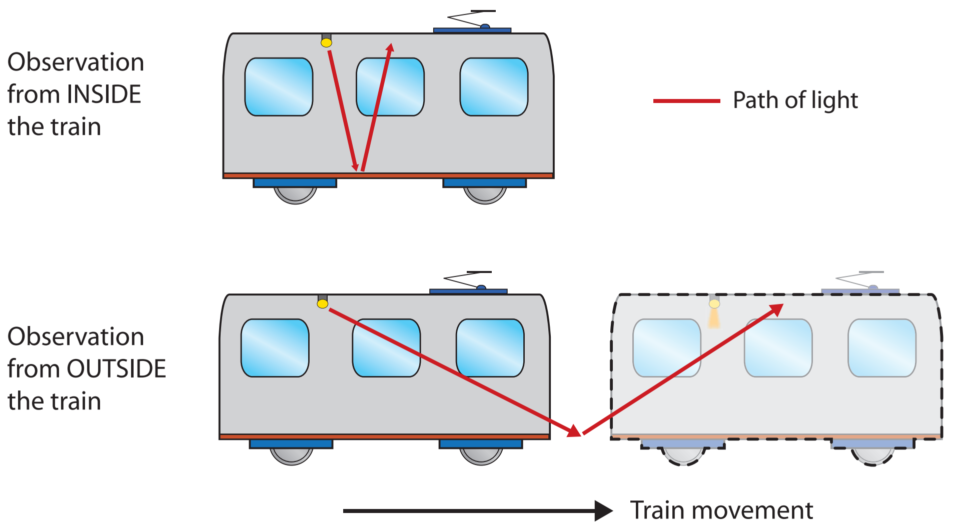
1.4.9 Analyse and interpret some of Einstein's thought experiment involving mirrors and trains and discuss the relationship between thought and reality

Make sure you understand everything in this dotpoint, and practice writing a response to this dotpoint. If you are not clear and concise, it's easy to not fully answer the question or to end up with an extremely long answer that wastes time in a test.

Einstein had two main thought experiments- looking at himself in a mirror on a train moving at the speed of light, and bouncing light from the roof to the floor and back in a moving train. Both these experiments showed that with conventional models such as vector addition, it would be possible for a stationary observer looking to the train to see light travelling faster than c. However, this ran against his principle of the speed of light being constant.

In the mirror thought experiment, Einstein wondered whether he would be able to see his face normally in a mirror held in front of him if the train was travelling constantly at the speed of light. He decided that he would be able to, because he was in an inertial frame and should have no way to determine he was moving at c. But with vector addition, a stationary observer would see light travelling away from Einstein's face at c, but as the train was moving at c as well, the observer would see light travel twice the distance in the same amount of time. Einstein's interpretation of this was that the time observed for light to travel that distance changed, so that a stationary observer would still see light travelling at c.

In the light bouncing experiment, light was seen to travel a longer path by an observer. Again, the interpretation was that time changes so that c remains constant. In terms of discussing the relationship between thought and reality, thought experiments can be valuable tools to "perform" experiments that cannot be performed in reality, such as a train moving at relativistic speeds, and to make meaningful conclusions as Einstein did. This makes them extremely useful tools. On the other hand, it is very easy to misinterpret thought experiments, either through flawed logic or failing to take account of other factors, possibly unknown to science that would affect an experiment in reality. So while they are very useful tools, they need to be used carefully when drawing conclusions.



Remember- The thought experiments were Einstein looking at a mirror on a train, and bouncing light from the roof of a train to the floor and back as observed by a stationary observer.

1.4.10 Identify that if c is constant then space and time become relative

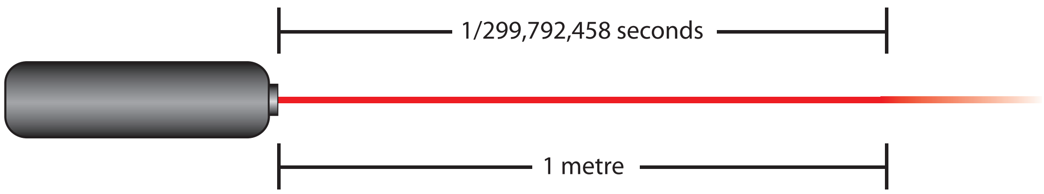
This is an identify dotpoint, and so requires very little detail. It would be better to study the previous dotpoint (1.4.9) as it goes into more detail about the impacts of the speed of light being constant.

In traditional physics, the behaviour of light had to adapt to the motion of the observer. With the speed of light being a constant under Einstein's theory, the dimensions involved in motion have to adapt to light. This means that space and time become relative to velocity so that c is always a constant.

Remember- When the speed of light is constant, space and time become relative.

1.4.11 Discuss the concept that length standards are defined in terms of time in contrast to the original metre standard

Originally, a metre was defined as $\frac{1}{10,000,000}^{\text{th}}$ of the circumference of the Earth, and then later as the distance between two lines on a platinum-iridium bar, which provided the standard measure of a metre. However, today the metre is defined as the distance light travels in $\frac{1}{299792458}$ seconds. This means that distance is calculated based on time- a unit of distance is measured in terms of how much distance light travels in a period of time. A light-year is another distance measured by time, and it is the distance light travels in one year.



Remember- One metre is the distance light travels in $\frac{1}{299792458}$ seconds.

1.4.12 Analyse information to discuss the relationship between theory and the evidence supporting it, using Einstein's predictions based on relativity that were made many years before evidence was available to support it

Ensure you memorise the evidence, and also make sure you can link it back to Einstein's theory clearly showing how the evidence supported the theory.

Einstein's key prediction that was made before available evidence was that space and time are relative to observed movement, and that the speed of light is constant. The consequences of this were that observed time could vary, so time is not constant. In 1971, the Hafele-Keating experiment took 4 synchronised atomic clocks, placed 2 of them on commercial airline flights, and flew them in opposite directions around the world. When later compared after circumnavigating the world, both the clocks showed less time had passed than the clocks on the ground, with differences of around 50 nanoseconds in an easterly direction, and around 270 nanoseconds in a westerly direction, which almost exactly matched up with Einstein's predictions.

Other experiments using muons found similar effects. The muon is a particle similar to an electron, but heavier. When stationary it has a half-life of around 2 microseconds, but when accelerated in a particle accelerator to speeds up to $0.9994c$, it was found their observed half-life was around 60 microseconds- confirmation of Einstein's theory. There is a distinct link between theory and evidence supporting it. No hypothesis can be considered a theory until there is evidence confirming that the hypothesis is correct. Therefore, Einstein's conclusions were merely predictions of what would happen at relativistic speeds and nothing more at the time he devised them, and his ideas only became theory later after evidence confirmed his ideas.

Remember- Longer muon decay in accelerators, and atomic clocks in aircraft circumnavigating the Earth.

1.4.13/1.4.16-1.4.21 Explain qualitatively and quantitatively the consequences of special relativity in relation to the relativity of simultaneity, the equivalence between mass and energy, length contraction, time dilation, and mass dilation

See the Formulae chapter for a comprehensive guide to quantitatively determining the effect of relative motion.

Relativity has many consequences. Among the most counter-intuitive ideas is the relativity of simultaneity- meaning that because of special relativity, events observed to be simultaneous in one frame may not be observed as simultaneous in another. Consider a train moving at a relativistic velocity (i.e. an appreciable portion of the speed of light, perhaps $0.5c$ or more). In the middle of a carriage is a light, and at either end of the carriage are doors with light sensors. When the light in the middle of the carriage is turned on, light travels to the doors, and the doors open as soon as their light sensors detect the light. To the person inside the train, both doors open at the same time because the distance to each door from the light source is equal. However, a person outside the train sees the doors opening as non-simultaneous. When the light turns on, the distance to each door is equal. However the observer from outside sees the train moving. This means that the light reaches the rear door faster than it reaches the front door (since the train is moving forwards, the front door is moving away from the point where the light was originally turned on). This illustrates the idea that simultaneity is dependant on the frame from which events are observed.

Mass and energy are linked by the formula $E = mc^2$, which shows the "rest energy" of an object and also the amount of energy released if matter is destroyed and converted to pure energy. There are several equations that together govern the mathematics of simple relativistic effects:

$$L_v = L_0\sqrt{1 - \frac{v^2}{c^2}} \quad (1.1)$$

$$T_v = \frac{T_0}{\sqrt{1 - \frac{v^2}{c^2}}} \quad (1.2)$$

$$M_v = \frac{M_0}{\sqrt{1 - \frac{v^2}{c^2}}} \quad (1.3)$$

Length contraction means that as observed velocity increases, length appears to contract in the direction of movement according to (1.1). Time dilation means moving clocks appear to run slower as observed velocity increases, according to (1.2). Mass appears to increase as observed velocity increases according to (1.3). All of these observations are true only when the frame being observed and the frame of observation are both inertial reference frames. Note also that these changes are actual changes in the properties of space-time. Moving clocks appear to run slower because in the moving frame, time is actually elapsing at a different rate to time in the frame from which the observation is being made.

Remember- $\sqrt{1 - \frac{v^2}{c^2}}$ *is the correction factor, and as relative velocity increases length gets shorter, time gets slower, and mass gets bigger.*

1.4.22 Discuss the implications of mass increase, time dilation and length contraction for space travel

Be very careful regarding the implications of time dilation. According to the twin paradox outlined by Einstein, the paradox exists because the other twin will appear younger for each of the twins. However, according to Einstein's theory of general relativity the non-accelerated frame takes precedence, and so the twin on the spacecraft will actually be younger.

Relativistic effects have several implications for space travel. Mass increase shows that as speed increases towards c, mass increases up to infinity. What this means is that as a spacecraft gets faster, its mass increases and its acceleration progressively decreases. While acceleration never gets to zero, because mass increases a spacecraft can never travel at the speed of light. Time dilation means that astronauts in a relativistic spacecraft will age slower than people back on Earth, which means that they can effectively live longer during relativistic flight compared to a stationary observer, who will pass away well before the astronaut. Finally, length contraction means that as a spacecraft speeds up, the apparent distance to objects ahead of it decreases. This means that trips on a relativistic spacecraft will appear to cover less distance to observers in the spacecraft.

Remember- Conventional spacecraft can never travel at the speed of light, astronauts will age more slowly, and trips will appear to cover less distance from within the spacecraft.

Chapter 2

Motors and Generators

"Genius is one percent inspiration, ninety-nine percent perspiration" -Thomas Edison

"If Edison had a needle to find in a haystack, he would proceed at once with the diligence of the bee to examine straw after straw until he found the object of his search. I was a sorry witness of such doings, knowing that a little theory and calculation would have saved him ninety percent of his labour" -Nikola Tesla

2.1 Current-carrying wires and the Motor Effect

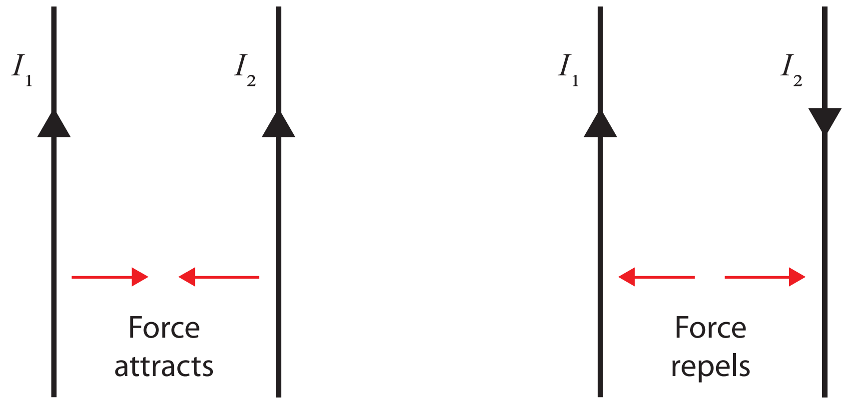
2.1.1 Discuss the effect on the magnitude of the force on a current-carrying conductor of variations in the strength of the magnetic field in which it is located, the magnitude of the current in the conductor, the length of the conductor in the external magnetic field and the angle between the direction of the external magnetic field and the direction of the length of the conductor

All of these variables can be summarised by the formula $F = BIlsin\theta$. When the strength of the field increases, so does force. When magnitude of the current is increased, and when the length of the conductor is increased, force increases. As far as angle goes, force is at a maximum when the angle is 90 degrees with the conductor perpendicular to the field, and force is zero when the conductor is parallel to the magnetic field.

2.1.3 Describe qualitatively and quantitatively the force between long parallel current carrying conductors

You may want to model this yourself by using the right-hand grip rule to determine how the magnetic fields in each wire interact to cause them to attract. Essentially, the wire on the right side has a magnetic field running upwards through the other wire. Then use the right hand palm rule to work out the direction of force.

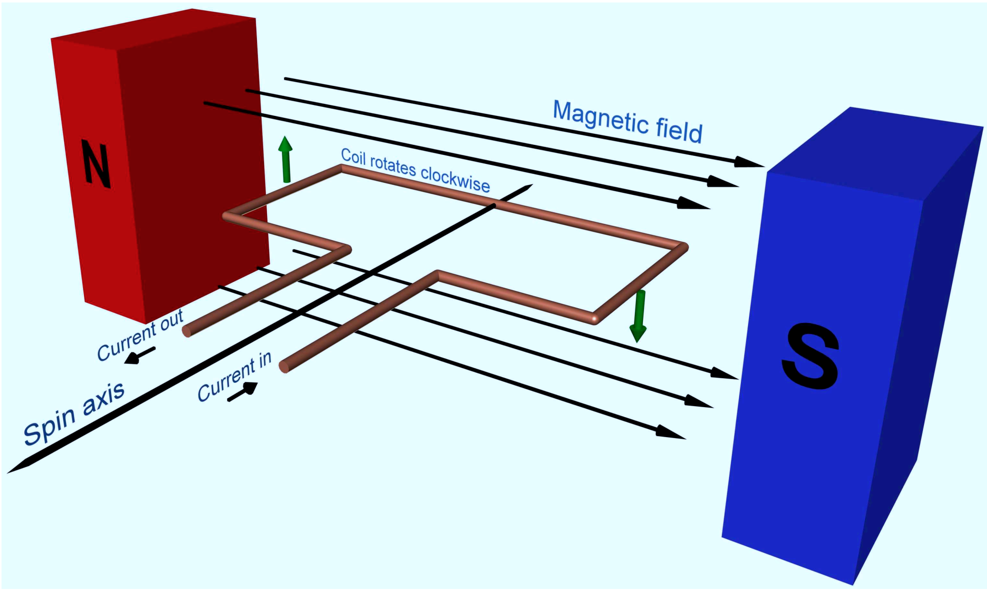
The force between parallel current carrying conductors depends on the direction of current flow. If current flow is in the same direction, then the wires will attract. If it is in opposite directions, then the wires will repel. The formula is $\frac{F}{l} = \frac{kI_1I_2}{d}$ and shows that as length and currents increase, force increases, and that as distance increases, force decreases in a linear relationship. This follows from the formula $B = \frac{kI}{d}$ which calculates the strength of the magnetic field produced by a conducting wire with current I, at distance d from the wire.



Remember- Wires with current flowing in the same direction attract each other.

2.1.5 Describe the forces experienced by a current-carrying loop in a magnetic field and describe the net result of the forces

A current carrying loop will experience force due to the motor effect. Perpendicular sides of the loop have current moving in opposite directions, so they experience opposite forces. If the coil is able to pivot around its centre, one of the sides will experience an upward force, and the other will experience a downwards force. Because of the structure of the loop, each of the sides produces torque, as they experience a force acting tangentially to the pivot point when the loop is horizontal. This causes the loop to rotate.



Remember- Opposite sides of the loop with have current flowing in opposite directions, so they experience opposite force, so the coil rotates.

2.1.6 Perform a first-hand investigation to demonstrate the motor effect

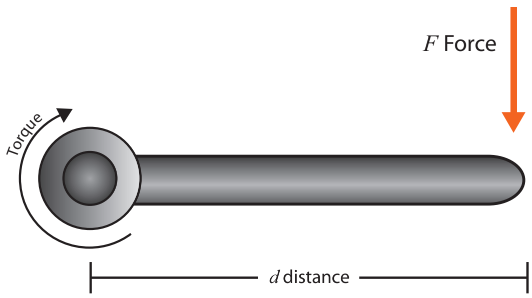
In our experiment, we had a wire sitting on a piece of wood. Magnets on either side of the wood set up a magnetic field passing through the wire, with the field lines perpendicular to the wire (in the horizontal plane). When we passed a current through the wire in the correct direction (according to the right-hand palm rule) the wire jumped upwards, due to the motor effect where moving charge in a magnetic field experiences force. The setup could only be used intermittently, because there was no load in the circuit. This meant large currents flowed through the wire, and operation for more than a few seconds caused dangerous overheating and the power supply to shut down.

Remember- The experiment made a wire jump up due to the motor effect.

2.1.7 Define torque as the turning moment of a force using $T = Fd$

Broadly speaking, there are 2 forms of motion. The first is linear motion, which occurs when an object travels through space. Examples of this include the motion of a ball as it is thrown, or the motion of the Earth around the sun. In both cases, the spatial position of the object changes. The second form of motion is rotational motion, which occurs when an object spins. Examples of this include the spinning of a CD in a drive, or the rotation of a fan. In both these cases, the objects are not moving through space but instead remain stationary while they rotate (the spinning of car wheels is also an example of rotational motion, but in that case the wheels also have a component of linear motion as they are moving through space with the car). Linear motion occurs when a linear force is applied to an object, for example when something is pushed or pulled. Rotational motion occurs when a rotational force is applied to an object, such as when it is twisted. The difference between the two is subtle. Linear force is a vector with both magnitude and direction. When a linear force is applied directly in line with an object's centre of gravity, then the object will travel through space without rotating. However, if a linear force is applied off centre, some distance away from the object's centre of gravity, then in addition to moving through space the object will also rotate around its centre of gravity. The rotational force that has been applied to cause the object to rotate is equal to Fd, where F is the magnitude of the linear force, and d is the distance between the point at which the force is applied and the object's centre of gravity. For simplicity, linear force is referred to simply as force, while rotational force is referred to as torque.

Torque can be considered the turning force on an object. It occurs when a force is applied to an object tangentially rather than straight at it. The torque depends on the force and the perpendicular distance from the pivot point, which is equal to Fd.



Remember- Torque is rotational force.

2.1.9 Identify that the motor effect is due to the force acting on a current-carrying conductor in a magnetic field

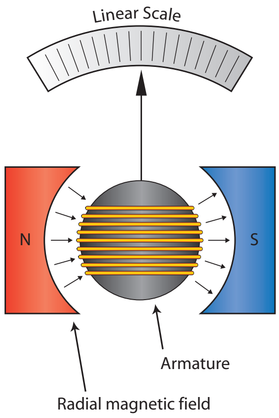
The motor effect is caused by the moving of electrons in a magnetic field. When placed in a magnetic field, moving charge experiences a force. This force is dependant on the direction of the field. When charge is moved through a wire, the wire experiences a force. This force is what constitutes the motor effect- the conversion of moving electric charge in a magnetic field into kinetic energy.

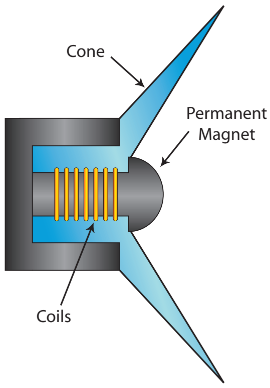
Remember- Moving charge in a magnetic field experiences force, and this can be used to move a conductor with electrons moving through it.

2.1.10/2.1.11 Identify data sources, gather and process information to qualitatively describe the application of the motor effect in the galvanometer and the loudspeaker

Make sure you can comprehensively and clearly describe how the galvanometer and loudspeaker work, and ensure that you explain how the motor effect is used in these applications.

The galvanometer and the loudspeaker are two devices which rely on the motor effect for their operation. The motor effect is where moving charge in a magnetic field experiences force, and leads to wires carrying current in a magnetic field experiencing force. In a loudspeaker, a solenoid is immersed in a static magnetic field. The solenoid is free to move as it is alternately attracted and repelled by the permanent magnet. This movement occurs because when current is passed through the solenoid, it causes the solenoid to experience force. This force moves the solenoid in motion that corresponds to the current being fed into it. If the current being fed in corresponds to an audio wave, the solenoid will oscillate in the same way as the audio wave. Because the solenoid is connected to a large cone, the solenoid causes the cone to vibrate as it moves. These vibrations result in the formation of pressure waves in the air, which are heard as sound. So the operation of a loudspeaker depends on the motor effect to move the solenoid, converting electrical energy into sound energy.





In a galvanometer, a coil of wire is wrapped around an iron core onto which is attached a needle. This entire assembly is free to rotate. A stator consisting of permanent magnets produces a radial magnetic field immersing the solenoid. The iron core is used to direct and intensify the magnetic field. When current is passed through the solenoid, a force results from the motor effect. Torque is thus produced, the same as in a motor, and causes the solenoid and the needle to rotate. Because a radial magnetic field is used, the torque produced is constant regardless of how far the coil is deflected. However, the galvanometer also incorporates a spring that is attached to the solenoid. The solenoid compresses the spring as it rotates, and in this way the solenoid rotates up until the torque experienced by the solenoid is fully countered by the spring. Because a radial magnetic field is used, the coil experiences constant torque. Further, the force exerted by the spring also increases linearly (using the formula $F = -kx$ which is outside the scope of the syllabus, where k is a constant describing the properties of the spring, and x is the degree to which it is compressed). Because torque and spring force scale linearly with current, a linear scale can be developed linking current to coil rotation. As the coil is connected to a needle, this setup can be used to assess how much current is flowing through a circuit.

Remember- A loudspeaker uses the motor effect to move the cone, and a galvanometer uses the motor effect and a radial magnetic field to measure current through the strength of the motor effect.

2.1.12 Describe the main features of a DC electric motor and the role of each feature

Direct Current (DC) motors consist essentially of 3 parts- the stator, the armature, and the commutator. In order for the motor effect to occur, a magnetic field is required. The stator consists of permanent magnets or coils of wire that produce a magnetic field that runs through the centre of the motor. The stator does not move during the operation of the motor, and is arranged around the armature which is at the centre of the motor. The stator provides a magnetic field that immerses the armature. The armature consists of loops of wire wrapped around a ferromagnetic core that experience a force when current is passed through them in the presence of a magnetic field. The armature is free to rotate, and is connected to whatever the motor is driving. The commutator is attached to one end of the armature, and is the means by which electricity is passed into the armature. It consists of a ring shaped conductor that is split into two parts, each part connected to one end of the coil that makes up the armature. Brushes on either side are connected to the circuit, one positive, one negative. Current flows through one of the brushes, into the commutator, then through the armature, back to the commutator, and out into the rest of the circuit via the other brush. The role of the commutator is to reverse the direction of current in the armature every half-turn. This causes the force experienced by the armature to reverse, and ensures that the torque experienced by the armature always occurs in the same direction.

Remember- Stator, armature, commutator, brushes.

2.1.13 Identify that the required magnetic fields in DC motors can be produced by current-carrying coils or permanent magnets

In order for a DC motor to operate, the armature must be immersed in a magnetic field. This allows moving charge in the armature to generate force. How this magnetic field is generated however, is immaterial. Permanent magnets as well as current-carrying coils can provide this field. Moving charge produces a magnetic field, and so current carrying coils can produce magnetic fields similar to those produced by bar magnets. This principle can be used to generate the field in a DC motor, just like with permanent magnets. If electromagnets are used, the wire is usually wrapped around an iron core to increase the strength of the field.

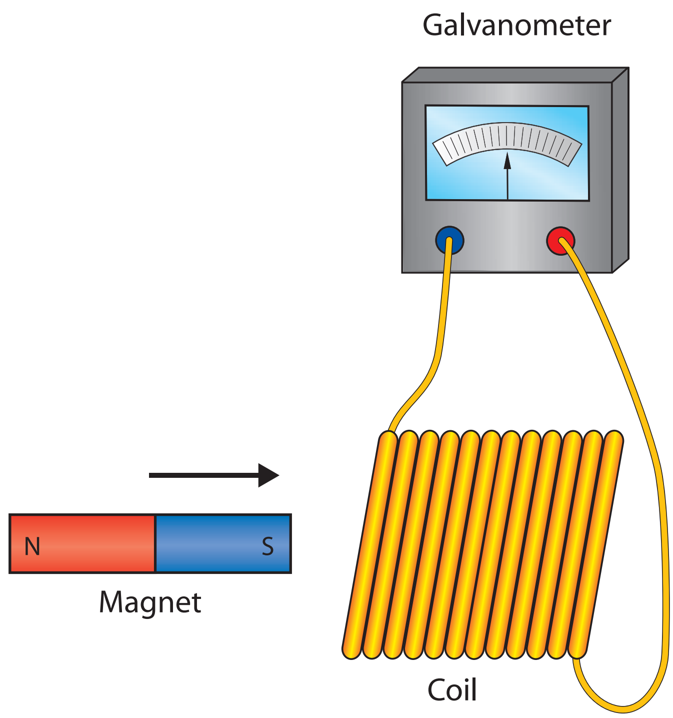
Remember- A DC motor needs a magnetic field, and this can be provided through either current-carrying field coils or through a permanent magnet.

2.2 Induction and Electricity Generation

2.2.1 Outline Michael Faraday's discovery of the generation of an electric current by a moving magnet

Note that Faraday's experiment is virtually identical to the prac performed below (2.2.2/2.3.5).

Following Oërsted's discovery that moving charge produced a magnetic field, Faraday wondered if the reverse was true- if a moving magnetic field could produce electromotive force (EMF). Faraday initially assembled a crude transformer, running a current through a primary coil and checking for current in a secondary coil that was immersed in the magnetic field produced by the primary coil. Faraday found that when the primary coil was connected and disconnected to a battery, the galvanometer needle moved slightly, but the effect was only momentary. Faraday then took an iron ring and wound a wire around it. When he moved a magnet in and out of the ring, a galvanometer showed a constantly changing current. From this, Faraday concluded that a moving magnet could be used to generate electric current.



Remember- Faraday built a DC transformer, but it did not work as transformers require AC current for operation. He then moved a magnet in and out of a wire loop and detected a current.

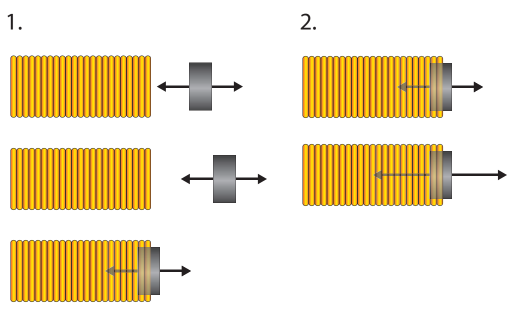
2.2.2/2.3.5 Perform an investigation to model the generation of an electric current by moving a magnet in a coil or a coil near a magnet (including "Plan, choose equipment or resources for, and perform a first hand investigation to demonstrate the production of an alternating current")

Note that this experiment addresses two dot points- creating an electric current by moving a magnet, and producing an alternating current.

In this experiment, we moved a magnet into a hollow coil. The coil was a length of thin wire wrapped around a cardboard cylinder, with around 200 turns. The coil was connected to a galvanometer so that current passing through the coil would be detected. We attached a strong ceramic magnet to the end of a small wooden stick, and then moved the magnet in and out of the coil repeatedly. This causes the coil to experience changing flux, and therefore a current was induced, which was detected by the galvanometer. In this way we modelled the generation of an electric current. Further, because we moved the coil in and out, in both directions, the current produced was an alternating current. This was shown by the needle on the galvanometer oscillating between positive and negative readings, showing the current changing direction.

2.2.3 Plan, choose equipment or resources for, and perform a first-hand investigation to predict and verify the effect on a generated electric current when the distance between the coil and magnet is varied, the strength of the magnet is varied, and the relative motion between the coil and the magnet is varied

This experiment used the same setup as that described previously in 2.2.2/2.3.5, with a ceramic magnet on a stick being moved in and out of a coil attached to a galvanometer. To test the effect of distance, we moved the magnet with a constant amplitude and period, while changing the centre of motion. When the centre of motion was at the very edge of the coil, so that the magnet passed in and out of the coil, current flow was maximised. When the centre of motion was the middle of the coil, some current was produced but it was diminished, because the coil experienced less change in flux (since the magnet was inside the coil the whole time). When the centre of motion was outside the coil, induced current also dropped. Using a stronger magnet induced a larger current, and when we altered the relative motion between the coil and the magnet by changing the speed of the magnet, we found that the induced current was larger when the magnet was moved faster.



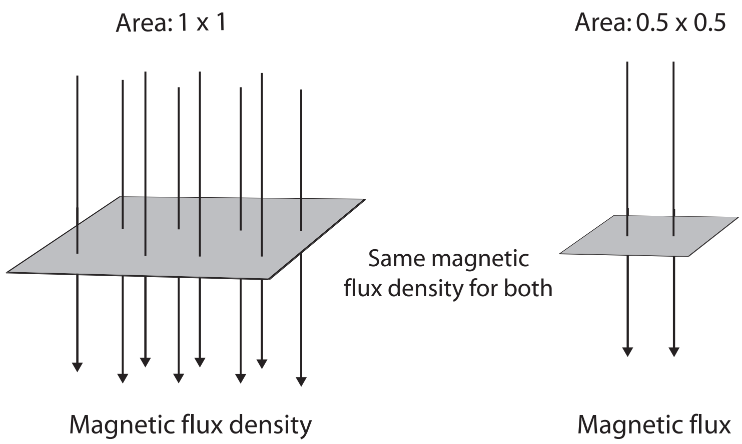
Remember- Current generation is maximised with the coil and magnet close together, with a strong magnet, and with a fast relative movement between the coil and magnet.

2.2.4 Define magnetic field strength B as magnetic flux density

Magnetic Flux Density is another name for magnetic field strength, which is measured in Teslas or in webers per square metre. It refers to how much magnetic flux is passing through a unit area.

2.2.5 Describe the concept of magnetic flux in terms of magnetic flux density and surface area

Magnetic flux density can be thought of as a measure of how many magnetic field lines pass through a square metre. Magnetic flux is a measure of how many magnetic field lines pass through a different area. It is found by multiplying the magnetic flux density by the area in question. So essentially, magnetic flux is a measure of the amount of magnetic field passing through an area.



2.2.6 Describe generated potential difference as the rate of change of magnetic flux through a circuit

According to Faraday, the voltage, the potential difference, or the emf (which all mean the same thing) is dependant on how fast magnetic flux is changed, that is, how quickly the amount of magnetic field passing through an area changes. According to Faraday's law, $\epsilon = -\frac{\Delta\Phi_b}{\Delta t}$, where $\Delta\Phi_b$ is the change in magnetic flux over time t. So the generated potential difference is essentially the rate of change of flux. The negative sign accounts for the direction of the induced emf, as explained in the next dotpoint (2.2.7/2.2.8).

2.2.7/2.2.8 Account for Lenz's Law in terms of conservation of energy and relate it to the production of back emf in motors

This is an important dotpoint that needs to be understood correctly. Make sure you thoroughly study this section and that you are able to clearly justify the existence of back emf. Also, make sure you practice writing explanations of Lenz's Law, because it is a concept that many students find difficult to understand.

Lenz's Law states that an induced emf always produces a magnetic field that opposes the change that produced it. This essentially means that when an induced emf is generated by moving a magnet, the induced emf will produce a magnetic field that exerts a force on the magnet in the opposite direction to the original movement of the magnet.

It comes about because of the law of conservation of energy. When a magnet is moved into a coil, the resulting current can flow in one of two directions. Each direction produces a magnetic field through the coil. This magnetic field can either attract the magnet further into the coil, or repel the magnet.

If the magnet was attracted, it would be sucked into the coil. This further movement would result in further change in flux, which would induce more emf. Effectively, the magnet would be sucked through the coil, generating energy.

However, this violates conservation of energy. If the magnet was sucked in, there would be energy output in the form of emf and charge movement, but there would be no energy input, no work done. This means that energy is being created, and according to conservation of energy, energy cannot be created nor destroyed.

So if the magnetic field induced by the magnet cannot attract it further into the coil, it must repel the magnet. In this case, in order to continue energy production the magnet must be forced into the coil- this kinetic energy input is then converted into emf, obeying conservation of energy. This gives rise to the production of back emf in motors.

As shown before, moving charge in a magnetic field experiences force. This force causes the motor to turn, and the charge movement is as a result of the supply emf. However, by Faraday's law, changing flux induces emf. The rotating coils of a motor experience changing flux, and this causes a current to be induced in them.

According to Lenz's law, the direction of emf must oppose the original change that produced it. In this case, it means that if the motor is spinning clockwise, the induced emf applies a force in an anticlockwise direction, slowing the motor.

Now the movement of the motor is the result of supply emf, and the supply emf causes the motor to spin in a particular direction, either clockwise or anticlockwise. As the induced emf causes torque in the opposite direction, the direction of emf must be opposite to the supply emf, hence the induced emf in a motor is referred to as back emf.

Remember- In accordance with conservation of energy, back emf always opposes supply emf in a motor.

2.2.8 Explain that, in electric motors, back emf opposes the supply emf

As shown before, back emf is induced in a rotating coil as found in a motor. The back emf causes torque that opposes the movement of the armature. However, the initial movement of the armature is caused by the supply emf running through the circuit in a particular direction. As back emf produces force in the opposite direction to the supply emf, which caused the armature to rotate in the original direction, the back emf must act in the opposite direction to the supply emf, therefore opposing it. The effect of back emf opposing supply emf is to reduce the net emf, thereby reducing the current. This means that a motor spinning rapidly uses far less current than a stationary motor, since the spinning motor has induced back emf that reduces the current.

Remember- Motors generate an emf while they operate, which opposes the supply emf

2.2.9 Explain the production of eddy currents in terms of Lenz's Law

Eddy currents are formed when there is a change in flux and therefore induced emf, but no conducting path in which electrons can flow. In this case, rather then flowing around in a circuit the electrons flow around in a circle. This circular movement of charge is an eddy current. When there is a change in flux, emf is induced, and according to Lenz's Law this emf must oppose the original movement that created it. This means that the charge experiencing the field produces a force that opposes the original movement of the conductor. As the charge moves, it gradually forms into a circular flow of electrons. This circular flow of electrons produces a magnetic field that will repel the original magnetic field that induced the eddy currents.

Remember- Eddy currents form according to Lenz's Law.

2.2.10 Gather, analyse and present information to explain how induction is used in cooktops in electric ranges

Induction cooktops use electromagnetic induction to produce heat. Beneath the cooktop is an induction coil consisting of a solenoid placed horizontally (i.e. with circular coils lying horizontally). When alternating current (AC) is passed through the coil, a magnetic field is formed that is aimed straight up through the cooking surface. However, AC is fed into the induction coil, and this causes the magnetic field formed to constantly change. This means that when a saucepan or pot is placed above the induction coil, it experiences changing flux. This causes eddy currents to be formed in the pan, which results in the pan heating up due to electrical resistance. An induction cooktop is much more efficient at converting electrical energy to heat because the pan is heated directly, rather than indirectly.

Remember- Induction cooktops use induction from a coil beneath the cooktop to heat pans.

2.2.11 Gather secondary information to identify how eddy currents have been utilised in electromagnetic braking

Electromagnetic braking is mainly used in trains, where it can silently and efficiently slow down the train without the noise and wear and tear of conventional friction braking. With electromagnetic braking, an electromagnet is placed underneath the train. When turned on while the train is moving, it causes the metal rails below it to experience a change in flux. According to Faraday's law, this causes eddy currents to be induced in the rails. According to Lenz's law, these eddy currents must have a magnetic field that opposes that change which produced them. This means that the eddy currents that form repel the electromagnet as it moves, exerting a force opposite to the direction it is moving in. This is therefore a braking force, acting against the movement of the train. By inducing eddy currents in tracks, trains can slow down. The other advantage is that because emf is dependant on rate of change of flux, when the train is travelling quickly there is a greater production of emf than when it is travelling slowly. This means that electromagnetic braking is most efficient at high speeds which are when it is needed most, because it is at high speeds that the most noise and heat are produced by frictional braking, which also results in wear and tear on the braking system. Alternatively, a magnetic field can be applied directly to the wheels of the train by electromagnets placed near the metal wheels. This also provides a braking effect.

Remember- Magnets mounted on a train are used as electromagnetic brakes.

2.3 Generators and Transmission

2.3.1 Describe the main components of a generator

Refer to 2.5.1 for a description of the AC induction-style generators used in power stations

All generators consist of two parts- a stator and a rotor. The stator consists of magnets, either permanent magnets or electromagnets that are arranged around the centre of the motor, such that the magnetic field produced immerses the rotor. The rotor is the rotating part of the motor and is attached to a spinning energy source, for example a windmill or a petrol engine. The rotor consists of a coil that rotates in a magnetic field, so that it experiences changing flux and therefore has an induced emf. AC generators have slip rings, where a ring is connected to each end of the rotor wire. The rings rotate with the rotor, and current is passed to a circuit from the rotor by brushes that are in contact with the slip rings. A DC generator has a commutator identical to that found in a motor, so that the direction of emf is always the same. The commutator is a ring split into two parts, each part connected to one end of the rotor wire and in contact with brushes that connect the rotor to the circuit via the commutator.

Remember- Generators consist of a stator and a rotor. They also have either slip rings or a commutator.

2.3.2 Describe the differences between AC and DC generators

Bear in mind that the DC generator does not produce a constant current. The current in a DC generator also fluctuates because the rate of change of flux is not always constant. The key point is that DC always flows in the same direction.

AC generators produce alternating current that switches direction periodically, while DC generators produce a current that, while varying in magnitude, always flows in the same direction. This stems from the fact that AC generators use slip rings with brushes to transfer electricity from the rotor to a circuit, while a DC generator uses a split-ring commutator to reverse current direction every half-turn.

Remember- DC generators produce current that always flows in the same direction, and they use a commutator instead of slip rings

2.3.3 Compare the structure and function of a generator to an electric motor

In terms of structure, standard AC motors and generators are identical, and DC motors and generators are identical. They consist of the same parts connected in the same way. The difference between them lies in function. The role of a motor is to turn electrical energy into kinetic energy, and the role of a generator is to convert kinetic energy into electrical energy. In a motor, electrical energy is fed in, in a generator, electrical current is extracted. A motor is connected to an object that the operators wants to rotate (such as wheels), while a generator is connected to a rotating object (such as a steam turbine). Essentially, motors and generators have the same structure but function in opposite directions.

Remember- Motors and generators have the same structure, but perform opposite tasks.

2.3.4 Gather secondary information to discuss advantages/disadvantages of AC and DC generators and relate these to their use

AC and DC generators produce electricity that is very different, and so each has its own advantages and disadvantages.

AC generators have several advantages, including the ability for the output voltage to be changed easily, as well as greater durability because slip rings encounter less wear and tear than a commutator. On the other hand, the output from an AC generator needs to be constantly shielded so that energy is not lost to the environment by induction (as AC current is always fluctuating, and therefore causes changing flux around the wire). Also, wires carrying high voltages are subject to arcing, and so are more dangerous to their surroundings. Stronger insulation is required compared to DC generated power.

DC generators have the advantage of producing electricity that doesn't induce emf in its surroundings, so less insulation and separation is required, as well as the fact that DC cable insulation can be lighter and therefore cheaper. However, the commutator in a DC generator is subject to wear and tear and is more prone to breakage. The commutator also undergoes sparking as it rotates, leading to further power loss and additional wear and tear. Since DC generators tend to produce low-voltage high-current electricity, a great deal of energy is wasted in power lines as heat.

Further, it is extremely difficult to change the voltage of DC power, which means it is difficult to reduce losses in transmission. These advantages and disadvantages mean that AC generators are used for large scale power generation where power is transmitted long distances, while DC generators are used for small-scale applications such as generators in vehicles.

Remember- AC can have its voltage transformed and can be transmitted efficiently, but it can also cause unwanted induction. It is hard to change DC voltage, and DC often has high current, but it is useful in small applications because induction is less of a problem.

2.3.6 Discuss the energy losses that occur as energy is fed through transmission lines from the generator to the consumer

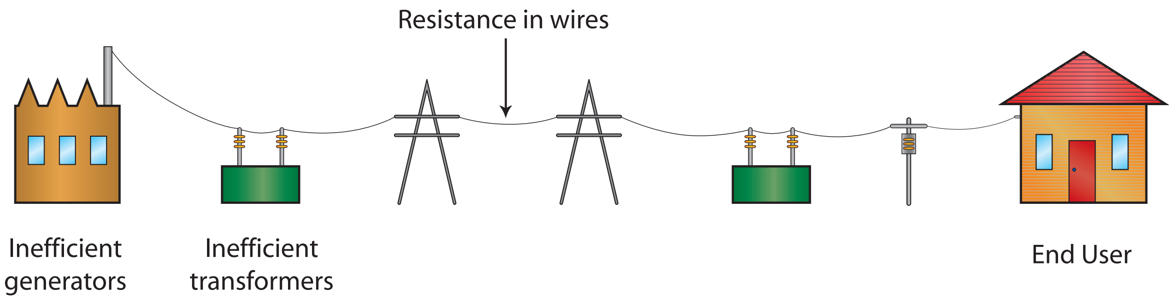
Don't forget to include relevant formulae in your answer to this dotpoint.

Moving electrical charge through a conductor wastes energy, because some of the electrical energy is converted to heat. The resistance of an object is essentially its capacity to convert electrical energy into undesired forms such as heat. This is because electrons collide with other atoms causing them to vibrate, resulting in heat, and in a loss of electrical energy. This is particularly problematic for power lines, because large amounts of electricity are passed through them for long distances. A portion of electricity passed through a power line is converted to heat, and this is how electricity is lost through transmission. The cost of lost energy can be very significant.

However, the formula $P = I^2R$ shows that the amount of energy lost (power consumed by the wire) is related to how much current is passing through the wire. By reducing the current, energy losses between the generator and the consumer can be minimised. This is done through the use of transformers, because transformers can be used to alter the voltage to current ratio without changing the total amount of energy.

From the generator, the voltage is stepped up by a transformer. According to $P = IV$, since the total power is constant, I must decrease when V increases. This means that the step up transformer produces electricity with low current, and this minimises heat losses through transmission lines. At the consumer's end, a step down transformer lowers the voltage so that it is appropriate for use by the consumer.

Further, there are additional losses in the transformer, largely due to induction producing eddy currents in the iron core. Not only is the induction of eddy currents inefficient because emf has been used to produce them, but the resulting eddy currents heat the iron core and therefore the transformer coils, increasing their resistance. These are dealt with firstly by laminating the iron core (see 2.4.5), and by using cooling fans to keep the transformer cool. In this way, transmission losses are minimised between the generator and the consumer.



Remember- Resistance in the wire causes heating, transformers are used to minimise current and thereby minimise energy loss.

2.3.7/2.3.8 Assess the effects of the development of AC generators on society and the environment

Make sure you cover the key points where AC had effects- transmission, economies of scale, the location of the generators closer to fuel and pollution moved outside the city.

AC generation and its ability to have its voltage changed by transformers has revolutionised society and had an environmental impact. The major problem with DC power was that it could not effectively be transmitted- as DC power could not have its voltage switched, large volumes of current had to be passed through wires, resulting in huge energy losses. This meant that DC generators would have to be close to consumers, and there would have to be many generators as the electricity could not be transmitted long distances. However, AC power can be transmitted long distances by altering its voltage. This meant that electricity generation could be shifted outside urban areas where consumers were located and instead located close to the natural resources required to run the generator, such as coal. This helped to bring down the price of electricity. Further, AC generation could be carried out on a large scale and then distributed over long distances to many people. This meant that economies of scale could be achieved, resulting in dramatically cheaper electricity as well as increased efficiency. This placed electricity within the reach of the majority of the population, rather than the rich, privileged minority who would have been the only people capable of affording electricity under a DC grid. Therefore, the uptake of electricity was rapid and widespread, dramatically changing society with its labour-saving benefits (although in some cases making unskilled jobs redundant- see 2.4.10).

In terms of the environment, by placing the generator away from the city, pollution levels in urban areas were reduced. Further, switching to electricity reduced the need to burn fuels in the home, further reducing pollution levels. So while coal was still burnt, and likely in greater quantities than before the uptake of AC generation, pollution was shifted away from urban areas and out into the rural areas where the generators are located, resulting in a cleaner urban environment. However, the pollution resulting from large-scale electricity generation is a significant contributor to global warming. Overall, AC generators dramatically changed society because they made the labour-saving benefits of electricity available to the majority of the population. While AC generators have resulted in a cleaner urban environment, they are still a large source of pollution and have a significant impact on global warming.

Remember- AC made electricity available to almost all the population, not just the rich people. However, it generated more pollution as electricity consumption rose. However, this pollution was not in cities but in other areas.

2.3.9 Analyse secondary information on the competition between Westinghouse and Edison to supply electricity to cities

Westinghouse and Edison were in direct competition to supply electricity to cities. Edison, who had invented appliances for DC power, planned out a DC power grid and advocated DC as a solution for powering cities. Westinghouse on the other hand owned the rights to the transformer and advocated AC power. The main problem with DC power was its inability to be transmitted- the furthest it could be sent at the time was 14km and that was with 38% of the energy lost to heat. Westinghouse's AC grid used transformers to slash losses to merely 1% by using high voltages unattainable with DC power to optimise transmission. Further than this, because of its inability to be transported, DC electricity would have to be generated by multiple generators throughout the city. This would have resulted in infrastructure difficulties in bringing fuel into cities, high levels of pollution, and more costly electricity because economies of scale could not be realised. Because AC power could be transported, it could be generated near the source of fuel on a large scale, resulting in much cheaper electricity. Edison temporarily achieved a propaganda victory by claiming AC power lines were unsafe, but the lines were kept out of reach and substations fenced off, and eventually the high efficiency and economies of scale made AC the victor.

Remember- AC could have its voltage changed, which made it easy to transport efficiently and generate on a large scale.

2.3.10 Gather and analyse information to identify how transmission lines are insulated from supporting structures and protected from lightning strikes

Power lines have two protective devices- insulation from supporting towers and protection against lightning strikes. In dry air, sparks can jump around 33cm from a 330kV source. This means that wires need to be held at least that far away from the supporting towers it is strung from. This is achieved by using disk-shaped ceramic insulators. The disks are stacked on top of each other, so that if it rains some of the disks remain and therefore do not conduct. Also, the disk shape means that current has a longer distance to traverse (since the current must go around the disks, instead of in a straight line), increasing safety. In terms of lightning, on power lines there is another single line strung at the very top of power poles, above the conducting wires. This wire is known as a shield conductor. In the event of a lightning strike, lightning hits points as high as possible, and so the shield conductor at the top will be hit instead of the lower conducting lines. The shield conductor is periodically earthed by having a connection to a wire that runs from the top of a power pole right down to the ground (known as an earth wire), so that lightning can travel from the sky to the ground via shield conductors rather than power lines. For high-voltage towers, the tower itself is taller than the height of the wires, so lighting will strike the top of the tower then travel down to the ground via the metal structure, thereby not interfering with the power lines.

Remember- Stacked ceramic disks isolate wires from towers, and a shield conductor above the transmission wires protects against lightning strikes.

2.4 Transformers

2.4.1 Describe the purpose of transformers in electrical circuits

A transformer is designed to change the voltage of electricity. Its purpose is to either step-up (raise) or step-down (lower) the voltage that is fed into it.

Remember- Transformers change the voltage of electricity.

2.4.2 Compare step-up and step-down transformers

Step-up and step-down transformers are almost identical. Both have an identical structure, with primary and secondary coils and an iron core. In both transformers, the number of turns in each of the coil varies, with one coil having more turns than the other. In a step-up transformer, the secondary coil has more turns than the primary coil. This results in a higher voltage output. In a step-down transformer, the secondary coil has less turns than the primary coil. This results in a lower voltage output. So essentially the difference between a step-up and a step-down transformer is whether the primary coil has more or less turns than the secondary coil.

Remember- Step-up transformers increase voltage, and step-down transformers decrease voltage.

2.4.3 Identify the relationship between the ratio of the number of turns in the primary and secondary coils and the ratio of primary to secondary voltage

The ratio between the ratio of the number of turns in the primary and secondary coils and the ratio of primary to secondary voltage is identical, according to the formula $\frac{V_p}{V_s} = \frac{n_p}{n_s}$.

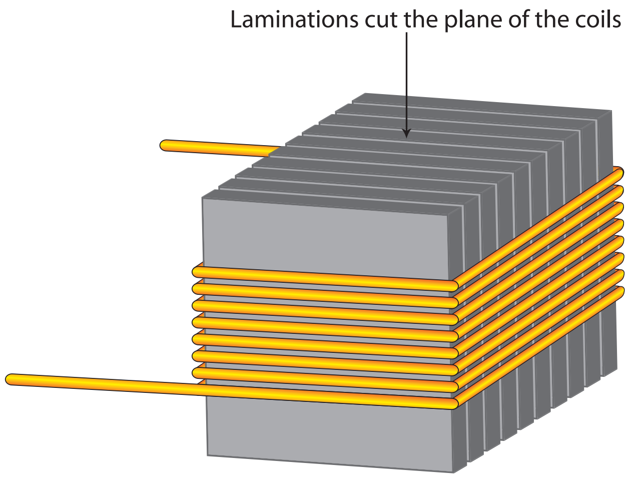
2.4.5 Gather, analyse and use available evidence to discuss how difficulties of heating caused by eddy currents in transformers may be overcome

Heating due to eddy currents isn't the only form of energy loss in transformers. Current in the coils causes them to heat up, increasing resistance. This heating is countered by the use of coolant to keep the coils conducting efficiently.

The founding principle of the transformer is the induction of current in the secondary coil because the secondary coil experiences changing flux. However, the iron core of the transformer also experiences changing flux, which induces eddy currents in the core, heating it up. There are two ways in which this can be addressed:

Firstly, instead of iron, ferrites, complex oxides of iron and other metals can be used. Ferrites are good at transmitting flux but poor at conducting electricity, so eddy currents and heating are minimised.

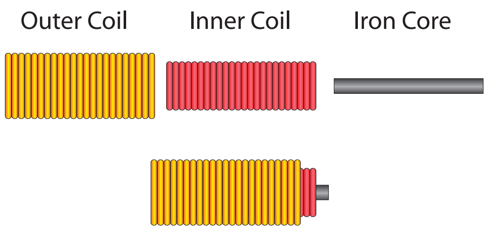
Alternatively, the iron core can be sliced into thin layers and then put back together with insulation between each layer. This process, known as lamination, breaks up large eddy currents and minimises them because currents can only form in each of the lamina. This means smaller eddy currents and therefore less heating. The laminations must not be in the same plane as the coils- instead they must "slice" this plane as thinly as possible to minimise eddy current formation.

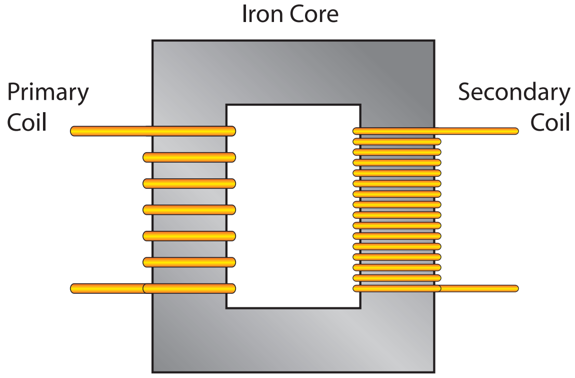


Remember- Laminations cut the plane of the coils to break up eddy currents.

2.4.6 Perform an investigation to model the structure of a transformer to demonstrate how secondary voltage is produced

In this experiment, we had a primary coil producing a changing magnetic field which was used to induce a current in a secondary coil. The setup consisted of a hollow coil that slid into the middle of a larger hollow coil. An iron core consisting of a solid iron rod fitted into the middle of the smaller coil. An AC power supply was connected to the primary coil, and a galvanometer was connected to the secondary coil. When we passed AC current through the large coil, the galvanometer detected current in the secondary coil, showing that induction was taking place. The iron core intensified the induction- when we removed the core the induced current dropped greatly in strength. This is because the iron core directs the magnetic field from the primary coil into the secondary coil, thereby increasing efficiency.





Remember- The primary coil induces a current in a secondary coil, the voltage is changed because they each have a different number of turns, and the iron core intensifies the effect.

2.4.7 Explain the role of transformers in electricity substations

Transformers are used in substations to step-up and step-down electrical energy for long distance transmission. At the generator, a step-up transformer at a substation raises the output voltage from 23kV to 330kV. This minimises losses during long distance transmission by reducing the current flowing through transmission wires. In substations located in urban areas, step-down transformers are used to reduce the voltage for transmission within cities or suburbs. So transformers convert voltages in substations to reduce losses when transmitting electricity.

Remember- Transformers are used in substations to change the voltage of electricity to minimise transmission losses.

2.4.7 Gather and analyse secondary information to discuss the need for transformers in the transfer of electrical energy from a power station to its point of use

Power losses in the transmission of electricity are largely caused by heating in transmission wires. The energy consumed is equal to I^2R (since the energy lost is the same as the power "used" by the wire, from $P = I^2R$), so it can be seen that power loss is dependant on the current flowing through the wire, as well as the wire's resistance. This heating is a huge problem, because it results in less energy reaching the point of use. However, transformers can be used to raise the voltage of electricity, and thereby reduce current. This dramatically reduces the power consumed by transmission wires, and thereby reduces wasted energy. Using transformers in the transfer of electrical energy from a power station to its point of use provides massive efficiency gains, reducing the fuel consumed by a power plant and reducing the price of electricity. Also, different devices require different voltages- computers and incandescent lights require much lower voltages than TV's and fluorescent lamps (which can require up to 10000V). Transformers are required to ensure each device is supplied with an appropriate voltage. However, high voltage power lines are subject to arcing and so need to be separated, as do substations which can be extremely dangerous for people nearby. Although transformers have dramatically increased the efficiency of electricity transmission, they have also produced safety concerns and have required specialised infrastructure to keep people safe.

Remember- Transformers are required for electricity transmission to reduce otherwise prohibitive losses.

2.4.8 Explain why voltage transformations are related to conservation of energy

According to conservation of energy, energy cannot be created nor destroyed, only transformed. Electrical energy is expressed as P, measured in watts. $P = IV$. Conservation of energy means that the energy in the secondary coil must equal the energy in the primary coil, so that $P_p = P_s$. This means $I_pV_p = I_sV_s$. Therefore, when voltage is changed in a transformer, the current then must also change so that P remains constant, according to conservation of energy. So when voltage is stepped up, current is reduced, and vice versa.

Remember- Voltage transformations are related to conservation of energy because the total power on either side of a transformer is the same.

2.4.9 Discuss why some electrical appliances in the home that are connected to the mains domestic power supply use a transformer

Many electrical appliances are designed to run on low DC voltages. This is particularly true of any device which uses a battery, because batteries are only capable of providing low DC voltages. The reason batteries are used is to provide portability- so that devices such as laptops and mobile phones can be moved around. Also, some circuits particularly those in computers, only function at low DC voltages- otherwise they would overheat and burn out. In these electrical appliances, a transformer is required, in addition with a rectifier, to convert household mains domestic power (240V AC) into low voltage DC for use in the appliance.

Remember- Home devices with transformers usually have low-voltage chips, or can run on batteries as well.

2.4.10 Discuss the impact of the development of transformers on society

The direct impact of transformers was to make AC power a viable solution. By allowing large scale generation from outside urban areas, the uptake of electricity was rapid. Therefore the impacts of transformers on society are the same as the impact of AC power, because the key impact of transformers was to provide efficient AC power distribution. Also see 2.3.7/2.3.8 on page 46

Transformers have had a significant impact upon society. The main reason AC power was successful over DC power was because the voltage could be changed to minimise transmission losses and dramatically slash losses in the electricity grid. These voltages changes were only made possible by the development of the transformer. It has resulted in the wide uptake of electricity and it helped lower the cost of electricity, making it accessible to almost everyone in economic terms. However, the widespread introduction of electricity made many unskilled jobs redundant and increased unemployment levels, which was detrimental to many people. Also, widespread demand for electricity led to large scale use of fossil fuels such as coal to power the generators, which has resulted in a great deal of atmospheric pollution in the form of sulfur and nitrogen oxides, as well as increased carbon dioxide levels which contribute to global warming. So transformers have had a huge impact on society, from bringing electricity into the reach of the broad public to indirectly causing environmental damage and social problems.

Remember- Transformers have led to the large scale uptake of electricity, with similar impacts to those described in 2.3.7/2.3.8.

2.5 AC Motors and Energy Transformations

2.5.1 Describe the main features of an AC motor

The AC induction generator used in large-scale power stations has a very similar structure to an AC induction motor. However, in an AC induction generator, the rotor is an electromagnet powered by a separate DC circuit, and the stator consists of 6 coils. A source of torque is used to rotate the electromagnet at 50 revolutions per second, which causes AC electricity to be generated in the field coils.

There are three types of AC motors- standard AC motors, universal motors and AC induction motors, and they each work differently. A standard AC motor is essentially identical to an AC generator, with a stator providing a magnetic field, a rotor that current is passed through, and slip rings connecting the rotor to a circuit. In addition, an AC motor usually has a fan to keep the rotor cool, a ferromagnetic core in the rotor to strengthen the magnetic field and it runs at 50 revolutions per second, the same as the frequency of AC power oscillation (50Hz). A universal motor is similar to a DC motor. It can operate on an AC or DC supply. Power is fed in, and runs through electromagnetic stators before entering a commutator. Each brush is connected to a wire that comprises one of the field coils, and is also connected to one end of a circuit. With a DC source, the commutator switches the current and the motor operates. With an AC source, although the direction of current being fed into the commutator is varying, the same variations are fed into the field coils, with the net effect that AC oscillation is cancelled out and the motor runs.

AC induction motors are entirely different. Induction motors have a rotor that is not connected to a power source- instead changing flux is used to induce a current in the rotor. This means that there is very low friction as the rotor is not actually in contact with the rest of the motor, and it also means there is very little wear and tear. AC induction motors have a more complicated stator with several field coil pairs. There are a total of 6 field coils, and each opposite pair is fed one phase of triple-phase AC power. This sets up a rotating magnetic field inside the stator. The rotor of an induction motor is generally similar to a squirrel cage (the type that allows pets to run endlessly), with two end rings and aluminium or copper bars linking the end rings to form a cylindrical shape. This cylinder is encased in a laminated iron armature so that the magnetic field passing through the rotor cage is intensified. As the field rotates, it induces current in the bars of the squirrel cage. This creates a force in the same direction as the rotation of the magnetic field, from Lenz's Law. The squirrel cage then rotates, 'chasing' the changing magnetic field.

Remember- AC motors have a stator, rotor and slip rings. They also use an iron core and usually a fan. A universal motor uses a commutator and has a magnetic field generated using field coils. AC induction motors have a stator with 3 pairs of field coils (for a total of 6), and a "squirrel cage" rotor.

2.5.2 Perform an investigation to demonstrate the principle of an AC induction motor

An AC induction motor relies on the principle that a moving magnetic field induces a current in the rotor with a direction that, according to Lenz's law, causes the rotor to spin in the same direction as the magnetic field. We demonstrated this principle by using a thin aluminium disk suspended by a string from a clamp on a retort stand so that the disk was free to rotate. To demonstrate the principle of an AC induction motor, we moved a strong ceramic magnet in circles around the circumference of the disk. The induced eddy currents caused the disk to rotate in the same direction as the magnet, thereby demonstrating the principle.

Remember- An aluminium disk was suspended by a string and rotated by moving a magnet.

2.5.3 Gather, process and analyse information to identify some of the energy transfers and transformations involving the conversion of electrical energy into more useful forms in the home and industry

Electricity is simply an easy way to transmit energy from point to point which enables energy to be collected and transmitted on a large scale. The advantage of electricity is not only that it is relatively easy to transport, but also that it is easy to convert it into other forms. In light bulbs, electrical energy is converted into light energy. In the home, it is also converted into heat in devices such as heaters and toasters, and into sound through speakers. In the industry electricity is most often converted into kinetic energy which drives machinery used in the production of goods. So generally electricity is converted into kinetic energy or electromagnetic radiation in the house and in industry.

Remember- All electrical devices convert electrical energy into other forms.

Chapter 3

Ideas to Implementation

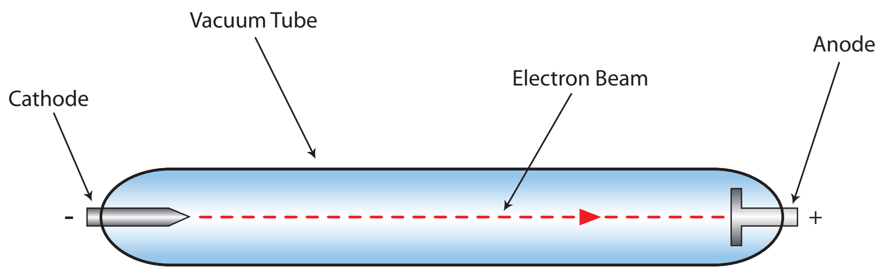
"A new scientific truth does not triumph by gradually winning over and converting its opponents- what happens is that the opponents gradually die out" -Max Planck

3.1 Cathode Rays

3.0.0 Describe cathode rays and cathode ray tubes

This is an additional dotpoint included to provide a quick general overview of what cathode rays are.

Cathode rays were first observed by Faraday in 1838, who noticed light emission from within the vacuum tube he was experimenting with. This led to the ongoing research into cathode rays that forms the majority of this HSC topic. A cathode ray tube is simply a vacuum tube with electrodes at either end. The electrodes are simply pieces of conductive metal, and have contacts outside the tube. When a high potential difference is applied to the tube, by passing high voltage electricity through the tube (by connecting the electrodes to a circuit), electrons jump from one electrode to the other, crossing the tube. This cannot occur in normal air because the high density of air molecules prevents the electrons from travelling large distances. However, this is not an issue in a vacuum tube. From this description, it is clear that cathode rays are in fact negatively charged electrons. The emission of light occurs when the electrons collide with particles inside the tube, causing the particles to emit light as they absorb and then release the energy carried by the electron (which is transferred to the particle in the collision). The appearance of the light, such as its shape and colour, is dependant on both the chemical composition of the gas inside the tube and on the gas pressure.



Remember- Cathode rays are the stream of electrons produced between electrodes in a vacuum tube.

3.1.1 Explain that cathode ray tubes allowed the manipulation of a stream of charged particles

Cathode ray tubes allowed the manipulation of a stream of charged particles in several ways. Firstly, and most importantly, cathode ray tubes are a source of a steady stream of charged particles, a prerequisite to their manipulation. The manipulation of charged particles can either be done remotely via electric and magnetic fields, or directly by obstructing the charged particles (examples include with thin metals, thick metals like the Maltese cross, and small paddlewheels). Cathode ray tubes enabled the manipulation of charged particles in both these ways. Obstructions could be placed inside the tube to block the cathode rays, and fields could operate within the tube by placing charged plates or field coils next to the tube. In this way, cathode ray tubes allowed the manipulation of a stream of charged particles.

Remember- Cathode ray tubes allowed the manipulation of charged particles because objects could be placed inside the tubes, and because fields could permeate the tubes.

3.1.2 Explain why the apparent inconsistent behaviour of cathode rays cause debate as to whether they were charged particles or electromagnetic waves

In a test you can write your answer in dot points.

Cathode rays had properties that could classify it as a wave or as a particle.

As a wave, they

- Travelled in straight lines
- Produced a shadow when obstructed by objects
- Could pass through thin metal foils without damaging them

As a particle, they

- Left the surface of the cathode at 90 degrees, not radiating like a wave
- Were deflected by magnetic fields
- Could turn a wheel in the path of the ray (i.e. they have momentum)
- Travelled far slower than light

The reason the debate ensued is because scientists wanted to determine the nature of cathode rays to the extent where they could classify it as a wave or particle, and the fact that cathode rays had conflicting properties made this very difficult. Crookes insisted it was a particle while Hertz maintained it was a wave. The debate was resolved when an electric field was used to deflect the rays by Thompson, which had been impossible up to that point because older vacuum pumps were not strong enough to remove enough air to make the effect visible, and because the electric fields that were used before were not strong enough. This evidence was strong because scientists knew it was impossible to deflect electromagnetic waves with an electric field, and since cathode rays were deflected this was taken as proof they were not electromagnetic waves, and were therefore particle streams.

Remember- Cathode rays had both wave and particle properties, and it wasn't until Thompson showed that they could be deflected with electric fields that the debate was resolved.

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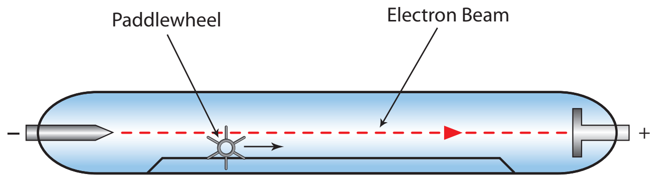
3.1.3 Perform an investigation to demonstrate and identify properties of cathode rays using discharge tubes containing a Maltese cross, electric plates, a fluorescent screen, a glass wheel, and analyse the information gathered to determine the sign of the charge of cathode rays

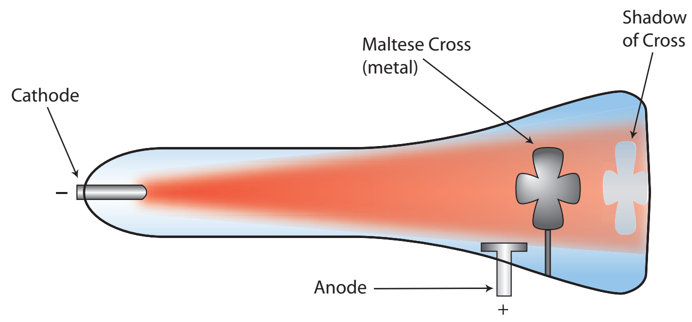
To perform this experiment we had several discharge tubes each with element from the list above.

The Maltese cross tube had an anode mounted on the base of the tube, underneath the Maltese cross which was situated between the end of the tube and the cathode. When cathode rays travelled from the cathode, they did so in a straight line, and were obstructed by the Maltese cross. This caused a shadow to be formed, showing that the cathode rays could be blocked relatively easily. Also, the shadow had a very sharp edge, indicating that diffraction was not occurring and that therefore cathode rays could be particles, not waves. The shadow also indicated that the cathode rays travelled in straight lines.

When electric plates were set up, the cathode ray beam was deflected. To perform this experiment, the tube had a curved screen set up inside it so that the horizontal path of the beam was visible. When we applied an electric field, we were able to bend the beam, showing the beam was electrically charged. As the beam deflected towards the positive plate, we determined the cathode rays to be negatively charged. We also deflected the beam with a magnetic field from a bar magnet.

Setting up a fluorescent screen in the path of the cathode ray beam caused it to light up as it was struck. This suggested that the cathode rays carried enough energy to produce the reaction in the screen necessary to produce light, a property exploited in many TVs and computer monitors. Lastly, when a glass paddlewheel was mounted inside the tube on runners so it was able to move, the cathode rays striking the wheel caused it to rotate and roll along the tube. The movement was away from the cathode, showing that the rays were emitted from the cathode. Through conservation of momentum, the fact that cathode rays could move a wheel by colliding with it strongly suggested that they had mass, and were therefore particles.



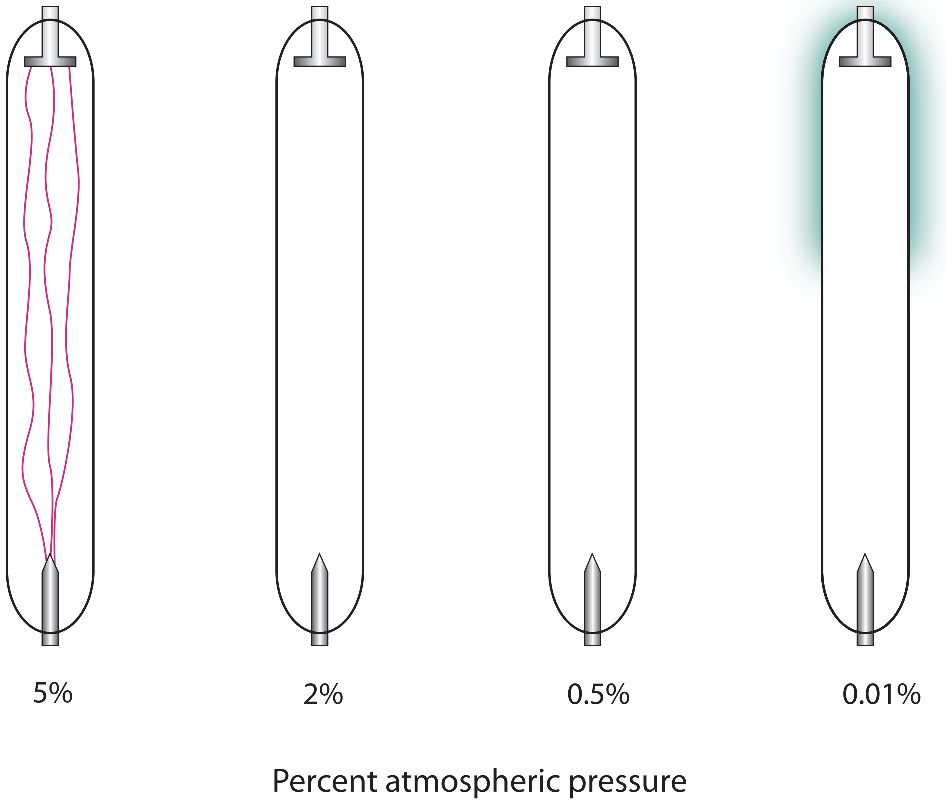


Remember- The negatively charged cathode rays were blocked by the Maltese cross, could spin a paddlewheel, caused a fluorescent screen to emit light, and were deflected by electric and magnetic fields.

3.1.4 Perform an investigation and gather first-hand information to observe the occurrence of different striation patterns for different pressures in discharge tubes

Most resources simply say 'less air' and 'still less air' when referring to the middle two tubes. Therefore, 2% and 0.5% are arbitrary figures here. Of course, the best option is to check when you're performing the experiment the pressure on the tubes (the pressures will depend on the exact tubes used, so there will probably be variation between schools etc.), but if you didn't, just remember the figures here.

Striation patterns refer to light and dark areas inside a discharge tube. Electrons colliding with air particles release light dependant on the energy of the electrons, but also on the amount of gas inside the tube. As the pressure of the gas changes, so too do the striation patterns. In this experiment, we had 4 discharge tubes each with different air pressures- 5%, 2%, 0.5%, and 0.01% (measured as a percentage of standard atmospheric pressure). With 5% air, glowing purple/pink streamers formed, extending all the way from the cathode to the anode. At 2%, the pattern changed to a series of alternating light and dark bands running perpendicular to the length of the tube. At 0.5%, the dark gaps between the lines widened (i.e. There were fewer lines), with the pink-purple glow concentrated around the anode, and a blue glow forming at the cathode. At 0.01%, there were no striations. Instead, the glass around the anode glowed yellow-green. The exact nature of the striation patterns varies depending on what gas is used eg. Normal air, hydrogen etc.



Remember- The striation patterns formed in a vacuum tube depend both on the gas inside the tube and on the pressure

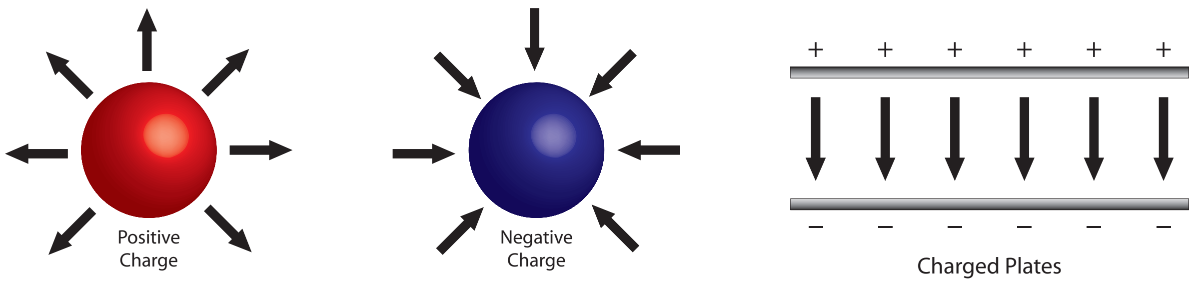
3.1.5 Identify that moving charged particles in a magnetic field experience force

See 3.1.9 for a mathematical description of the force on the particle.

When a moving charged particle travels through a magnetic field, it experiences a force related to its velocity and its direction of travel relative to a field. If the particle is travelling along with or parallel to field lines, there is no applied force. Maximum force is applied if the particle is travelling at 90 degrees to the field lines.

3.1.6/3.1.8 Discuss qualitatively the electric field strength due to a point charge, positive and negative charges and oppositely charged parallel plates

For a point charge, the electric field strength depends entirely on the magnitude of charge the object has. The field extends outward in all directions and so obeys inverse square law, rapidly diminishing as distance from the charge increases. For a positive charge, the field lines radiate outwards, indicative of the direction in which a positive test charge would experience force. For a negative charge, the field is identical except the field lines run in the opposite direction, pointing inwards to the point charge, indicative of the fact that a positive charge would be attracted to the negative charge. Oppositely charged parallel plates have a uniform field (in both direction and strength) running between them from the positive plate to the negative plate. Unlike a point charge where the direction of the electric field changes depending on where the field is being examined, the electric field lines between parallel plates always run in the same direction. Also, unlike a point charge where the field exists all around the point charge, the electric field from parallel charged plates only exists in between the plates. The spacing of field lines between the plates indicates field strength.



Remember- The field lines point away from a positive charge, towards a negative charge, and run from positive to negative between charged plates.

3.1.7 Identify that charged plates produce an electric field

See 3.1.9 for a mathematical description of the field between the plates.

Charged plates- that is, plates with a potential difference between them, produce an electric field running between them. The field lines run from the positive plate to the negative plate, are parallel, and the field strength is equal at all points between the plates. The field does not exist outside the space between the plates.

3.1.9 Describe quantitatively the force acting on a charge moving through a magnetic field, using $F = qvBsin\theta$ (including "Describe quantitatively the electric field due to oppositely charged parallel plates")

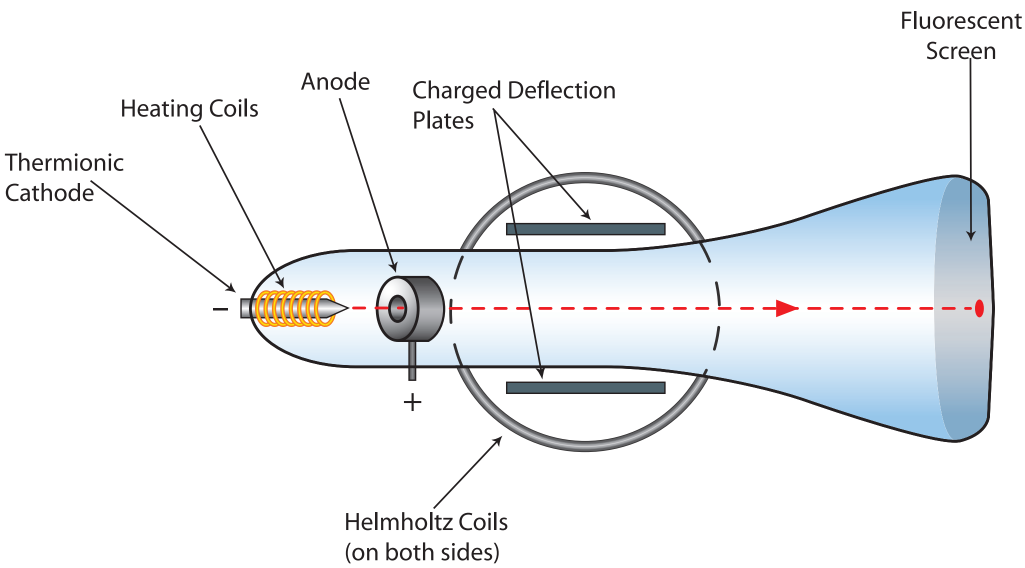
When a charged particle moves through a magnetic field, it experiences a force that is equal to $qvBsin\theta$. This shows that the force experienced by a charged particle depends on 4 things- its velocity, its charge, magnetic field strength, and the angle that it makes with the field. The right-hand palm rule is used to calculate the direction in which this force is applied. To make the force larger, all of these attributes can be increased, including the angle, making force directly proportional to all of them.

The field between the parallel plates depends on only two things- the potential difference between the plates and the distance between them. It is calculated according to $E = \frac{V}{d}$, where E is the field strength, V is the potential difference and d is the distance separating the plates in metres. From this, E is proportional to V and inversely proportional to d. The field is at right angles to the plates in all directions and is uniform in strength.

3.1.10 Outline Thompson's experiment to measure the charge/mass ratio of an electron

An examination of the mathematics behind Thompson's experiment is not vital to addressing this dotpoint, and hence has not been included here. However, it is important that you understand the process he used, so refer to Appendix D for a mathematical overview.

Thompson carried out vitally important work to determine the charge-to-mass ratio of an electron. He accomplished this using a modified cathode ray tube. The first part contained a thermionic cathode (a thermionic cathode is one which is heated by a separate heating circuit, in order to release more electrons) and an anode with a small hole through the centre to produce a thin stream of electrons travelling into space rather than between a potential difference. The second part was a velocity filter, consisting of charged plates above and below the beam set to deflect the electrons upward, and a Helmholtz coil mounted on either side of the tube producing a magnetic field to deflect the electrons downwards. Finally, at the end of the tube was a fluorescent screen which indicated how the electrons were being deflected, if at all. Thompson used both the fields simultaneously and balanced them so that the electrons travelled on the original path they took when the fields were off, as gauged by the fluorescence on the screen. This also had the effect of filtering electron velocities such that only electrons with a single particular velocity travelled through the system uninterrupted. By equating the two field strengths, a formula for the electron velocity was produced related to the strength of both fields. By equating the potential energy and kinetic energy of the electrons at the cathode and anode respectively, and substituting the potential difference across the tube and the velocity of the electrons, he was able to calculate the charge-to-mass ratio of the electron.



3.1.11 Outline the role of electrodes in the electron gun, the deflection plates or coils and the fluorescent screen in the cathode ray tube of conventional TV displays and oscilloscopes

The cathode ray tube in a display uses 3 parts- the electron gun, deflection plates and fluorescent screen, to form an image. The electron gun is used to produce a fast-moving stream of electrons. The electrodes have two roles- firstly to emit electrons to form the stream (as performed by the heated thermionic cathode) and secondly to accelerate the electrons to very high speeds (accomplished by a very large potential difference between the anode and the cathode). The anode has a hole in it to allow the stream of electrons to leave the electron gun. The deflection plates or coils are used to change the direction of the electron beam. This is because to form an image on the fluorescent screen (as opposed to a dot), the electron beam must sweep over the screen rapidly. This is accomplished by the deflection plates that guide the electron beam to particular parts of the screen. Deflection coils are used in TVs because magnetic fields can deflect the beam through larger angles which is necessary when using a large screen. The fluorescent screen is coated with phosphors that emit light when struck by electrons, which makes the electron beam visible. This is vital to the formation of an image that is viewed on an oscilloscope or TV.

Remember- The cathode ray tube in TVs and oscilloscopes uses electrodes in an electron gun to produce a beam of electrons, deflection plates/coils to steer the beam, and a fluorescent screen to turn the beam into light.

3.2 Photoelectric Effect and Quantised Radiation

3.2.0 The photoelectric effect

This is an additional dotpoint providing an overview of the photoelectric effect.

The photoelectric effect occurs when electromagnetic radiation (such as UV light) is shone on the surface of a metal. Photons are absorbed by electrons in the metal, which causes the electrons to be physically ejected from the surface of the metal. The velocity with which the electrons are ejected is dependant on the frequency of the radiation, while the quantity of electrons ejected depends on the intensity of the light.

The frequency of light at which the photoelectric effect commences is called the 'threshold frequency'. Below this frequency, no electrons are emitted from the metal. The threshold frequency depends on the particular metal involved. The energy of the photon with a frequency equal to the threshold frequency is the 'work function' i.e. the work function is the value of E for $E = hf_{threshold}$.

3.2.1 Outline qualitatively Hertz's experiments in measuring the speed of radio waves and how they relate to light waves

Make sure you can clearly describe how Hertz measured the speed of radio waves. It's a popular exam question that people often find difficult to answer properly. It may help to read through dotpoint 3.2.2 first, for a description of the apparatus Hertz used.

Hertz was able to conclude that the radiation he was dealing with was part of the electromagnetic spectrum by analysing its properties in comparison to light. He carried out experiments to show that

- It could be reflected by metal plates
- It could be refracted by pitch or asphalt blocks
- It could be diffracted around obstructions
- It could be polarised (when he rotated the receiving coil he found that the sparks were stronger at certain angles compared to others)

And most importantly, that it travelled at the speed of light. Hertz connected the two loops together with a wire, so that there was interference between the AC wave in the wire and the wave caused by EMR transmission. From this, he was able to calculate the wavelength of the radio waves, and knowing the frequency of his wave generator he was able to show that the radio waves travelled at the speed of light.

3.2.2 Describe Hertz's observation of the effect of a radio wave on a receiver and the photoelectric effect he produced but failed to investigate

Hertz discovered in 1887 that radio waves are capable of inducing currents in a receiver. In his experiment, he had a spark gap with a parabolic reflector connected to an induction coil that was constantly producing high voltage AC power and so constantly causing the spark gap to spark. A wire ring with a gap similar or identical to the spark gap in the transmitter was capable of receiving the radio waves, converting them to a spark between the gap in the receiver. This was clear proof that transmission and reception were occurring because there was no other source of electricity to the receiver to cause the spark. So Hertz observed that radio waves could induce currents in a receiver.

When he tried to enclose the receiver in a dark box to see the spark more clearly, the spark greatly diminished in size. Hertz concluded this was because light or more specifically, EMR, was affecting the size of the induced spark, and by irradiating the receiver with different frequencies of EMR he found that UV light maximised this effect. This was because of the photoelectric effect knocking electrons from the surface of the wire making it easier for them to jump the gap, although Hertz did not investigate this.

Wilhelm Hallwachs subsequently carried out experiments in which he shone different frequencies of EMR onto gold-leaf electroscopes to investigate the effect. A negatively charged electroscope would discharge in the presence of UV light while a positively charged electroscope would not. This was further evidence for the photoelectric effect, although it did not provide an explanation.

Remember- Hertz used rings with spark gaps to demonstrate induction, and found the effect was amplified when UV light was shone on the receiving ring. However, he never investigated this effect.

3.2.4 Identify Planck's hypothesis that radiation emitted and absorbed by the walls of a black body cavity is quantised

Classical theory predicted that the radiation emitted by a black body should continuously increase in intensity as the wavelength became shorter, forming a continuous spectrum with intensities effectively corresponding to an exponential curve. This was not supported by experimental data which showed that the amount of energy radiated reaches a maximum at a wavelength that depends on the temperature of the black body, and then drops sharply for smaller wavelengths. Also, an exponential curve would violate conservation of energy since the total energy (the area under the graph) would be infinite. Planck resolved this problem with his hypothesis of quantised radiation which explained the experimental data, stating that radiation could only occur in small packets which he called "quanta". The energy contained within a single quanta is dependant only on the frequency of the radiation according to the formula $E = hf$. Further, the vibration states of atoms in the black body cavity were also quantised, meaning that they could only have specific discrete frequency values. Since energy is only emitted when these atoms change vibrational states moving to a less energetic state, the energy released is also quantised.

Remember- Planck devised a theory to explain black body radiation, in which light was not considered a wave but as packets of energy that occurred only in multiples of a particular value.

3.2.5 Identify Einstein's contribution to quantum theory and its relation to black body radiation

Einstein's contribution was twofold. Firstly, he used Planck's formula to create a more detailed quantum theory of light (with light packets called "photons"), and secondly he created an explanation for the photoelectric effect. In terms of defining light, he set up a concrete explanation for the particle theory, explaining intensity and frequency in terms of energy of and quantity of photons. He also stated that photons were the smallest units of light possible. In terms of its relation to black body radiation, Einstein's theories came about directly because of the work undertaken by Planck regarding black bodies. Einstein's work led him to explain the photoelectric effect in terms of work function and threshold frequency, also providing an explanation for photoelectron kinetic energy that matched Lenard's puzzling results. Further, Einstein brought quantum theory further into the mainstream where other scientists continued to build on it.

Remember- Einstein applied Planck's theories to black body radiation to produce a comparatively more detailed model of light as a particle, which served to bring quantum theory closer to mainstream science.

3.2.6 Identify data sources, gather, process and analyse information and use available evidence to assess Einstein's contribution to quantum theory and its relation to black body radiation

Unlike 3.2.5, the focus of this dotpoint is not so much on what the contribution was, but how valuable it was to science. As such, when answering this dotpoint bear in mind that you need to make a conclusion as to the value of Einstein's contribution.

Einstein made a very significant contribution to quantum theory by taking Planck's theories about black body radiation and applying them to solve a separate problem. Further, he expanded on the work of Planck and turned quantum theory into a set of ideas with concrete principles and modelling. Effectively, he took it seriously while Planck simply deemed it a mathematical trick. By using quantum theory to explain the photoelectric effect, solving a real problem with a concrete model for the solution that fully explained experimental observations, Einstein validated quantum theory, endorsed its solving of black body radiation, and opened the door for further research based on quantum ideas. Therefore Einstein made a significant contribution to quantum theory and its relation to black body radiation.

Remember- Einstein contributed significantly to quantum theory by applying Planck's black body radiation theory to the photoelectric effect, thereby solving a real world problem.

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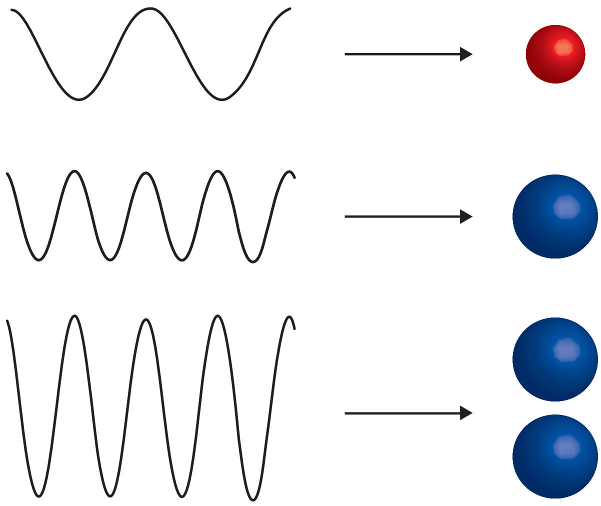
3.2.7 Explain the particle model of light in terms of photons with particular energy and frequency

The particle model of light considers light to be transmitted by small particles. These particles have mass that depends on their energy, with more energetic photons having greater mass (although their rest mass is 0). To increase the energy of a photon, the frequency, not the amplitude of the light is increased. To increase the amplitude the number of photons is increased. Photon energies can only occur in multiples of Planck's constant.



Remember- Under the particle model, light exists as particles. More particles means greater intensity, and more energetic particles means higher frequency light.

3.2.8 Identify the relationships between photon energy, frequency, speed of light and wavelength

According to $E = hf$ and $c = f\lambda$, the relationships between variables can be deduced. Since the speed of light is constant, if the frequency of the light increases then wavelength decreases and vice versa. With photon energy, h is constant, so when f is increased photon energy increases (E is directly proportional to f). Therefore it is inversely proportional to the wavelength λ, as deduced from the relationship between wavelength and frequency.

3.2.10 Identify data sources, gather, process and present information to summarise the use of the photoelectric effect in solar cells and photocells

Essentially, a solar cell consists of a junction between a P-type and N-type semiconductor that is exposed to light. Electrons are ejected from the N layer due to the photoelectric effect, and they then travel around a circuit to reach the P layer. This movement of electrons results in a potential difference that can be used to do work. In a photocell, the resistance of a circuit changes depending on how much light is falling on a semiconductor. Essentially, by monitoring voltage, current flow and resistance, a quantifiable measurement of light is possible because these properties change when a semiconductor experiences the photoelectric effect.

Remember- In solar cells the photoelectric effect is used to push electrons around a circuit, while in photocells it is used to measure light intensity.

3.2.11 Process information to discuss Einstein and Planck's differing views about whether science research is removed from social and political forces

Einstein and Planck initially held differing views as to the relationship between science and politics, but in the end they both came to realise the two were intrinsically linked.

Einstein at first refused to support the war or use science to help governments fight the war, believing that science was removed from social and political forces. However, in the end he came to the realisation that the two are in fact linked together, and he ended up helping with the Manhattan project which almost certainly contributed to the ending of the war.

Planck initially felt that science definitely had a role to play in terms of politics, but eventually he turned against the Nazi regime, criticising it, believing that science should be separate. However, he understood that there is an unavoidable link between science and politics. Even after Planck attempted to separate science from politics, research science for the military continued through other scientists.

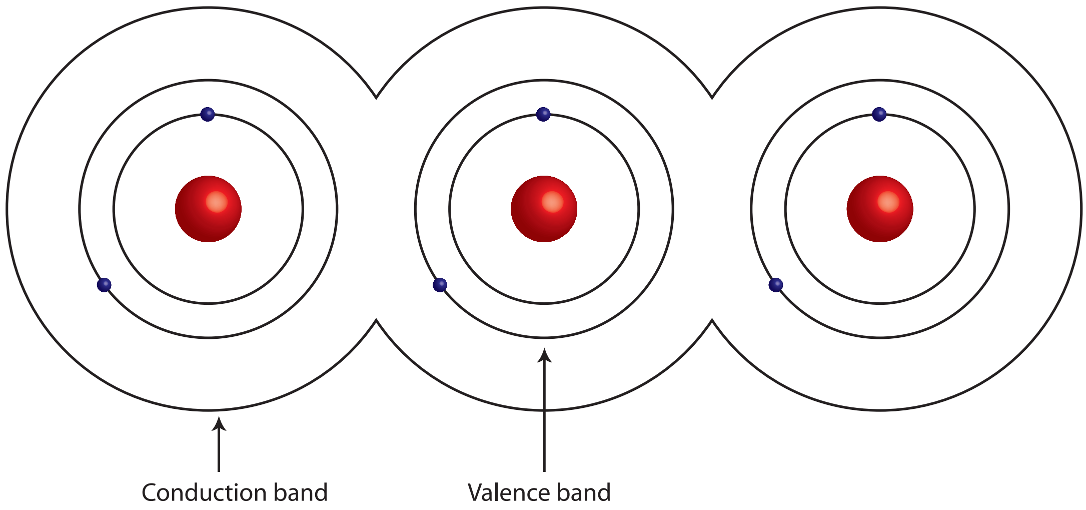
In a way, both Planck and Einstein are representative of the wider debate in science that continues even today as to the role the government's agenda should be in terms of scientific research, but they, like today's scientists, realised that science and politics can never be separated, even if that is the ideal situation.

Remember- Both scientists eventually agreed that science and politics are inextricably linked. They also agreed that ideally they would be separate. Einstein initially believed they had to be kept separate but then realised they couldn't. Planck initially believed they had to be kept together, but then realised they shouldn't.

3.3 Semiconductors and Transistors

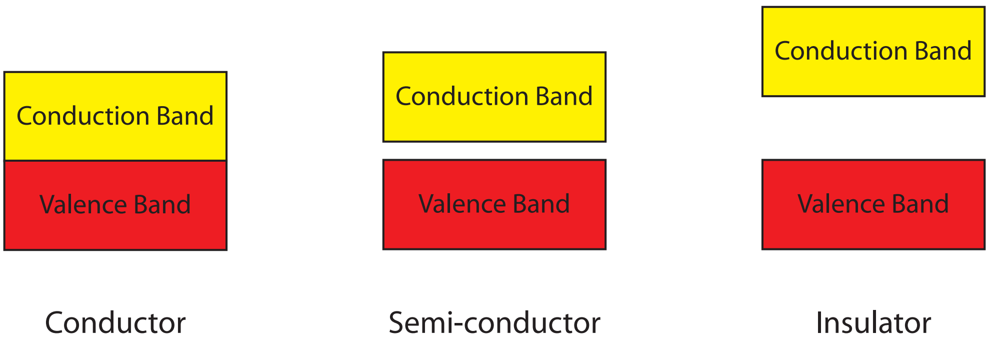
3.3.1 Identify that some electrons in solids are shared between atoms and move freely

In solids, electron shells are replaced by electron band structures (because the energy levels of neighbouring atoms shift according to Pauli's exclusion principle, with the energy levels clustering into broad band structures). These consist of the conduction band and the valence band. The valence band can be thought of as the normal outer shell of an atom where electrons are chained to that particular atom, while the conduction band can be thought of as a level where electrons are free to move between other atoms in the solid structure. Only electrons in the conduction band are shared- those in the valence band are not and remain immobile.



3.3.2 Describe the difference between conductors, insulators and semiconductors in terms of band structures and relative electrical resistance

Because electrons can only move between atoms and therefore conduct electricity in the conduction band, the relative positions of the conduction band and valence band play a large part in determining the conducting properties of a material. In conductors, the conduction and valence bands overlap- this means that electrons in their normal valence positions can, without gaining any energy, be in the conduction band and move freely between atoms. Because it is so easy for electrons to move into the conduction band, there is little resistance. With insulators, there is a very large energy gap between the valence and conduction bands- this is known as the forbidden energy gap. In order to conduct electricity, electrons in an insulator must gain enough energy to jump from their normal valence band positions over the forbidden energy gap and into the conduction band- because this process requires a great deal of energy input it is very difficult to cause insulators to be conductive, and so they have high electrical resistance. Intrinsic semiconductors (pure semiconductor crystals consisting of only one element) have band gaps smaller than for insulators but bigger than conductors- they lie in between, so are initially insulators but when heated moderately become conductive. Other moderate energy input will cause conductivity. Extrinsic semiconductors (semiconductor crystals with deliberate impurities consisting of small quantities of a group 3 or group 5 element) also contain an extra energy level inside the forbidden energy gap for electrons to exist, reducing the energy required to get an electron into the conduction band.



Remember- Conductivity depends on the gap between the valence band the conduction band. Insulators have a large gap, semiconductors have a small gap, and conductors have no gap.

3.3.3 Identify absences of electrons in a nearly full band as holes, and recognise that both electrons and holes help to carry current

See 3.3.7 for a diagram of a semiconductor lattice showing holes due to Group 3 impurities. 3.3.7 also covers the use of Group 5 impurities, which are beyond the scope of this particular dotpoint.

In a crystal lattice of a pure (intrinsic) semiconductor, all the outer shells are (theoretically) filled and there are no electrons available to conduct electricity (since free electrons in the conduction band are required). When a Group 3 impurity exists, an impurity with one less electron than a Group 4 semiconductor such as silicon or germanium, there is a hole in the crystal lattice structure where there should have been a bond electron. This hole forms a positive region of space, and because it's charged it is capable of moving charge. To move the hole, bonds within the lattice switch around and change so that the position of the hole in the lattice changes. In this way, holes are able to carry current, helping to make a semiconductor conductive, with holes effectively behaving as if they were positive point charges (although the reality is they are regions of empty space that are positive relative to the lattice). With the application of additional energy to move lattice electrons into the conduction band (as described in 3.3.2), electrons can also carry current through the lattice.

Remember- Holes are positive points in a crystal lattice that behave as point charges, and both holes and electrons can carry current.

3.3.4 Compare qualitatively the number of free electrons that can drift from atom to atom in conductors, semiconductors and insulators

Under normal conditions, conductors have very many free electrons that can drift from atom to atom (on the order of the number of atoms in the lattice), whereas in semiconductors and insulators very few, if any electrons are free and able to drift from atom to atom. However, with semiconductors if energy is applied to the system in the form of heat or a strong electrical field, the number of free electrons increases greatly causing it to conduct (although not to the same extent as straight conductors).

Remember- Conductors have many free electrons, insulators have very few.

3.3.5 Perform an investigation to model the behaviour of semiconductors, including the creation of a hole or positive charge on the atom that has lost the electron and the movement of electrons and holes in opposite directions when an electric field is applied across the semiconductor

Make sure that you are able to clearly explain this experiment. Don't forget to talk about how holes and electrons move in opposite directions.

We modelled a semiconductor using marbles in a Petri dish, with each marble representing an electron. Removing a marble from the dish represented the creation of a hole. As the dish is disturbed by moving it, simulating the application of an electric field, the position of the hole changed as marbles moved in to fill it, moving the hole elsewhere in the dish. The gap and the marble moved in opposite directions, as a new gap was created when a marble moved to fill the old gap.

Then we modelled semiconductors using marbles as atoms and a metal ball bearing as an extra free electron that was capable of moving around the dish as the dish moved. When we moved the dish, the ball bearing moved from marble to marble, showing the movement of free electrons.

Remember- Swirling marbles in a dish along with a ball bearing.

3.3.6 Identify that the use of germanium in early transistors is related to lack of ability to produce other materials of sufficient purity

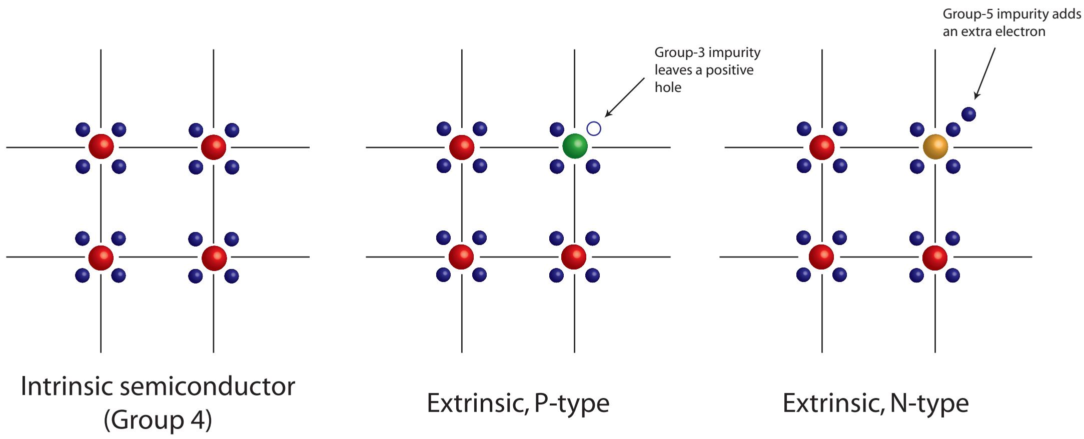
During early research with transistors and semiconductors, germanium was the semiconductor of choice. The main reason germanium was used was because of purification- in order to operate with predictable properties, the semiconductor crystal needed to be very pure. The only two semiconductors suitable for transistor use are germanium and silicon, being Group 4 semiconductors and somewhat easily available. Silicon was in fact the superior material, being more abundant and therefore cheaper, easier to dope, and having superior thermal properties (germanium became too conductive with only moderate heating making germanium chip performance highly dependant on temperature).

However, in the 1940's at the start of semiconductor research, scientists were only able to purify germanium. The techniques that they used to purify germanium crystals could not be applied to silicon crystals. This meant that although silicon was the superior material, it could not be used because silicon crystals could not be manufactured pure enough to make reliable chips. Germanium was therefore used in early transistors until suitable purity silicon was developed.

Remember- Germanium was used in early transistors because scientists couldn't purify silicon.

3.3.7 Describe how "doping" a semiconductor can change its electrical properties

The process of doping a semiconductor involves adding a Group 3 or Group 5 element as an impurity into the crystal structure of the semiconductor to reduce the energy input required for the semiconductor to become conductive. Only tiny amounts of the impurities are added- too much, and the semiconductor's conductive properties become unpredictable. If a Group 3 element is added, then because it has one less electron in its outer shell the lattice structure will be missing an electron- in this way a hole is produced, and this hole is capable of moving charge. Similarly, if a Group 5 element is added there will be an extra, free electron in the lattice structure which is free to move between atoms and carry charge.



Remember- Adding impurities to "dope" a semiconductor makes it more conductive.

3.3.8 Identify differences in p-type and n-type semiconductors in terms of the relative number of negative charge carriers and positive holes

P-type semiconductors have been doped with Group 3 elements whereas n-type semiconductors have been doped with Group 5 elements. This means that although they both are capable of carrying charge, the p-type semiconductor has positive holes to move charge whereas n-type semiconductors have extra electrons- negative charge carriers, to do the same. Holes and electrons flow in opposite directions in the crystal structure to conduct electricity, but they both enable the passage of current through the lattice.

Remember- "P-type" stands for "positive" and so uses Group 3 elements. "N-type" is for "negative" and so uses Group 5.

3.3.9 Describe differences between solid state and thermionic devices and discuss why solid state devices replaced thermionic devices

This dotpoint is focussed on the differences between solid state and thermionic devices in terms of their performance and usage. See the Extra Content chapter for an overview of the physics behind their operation.

Although thermionic devices and solid state transistors perform exactly the same function (amplification of a signal or electrical switching), solid state devices almost completely replaced thermionic devices because of their vastly superior properties in terms of operation.

Attribute	Thermionic device	Solid state device
Cost	Expensive	Cheap
Dimensions	Bulky and heavy	Small and lightweight
Durability	Fragile, easily broken	Durable and reliable
Lifespan	Short lifespan	Long lifespan
Warm-up time	Significant	None
Energy efficiency	Large power requirements	Very low power

Although some audio enthusiasts claim valves are still better devices for amplification, it is generally accepted that transistors are superior to valves in almost every way. This led to solid state devices replacing valves.

3.3.10 Gather, process and present secondary information to discuss how shortcomings in available communication technology lead to an increased knowledge of the properties of materials with particular reference to the invention of the transistor

The biggest problem with communication technology in the early days of the radio was amplification- the received signal was extremely weak and could not produce a loud sound without being amplified. This meant researchers were always trying to improve amplification technology to address the shortcomings with valves such as their high failure rate, high power consumption, their weight and their warm-up time. When they first determined some of the properties of semiconductors this need for better amplifiers fuelled heavy research into the properties of semiconductors and the ways in which they could be used as amplifiers in the form of transistors. So the shortcomings in available communications technology led to the rapid development of the transistor which would have otherwise taken many years longer.

Remember- The drive for transistors to replace valves was brought about not only by the limitations of valves but also because of the high demand for communications technology.

3.3.11 Identify data sources, gather, process, analyse information and use available evidence to assess the impact of the invention of transistors on society with particular reference to their use in microchips and microprocessors

The invention of the transistor has dramatically changed society, largely through the use of microprocessors and microchips. They have enabled the building of small, efficient computers that now have widespread applications throughout society as well as in scientific research. It has allowed the automation of repetitive tasks which has led to higher quality of life, at the expense of jobs and a rise in unemployment. However, in terms of communication it has had a tremendous benefit enabling the internet which has drastically changed society for the better. So overall transistors have had an extremely positive impact on society.

3.4 Superconductors

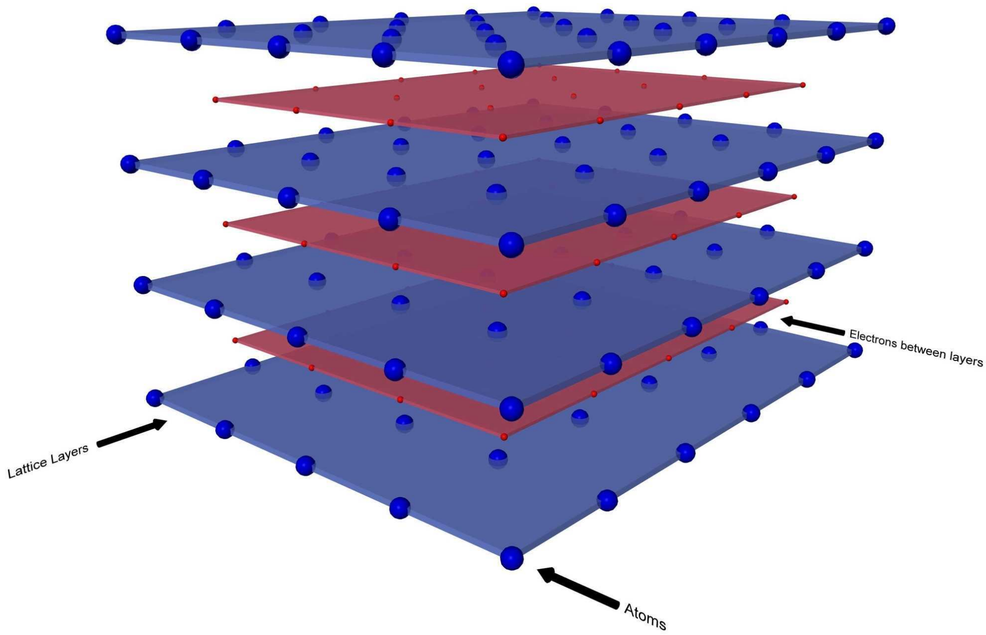
3.4.1 Outline the methods used by the Braggs to determine crystal structure

Diffraction occurs when waves bend around obstructions, and interference patterns result when waves interfere. Diffraction can often result in interference patterns when the bent wave (acting as a point source) interferes with the original wave. A diffraction grating uses small obstructions with separations similar to the wavelength of the wave in question placed side by side to produce a predictable interference pattern that is directly linked to the spacing within the diffraction grating. The Braggs realised that the spacing between layers in a crystal lattice were similar to the wavelength of x-rays, and would therefore act as a diffraction grating. Further, they realised that from the interference pattern they obtained they could calculate the spacing between the lattice layers. The Braggs used an x-ray tube as their x-ray source, and the x-rays travelled through a hole in a shield which acted as a collimator to produce a tightly focussed beam of x-rays. The waves then reflected through a crystal target which acted as a diffraction grating, and then the x-rays travelled to a sensor to analyse the interference pattern. From this they could calculate lattice separation distance, which was of great importance to science and understanding crystal structures.

Remember- The Braggs used diffraction and interference patterns with x-rays to calculate the spacing between crystal lattice layers.

3.4.2 Identify that metals possess a crystal lattice structure

Metals, like many other molecules, have a crystal lattice structure in their solid state. This means that they exist as a 3-dimensional grid of atoms arranged into layers. It is a repeating structure where each atom occupies a well-defined equilibrium distance from its neighbours. In the case of metals, free electrons exist in between lattice layers and conduct electricity.



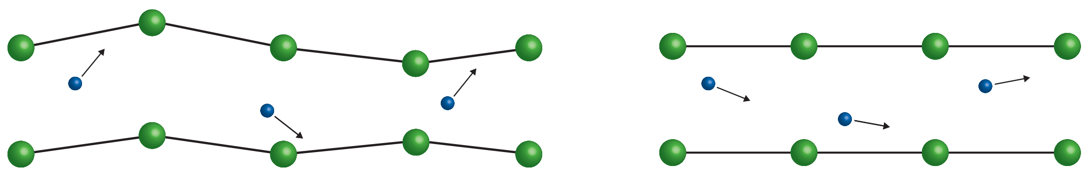
3.4.3 Describe conduction in metals as a free movement of electrons unimpeded by the lattice

A metal has free electrons that exist in the space between metal ions in the lattice. This means that they exist in a more-or-less empty space containing no lattice ions, leaving them free to travel without being impeded by the lattice. However, collisions between the electron and the lattice still occur, as do collisions between electrons and other electrons. When an electric field or potential is applied to a metal, the metal conducts because the electrons move freely between the lattice layers.

Remember- Conduction occurs when electrons travel through the metal lattice, thereby moving charge.

3.4.4 Identify that resistance in metals is increased by the presence of impurities and the scattering of electrons by lattice vibrations

In order to conduct electricity, electrons must travel through the space between lattice layers. Resistance is low when the electrons are free to travel unimpeded, and resistance is high when the passage of electrons is obstructed. Impurities in a metal distort the lattice structure and electrons collide with the impurity, increasing resistance. Similarly, vibrations in the lattice (often caused by heating) destabilise the structure and make it harder for electrons to flow, increasing resistance.



Lattice vibrations increase resistance by scattering electrons

Electrons travel smoothly through a steady lattice

Remember- Impurities and lattice vibrations increase resistance.

3.4.5 Describe the occurrence in superconductors below their critical temperature of a population of electrons unaffected by electrical resistance

Phonons are a particular type of quantum particle. They represent quantised vibration states within a crystal structure. It is not necessary to know precisely what they are, only the role that they play in the formation of Cooper pairs.

Superconductors are materials that exhibit no resistance. They only occur at low temperatures because at higher temperatures electron pairs are not capable of forming. In a superconductor, lattice vibrations are eliminated due to the low temperature. As an electron travels through the lattice, it attracts lattice ions causing a lattice distortion- a small region of positive space that attracts another electron. The two electrons then exchange phonons and bind, forming a Cooper pair of electrons which behaves as a single particle. Because the two electrons are interacting with each other they interact less with the lattice, and so travel through it very easily with very little resistance. So below the critical temperature, when a material becomes a superconductor pairs of electrons form that are unaffected by electrical resistance.

Remember- Superconductivity occurs at low temperatures when electrons swap phonons to form Cooper pairs that interact far less with the lattice, resulting in superconductivity.

3.4.6 Process information to identify some of the metals, metal alloys, and compounds that have been identified as exhibiting the property of superconductivity and their critical temperatures

You shouldn't need to remember this list, since in a test they will most likely give you a table of data to use in an answer. However, it will be useful to remember one or two values from this table so you can add them to any answer to show depth of knowledge. Also make sure you remember that 138K is the maximum temperature for superconductivity as of 2009 (though it probably isn't necessary to remember the exact material).

Material	**Critical temperature (K)**
Zinc	0.85
Aluminium	1.175
Mercury	4.15
Lead	7.196
Tin	7.72
$AuBa_2Ca_3Cu_4O_{11}$	99
$Ba_2Ca_2Cu_3O_{8.33}$	138

3.4.7 Discuss the BCS theory

If asked a question like this in an exam, ensure you describe the BCS theory before discussing it. Refer to 3.4.5 for a description of the theory.

The BCS theory of superconductivity is simply the idea that lattice distortions at low temperatures lead to the formation of Cooper pairs. This theory is extremely successful at explaining superconductivity in Type 1 superconductors (substances that have a critical temperature below 30K) as it is almost 50 years old now, and still used. It provided a concrete framework on which to model superconductivity that was vital to understanding how it works. However, it is unable to explain superconductivity in Type 2 superconductors- the ceramic variety that can be superconductors at far higher temperatures. This is because the model predicts 30K as being the maximum temperature at which Cooper pairs are able to form. So while it is extremely important to understanding Type 1 superconductors, it does little to explain Type 2 and so is an incomplete theory.

Remember- The BCS theory explains Type 1 superconductivity but cannot explain Type 2 semiconductors.

3.4.8 Discuss the advantages of using superconductors and identify limitations to their use

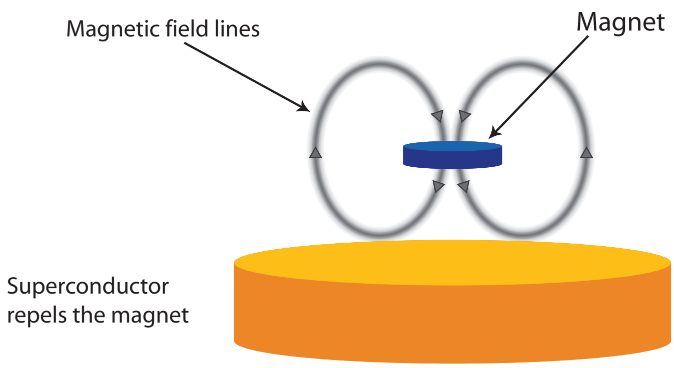
There are many advantages to using superconductors. These are mainly that they operate with very little loss and so are extremely efficient, and also that they generate no waste heat because they are perfect conductors. They are capable of generating very strong magnetic fields per unit of weight, useful for MRI scanners, and could be used to make very efficient motors, generators and batteries. There are two key limitations to superconductors, however. Firstly, it is very difficult to cool superconductors to below their critical temperatures- they require a constant supply of liquid nitrogen at the moment (given the low temperatures currently needed to achieve superconductivity), and secondly it is very hard to shape ceramic superconductors as they are not ductile, making it difficult to turn superconductors into wires.

Remember- Superconductors increase efficiency and can reduce size and weight, but are difficult to manufacture and require cooling.

3.4.9 Analyse information to explain why a magnet is able to hover above a superconducting material that has reached the temperature at which it is superconducting

A magnet is able to hover over a superconducting material for two reasons- firstly because magnetic fields are excluded from the superconductor, forcing the magnet to be repelled from the superconductor thus causing it to rise up (this is the Meissner effect), and secondly due to the phenomenon of quantum pinning which stops the magnet from moving horizontally off the superconductor.

The Meissner effect is separate to the induction of eddy currents which would theoretically perfectly oppose the magnetic field of a magnet. This is shown to be true because if a magnet is placed on a superconductor as it is being cooled, it will jump into the air as the superconductor becomes superconducting- this shows it is not an induction phenomenon as change in magnetic flux is required to induce eddy currents. Therefore the levitation occurs due to the exclusion of magnetic fields from the superconductor.



Remember- A magnet can float above a superconductor due to the Meissner effect.

3.4.10 Perform an investigation to demonstrate magnetic levitation

In this experiment, we had a ceramic superconducting disk in a Petri dish and a small magnetic cube. We poured liquid nitrogen onto the superconducting disk (and into the dish) to lower it below its critical temperature, making it superconductive. When we used insulated plastic tongs to place the magnet just above the disk, the magnet floated. Nudging it with the tongs caused it to rotate. Eventually, the magnet fell as the disk warmed up and lost its superconductivity. In our second trial, we left the magnet on the disk before pouring liquid nitrogen. As the disk cooled, the magnet suddenly floated upwards off the disk. This showed that the Meissner effect is due to the exclusion of magnetic fields from superconductors, rather than the formation of perfect eddy currents due to changes in flux (because for eddy currents to form there must be an initial change in flux to create them. In the experiment the magnet rose upwards by itself. In fact, the movement of the magnet upwards would have ordinarily induced eddy currents that would drag the magnet down. So this is compelling evidence that the levitation of the magnet is due to the exclusion of the field and not due to eddy currents).

Remember- The exclusion of the magnetic field from the superconductor caused the magnet to levitate.

3.4.11 Gather and process information to describe how superconductors and the effects of magnetic fields have been applied to develop a maglev train

Note that this dotpoint is not only about how superconductors are used in maglev trains, but also how superconductors make maglev trains possible. Often questions will require to you to examine the benefits of using superconductors for maglev trains, in addition to outlining how they are used.

A maglev train relies on superconductors for operation, because superconductors are extremely light, extremely strong magnets, making them well suited to levitate a heavy load such as the train. Superconductors are used in two areas- to levitate the maglev train, and to propel the train. The tracks and the train both have superconductors. Superconductors on the train consist of a looped superconductor on either side of the train. The superconductor is charged with electric current when it is made, and because it is looped (physically, with one end joined to the other), the current flows continuously. This sets up a strong, constant magnetic field. Superconducting electromagnets on the track, positioned above and below the train's magnetic loops, repel the train from the bottom, and attract the train from the top, causing the train to float. The track magnets are mounted on the vertical sides of the track. Additional superconducting electromagnets on the track serve to propel the train. These electromagnets are situated all along the side of the track. Magnets in front of the train attract the train's magnets, while magnets on the track behind the train repel the train. By constantly changing the polarity of the track magnets, the train is attracted and repelled in the same direction constantly, causing the maglev train to move rapidly along the track. Superconductors are vital to the development of maglev trains, because permanent magnets would be too heavy to generate the same field strength, and conventional electromagnets would lose too much energy as waste heat due to electrical resistance.

Remember- Superconductors are used in maglev trains because they are light and can produce the incredibly strong magnetic fields required to levitate and propel a train.

3.4.12 Process information to discuss possible applications of superconductivity and the effects of those applications on computers, generators and motors, and transmission of electricity through power grids

Superconductors offer great potential in a variety of fields, offering increased performance and efficiency compared to conventional conductors. However, there are still two major obstacles that impede the use of superconductors in virtually all their applications. Firstly, superconductors must be extremely cold, necessitating liquid nitrogen cooling. In some cases this is merely inconvenient, such as in a maglev train, but in applications such as computers, it is extremely difficult and unwieldy to use liquid nitrogen as a coolant, although it has been accomplished by some computer enthusiasts. Secondly, at present type-2 superconductors, (the only realistic option for real-world applications because they only require liquid nitrogen cooling, as opposed to type-1 superconductors with lower critical temperatures), are ceramic compounds that are not ductile. This makes it extremely difficult to use in electrical circuits that rely on ductility to produce a long wire to transfer electricity. Because they are not ductile, they would also be difficult materials to use in computer processors.

However, once these obstacles are overcome, using superconductors in place of standard conductors would bring tremendous benefits. In computers, a great deal of energy is wasted as heat. Further, heating makes it difficult for processors to operate properly, as it changes the properties of the silicon presently used. By using a superconductor, there will be little, if any, waste heat produced, resulting in a processor that can function at far faster speeds. Further, by replacing transistors with superconducting quantum switches (SQUID, or **s**uperconducting **qu**antum **i**nterference **d**evice), the processor can operate faster still. In motors and generators, they can be used to operate at high currents with no losses and no heat production, resulting in extremely efficient motors and generators. According to $V = IR$, current output will be maximised when there is low resistance, showing that a superconductor will improve current output. Finally, in terms of transmission, a great deal of energy is wasted in the transmission of electricity through conversion to heat in wires. By using superconducting wires, energy loss through the electricity grid will be eliminated, resulting in greater efficiency, with possible impacts such as reduced cost of power, or a reduced need for additional electricity generation capacity. A superconducting electricity grid was successfully trialled in America 4 years ago, and is presently used in parts of the New York grid.

Remember- Superconductors can be used in generators, computer chips and electricity grids, although at present there are challenges that need to be resolved first.

Chapter 4

Quanta to Quarks

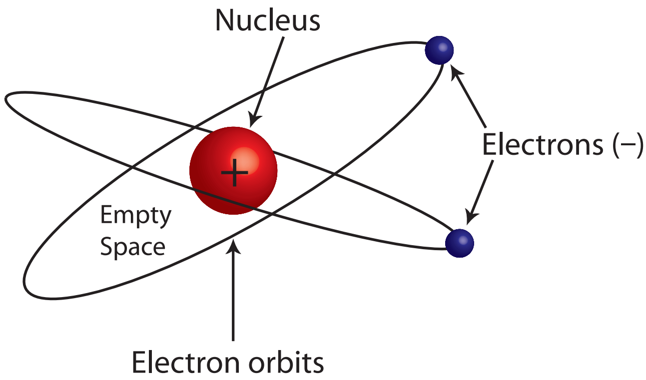
"God does not play dice." -Albert Einstein

"Stop telling God what to do with his dice." -Niels Bohr

4.1 Atomic Structure

4.1.1 Discuss the structure of the Rutherford model of the atom, the existence of the nucleus and electron orbits

The Rutherford atom consisted of a small positive nucleus with negatively charged electrons orbiting the nucleus. The Rutherford atom was devised following Rutherford's experiments in which he fired positively charged alpha particles at thin gold foil. Rutherford found that while most alpha particles passed straight through the foil, a small proportion of them were reflected back. He hypothesised that they had encountered very dense areas of positive charge. The fact that most alpha particles passed through the gold foil led Rutherford to model the atom with a great deal of empty space. Rutherford modelled the atom with a dense, positively charged nucleus, negatively charged electrons that orbited the nucleus, and free space between the nucleus and the electrons. The model was essentially a simplified version of what we use today- it was groundbreaking at the time as it was a step in the right direction for other scientists to build on, but it lacked a description of where the electrons were and failed to address how atoms had stability without energy emission from accelerating electrons.



Remember- The Rutherford atom had a positive nucleus, negative electrons orbiting the nucleus, and empty space between the electrons and the nucleus.

4.1.2 Analyse the significance of the hydrogen spectrum in the development of Bohr's model of the atom

Bohr's model of the atom was quite similar to Rutherford's, but with two important differences- firstly, it assigned positions to the electrons, but secondly the electron energy levels were quantised. This was radically new, the idea that electrons had energy states and could absorb and emit energy to change states, and had no evidence. Bohr realised that if his model was correct, each atom would have a spectral fingerprint related to the differences between electron energy levels in that atom. The Rydberg equation, otherwise known as the Balmer equation, gave him evidence for the quantised emission of energy from the hydrogen atom, leading to him going on to further his model and define his postulates. So the hydrogen spectrum was very significant to the development of Bohr's model of the atom, because without an understanding of it Bohr may not have continued to work on his model.

Remember- The hydrogen spectrum was extremely significant because it provided the only evidence at the time for an otherwise purely theoretical model.

4.1.3 Perform a first-hand investigation to observe the visible components of the hydrogen spectrum

In our experiment, we had a discharge tube (vacuum tube with a cathode and anode, powered by a high-voltage induction coil) with low-pressure hydrogen inside it. When high-voltage current was passed through the tube, the hydrogen fluoresced, emitting light that was visible in our darkened room. We observed the visible components of the spectrum with handheld spectrometers that used a diffraction grating to split the light. Using the spectrometer, we could clearly observe the red and blue/violet hydrogen emission lines, although the violet lines were very hard to observe. The red line was very clear and intense compared to the other observed lines.

Remember- Hydrogen discharge tube observed with a spectrometer.

4.1.4 Discuss Planck's contribution to the concept of quantised energy

The concept of quantised energy is that energy can only occur in small packets of fixed amounts, and distinguished between energy increases due to increased intensity (bigger packets) and energy increases due to greater intensity (more packets). This was developed entirely by Planck in his work on black body radiation, and although Einstein significantly improved upon Planck's ideas, the underlying idea was Planck's alone, and so Planck made a huge contribution to the underlying concept of quantised energy. However, his involvement was limited to developing the mere concept-others developed it into a functional model.

Remember- Planck developed the concept of quantised energy, but not a functioning model.

4.1.5 Define Bohr's postulates

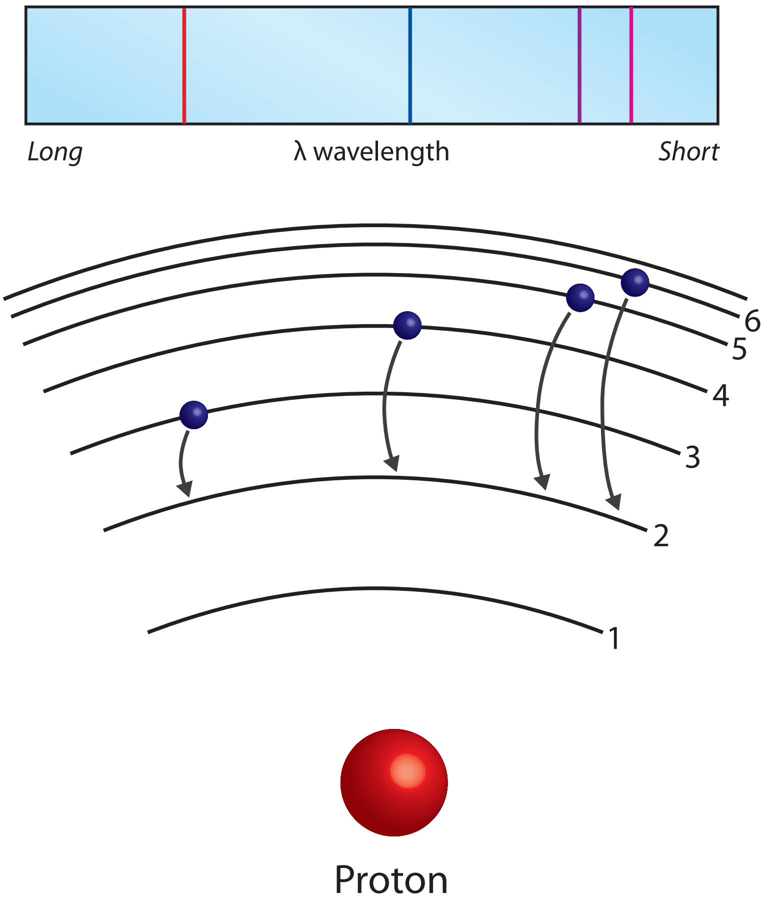
Bohr had 3 postulates. The first was that electrons in an atom exist in stationary states of stability and emit no energy when in these states. The second was that energy is only lost or gained by an electron when it moves from state to state, and when it moves from a high energy state to a low energy state it releases a photon with energy equal to the difference between the states (and therefore a characteristic frequency). His third postulate was that electron angular momentum in a stationary state is equal to an integer multiple of $\frac{h}{2\pi}$ (i.e. $mvr = \frac{nh}{2\pi}$).

4.1.6 Describe how Bohr's postulates led to the development of a mathematical model to account for the existence of the hydrogen spectrum (the Rydberg equation)

Balmer originally devised the equation empirically by examining the lines in the hydrogen spectrum and creating a formula to fit them. Rydberg used Bohr's postulates and manipulated them (especially the third) to create the same formula (derived from calculating differences in energy states). Essentially, there were two paths to the Rydberg equation and one of them used Bohr's postulates to arrive at the equation, while the other didn't.

4.1.8 Process and present diagrammatic information to illustrate Bohr's explanation of the Balmer series

In this diagram, the energy levels described by Bohr are clearly marked. According to Bohr, the Balmer series (shown on the top of the diagram as the hydrogen spectrum) was caused by electrons changing energy levels. The electron makes a transition from a higher energy level to a lower energy level, in the process releasing light. As shown, larger energy changes produce more energetic photons, as seen in the Balmer series, and further, this diagram shows how the Balmer series is formed by successive electron transitions to the 2nd shell (transitions to other shells produce additional lines named after their discoverers).



Remember- Bohr explained the Balmer series as being the result of successive electron transitions down to the 2nd shell.

4.1.9/4.1.10 Discuss the limitations of the Bohr model of the hydrogen atom (including "Analyse secondary information to identify the difficulties with the Rutherford-Bohr model, including its inability to completely explain the spectra of larger atoms, the relative intensity of spectral lines, the existence of hyperfine spectral lines, and the Zeeman Effect")

For all the questions the Bohr model answered, it posed still more. There was still no explanation for there being no energy emission from accelerating electrons as Maxwell predicted- instead it was simply an assumption. Further, there was no evidence for the Bohr model to give it scientific credibility. Finally, in terms of explaining spectral lines there were observed effects that simply could not be explained. These were

- Relative intensity of spectral lines- When observing spectra, some lines were much brighter than others. The Bohr model could not explain why some lines were more intense than others (i.e. why some electron transitions were preferred to others)
- Hyperfine splitting- When the spectral lines were examined closely, it was observed that each line actually consisted of many small lines, the existence of which the Bohr model could not explain as it only predicted one clear line for each transition
- Larger atoms- The Bohr model could not explain the spectra of larger atoms with more than one electron, a problem that Bohr tried unsuccessfully to solve.
- Zeeman effect- The Zeeman effect occurs when a magnetic field is passed through the discharge tube. The magnetic field increases the hyperfine splitting of spectral lines, further breaking them up. Again, the Bohr model was unable to explain the experimental evidence

Although the Bohr model lay down the framework for the quantum model of the atom, which ended in a scientific revolution out of which quantum mechanics (a vital part of modern physics) emerged, it was left to future scientists such as Pauli and Heisenberg to fully explain these phenomena.

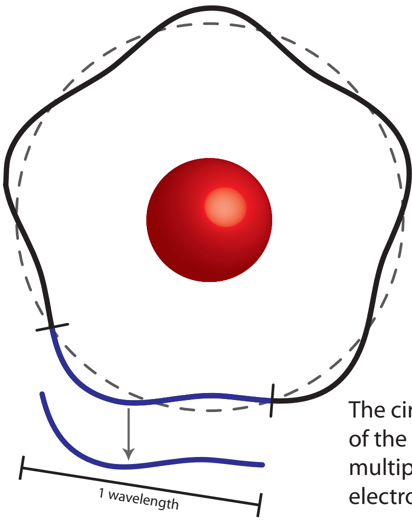
Remember- Relative intensity, hyperfine splitting, larger atoms, Zeeman effect.

4.2 Matter Waves and the Quantum Atom

See 4.2.5 for the mathematical link between de Broglie's matter waves, and Bohr's postulates.

4.2.1 Describe the impact of de Broglie's proposal that any kind of particle has both wave and particle properties

The immediate and most important impact that de Broglie's proposal had was to provide a model to accompany Bohr's first assertion that there were stable orbits where electrons did not emit energy. Under the first postulate, Bohr simply claimed they would not emit energy, directly contravening Maxwell's theories without explanation. This, without a model to explain it, deprived the Bohr atom from receiving scientific credibility, and as such it was rejected by the scientific community. De Broglie's proposal gave a workable solution to explain stable orbits that don't emit energy, and this gave the Bohr model the credibility it required to be accepted and developed upon by the scientific community, which proved vital in terms of understanding the structure of the atom. Later, de Broglie's proposal was used to exploit the wave nature of electrons in electron microscopes which could be used to image objects at far greater resolutions than was possible with light due to the smaller wavelength of electrons. De Broglie's proposal also reconciled Einstein's theory of light with classical physics by showing that light could have both wave and particle nature.

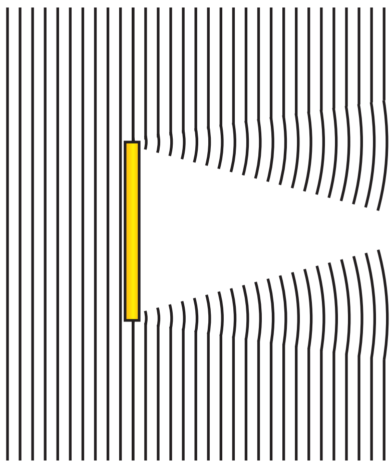


Remember- de Broglie's proposal provided a model to solve one of the biggest problems with the Bohr atom, namely the stability of orbits. Later it was used as the foundation for electron microscopes.

4.2.3 Define diffraction and identify that interference occurs between waves that have been diffracted

The diagram for this dotpoint has been deliberately oversimplified to show the obstruction of the original wave, and the generation of point-source waves at the corners of the object. In reality, there will be actual interference between the original and the diffracted waves (not shown in this diagram)

Diffraction is the bending of waves around obstructions. It is solely a wave property, and is observed when the passage of a wave is obstructed by an object. The wave can bend around the object and exist where there should be a shadow from the object- this effect is strongest when the size of the object is of the same order as the wavelength of the wave. The corner of the object acts as a point source for the wave, resulting in a curved wave that radiates outward. There are now two waves- the point source and the main wave, and because they exist in the same location interference occurs between the two waves. This means that the process of diffraction results in an interference pattern. This is because at some points the waves interfere destructively and at others they interfere constructively. This results in lines of light and dark, or light and dark rings if it is a circular obstruction.



Remember- Diffraction is when waves bend around objects, and since the corners of the object act as point sources interference occurs between the original wave and the new point source waves.

4.2.4 Describe the confirmation of de Broglie's proposal by Davisson and Germer

Davisson and Germer were studying the surface of nickel with an electron beam, expecting that even the smoothest surface would appear rough to the electrons. In their experiment an accident occurred and the nickel oxidised when it was exposed to air. To remove the oxide film, they heated the nickel to near its melting point, resulting in the formation of crystals larger than the width of their electron beam. Then, when they fired the beam at the nickel and reflected it to a detector, they observed an interference pattern very similar to an x-ray diffraction pattern, confirming the wave nature of electrons and confirming their wavelength as being very close to what de Broglie predicted.

Remember- Davisson and Germer observed the electron diffraction de Broglie had predicted.

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4.2.5 Explain the stability of the electron orbits in the Bohr atom using de Broglie's hypothesis

Electrons under the de Broglie hypothesis exist as standing waves around the nucleus. This means that they have a closed orbit with no movement of energy, and therefore the orbit is stable with no energy emission. This was the model to explain the stability of electron orbits. The electron orbits must have a circumference equal to a multiple of the wavelength of the electron, as this allows for a standing wave. Therefore,

$$2\pi r = n\lambda$$

and according to de Broglie,

$$\lambda = \frac{h}{mv}$$

Multiplying de Broglie's equation by n gives

$$n\lambda = \frac{nh}{mv}$$

and therefore from the first equation,

$$2\pi r = \frac{nh}{mv}$$

Rearranging,

$$mvr = \frac{nh}{2\pi}$$

which was Bohr's third postulate. Therefore, using de Broglie's theory of matter waves not only could there be an explanation for Bohr's first postulate, but it was also possible to mathematically derive Bohr's third postulate that had initially been nothing more than an assertion.

Remember- Stable orbits in the Bohr atom exist at radii where the circumference of the orbit is a multiple of the wavelength of an electron.

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4.2.6 Gather, process, analyse and present information and use available evidence to assess the contributions made by Heisenberg and Pauli to the development of atomic theory

See 4.3.7 for Pauli's proposal theorising the existance of the neutrino

Heisenberg and Pauli both made very significant contributions to quantum theory, Heisenberg through his uncertainty principle and Pauli through his exclusion principle.

Heisenberg firstly devised matrix mechanics to explain the atom in terms of quantum probabilities, rather than mixing classical and quantum theory as Bohr had done. This led to an entirely quantum theory of the atom, helping to mathematically understand its nature. Secondly, he devised the uncertainty principle which essentially stated that the more was known about the momentum of a particle, the less could be known about its position in space and vice versa. This changed the way science viewed atomic structure, and is perhaps one of the most important central principles of quantum mechanics, that knowledge of one thing can be mutually exclusive to knowledge of another. This isn't just due to measurements changing quantities- it's a fundamental property of quantum mechanics. Heisenberg's work greatly changed the way in which scientists approached quantum physics.

Eventually, it was realised that the position and properties of an electron could be described in terms of 4 quantum numbers. Pauli's exclusion principle stated that no two electrons could have all 4 numbers exactly the same- this explained the maximum number of electrons in each shell, and provided a quantum explanation for the position of the first 20 elements in the periodic table. Further, Pauli was able to use his work with quantum numbers to explain the Zeeman effect. Pauli also proposed the existence of the neutrino, another significant subatomic particle.

Remember- Heisenberg devised matrix mechanics and the uncertainty principle, and Pauli developed the exclusion principle and the neutrino.

4.3 Nuclear Physics and Nuclear Energy

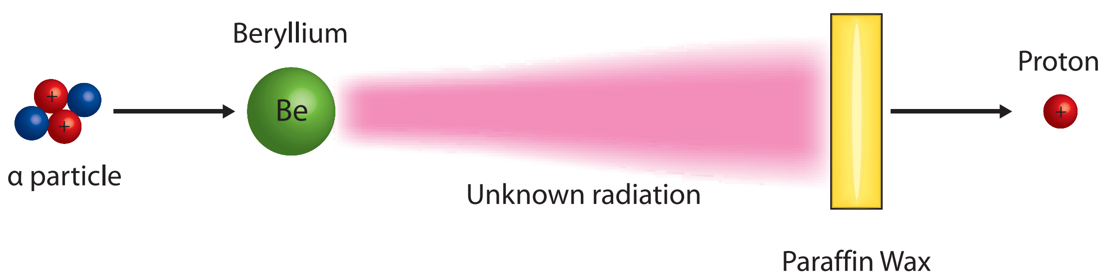
4.3.1 Define the components of the nucleus (protons and neutrons) as nucleons and contrast their properties

Protons and neutrons are both nucleons- particles found in the nucleus, and are slightly different. Both have masses on the same order (measured in amu) but the neutron is slightly heavier than the proton. In terms of charge, the proton has the same charge as an electron only positive, while the neutron has no charge at all. Protons are therefore affected by magnetic and electric fields, while neutrons are not.

4.3.2 Discuss the importance of conservation laws to Chadwick's discovery of the neutron

Don't forget that the focus of this dotpoint is the use of conservation laws in regard to discovering the neutron. In an exam make sure you don't waste time by going into too much detail about the experiment itself.

Chadwick predicted the existence of the neutron based on an experiment that otherwise had no other explanation. When a beryllium atom was bombarded by alpha particles, it emitted a form of radiation. This radiation could not be detected in a cloud chamber and didn't appear to be a particle- in fact it was initially thought to be gamma radiation. The radiation was capable of knocking protons out of a block of paraffin wax, with the protons travelling away with considerable momentum. In terms of conservation laws there were two applicable to this- conservation of atomic mass and number, and conservation of momentum/energy. Chadwick found that the energy required to eject the proton with the observed momentum could not have been produced by EMR as the energy required would be insufficient (and conservation of momentum would be violated as the photon would not contain enough momentum). However, he realised that a neutral particle would be capable of colliding with a proton and imparting the observed momentum without violating conservation laws. So conservation of momentum was vital in terms of discovery of the neutron. Secondly, the nuclear reaction was ${}^{9}_{4}\text{Be} + {}^{4}_{2}\text{He} \longrightarrow {}^{12}_{6}\text{C} + ?$. By adding mass numbers, according to conservation of atomic mass there would have to be an unknown particle with ${}^{1}_{0}?$ to explain the reaction- so through conservation of mass Chadwick was able to prove the existence of the neutron (and show that the initially observed radiation was in fact a particle).



Remember- Chadwick used conservation of energy to determine the radiation was a particle, and conservation of mass to determine its mass and charge.

4.3.3 Define the term transmutation

Transmutations are nuclear reactions where one element is transformed into another because the number of protons in the nucleus changes- this can occur either due to alpha or beta decay.

4.3.4 Describe nuclear transmutations due to natural radioactivity

Some atoms are inherently unstable because their nuclei exist outside the zone of stability in terms of proton-neutron ratio, or because they have too many protons. This can cause natural radioactive decay to occur, resulting in nuclear transmutation. There are two forms of natural radioactive decay that result in transmutations- alpha and beta decay. In alpha decay, the nucleus emits an alpha particle consisting of two protons and two neutrons, in the process reducing its mass by 4 and its atomic number by 2. A common example is the alpha decay of uranium-238, which occurs according to

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

More accurately, the alpha particle doesn't have any electrons, thus a more complete equation would be

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

However, the alpha particle rapidly gains electrons from surrounding atoms (hence why alpha radiation is the least penetrative form of nuclear radiation) and the Thorium ion formed rapidly loses its extra electrons. Therefore, the charges are typically omitted since they are so short lived.

In beta decay, a neutron decays into a proton (which stays in the nucleus raising the atomic number by one), an electron (which is emitted), and an antineutrino (which is also emitted). In the typical case of beta decay

$$^{1}_{0}\text{n} \longrightarrow {}^{1}_{1}\text{p} + {}^{0}_{-1}\text{e} + \bar{\nu}$$

This form of beta decay is known as 'beta-minus'. There is another form of beta decay, 'beta-plus', where the proton decays into a neutron, a neutrino, and a positron (antielectron). However, beta-plus decay is not included in the HSC- only beta-minus is considered.

Remember- Alpha decay releases 2 protons and 2 neutrons (an alpha particle) while beta decay releases an electron (a beta particle), an antineutrino, and converts a neutron into a proton.

4.3.5 Describe Fermi's initial experimental observation of nuclear fission

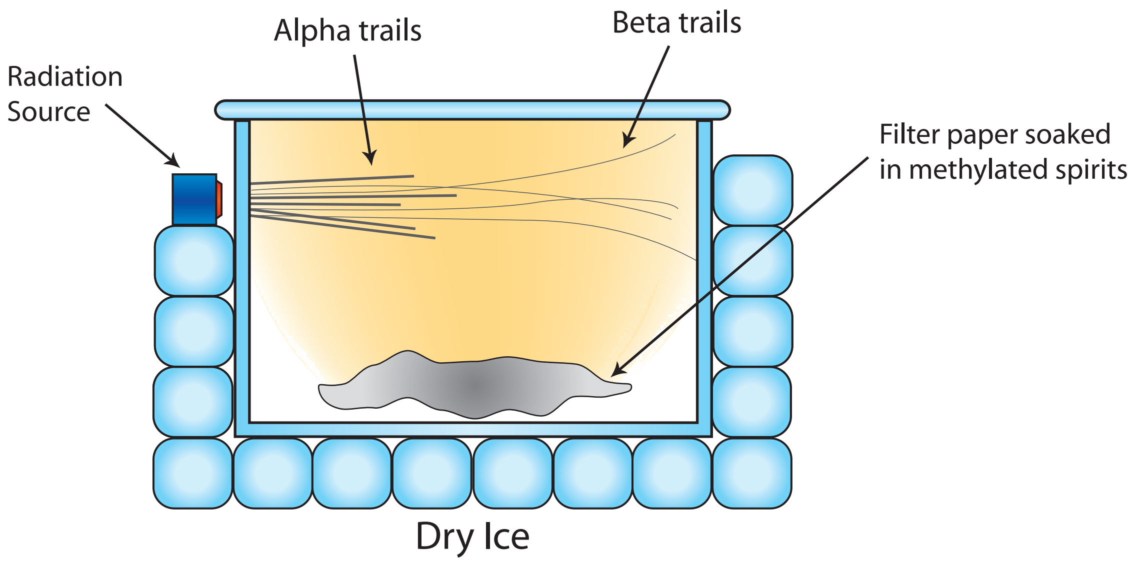
Fermi initially joined the many other scientists who were using neutron bombardment of heavy nuclei in order to investigate their properties. Fermi was trying to cause uranium to undergo beta decay to produce transuranic elements heavier than uranium. What he initially found was that slow neutrons (slowed by a paraffin wax block) were far more effective than fast neutrons, because they had a greater chance of being captured by the nuclei (since slow neutrons spend more time close to the nucleus, because they travel slower). But most importantly, what he observed was that when he bombarded the nuclei with neutrons, instead of producing a single heavy radioisotope he found 4 separate products each with different half lives. This was his first observation of fission, although he did not realise what was happening in his experiment.

Remember- Fermi was the first to observe nuclear fission when he realised that following a nuclear reaction there was more than one product.

4.3.6 Perform a first-hand investigation or gather secondary information to observe radiation emitted from a nucleus using a Wilson Cloud Chamber or similar detection device

The shape of the trails can be directly linked to the properties of alpha and beta particles. Alpha particles form strong trails because they are more highly charged, and therefore ionise more air as they travel (resulting in more condensation), while beta particles form less intense trails because their ionisation strength is not as great. However, alpha particles trails are shorter, because their strong charge causes them to attract electrons rapidly, so before they travel a long distance they get converted to neutral helium, and can therefore no longer ionise the air. In fact, this is the same reason that alpha radiation is both not very penetrative, yet highly dangerous inside the body. Beta particles react less with their surroundings, which is why they travel a longer distance. Finally, the alpha trails are relatively straight, because the large mass of the alpha particle means that it is deflected less by other particles as it travels. On the other hand, beta particles have a very low mass, and so are very susceptible to having their path changed through interactions with other particles. However, their path is still relatively straight because their high velocity and low charge means that they are less likely to have their path changed.

In this experiment, we constructed a cloud chamber by filling a transparent glass container with a supersaturated vapour. We did this by placing filter paper soaked in methylated spirits inside the container, then cooling the container with dry ice placed below the container. When we placed a radiation source next to the chamber, we were able to observe trails left by alpha and beta particles. This is because when the charged particles travel through the chamber, they ionise the surrounding air. The ions created served as points for the vapour to condense, leaving a trail. The trails from alpha particles were straight, relatively short, and thick/well-defined, while the trails from beta particles were longer and thinner, though they too were straight. As the gamma radiation did not create a stream of ions for condensation, gamma emissions were not visible.

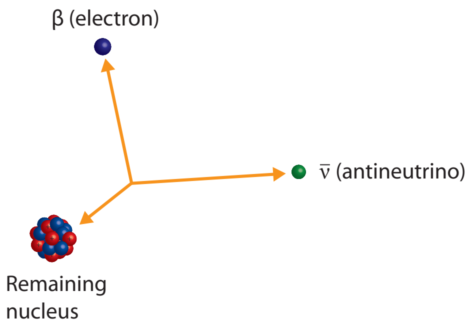


Remember- Alpha particles produce short, straight trails, beta particles produce longer, less straight trails, and gamma radiation doesn't produce any trail.

4.3.7 Discuss Pauli's suggestion of the existence of the neutrino and relate it to the need to account for the energy distribution of electrons emitted in beta decay

During beta decay, initially scientists thought only beta particles were emitted. When they evaluated the energies involved, they came up with a figure for the maximum kinetic energy that a beta particle should have. All beta particles should have been emitted with this velocity, but this wasn't the case. Instead, almost none were emitted with the full amount of kinetic energy, and most of them were emitted with significantly less. This meant that the slow beta particles were missing kinetic energy, leading to a violation of conservation of energy. Also, the sum of the momentums before and after beta decay was not equal- assuming the nucleus starts off stationary, the sum of momentums should be zero. However, when the momentums of the beta particle and the remainder of the nucleus were added, it was not zero, so conservation of momentum was being violated.

Pauli realised that conservation of energy (and momentum) could be resolved if there was an additional particle being emitted in beta decay- the neutrino, so named as it means little neutral one. The sum of all 3 momentums was equal, thereby maintaining conservation of momentum, although the neutrino couldn't be detected at the time. So the proposal of the neutrino explained the variable kinetic energies of beta particles, and resolved conservation of momentum. It was an excellent idea in this regard, but critically it lacked evidence because scientists at the time could not detect neutrinos. They were only detected 20 years later using more advanced techniques (Later they were shown to be antineutrinos, rather than neutrinos).



Remember- Pauli suggested the existence of the neutrino to account for variable beta particle velocities and to fulfil conservation of momentum.

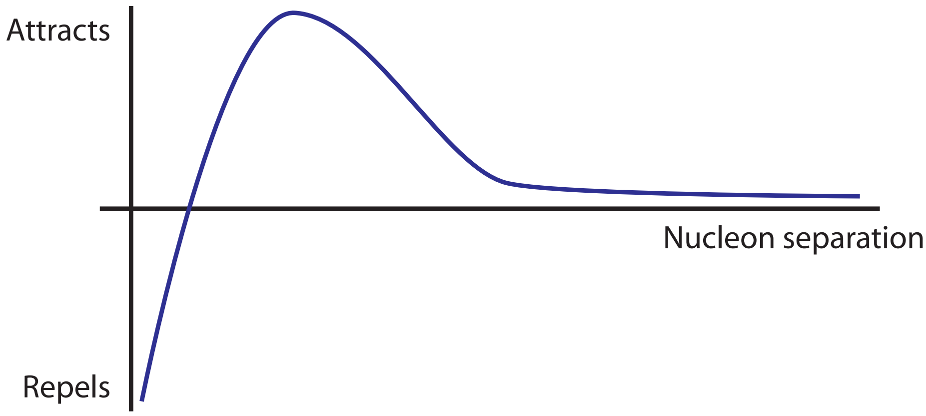
4.3.8 Evaluate the relative contributions of electrostatic and gravitational forces between nucleons

Electrostatic repulsion between like-charged positive protons and gravitation attraction between masses in the nucleus are two of the forces that act between nucleons. However, in terms of relative contributions i.e. relative strength, electrostatic repulsion is far stronger than gravitational attraction. Indeed, the force of gravitational attraction is so insignificant that it can be disregarded in most calculations regarding forces acting between nucleons. The end result of this is that if electrostatic repulsion is forcing the nucleus apart, and gravitational attraction cannot hold it together, then there must be another strong force acting to hold the nucleus together, to prevent it from disintegrating.

Remember- Electrostatic repulsion is far stronger than gravitational attraction within the nucleus.

4.3.9 Account for the need for the strong nuclear force and describe its properties

The strong nuclear force is required to hold the nucleus together (as observed countless times because nuclei don't just fly apart) given that the only significant other force is electrostatic repulsion in the nucleus. Therefore, the strong nuclear force is needed to be an attractive force that opposes electrostatic repulsion and holds the nucleus together. The strong nuclear force is experienced only over very short distances- at extreme short distances it is repulsive, then it becomes attractive as distance increases, then increasingly weaker at large distances (while electrostatic repulsion remains relatively strong). This means that there is a balance of separation where at a particular point, the two forces are balanced and the nucleus is stable. Incidentally, the strong nuclear force is only repulsive at extremely small distances- at reasonably small distances it is attractive, and far stronger than the electrostatic force in terms of magnitude. In fact, the strong nuclear force is the strongest known force in the universe. The force is independent of charge and only acts on neighbouring nucleons, not on the entire nucleus.

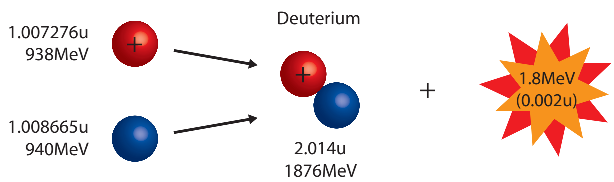


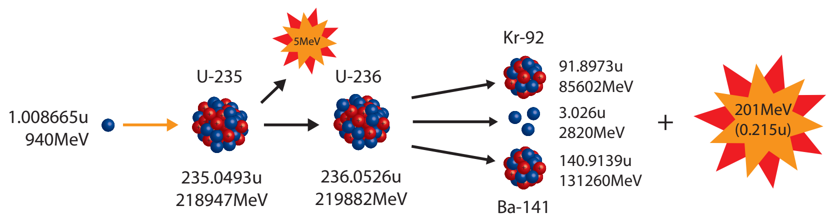
Remember- The strong nuclear force is required to hold together the nucleus given that gravitational attraction is so much weaker than electrostatic repulsion. It repels at extremely short distances, then attracts with decreasing strength at increasing distances.

4.3.10 Explain the concept of a mass defect using Einstein's equivalence between mass and energy

See the Extra Content chapter for an explanation of the apparent contradiction described in this dotpoint, where both fusion and fission release energy. Also note that the correct unit for 'atomic mass unit' is simply 'u', not 'amu'.

The actual mass of a nucleus is always less then the sum of the masses of the constituents of the nucleus. This means that a helium nucleus with 2 neutrons and 2 protons has less mass than the combined mass of 2 neutrons and 2 protons measured separately. This implies that there is missing mass- this missing mass is called mass defect. It is related to the need for nucleons to lose energy in order to bind together, a stable bond being representative of a low energy state. In order for the nucleons to bond together, they need to lose energy. They do this by losing mass, as according to Einstein mass and energy are equivalent. The mass defect is calculated by simply taking the difference between the mass of the nucleus and the sum of its constituents, usually all carried out in amu. Further, this mass loss can be expressed in energy terms, as MeV, according to $1\text{u} = 931.5\text{MeV}$. The mass defect in terms of energy is also known as the binding energy- the energy required to completely separate out all the parts of the nucleus by breaking bonds. Binding energy is the energy input required to restore the nucleons to their original energy states, thereby breaking the bonds that hold them together in the nucleus. This is also related to the release of energy in fission- the binding energy of a single atom is less than the binding energy of the two atoms produced when the single atom is split. If the total binding energy has increased, that means that more energy is now required to break the bonds, and therefore some energy must have been emitted in the splitting process- this is the energy release from fission (similarly, when split the total mass defect of two smaller nuclei is more than the mass defect of just one nucleus)





Remember- Binding energy is the energy required to break a nucleus into its constituents, and mass defect is binding energy expressed in amu by using Einstein's equivalence between mass and energy.

4.3.12 Describe Fermi's demonstration of a controlled nuclear chain reaction in 1942

Fermi realised that since the fission of a uranium atom released 3 neutrons, and that since only 1 neutron is required to cause fission in a uranium nucleus, a chain reaction of nuclear fission could be produced that would release a great deal of energy. If neutrons were absorbed such that not all of them produced additional fission, a controlled chain reaction could be produced to release power. This is exactly what Fermi demonstrated in 1942 in a squash court in Chicago at Stagg Field, when he took 50 tonnes of natural uranium in 20000 slugs, in a reactor with 400 tonnes of graphite as a moderator. He used cadmium control rods to prevent the reaction from going out of control. His reaction was successful and was able to generate 0.5 watts in a self-sustaining reaction.

Remember- Fermi built a nuclear reactor at Stagg Field in Chicago with a graphite moderator and cadmium control rods.

4.3.13 Compare requirements for controlled and uncontrolled nuclear chain reactions

To produce an uncontrolled nuclear chain reaction, all that is required is a mass of fissionable material such as Uranium-235 greater than the critical mass specified for that material. The critical mass for a material is the minimum amount of material required so that the neutrons emitted from fission go on to cause further fission reactions in a chain reaction, sustaining the reaction. So for an uncontrolled reaction, all that is required is a source of neutrons, a means of slowing them down, and a super-critical mass of fissionable material. A large lump of fissionable material will generally meet all 3 criteria, as the material itself is a super-critical mass, a source of neutrons, and a means for slowing down neutrons.

To produce a controlled reaction, a reactor is required with a mechanism to capture neutrons so that the overall number of neutrons that cause fission is constant. Normally uranium releases 3 neutrons- the control rods in a reactor capture two of the neutrons so that only one goes on to cause another fission reaction. If all 3 neutrons caused fission, each stage of fission would have triple the number of reactions, resulting in exponential growth of energy release and an uncontrolled reaction. By absorbing excess neutrons, the reaction is controlled and doesnt spiral into an explosion. Also, a moderator is used to slow fast neutrons in the reactor. Fast neutrons travel past nuclei rapidly and have a low chance of being absorbed, causing fission. Slow neutrons spend much longer in the vicinity of atomic nuclei (since they are travelling slower) and so have a much greater chance of being captured by the nucleus. So a controlled nuclear reaction needs a super-critical mass of fissionable material, a source of neutrons, a way to slow those neutrons down, and a mechanism to absorb excess neutrons from the reaction.

Remember- An uncontrolled reaction requires a critical mass of fissionable material, along with a moderator and source of neutrons (which is often the material itself). A controlled reaction also needs a control mechanism to capture excess neutrons.

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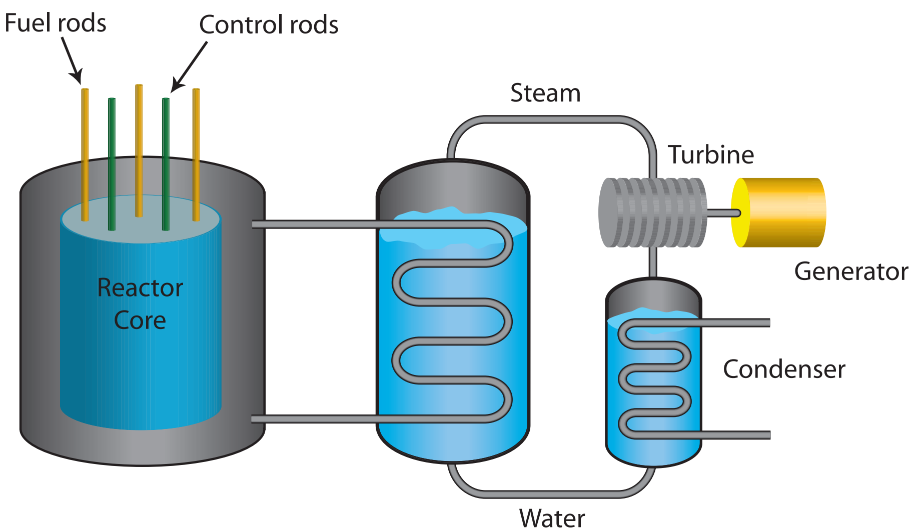
4.4 Applications of Nuclear Physics

4.4.1 Explain the basic principles of a fission reactor

A fission reactor uses a nuclear reaction to generate electricity. As with all generators, this involves producing rotation to turn a generator. In a nuclear reactor, heat from the nuclear reaction is used to produce steam which turns a turbine, in the same way that burning coal generates steam in a coal power plant. As outlined before, there are several requirements for a controlled reaction. These must be met in a fission reactor to ensure that firstly a reaction takes place, and secondly that the reaction doesn't go out of control and produce an explosion. In addition to this, there are several key components to a fission reactor. Fuel rods consisting of enriched uranium are placed inside the reactor to provide the critical mass required. Control rods consisting of cadmium or boron are also placed in the reactor, such that they can be moved in and out to control the reaction. The control rods absorb excess neutrons to prevent the reaction from taking place too quickly. When they are lowered, more neutrons are absorbed and the reaction slows, and when pulled out the reaction rate increases. The entire reactor is immersed or surrounded by a moderator to slow down neutrons and thus increase the rate of reaction. The moderator consists of either heavy water, graphite, or various other organic compounds. A coolant is required to extract heat from the reaction and to prevent the reactor from melting. The coolant flows through the reactor then out into a heat exchanger that takes heat extracted from the coolant and uses it to boil water. Spent fuel rods that have been depleted in the reactor are extracted and processed or stored. They are extremely radioactive, making them very difficult to dispose of. Finally, the reactor is surrounded by multiple layers of shielding. There is a graphite shield that reflects neutrons back into the core, followed by a thermal shield to prevent unwanted heat loss from the core, a pressure vessel surrounding the core to isolate and contain everything inside the core, and lastly a biological shield of about 3 metres of concrete mixed with lead pellets, to absorb gamma rays and neutrons.



Remember- A nuclear reactor has a reactor core with fuel rods, control rods and a moderator. Coolant is heated inside the core and pumped out where it boils water. The steam produced turns a turbine, and is then condensed back into water. Shielding is used inside the reactor to prevent radiation and heat from escaping.

4.4.2 Gather, process and analyse information to assess the significance of the Manhattan Project to society

The Manhattan Project was one of the most significant scientific undertakings of the 20th century because of the dramatic impacts it had on society. It consisted of American efforts to produce nuclear weaponry, which were eventually successful and resulted in the deployment of nuclear weapons over Japan in 1945. In terms of impact on society, there were direct scientific impacts, namely the development of nuclear power offering a possible solution to the depletion of fossil fuels and a way of reducing greenhouse gas emissions from power generation. Much more significant however, were the social impacts that atomic weaponry had on global politics. To begin with, nuclear power had terrified the world with its incredible destructive power as witnessed in Japan. As a result, countries with nuclear weapons, primarily the USA and Russia in the period following WW2, became very reluctant to use them, firstly because of their long term destructive power, but secondly because of fear that retaliation would take the form of nuclear reprisal. As a result, although significant political tension built between Russia and USA, it never broke out into conflict, as either side was concerned that aggressive action would result in nuclear warfare, resulting in mutually assured destruction. Where a conventional war would have broken out previously, peace was maintained due to the development of nuclear weaponry. In modern times however, nuclear power is proving to be a dangerous bargaining chip for rogue states such as North Korea and Iran which are using nuclear weapons as leverage in negotiations with the Western world. It has led to a situation where small nations with comparatively weak conventional forces can use the threat of nuclear warfare to negotiate equally with large nations such as the USA. This has led to significant problems in terms of global politics and the power balance between nations necessary to maintain peace. Arguably however, even in these situations the threat of mutually assured destruction is preventing warfare. As a result of the nuclear threat, the UN and the USA are focussing on a diplomatic, sanctions-based approach to resolving conflict rather than an aggressive military approach. Overall, although the Manhattan Project led to the deaths of many Japanese people in Hiroshima and Nagasaki, and although it resulted in a build-up of nuclear arsenals across many nations providing a constant threat to global security, in the end the resulting nuclear stalemate has prevented several wars and therefore averted many possible deaths.

Remember- Although the Manhattan project led to many deaths at the end of WW2, the threat of nuclear war has prevented conflict in the decades after.

4.4.3 Describe some medical and industrial applications of radioisotopes

There are many applications of radioisotopes in medical and industrial fields. In the medical field, radioisotopes are mainly used for imaging/diagnosis and for treatment. In imaging, the transmission of radiation through the body and the degree to which radiation is absorbed can be used to remotely examine the body. They are often used to examine brain activity (using Positron Emission Tomography). By injecting radioisotopes into the body and examining where they end up (made possible because the radioisotopes are emitting radiation), the circulatory system can be investigated. Finally, radioisotopes are frequently used to kill cancer cells, the radiation destroying them. In industry, they are used to examine stress fractures in metals such as in aircraft wings (because although the fractures may not be visible, radiation can pass through them), detecting leaks in pipes that may be otherwise difficult to find (since radiation will escape from a leaking pipe), and to irradiate medical supplies and food to kill bacteria.

Remember- Radioisotopes are in medicine used for imaging and cancer treatment, while in industry they are used to examine stress fractures and to sterilise objects and food.

4.4.4 Identify data sources and gather, process and analyse information to describe the use of a named isotope in medicine, agriculture and engineering

Iridium-192 is used in medicine to kill cancerous tumours. Iridium-192 pellets are implanted into the tumour where gamma emissions kill the cancer cells. Because the cancer cells are directly exposed to the radiation since they surround the pellet, damage to healthy cells is minimised (as opposed to external irradiation). Because it has a half-life of around 80 days the iridium must be surgically removed after treatment is complete to prevent over-exposure to radiation. The iridium undergoes beta decay, and transmutates to turns to inert platinum that poses no health risk. This makes iridium implants an extremely effective way to treat cancer.

In engineering, cobalt-60 is used to detect stress fractures in metals, particularly in aircraft. Stress fractures occur when metals are repeatedly exposed to strong forces, such as those experienced by the wings of an aircraft. Small fractures can form in the metal, which can eventually result in a catastrophic failure (e.g. there were several cases where early jet aircraft had fuselage explosions because the metals used to construct the aircraft eventually broke apart due to stress). These fractures are the precursors to actual breaks in the metal, but they are extremely hard to detect. By placing cobalt-60 on one side of the metal, and a gamma detector on the other side (often photographic film), the cracks can be identified easily and non-destructively because the gamma radiation only penetrates in areas where stress fractures have formed.

In agriculture, the elements that plants require can be substituted with radioisotopes of the same element. This allows the path of the material to be tracked through the plant's structure. For example, replacing the phosphorus in soil with a mix containing radioactive phosphorus-32 will allow the path of phosphorus to be tracked into plants. By measuring how radioactive the plants are, how much phosphorus was used by the plant can be determined, as well as the areas in the plant where the phosphorus is concentrated. This has benefits in terms of better understanding the conditions favourable for plant growth, thereby maximising yield and increasing efficiency of the farming process.

Remember- Iridium-192 is implanted to kill cancer cells, cobalt-60 is used is used to detect fractures in metal, and phosphorus-32 is used to trace element flow in plants.

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4.4.5 Describe how neutron scattering is used as a probe by referring to the properties of neutrons

In the same way that an electron microscope uses electrons to probe materials, neutrons too can be used in microscopes. However, unlike electrons, neutrons do not carry charge and are therefore not affected by the nuclei of atoms which would deflect electrons. They are therefore extremely useful for imaging crystal structures, as well as substances containing light atoms such as hydrogen. While electrons do pass through crystals and diffract, they are deflected by charges in the crystal, resulting in errors. Neutrons penetrate crystals very effectively, allowing for a clearer and more accurate interference pattern to be produced. According to the de Broglie equation, neutrons have a wavelength shorter that light, similar to the wavelength of an electron.

Remember- Neutrons can be used as effective probes because they have wavelengths similar to electrons. However, because they are not charged they can image objects where charge interferes with electrons.

4.4.6 Identify ways in which physicists continue to develop their understanding of matter, using accelerators as a probe to investigate the structure of matter

Physicists now develop their understanding of matter by examining the component of atoms to better understand them. This necessitates separating the atom into its components, requiring large inputs of energy and sophisticated equipment that was previously unavailable. However, modern particle accelerators are used to break atoms into their components, which are then examined, developing our understanding of matter.

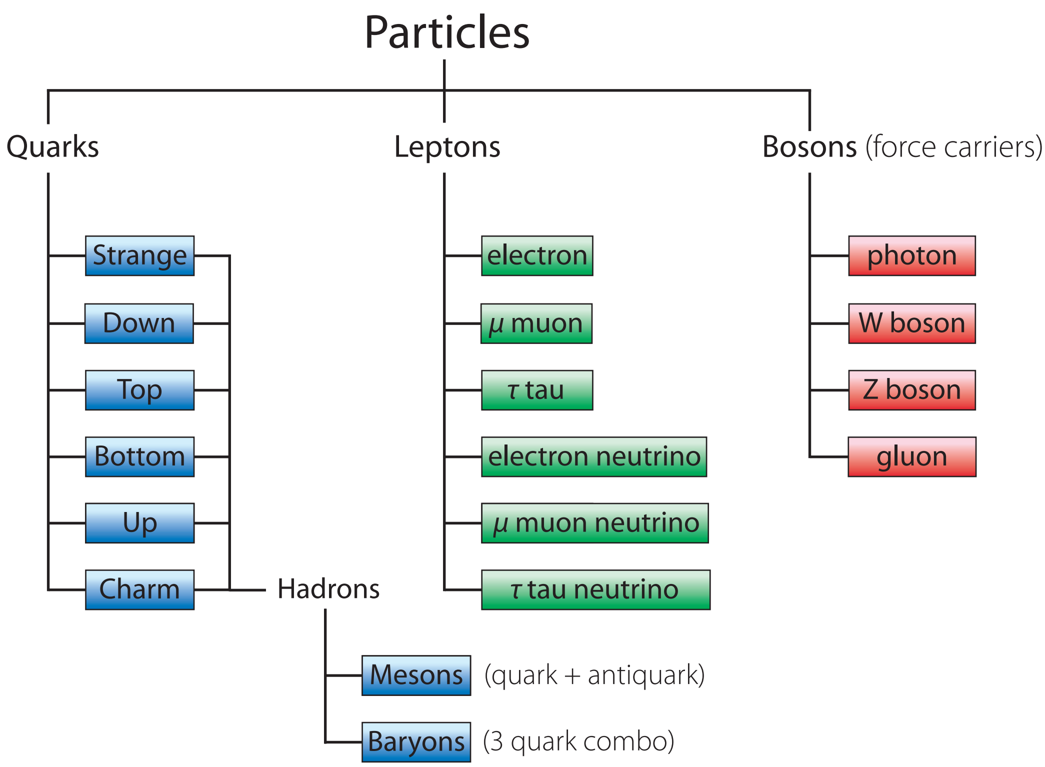
All particle accelerators use magnetic fields to accelerate charged atoms or particles to very high velocities. The three most common types are the linear accelerator, the cyclotron and the synchrotron. A linear accelerator is simply a very long track down which an atom is propelled. It is simple, but its main constraint is size, and energy input is dependant on the length of the accelerator. A cyclotron uses high-frequency AC current to generate a magnetic field that causes the electron to accelerate in a spiral. This reduces the size of the reactor, while at the same time using relatively simple equipment. A synchrotron is a complete circle in which a particle travels. While the particle can be accelerated indefinitely, powerful computers are required to manipulate the magnetic field in the synchrotron in order to propel the particle. Particle accelerators also usually have the ability to generate collisions between high-energy accelerated particles, allowing scientists to examine the properties of matter from the collision. So through using particle accelerators, scientists are able to develop their understanding of matter.

Remember- Scientists are now trying to understand the components of atoms. Accelerators provide the high energies required to break atoms into their components.

4.4.7 Discuss the key features and components of the standard model of matter, including quarks and leptons

The standard model of matter is a theory that states all matter is composed of small elementary particles that exist by themselves or group together to form subatomic particles and to transmit force (because under quantum theory, forces that result due to a field are caused by particles travelling between the objects). There are broadly 3 types of particles. Bosons are force-carrying particles, examples of which include photons that carry electric and magnetic force, gluons that carry the strong nuclear force, and gravitons that cause gravity. Leptons are single elementary particles that exist by themselves and are not affected by the strong nuclear force. They include electrons, muons and taus as well as their neutrino subsidiaries (the electron, muon and tau neutrinos respectively). Quarks are the building blocks of hadrons, which are groups of quarks.

There are 6 types of quarks- up, down, top, bottom, strange and charm, each with different properties. Baryons are groups with 3 quarks, such as protons and neutrons, while mesons are pairings of a quark and an antiquark. Because quarks each have a half-integer spin value (spin being one of Pauli's quantum numbers), combining two gives a whole integer, while combining three gives a half-integer. Therefore, baryons have half-integer spin values while mesons have whole integer spin values. Thus baryons are also fermions, as fermions are particles that have half-integer spins and therefore obey Pauli's exclusion principle. Bosons are not fermions.



Chapter 5

Formula Guide

5.1 Space

Universal Gravitation

$$F = \frac{Gm_1 m_2}{r^2}$$

$$\text{Force} = \frac{\text{gravitational constant}(6.67 \times 10^{-11}) \times \text{mass of first object} \times \text{mass of second object}}{\text{distance between the objects}^2}$$

Usage Tip: *This formula gives the magnitude of gravitational attraction between the masses and is exerted equally on both masses. Be careful when you use it, it may not give you the answer you require.*

Gravitational Acceleration

$$g = \frac{Gm_p}{r_p^2}$$

$$\text{Gravitational acceleration} = \frac{\text{gravitational constant}(6.67 \times 10^{-11}) \times \text{mass of planet (or object)}}{\text{radius of planet or object}^2}$$

Gravitational acceleration on the left side of this equation is measuring the acceleration at the *surface* of the planet or object

Usage Tip: *This formula is derived from Universal Gravitation by $F = ma$, in this case a representing g. Substituting mg for F in the universal gravitation formula and cancelling the mass of the object from $F = mg$ gives the gravitational acceleration. The radius is required to calculate the acceleration at the surface of the object. Alternatively, the distance from the centre of the object could be used- to calculate the acceleration at a point above the surface, it would be (r_{object} + altitude)^2. Note also that because the bottom of the equation is r^2, gravitational acceleration and therefore field strength obeys the inverse square law.*

Weight Formula

$$W = mg$$

$$\text{Weight force} = \text{mass of the object} \times \text{gravitational acceleration}$$

Usage Tip: *Weight force is simply the force that a gravitational field exerts on an object. As the formula shows, this force increases as the mass of the object increases so that any object in the field accelerates at a constant rate.*

Potential Energy

$$E_p = -\frac{Gm_1m_2}{r}$$
$$\text{Potential energy} = -\frac{\text{gravitational constant}(6.67 \times 10^{-11}) \times \text{first mass} \times \text{second mass}}{\text{distance between the objects}}$$

Usage Tip: *The reason this formula is negative is actually simple. When you move an object away from a gravitational field, it gains energy. A stone at the top of a building has more E_p than a stone on the ground. However, at an infinite distance from a planet, the field strength is 0 and the object doesn't have any energy due to the gravitational field. So because E_p increases as the distance increases, and is 0 when distance is infinite, E_p takes a negative value. In this definition, it's the work done to move an object from an infinite distance to a point in a gravitational field. Note also that the bottom of the formula is simply r, not r^2. The equation is similar to Universal Gravitation but with those two key differences.*

Velocity Equations

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

where

$$v = \text{final velocity (m/s)}$$
$$u = \text{initial velocity (m/s)}$$
$$a = \text{acceleration (m/s}^2\text{)}$$
$$s = \text{displacement (m)}$$
$$t = \text{time (s)}$$

Usage Tip: *Select one based on the unknown required. There are 5 variables between them. Questions will provide 3 variable values, so the choice of equation will be the equation with those 3 values and the variable required to solve for.*

Escape Velocity

$$v_{\text{escape}} = \sqrt{\frac{2Gm_p}{r_p}}$$
$$\text{Escape velocity} = \sqrt{\frac{2 \times \text{gravitational constant}(6.67 \times 10^{-11}) \times \text{mass of the planet}}{\text{radius of the planet}}}$$

Usage Tip: *This lends itself to two key observations. Firstly, the obvious fact that the greater the mass of the planet, the higher the escape velocity, but further, that the bigger the planet, the lower the escape velocity, regardless of mass. The key reason for this is that the escape velocity depends on the distance not from the planet, but from the centre of the field. Assuming a big planet and small planet have the same mass, a rocket at the surface of the big planet will be further from the centre of the field than a rocket at the surface of the small planet. Because the rocket on the larger planet starts out further from the centre of the field, the escape velocity is lower*

G-Forces

$$F_{\text{gravities}} = \frac{mg + ma}{mg_{\text{earth}}}$$
$$\text{Force (in G's)} = \frac{\text{mass} \times \text{acceleration due to gravity} + \text{mass} \times \text{acceleration of reference frame}}{\text{mass} \times \text{Earth's gravitational acceleration } (9.8\text{m/s}^2)}$$

Usage Tip: *G-Force is essentially the ratio of the force experienced by an object to the force it experiences at rest on Earth. This means that 2 G's are eqivalent to twice the Earth's gravitational acceleration (ie. 2 G's is 19.6m/s^2). When calculating G Force, make sure that you add on the effect of any gravitational field present- not just the acceleration of a rocket etc.*

Centripetal force

$$F_c = \frac{mv^2}{r}$$

$$\text{Centripetal force} = \frac{\text{mass of the object} \times \text{the object's velocity}^2}{\text{radius of its circular motion}}$$

Usage Tip: *Centripetal force is the force required to keep an object in circular motion at a specified velocity. From $F = ma$, it can be seen that centripetal acceleration is simply $\frac{v^2}{r}$. Don't forget in an orbit, r is equal to orbital altitude plus the radius of the Earth, orbital radius being measured from the Earth's centre (i.e. the centre of the field).*

Orbital Period

$$T = \frac{2\pi r}{v}$$

$$\text{Period} = \frac{2 \times \pi \times \text{radius of the orbit}}{\text{orbital velocity}}$$

Usage Tip: *As can be seen here, the period is just the time taken for the satellite to travel along the length of a circular orbit i.e. the circumference*

Orbital Velocity

$$v = \sqrt{\frac{Gm_p}{r}}$$

$$\text{Orbital velocity} = \sqrt{\frac{\text{gravitational constant}(6.67 \times 10^{-11}) \times \text{mass of the planet or central body}}{\text{orbital radius}}}$$

Usage Tip: *Again, orbital radius is measured to the Earth's centre and is not the same as orbital altitude*

Kepler's Law of Periods

$$\frac{r^3}{T^2} = \frac{Gm_p}{4\pi^2}$$

$$\frac{\text{Orbital radius}^3}{\text{Orbital period}^2} = \frac{\text{gravitational constant}(6.67 \times 10^{-11}) \times \text{mass of the planet}}{4 \times \pi^2}$$

Usage Tip: *This is derived by taking the orbital period formula, switching v and T, then substituting into the orbital velocity formula and rearranging. Essentially, it states that in any system, $\frac{r^3}{T^2}$ for any satellite is a constant, as long as they are orbiting the same central body. Kepler's law is used for calculating orbital radius or orbital period when the orbit of another satellite of the same system is known, or when the mass of the central body is known and the radius or period is provided*

Slingshot Effect

$$v_{\text{final}} = v_{\text{initial}} + 2V_{\text{initial}}$$

$$\text{Final probe velocity} = \text{initial probe velocity} + 2 \times \text{planet's initial velocity}$$

Usage Tip: *This formula may not be necessary, but it's included in the Jacaranda textbook. It's derived by the assumption that the slingshot effect is an elastic collision. Thus two expressions are written, one equating the total momentum of the system before and after and one equating the total kinetic energy before and after, and then solving simultaneously. It probably isn't necessary to derive it, but in order to reduce variables, the mass of the planet is expressed as Km where m is the mass of the probe and K is a value such that Km is the mass of the planet. The K's eventually cancel out, but are necessary to derive the equation*

Correction Factor

$$\text{CF} = \sqrt{1 - \frac{v^2}{c^2}}$$
$$\text{Correction factor} = \sqrt{1 - \frac{\text{relative velocity}^2}{\text{speed of light}^2}}$$

This formula is not explicitly provided by itself nor is it used by itself. But it is a key part of all calculations involving relativity that are encountered in the syllabus. Essentially, the correction factor is the mathematical factor that corrects for relativistic effects. All that needs to be known is the effect relativistic speeds have and the correction factor can be easily applied. Note also that the correction factor is always a value between 0 and 1. The syllabus deals with three scenarios- time, length and mass. Time dilates, so at relativistic speeds the time taken for an event to occur in the eyes of an observer increases. So the original time taken is divided by the correction factor so that it gets bigger, giving the observed time. Conversely, if the observed time is provided, it is multiplied by the correction factor to reduce it to the value in the other frame. Length contracts, so to calculate observed length the length in the other frame is multiplied by the correction factor so that it becomes smaller. Mass dilates at relativistic speeds, so the original mass of an object is divided by the correction factor so that the observed mass is bigger. Simply put, observed time is longer, observed length is smaller, observed mass is bigger. Apply the correction factor to real figures to agree with these ideas, and you will always be correct.

Warning: The relative velocity could exceed the speed of light, for example, if both objects were heading in opposite directions at $> 0.5c$ each. This formula is incapable of dealing with such situations. However, these situations are not considered in the HSC course.

Usage Tip: *If instead of providing a specific velocity, a question provides a multiple of c, such as a spaceship travelling at 0.6c relative to an observer, this can be substituted directly into the formula to give $\sqrt{1 - 0.6^2}$, because 0.6 is the ratio of spacecraft velocity to the speed of light (i.e. $\frac{v}{c}$), thus* $0.6^2 = \frac{v^2}{c^2}$

Mass and Energy

$$E = mc^2$$
$$\text{Energy} = \text{mass of the object} \times \text{speed of light}^2$$

Usage Tip: *This formula only applies to the rest state. If an object is moving, add its kinetic energy to the right side of the equation*

5.2 Motors and Generators

Force on a Wire

$$F = BIl\sin\theta$$
$$\text{Force} = \text{field strength} \times \text{current} \times \text{length} \times \sin\theta$$

where

$$\theta = \text{angle between the field and the wire}$$

Usage Tip: *When the wire is perpendicular to the field, θ is 90, not 0. It's the angle the wire makes with the field lines.*

Magnetic field strength from a long conductor

$$B = \frac{kI}{d}$$
$$\text{Field strength} = \text{constant } (2 \times 10^{-7}) \times \frac{\text{current through the wire}}{\text{distance from the wire}}$$

Force between two parallel conductors

$$\frac{F}{l} = \frac{kI_1I_2}{d}$$
$$\frac{\text{Force}}{\text{Length of finite conductor}} = \frac{\text{constant } (2 \times 10^{-7}) \times \text{first current} \times \text{second current}}{\text{distance separating the wires}}$$

Usage Tip: *The question will have one 'very long' conductor and then a wire of a fixed length. The fixed length is l, it doesn't matter which wire is 1 and 2*

Torque

$$T = Fd\sin\theta$$
$$\text{Torque} = \text{force} \times \text{distance from pivot point} \times \sin\theta$$

where

$$\theta = \text{angle between direction of applied force and line joining point of application to pivot point}$$

Usage Tip: *This is when the force is not applied tangentially, but when the force is applied at an angle. This is necessary because in a motor the force acts in the same direction but the angle changes as the coils rotate*

Torque in a motor

$$T = BAIn\cos\theta$$
$$\text{Torque} = \text{magnetic field strength} \times \text{area of the coil} \times \text{current} \times \text{number of loops in the coil} \times \cos\theta$$

Usage Tip: *θ is the angle between the field lines and the plane of the coil such that when the coil is perpendicular to the field, θ is 90 and so $\cos\theta$ is zero. θ is not the angle between the vertical and the coil. Area is used because although the distance to the pivot point is only half the side length of the coil, there are two sides generating torque and so twice the force. The formula simplifies into area*

Magnetic Flux

$$\Phi_B = B_{\perp}A$$
$$\text{Flux} = \text{field strength} \times \text{area}$$

Usage Tip: *Flux is not a measure of how strong the field is but a measure of the amount of magnetic field in an area. Flux is maximum when the magnetic field lines are perpendicular to the area because then the cross-section is maximised. If the field lines are parallel to the area then the cross-sectional area is 0 so there is no flux. So B is really the component of the flux density that is perpendicular to A, or alternatively area A should be recalculated based on the angle to the field*

Faraday's Law

$$\epsilon = -\frac{n\Delta\Phi_B}{\Delta t}$$
$$\text{EMF (or voltage)} = -\frac{\text{number of coil turns} \times \text{change in flux}}{\text{time taken for the change}}$$

Usage Tip: *Essentially Faraday's law says two things- that the bigger the change in flux, the more EMF and the faster the change happens, the more EMF. The negative sign is due to Lenz's Law and indicates the direction of the induced EMF. Note $\Delta\Phi_B = \Phi_{BFinal} - \Phi_{BInitial}$. Also, because $\Phi_B = BA$, $\Delta\Phi_B$ can be because of a change in field strength as occurs in a transformer, a change in area as occurs in a motor, or a mix of both.*

Transformer Voltage Equation

$$\frac{V_p}{V_s} = \frac{n_p}{n_s}$$
$$\frac{\text{Primary voltage}}{\text{Secondary voltage}} = \frac{\text{number of primary coil turns}}{\text{number of secondary coil turns}}$$

Usage Tip: *This equation stems from applying Faraday's Law to each of the coils and then combining them. Questions will usually give you 3 of the variables then ask to solve for the fourth*

Transformer Current Equation

$$\frac{I_s}{I_p} = \frac{n_p}{n_s}$$
$$\frac{\text{Secondary current}}{\text{Primary current}} = \frac{\text{number of primary coil turns}}{\text{number of secondary coil turns}}$$

Usage Tip: *Be careful which current and coil goes on top and which goes on the bottom. This equation comes from $P = IV$. Since the power on both sides of the transformer is the same, $V_pI_p = V_sI_s$, then rearranging yields $\frac{I_s}{I_p} = \frac{V_p}{V_s} = \frac{n_p}{n_s}$. This equation thus relies on conservation of energy, because it is derived through $P_p = P_s$ which is essentially a statement of conservation of energy. This formula only applies to a perfect transformer with no energy loss but is sufficient for all work in the HSC course.*

Power Loss

$$P_{\text{loss}} = I^2R$$
$$\text{Power loss} = \text{current in wire}^2 \times \text{resistance of the wire}$$

Usage Tip: *This equation lets you calculate the power loss through transmission and is needed when showing the advantage of using transformers in power distribution. It comes from substituting $V = IR$ into $P = IV$. P is the power consumed by a device, and therefore the loss in the wire*

5.3 Ideas to Implementation

Force acting on a charge in a magnetic field

$$F = qvB\sin\theta$$
$$\text{Force} = \text{charge of particle} \times \text{velocity of particle} \times \text{field strength} \times \sin\theta$$

where

$$\theta = \text{angle between the particle's direction of movement and field lines}$$

Usage Tip: *Be careful when calculating. A force will only be produced if the charge is* **not** *travelling parallel to the field lines. Maximum force is when it travels in any direction perpendicular to the field lines- use right hand palm rule. Otherwise, the force experienced depends on the component of velocity perpendicular to the field, hence the use of* $\sin\theta$*. Field strength is measured in Teslas*

Force acting on a charge in an electric field

$$F = qE$$
$$\text{Force} = \text{Charge of the point charge in question} \times \text{electric field strength (V/m)}$$

Usage Tip: *Electric field strength is in volts/metre (V/m) and is calculated with the next formula. This formula is pretty self-explanatory*

Electric field strength

$$E = \frac{V}{d}$$
$$\text{Electric field strength} = \frac{\text{potential difference}}{\text{distance}}$$

Usage Tip: *The common application of this formula is with charged metal plates, so that the potential difference between them is fixed and the distance is simply the distance between the plates. Don't forget to convert the distance to metres before calculating field strength*

5.4 Quanta to Quarks

Photon energy

$$E = hf$$
$$\text{Photon energy} = \text{Planck's constant } (6.63 \times 10^{-34}) \times \text{frequency}$$

Usage Tip: *This is the main formula used to calculate photon energy and shows that it is only related to the frequency of the photon*

Wave equation for light

$$c = f\lambda$$
$$\text{Speed of light } (3 \times 10^8 \text{m/s}) = \text{frequency} \times \text{wavelength}$$

Usage Tip: *This is a sort of derivative from the normal wave equation that has v instead of c. The use of c makes this formula specific for light, and highlights the inverse relationship between frequency and wavelength. Also self-explanatory*

Bohr's Third Postulate

$$mvr = \frac{nh}{2\pi}$$
$$\text{Mass of electron} \times \text{velocity of electron} \times \text{radius of orbit} = \frac{n \times \text{Planck's constant}(6.63 \times 10^{-34})}{2 \times \pi}$$

Usage Tip: *This was Bohr's assumption but it's also possible to derive it from de Broglie's equations*

Energy levels in Hydrogen

$$E_n = E_1 \times \frac{1}{n^2}$$
$$\text{Energy at the n}^{\text{th}} \text{ level} = \text{energy at the first level} \times \frac{1}{n^2}$$

Usage Tip: *This formula comes from mixing classical and quantum physics between Rutherford's model of the atom and between the radius of possible energy levels according to Bohr. It's not mentioned in the syllabus at all, so just knowing it should be enough*

Wavelength of hydrogen spectra

$$\frac{1}{\lambda} = R_H \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$
$$\frac{1}{\text{Wavelength of light}} = \text{Rydberg's Constant } (1.097 \times 10^7) \times \left(\frac{1}{\text{final energy level}^2} - \frac{1}{\text{initial energy level}^2} \right)$$

Usage Tip: *Pretty obvious, nothing very special here so just make the substitutions. For the Balmer series take $n_f = 2$. Also, don't forget that the expression is $\frac{1}{\lambda}$, not λ so proceed accordingly at the end. It's easy to forget that last step*

De Broglie's matter wave equation

$$\lambda = \frac{h}{mv}$$
$$\text{Wavelength} = \frac{\text{Planck's constant}(6.63 \times 10^{-34})}{\text{mass} \times \text{velocity}}$$

Chapter 6

Exam Verb Guide

6.1 HSC Exam Verbs

In 2002 the Board of Studies introduced a glossary of verbs to make it easier for students to answer questions. This means that in any physics question there is a directive verb telling you what to do. To answer the question, you need to *completely* deal with the verb. Note that going beyond the verb doesn't give more marks. This means that to maximise marks, you need to write as little as possible while ensuring that you cover all the relevant criteria for the question. This necessitates a highly targeted and logical approach to writing answers, a skill that comes through firstly knowing and understanding the meaning of all the verbs in the course, and secondly through plenty of practice.

Identify

Identify is the most basic verb encountered, and it requires you to merely state a fact. For example, *Identify that moving charged particles in a magnetic field experience a force*. All that is required is to state the fact that moving charged particles in a magnetic field experience a force. *Identify* questions are rarely used by themselves as they are effectively too simple to answer and do not differentiate enough between candidates. This means that if an *identify* question is encountered, it is most likely to be a 1-mark freebie. However, it's hard to know how much depth to go into when answering an *identify* question. Often the *identify* verb is used to explore key concepts that are built upon by other dotpoints. It can be hard to tell which information is relevant to fully answering an *identify* question. Generally, you will need to carefully read the question and make a judgement based on how much writing space is available and how much time you have in the exam room. The more you write, the safer you are, but it comes at the expense of other questions and you don't want to be wasting time on a 1-mark question.

Explain

Explain requires you to go into detail about the subject matter. Where *identify* is simply about the surface, *explain* is about the processes leading to it. For example, *Explain that cathode ray tubes allowed the manipulation of a stream of charged particles.* Often when approaching an *explain* question, it can be helpful to consider where you want to end up first, then structure your answer around that. In this case, the surface or end result is that cathode ray tubes allow the manipulation of a stream of charged particles. This is where the answer ends, and it needs to be clearly stated in your answer. However, *explain* needs to go into depth about how this manipulation is accomplished- the underlying processes. To answer this dotpoint will require identifying what a cathode ray tube is, especially that it provides a stream of charged particle, identifying that charged particles can be manipulated by obstructions and fields, explaining how this manipulation occurs (deflection and blocking in this case), and linking them together and explaining that cathode ray tubes allow this manipulation.

Define

In a way, *define* is easier than *explain* because it's a more complicated version of *identify*. *Define* requires greater depth of knowledge i.e. a longer, more detailed answer, but it still is essentially *identify*. *Define Bohr's postulates* would be the same as identifying each of them with a high level of detail.

Compare

Compare is examining similarities and differences between things. Less detail is required in terms of identification and explanation because the focus of the answer is on the comparison. For example, *Compare step-up and step-down transformers.* The answer should be thought of in two parts- similarities and differences, and structured around these two areas. They are similar because they both have two coils where electron movement in one induces a current in the other. They are different because in a step-up transformer the secondary coil has more turns, whereas in a step-down transformer the secondary coil has fewer turns so that the step-up produces a higher voltage while the step-down produces a lower voltage than the input. "Whereas" is an important word in writing comparisons because it shows to the examiner that you are directly examining differences between two things. Whenever you examine differences, always use the word "whereas". This will make it clear to both you and the examiner what you are contrasting.

Contrast

Contrast is exactly half of *compare*. Where in *compare* both similarities and differences need to be addressed, with *contrast* you only need to talk about differences. This means *contrast* is effectively "show how they're different". *Contrast* is rarely used in the syllabus but can often be found in exam questions. For example, *Contrast step-up and step-down transformers.* To answer this, you now only need to "show how they're different". Step-up has more turns in secondary coil and higher output voltage, *whereas* step-down has fewer turns in secondary coil and lower output voltage. When answering *contrast*, to get more marks you show more differences. There were 2 listed in this example, the only way to get more marks is to add more differences. Providing similarities will give NO marks and is therefore a waste of your exam time.

Discuss

This is probably the most common verb used in tests because it's comprehensive and really tests depth of knowledge. Broadly, it consists of two parts. The first is the simple verbs identify/explain, and so the first part of a discuss answer will involve identifying or explaining relevant issues. Though you need to go through this first step, think through your answer first because it is a waste of time explaining irrelevant issues. The second part of a *discuss* answer is provide arguments for and against the issues being discussed. This can only be developed by practice, since it its challenging to learn how to formulate arguments through analysis of issues (although you can memorise points for and against, it is essential that you can also make up points for questions that don't directly match syllabus dotpoints). For example, *Discuss the BCS theory.* This answer would be divided into parts. The answer would consist firstly of "What is BCS theory? How does it work? What does it accomplish?", then arguments for or supporting BCS theory, and finally arguments against BCS theory. Generally, any discuss question can be divided into these parts:

- Identify what is being discussed, explain it, and identify the key issues
- Provide arguments for
- Provide arguments against

In some cases there won't be arguments for and against. These cases require a structured comparison of all the elements of the question. For example, *Discuss qualitatively the electric field strength due to a point charge, positive and negative charges and oppositely charged parallel plates.* Point charge has a field that radiates outward with field strength obeying inverse square law. Positive charges repel positive, negative attracts. Parallel plates have a constant field strength with the field running in one direction between the plates.

Analyse

Analyse is a more advanced version of *explain*. It requires you to not only explain what is happening in a system, but to also use data or process information in order to draw conclusions. For example, *Analyse information to explain why a magnet is able to hover above a superconducting material that has reached the temperature at which it is superconducting*. This dotpoint requires you to use provided information to explain the Meissner effect. However, even if no information is provided, answering this dotpoint will involve firstly identifying that a magnet can hover over a superconductor, and then explain why the Meissner effect occurs and how this produces hovering. Of course, if information is provided it will need to be integrated into your answer. Generally *analyse* isn't used in exams as it is more productive for examiners to use *discuss*.

Evaluate

Evaluate is essentially a biased version of *discuss*. To answer an *evaluate* question, you need to firstly answer the question as if it was a discuss question, and then weigh up the for/against points you've provided and use them to draw a conclusion. Generally, less time will be spent on explanation in *evaluate* compared to *discuss* because the emphasis is on the conclusion and the issues, not explanation. Evaluation requires a clear, structured approach with a logical conclusion that flows from the arguments you've made. For example, *Evaluate the relative contributions of electrostatic and gravitational forces between nucleons*. As with *discuss* you first need to identify the two forces and explain their operation. As with a "comparing" *discuss* question, you need to compare their effects, particularly in terms of strength. But because this is an *evaluate* question, a judgement must be clearly made e.g. gravitational forces are insignificant in interactions between nucleons compared to electrostatic forces. Ensure that the conclusion you provide directly addresses the question. The essential part is to read the question and decide what needs to be done to completely answer it. Note that *evaluate* is very similar to *assess* and they can be considered the same.

Justify

Justify is pretty much "prove something". Though it doesn't appear in the syllabus explicitly, it can appear in exams, particularly regarding pracs. For example, in the pendulum prac, *justify timing the pendulum over 10 swings*. This is basically asking you to "prove why it is good to time the pendulum over 10 swings". The argument you make must be clear and logical to fully answer the question. This would involve firstly stating its effect- timing over 10 swings increases reliability. Then you would need to explain errors that affect reliability- random influences and reaction time error to name two, and finally you would need to explain how timing over 10 swings minimises this error and is therefore why that was the procedure. The last step, explaining how timing over 10 swings minimises error, is the justification but to perform this final step the framework for your justification needs to be set up in your response beforehand.

General Tips

As can be seen, almost all the verbs require some degree of identification and explanation. When answering a question, make sure you set up your response by identifying and explaining *relevant* concepts. Don't waste time by writing about irrelevant things, so before you start writing think about the answer in its entirety so you can decide what's relevant.

Never write an answer that requires more than a basic degree of assumed knowledge- assume the marker only knows the bare minimum (i.e. terminology and basic concepts) and requires everything to be spelt out in terms of interactions and effects. Don't assume anything.

Finally, don't write simply *anything*, be concise and relevant. Don't waffle- get to the point and show depth of knowledge. You'll find it easier to think about the science behind your answer this way, and the examiner will find it easier to gauge your knowledge.

Chapter 7

Exam Technique

7.1 In-exam hints

There are many sources of information on how best to approach exams, but this section examines hints that are specific to the HSC Physics exam.

Read the question first

This is easily the most important thing to remember. Often the question will not be exactly what is written in a syllabus dotpoint. This means that you will have to shift the emphasis of your answer, or even omit irrelevant information, in order to most efficiently get full marks.

Pick out key verbs

Tying in with reading the question first, make sure that when you read the question you look out for the key verbs. It probably isn't necessary to highlight them, but it can help. This step is vital because it helps you decide the structure of your answer. If you familiarise yourself with all the verbs in the Verb Guide chapter, you will notice that each of them follows a particular structure that can be applied to any question using that verb. Using a memorised structure will help you comprehensively answer the question and help you avoid leaving important things out.

Analyse the question as a whole first, think about what it is asking

Although the syllabus dotpoints are themselves questions, exams will rarely ask questions identical to syllabus dotpoints. This means that any given exam question will be different from its corresponding syllabus dotpoint, and therefore the question you answer the same will almost certainly be different to the answer for the syllabus dotpoint. Therefore it's important to read through the entire question as a whole, to get a feel for exactly what the question is asking. Often if you skim read the question, identify the relevant dotpoint and then write out the answer as if it was the dotpoint, you will miss key areas and lose marks.

Double check answers

It seems obvious, but it's a key mistake that is often made. When you're checking your work, don't just skim through the question and then carefully go through your answer. You're better off reading the question thoroughly and then skimming through your answer. This is because you are more likely to have misread the question or missed key information than you are to have made any serious errors in your written answer.

Label your graph

Putting a title on a graph is actually worth marks. All you have to do is think of a name, and write it down. However, many people forget to title graphs or label axes because it seems so trivial. This is another free mark you need to be careful to collect.

Triple check equations

Double check all your answers, but triple check anything with an equation in it. Mathematical errors are easy to make, even in the simplest questions. Extension 2 maths students make careless mistakes in projectile motion questions all the time, even though they know how to do them at a far more advanced level than required for HSC Physics. Common errors include things like forgetting to take into account elevations (eg. A projectile fired off a cliff has the cliff's extra height). Make sure you literally go through the entire question a second time as if you hadn't done it before. The maths in HSC Physics isn't all that difficult and so it shouldn't take too long to go through all the mathematical questions in this manner.

Write over the lines, but don't write about too much

In general, there are never enough lines for you to write on if you want to completely answer a question. Think of the lines only as guides to answer length- feel free to exceed them by as much as you like. However, it's vital to remember that you're only going to get marks for relevant things. It's a complete waste of time writing about irrelevant things, and in some cases it can cost you marks (for example, if you accidentally contradict yourself). So write as much as you want, but only about relevant things.

When using the right hand screw rule or palm rule, use your right hand

It seems simple enough, but if like most students you're right-handed it's easy to use the hand that isn't holding a pen. Use your left hand for conventional current, and you'll lose marks instantly. Don't give away free marks- use the correct hand. Right hand for conventional current, left hand for electrons.

Choose your jargon carefully

Jargon, otherwise known as terminology, is important to use. But if you find yourself using words like "diamagnetic" you've probably gone too far. Using lengthy, complicated words can make it more confusing for you in an exam situation, so it's often safer to stick to words that are mentioned in the syllabus. Long words don't mean more marks. Clear, logical explanations with reasonable technical language do.

Draw diagrams in pencil

If you don't already draw diagrams on your exam paper, you should seriously think about it. Drawing diagrams can be a very effective way of demonstrating your understanding of key concepts- firstly, it conveys a lot of information quickly, but secondly, it will probably help you keep your answer clear and easy to read. Diagrams are especially useful for questions concerning Einstein's thought experiments, which involve abstract but complex ideas. Similarly, make sure you draw your diagram in pencil first, because it'll just turn your paper into a mess if you keep making changes to it in pen.

Chapter 8

Extra Content

8.1 Centrifugal Force

Many people are confused by the term "centrifugal force" in relation to uniform circular motion. To begin with, a "real" force is a force that is either an "action" or a "reaction" force (the difference between the two was studied in Year 11). A "fictitious" force is one that appears to be an "action" force in some frames of reference, but appears as a "reaction" force in others. The implication of this is that real "action" forces appear as "action" forces in all frames of reference.

The important concept to understand is that centrifugal force can be a real force or a fictitious force, depending on the frame of reference. This means that some observers will see it as a real force, while others will see it as a fictitious force. As a real force, centrifugal force appears as a "reaction" force, while as a fictitious force, centrifugal force appears as an "action" force.

As with before, an ideal analogy is the Luna Park ride "Rotor". Rotor consists of a hollow cylinder in which the riders stand. When the ride is started, it spins rapidly. This causes the riders to be pinned against the wall of the ride (the floor subsequently drops down while the riders remain in place due to the rotation). The riders who spin inside the ride are the first frame of reference- the frame inside the spinning object. There is a second frame however. It consists of the observers at the top of the ride, who look down into the spinning cylinder. They do not spin, and instead see the ride along with the riders rotating. Importantly, the first frame of reference (the riders) is a non-inertial frame because it is rotating, and the second frame (the observers) is an inertial frame because it is not accelerating.

To begin with, we need to examine what happens from the external, inertial frame of reference. At any point, the riders have a velocity that is *tangential* to the cylinder. This is like spinning a rock tied to a string- if you let go of the string the rock flies off in a straight line at a tangent to its circular path. But a tangent is a straight line- if the riders have a velocity that is tangential to the cylinder, then why do they not travel in a straight line? They don't travel in a straight line because the walls of the cylinder exert a centripetal force that curves the riders around in a circular path. The "action" force is the centripetal force that results from the walls pushing the riders towards the centre of the ride (thereby curving their straight-line velocity into a circle). Along with the "action" force is a "reaction" force- the return force that the riders exert on the wall, *because* the wall is exerting force on them. This "reaction" force is centrifugal force, and appears as a real force.

However, the riders inside the ride are not aware of their tangential velocity. Although aware they are rotating, they do not know they have the straight-line inertia that results from having tangential velocity (it is this straight-line inertia that is responsible for the centripetal force exerted by the walls of the ride). Instead, they perceive a force that pushes them against the walls of the ride. This force is an "action" force as it is being exerted on the wall by them, and the wall pushes back with a "reaction" force. The "action" force in this case is the fictitious centrifugal force- it is fictitious because the same force is a "reaction" force when viewed from outside the ride. When performing calculations, centrifugal force *can* be used, often with perfectly fine results. Some calculations can be made easier because centrifugal force is equal to centripetal force during uniform circular motion (only centrifugal force occurs in the opposite direction). However, it is important to remember that centrifugal force is *really* a "reaction" force- this is why it is a fictitious force when it appears to be an "action" force.

Normally when diagrams are drawn, they are presented as viewed from an inertial reference frame. This means that centrifugal force would appear to be a reaction force. Normally reaction forces aren't drawn in diagrams, for simplicity. This means that in almost all cases, you will not have to concern yourself with centrifugal force. In the unlikely event that you do have to deal with centrifugal force, remember that it is a reaction force that disappears as soon as centripetal force disappears, no matter what frame you're working in.

8.2 Thompson and the charge-to-mass ratio of an electron

The exact method that Thompson used to calculate the charge-to-mass ratio of an electron is disputed, with any number of different methods suggested. Although some sources say that he calculated the radius of the curved electron beam when deflected by the magnetic field only, this leaves room for additional measurement error and is complicated. The simplest and most elegant method involves potential energy.

The first step is to set up the apparatus so that the electrons travel in a straight line, balancing magnetic field strength and electric field strength. This means that electric field strength

$$F = qE$$

and magnetic field strength

$$F = qvB$$

are equal. From this,

$$qE = qvB$$

and therefore

$$v = \frac{E}{b}$$

which is an expression for electron velocity based on the known field strengths.

According to conservation of energy, an electron at the cathode in the tube will have potential energy due to the electric field equal to the kinetic energy the electron has at the anode after it crosses the field. At the cathode, the potential energy expression is

$$E_p = qV$$

which is the charge on the electron multiplied by the potential difference between the cathode and anode. The kinetic energy at the anode is simply

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

Since these energies are equal

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

and

$$\frac{q}{m} = \frac{\frac{1}{2}v^2}{V}$$

This is the charge-to-mass ratio of an electron. The substitution

$$v^2 = \left(\frac{E}{b}\right)^2$$

is made, since the field strengths in the velocity filter determine the velocity. The voltage difference V is already known

8.3 Solid state and thermionic devices for amplification

Solid state and thermionic devices are both designed to do the same thing- to amplify a signal by using changes in a small current to guide changes in a large current.

Thermionic devices consisted of what is effectively a cathode ray tube, with a thermionic cathode. Electrons could only flow from the cathode to the anode because if they tried to travel in the other direction, they would be opposed by the large potential difference between the two. A "grid" of wire made up the third electrode in the triode valve, set between the anode and cathode. A small voltage set up in the grid could repel electrons travelling from the cathode to the anode, stopping the current which could be quite sizable in the tube. In this way, changes in one circuit could produce changes in another circuit.

A solid state transistor consists of two junctions between an n-type semiconductor and a p-type. If there is only one junction then it is a diode. In a junction, electrons can only travel from a p-type layer to an n-type layer, giving the transistor a bias. This is true in a transistor as well, which consists of one semiconductor type sandwiched between two of the other type. In a PNP transistor the electrons flow from P to N (emitter to base), but do not flow from the base to the collector. This is the case normally unless a voltage is applied to N. When this happens, electrons can flow from N to the collector and the transistor conducts electricity.

8.4 Mass defect

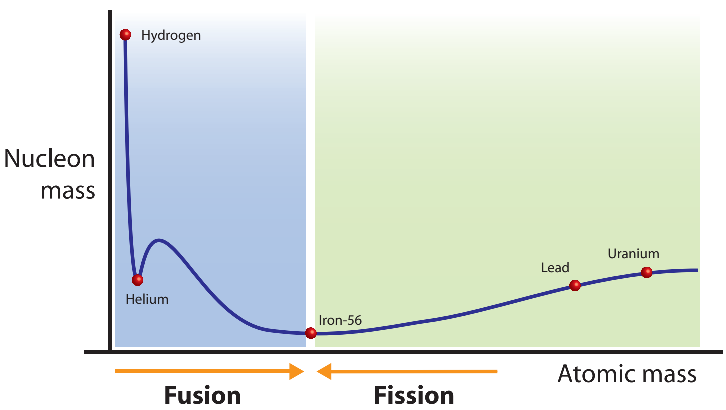
From 4.3.10 on page 99, it seems contradictory that energy can be released through *fusion*, by putting atoms together, but at the same time, energy can also be released through *fission*, by splitting apart atoms. How can these two seemingly opposite facts be reconciled? Quite simply, it turns out.

The whole point of mass defect is that the mass of nucleons is dependant on the way the nucleons are bound- that is to say, under certain binding conditions (such as in the nucleus of an atom), the mass of the nucleons can be reduced. We know this is the case, because the mass of a nucleus is less than the sum of the masses of the individual nucleons themselves. It follows then, that if the nucleus is missing mass, then the constituents of the nucleus must also be missing mass, since it would be impossible for all the nucleons to have their normal masses, and at the same time have a nucleus with missing mass.

The best way of looking at mass defect in this case is to examine the average nucleon mass- that is, the average mass of each nucleon in the nucleus. This is obtained simply by dividing the actual mass of the nucleus, measured in amu, by the number of nucleons in the nucleus. This then yields an average mass per nucleon.

Given that $E = mc^2$, we know that any time the nucleus loses mass, energy is released. Therefore, in terms of nucleon mass, any time the average nucleon mass decreases, energy is released. From this, it follows that *any* nuclear reaction that causes the average nucleon mass to decrease will release energy.

All that is required now is the actual average nucleon mass for each element, shown in this diagram:



This qualitative graph shows several things. Firstly, for elements from hydrogen to iron, fusion releases energy. It is clear from this diagram that the reason this happens is because at these low atomic numbers, increasing the size of the nucleus decreases the mass of the nucleons, releasing energy. It also shows clearly that fission will not release energy, since to split helium into hydrogen will require energy equal to the missing mass, from $E = mc^2$.

It also shows that for elements heavier than iron, fission releases energy. The same logic is true here- when large nuclei are split, their constituants will all have lower average nucleon masses, and therefore energy will be released. Similarly, fusing these heavy elements will require energy input, because the average nucleon mass needs to be increased.

Also of note is the fact that iron-56 is at the very bottom of the curve- this means that any nuclear reaction involving iron-56 needs energy input, and therefore iron-56 can never be used in a nuclear reaction to release energy.

Lastly, although fission of heavy atoms releases significantly more energy on a per-atom basis than the fusion of light atoms (see the diagram on page 99), fusion releases much more energy per unit of mass. This is the because the release of energy due to fission occurs due to the changing nucleon masses over the entire nucleus of 200+ nucleons. Therefore, the small energy difference between nucleon masses (for example, the difference between uranium and lead as illustrated on the previous page) is multiplied by the number of nucleons to give the energy released by the complete reaction. In the fusion of small atoms, very small numbers of nucleons are reacted, and therefore the total energy released is much smaller, regardless of the difference in nucleon masses.

However, when the quantities of the materials being reacted are measured in mass, and not in the number of atoms, fusion releases much more energy. This is because 1g of hydrogen contains far more atoms than 1g of uranium- in fact, the ratio of hydrogen atoms to uranium atoms is the same as the ratio of the atomic masses. This means that the difference in number of nucleons approximately cancels out, and the main factor determining the amount of energy released is not the number of nucleons, but the difference in nucleon masses. Since the difference in masses between hydrogen and helium is significantly bigger than the difference between uranium and lead, the hydrogen fusion reaction will release more energy per-gram than the uranium fission reaction.

Chapter 9

Dotpoint Checklist

9.1 Space

When revising for your Trials and HSC, use this checklist to mark off dotpoints you've studied, to ensure that you've completely covered the syllabus.

☐ ☐ 1.1.1 Define weight as the force on an object due to a gravitational field (page 2)

☐ ☐ 1.1.3 Explain that a change in gravitational potential energy is related to work done (page 2)

☐ ☐ 1.1.4 Perform an investigation and gather information to determine a value for acceleration due to gravity using pendulum motion or computer-assisted technology and identify reasons for possible variations from the value 9.8m/s^2 (page 3)

☐ ☐ 1.1.5 Gather secondary information to predict the value of acceleration due to gravity on other planets (page 4)

☐ ☐ 1.1.6 Define gravitational potential energy as the work done to move an object from a very large distance away to a point in a gravitational field (page 5)

☐ ☐ 1.2.1 Describe the trajectory of an object undergoing projectile motion within the Earth's gravitational field in terms of horizontal and vertical components (page 6)

☐ ☐ 1.2.2 Describe Galileo's analysis of projectile motion (page 6)

☐ ☐ 1.2.4 Explain the concept of escape velocity in terms of the gravitational constant and the mass and radius of the planet (page 7)

☐ ☐ 1.2.5 Outline Newton's concept of escape velocity (page 7)

☐ ☐ 1.2.6 Identify why the term "g forces" is used to explain the forces acting on an astronaut during launch (page 8)

☐ ☐ 1.2.7 Perform a first-hand investigation, gather information and analyse data to calculate initial and final velocity, maximum height reached, range and time of flight of a projectile for a range of situations by using simulations, data loggers and computer analysis (page 8)

☐ ☐ 1.2.8 Analyse the changing acceleration of a rocket during launch in terms of the Law of Conservation of Momentum and the forces experienced by astronauts (page 9)

☐ ☐ 1.2.9 Discuss the effect of the Earth's orbital motion and its rotational motion on the launch of a rocket (page 10)

☐ ☐ 1.2.10 Analyse the forces involved in uniform circular motion for a range of objects including satellites orbiting the Earth (page 11)

☐ ☐ 1.2.12 Compare qualitatively low Earth and geo-stationary orbits (page 12)

☐ ☐ 1.2.13 Identify data sources, gather, analyse and present information on the contribution of one of the following to the development of space exploration: Tsiolkovsky, Oberth, Goddard, Esnault-Pelterie, O'Neill or von Braun (page 13)

☐ ☐ 1.2.14 Define the term orbital velocity and the quantitative and qualitative relationship between orbital velocity, the gravitational constant, mass of the central body, mass of the satellite and the radius of the orbit using Kepler's Law of Periods (page 13)

☐ ☐ 1.2.16 Account for the orbital decay of satellites in low Earth orbit (page 14)

☐ ☐ 1.2.17/1.2.18 Discuss issues associated with safe re-entry into the Earth's atmosphere and landing on the Earth's surface (including "Identify that there is an optimum angle for safe re-entry for a manned spacecraft into the Earth's atmosphere and the consequences of failing to achieve this angle") (page 14)

☐ ☐ 1.3.1 Describe a gravitational field in the region surrounding a massive object in terms of its effect on other masses in it (page 15)

☐ ☐ 1.3.2 Define Newton's Law of Universal Gravitation (page 15)

☐ ☐ 1.3.4 Present information and use available evidence to discuss the factors affecting the strength of gravitational force (page 15)

☐ ☐ 1.3.5 Discuss the importance of Newton's Law of Universal Gravitation in understanding and calculating the motion of satellites (page 16)

☐ ☐ 1.3.6 Identify that a slingshot effect can be provided by planets for space probes (page 17)

☐ ☐ 1.4.1 Outline the features of the aether model for the transmission of light (page 18)

☐ ☐ 1.4.2 Describe and evaluate the Michelson-Morley attempt to measure the relative velocity through the aether (page 19)

☐ ☐ 1.4.3 Gather and process information to interpret the results of the Michelson-Morley experiment (page 20)

☐ ☐ 1.4.4 Discuss the role of the Michelson-Morley experiments in making determinations about competing theories (page 20)

☐ ☐ 1.4.5 Outline the nature of inertial frames of reference (page 21)

☐ ☐ 1.4.6 Perform an investigation to help distinguish between non-inertial and inertial frames of reference (page 22)

☐ ☐ 1.4.7 Discuss the principle of relativity (page 23)

☐ ☐ 1.4.8 Describe the significance of Einstein's assumption of the constancy of the speed of light (page 24)

☐ ☐ 1.4.9 Analyse and interpret some of Einstein's thought experiment involving mirrors and trains and discuss the relationship between thought and reality (page 25)

☐ ☐ 1.4.10 Identify that if c is constant then space and time become relative (page 26)

☐ ☐ 1.4.11 Discuss the concept that length standards are defined in terms of time in contrast to the original metre standard (page 26)

☐ ☐ 1.4.12 Analyse information to discuss the relationship between theory and the evidence supporting it, using Einstein's predictions based on relativity that were made many years before evidence was available to support it (page 27)

☐ ☐ 1.4.13/1.4.16-1.4.21 Explain qualitatively and quantitatively the consequences of special relativity in relation to the relativity of simultaneity, the equivalence between mass and energy, length contraction, time dilation, and mass dilation (page 28)

☐ ☐ 1.4.22 Discuss the implications of mass increase, time dilation and length contraction for space travel (page 29)

9.2 Motors and Generators

☐ ☐ 2.1.1 Discuss the effect on the magnitude of the force on a current-carrying conductor of variations in the strength of the magnetic field in which it is located, the magnitude of the current in the conductor, the length of the conductor in the external magnetic field and the angle between the direction of the external magnetic field and the direction of the length of the conductor (page 32)

☐ ☐ 2.1.3 Describe qualitatively and quantitatively the force between long parallel current carrying conductors (page 32)

☐ ☐ 2.1.5 Describe the forces experienced by a current-carrying loop in a magnetic field and describe the net result of the forces (page 33)

☐ ☐ 2.1.6 Perform a first-hand investigation to demonstrate the motor effect (page 33)

☐ ☐ 2.1.7 Define torque as the turning moment of a force using $T = Fd$ (page 34)

☐ ☐ 2.1.9 Identify that the motor effect is due to the force acting on a current-carrying conductor in a magnetic field (page 34)

☐ ☐ 2.1.10/2.1.11 Identify data sources, gather and process information to qualitatively describe the application of the motor effect in the galvanometer and the loudspeaker (page 35)

☐ ☐ 2.1.12 Describe the main features of a DC electric motor and the role of each feature (page 36)

☐ ☐ 2.1.13 Identify that the required magnetic fields in DC motors can be produced by current-carrying coils or permanent magnets (page 36)

☐ ☐ 2.2.1 Outline Michael Faraday's discovery of the generation of an electric current by a moving magnet (page 37)

☐ ☐ 2.2.2/2.3.5 Perform an investigation to model the generation of an electric current by moving a magnet in a coil or a coil near a magnet (including "Plan, choose equipment or resources for, and perform a first hand investigation to demonstrate the production of an alternating current" (page 38)

☐ ☐ 2.2.3 Plan, choose equipment or resources for, and perform a first-hand investigation to predict and verify the effect on a generated electric current when the distance between the coil and magnet is varied, the strength of the magnet is varied, and the relative motion between the coil and the magnet is varied (page 38)

☐ ☐ 2.2.4 Define magnetic field strength B as magnetic flux density (page 39)

☐ ☐ 2.2.5 Describe the concept of magnetic flux in terms of magnetic flux density and surface area (page 39)

☐ ☐ 2.2.6 Describe generated potential difference as the rate of change of magnetic flux through a circuit (page 39)

☐ ☐ 2.2.7/2.2.8 Account for Lenz's Law in terms of conservation of energy and relate it to the production of back emf in motors (page 40)

☐ ☐ 2.2.8 Explain that, in electric motors, back emf opposes the supply emf (page 41)

☐ ☐ 2.2.9 Explain the production of eddy currents in terms of Lenz's Law (page 41)

☐ ☐ 2.2.10 Gather, analyse and present information to explain how induction is used in cooktops in electric ranges (page 41)

☐ ☐ 2.2.11 Gather secondary information to identify how eddy currents have been utilised in electromagnetic braking (page 42)

☐ ☐ 2.3.1 Describe the main components of a generator (page 43)

☐ ☐ 2.3.2 Describe the differences between AC and DC generators (page 43)

☐ ☐ 2.3.3 Compare the structure and function of a generator to an electric motor (page 44)

☐ ☐ 2.3.4 Gather secondary information to discuss advantages/disadvantages of AC and DC generators and relate these to their use (page 44)

☐ ☐ 2.3.6 Discuss the energy losses that occur as energy is fed through transmission lines from the generator to the consumer (page 45)

☐ ☐ 2.3.7/2.3.8 Assess the effects of the development of AC generators on society and the environment (page 46)

☐ ☐ 2.3.9 Analyse secondary information on the competition between Westinghouse and Edison to supply electricity to cities (page 47)

☐ ☐ 2.3.10 Gather and analyse information to identify how transmission lines are insulated from supporting structures and protected from lightning strikes (page 47)

☐ ☐ 2.4.1 Describe the purpose of transformers in electrical circuits (page 48)

☐ ☐ 2.4.2 Compare step-up and step-down transformers (page 48)

☐ ☐ 2.4.3 Identify the relationship between the ratio of the number of turns in the primary and secondary coils and the ratio of primary to secondary voltage (page 48)

☐ ☐ 2.4.5 Gather, analyse and use available evidence to discuss how difficulties of heating caused by eddy currents in transformers may be overcome (page 49)

☐ ☐ 2.4.6 Perform an investigation to model the structure of a transformer to demonstrate how secondary voltage is produced (page 50)

☐ ☐ 2.4.7 Explain the role of transformers in electricity substations (page 51)

☐ ☐ 2.4.7 Gather and analyse secondary information to discuss the need for transformers in the transfer of electrical energy from a power station to its point of use (page 51)

☐ ☐ 2.4.8 Explain why voltage transformations are related to conservation of energy (page 51)

☐ ☐ 2.4.9 Discuss why some electrical appliances in the home that are connected to the mains domestic power supply use a transformer (page 52)

☐ ☐ 2.4.10 Discuss the impact of the development of transformers on society (page 52)

☐ ☐ 2.5.1 Describe the main features of an AC motor (page 53)

☐ ☐ 2.5.2 Perform an investigation to demonstrate the principle of an AC induction motor (page 54)

☐ ☐ 2.5.3 Gather, process and analyse information to identify some of the energy transfers and transformations involving the conversion of electrical energy into more useful forms in the home and industry (page 54)

9.3 Ideas to Implementation

☐ ☐ 3.0.0 Describe cathode rays and cathode ray tubes (page 56)

☐ ☐ 3.1.1 Explain that cathode ray tubes allowed the manipulation of a stream of charged particles (page 56)

☐ ☐ 3.1.2 Explain why the apparent inconsistent behaviour of cathode rays cause debate as to whether they were charged particles or electromagnetic waves (page 57)

☐ ☐ 3.1.3 Perform an investigation to demonstrate and identify properties of cathode rays using discharge tubes containing a Maltese cross, electric plates, a fluorescent screen, a glass wheel, and analyse the information gather to determine the sign of the charge of cathode rays (page 58)

☐ ☐ 3.1.4 Perform an investigation and gather first-hand information to observe the occurrence of different striation patterns for different pressures in discharge tubes (page 59)

☐ ☐ 3.1.5 Identify that moving charged particles in a magnetic field experience force (page 60)

☐ ☐ 3.1.6/3.1.8 Discuss qualitatively the electric field strength due to a point charge, positive and negative charges and oppositely charged parallel plates (page 60)

☐ ☐ 3.1.7 Identify that charged plates produce an electric field (page 60)

☐ ☐ 3.1.9 Describe quantitatively the force acting on a charge moving through a magnetic field, using $F = qvBsin\theta$ (including "Describe quantitatively the electric field due to oppositely charged parallel plates" (page 61)

☐ ☐ 3.1.10 Outline Thompson's experiment to measure the charge/mass ratio of an electron (page 62)

☐ ☐ 3.1.11 Outline the role of electrodes in the electron gun, the deflection plates or coils and the fluorescent screen in the cathode ray tube of conventional TV displays and oscilloscopes (page 63)

☐ ☐ 3.2.1 Outline qualitatively Hertz's experiments in measuring the speed of radio waves and how they relate to light waves (page 64)

☐ ☐ 3.2.2 Describe Hertz's observation of the effect of a radio wave on a receiver and the photoelectric effect he produced but failed to investigate (page 65)

☐ ☐ 3.2.4 Identify Planck's hypothesis that radiation emitted and absorbed by the walls of a black body cavity is quantised (page 65)

☐ ☐ 3.2.5 Identify Einstein's contribution to quantum theory and its relation to black body radiation (page 66)

☐ ☐ 3.2.6 Identify data sources, gather, process and analyse information and use available evidence to assess Einstein's contribution to quantum theory and its relation to black body radiation (page 66)

☐ ☐ 3.2.7 Explain the particle model of light in terms of photons with particular energy and frequency (page 67)

☐ ☐ 3.2.8 Identify the relationships between photon energy, frequency, speed of light and wavelength (page 67)

☐ ☐ 3.2.10 Identify data sources, gather, process and present information to summarise the use of the photoelectric effect in solar cells and photocells (page 68)

☐ ☐ 3.2.11 Process information to discuss Einstein and Planck's differing views about whether science research is removed from social and political forces (page 68)

☐ ☐ 3.3.1 Identify that some electrons in solids are shared between atoms and move freely (page 69)

☐ ☐ 3.3.2 Describe the difference between conductors, insulators and semiconductors in terms of band structures and relative electrical resistance (page 70)

☐ ☐ 3.3.3 Identify absences of electrons in a nearly full band as holes, and recognise that both electrons and holes help to carry current (page 71)

☐ ☐ 3.3.4 Compare qualitatively the number of free electrons that can drift from atom to atom in conductors, semiconductors and insulators (page 71)

☐ ☐ 3.3.5 Perform an investigation to model the behaviour of semiconductors, including the creation of a hole or positive charge on the atom that has lost the electron and the movement of electrons and holes in opposite directions when an electric field is applied across the semiconductor (page 72)

☐ ☐ 3.3.6 Identify that the use of germanium in early transistors is related to lack of ability to produce other materials of sufficient purity (page 72)

☐ ☐ 3.3.7 Describe how "doping" a semiconductor can change its electrical properties (page 73)

☐ ☐ 3.3.8 Identify differences in p-type and n-type semiconductors in terms of the relative number of negative charge carriers and positive holes (page 73)

☐ ☐ 3.3.9 Describe differences between solid state and thermionic devices and discuss why solid state devices replaced thermionic devices (page 74)

☐ ☐ 3.3.10 Gather, process and present secondary information to discuss how shortcomings in available communication technology lead to an increased knowledge of the properties of materials with particular reference to the invention of the transistor (page 75)

☐ ☐ 3.3.11 Identify data sources, gather, process, analyse information and use available evidence to assess the impact of the invention of transistors on society with particular reference to their use in microchips and microprocessors (page 75)

☐ ☐ 3.4.1 Outline the methods used by the Braggs to determine crystal structure (page 76)

☐ ☐ 3.4.2 Identify that metals possess a crystal lattice structure (page 76)

☐ ☐ 3.4.3 Describe conduction in metals as a free movement of electrons unimpeded by the lattice (page 77)

☐ ☐ 3.4.4 Identify that resistance in metals is increased by the presence of impurities and the scattering of electrons by lattice vibrations (page 77)

☐ ☐ 3.4.5 Describe the occurrence in superconductors below their critical temperature of a population of electrons unaffected by electrical resistance (page 78)

☐ ☐ 3.4.6 Process information to identify some of the metals, metal alloys, and compounds that have been identified as exhibiting the property of superconductivity and their critical temperatures (page 78)

☐ ☐ 3.4.7 Discuss the BCS theory (page 79)

☐ ☐ 3.4.8 Discuss the advantages of using superconductors and identify limitations to their use (page 79)

☐ ☐ 3.4.9 Analyse information to explain why a magnet is able to hover above a superconducting material that has reached the temperature at which it is superconducting (page 80)

☐ ☐ 3.4.10 Perform an investigation to demonstrate magnetic levitation (page 80)

☐ ☐ 3.4.11 Gather and process information to describe how superconductors and the effects of magnetic fields have been applied to develop a maglev train (page 81)

☐ ☐ 3.4.12 Process information to discuss possible applications of superconductivity and the effects of those applications on computers, generators and motors, and transmission of electricity through power grids (page 82)

9.4 Quanta to Quarks

☐ ☐ 4.1.1 Discuss the structure of the Rutherford model of the atom, the existence of the nucleus and electron orbits (page 84)

☐ ☐ 4.1.2 Analyse the significance of the hydrogen spectrum in the development of Bohr's model of the atom (page 85)

☐ ☐ 4.1.3 Perform a first-hand investigation to observe the visible components of the hydrogen spectrum (page 85)

☐ ☐ 4.1.4 Discuss Planck's contribution to the concept of quantised energy (page 86)

☐ ☐ 4.1.5 Define Bohr's postulates (page 86)

☐ ☐ 4.1.6 Describe how Bohr's postulates led to the development of a mathematical model to account for the existence of the hydrogen spectrum (the Rydberg equation) (page 86)

☐ ☐ 4.1.8 Process and present diagrammatic information to illustrate Bohr's explanation of the Balmer series (page 87)

☐ ☐ 4.1.9/4.1.10 Discuss the limitations of the Bohr model of the hydrogen atom (including "Analyse secondary information to identify the difficulties with the Rutherford-Bohr model, including its inability to completely explain the spectra of larger atoms, the relative intensity of spectral lines, the existence of hyperfine spectral lines, and the Zeeman Effect") (page 88)

☐ ☐ 4.2.1 Describe the impact of de Broglie's proposal that any kind of particle has both wave and particle properties (page 89)

☐ ☐ 4.2.3 Define diffraction and identify that interference occurs between waves that have been diffracted (page 90)

☐ ☐ 4.2.4 Describe the confirmation of de Broglie's proposal by Davisson and Germer (page 90)

☐ ☐ 4.2.5 Explain the stability of the electron orbits in the Bohr atom using de Broglie's hypothesis (page 91)

☐ ☐ 4.2.6 Gather, process, analyse and present information and use available evidence to assess the contributions made by Heisenberg and Pauli to the development of atomic theory (page 92)

☐ ☐ 4.3.1 Define the components of the nucleus (protons and neutrons) as nucleons and contrast their properties (page 93)

☐ ☐ 4.3.2 Discuss the importance of conservation laws to Chadwick's discovery of the neutron (page 93)

☐ ☐ 4.3.3 Define the term transmutation (page 94)

☐ ☐ 4.3.4 Describe nuclear transmutations due to natural radioactivity (page 94)

☐ ☐ 4.3.5 Describe Fermi's initial experimental observation of nuclear fission (page 95)

☐ ☐ 4.3.6 Perform a first-hand investigation or gather secondary information to observe radiation emitted from a nucleus using a Wilson Cloud Chamber or similar detection device (page 96)

☐ ☐ 4.3.7 Discuss Pauli's suggestion of the existence of the neutrino and relate it to the need to account for the energy distribution of electrons emitted in beta decay (page 97)

☐ ☐ 4.3.8 Evaluate the relative contributions of electrostatic and gravitational forces between nucleons (page 97)

☐ ☐ 4.3.9 Account for the need for the strong nuclear force and describe its properties (page 98)

☐ ☐ 4.3.10 Explain the concept of a mass defect using Einstein's equivalence between mass and energy (page 99)

☐ ☐ 4.3.12 Describe Fermi's demonstration of a controlled nuclear chain reaction in 1942 (page 100)

☐ ☐ 4.3.13 Compare requirements for controlled and uncontrolled nuclear chain reactions (page 100)

☐ ☐ 4.4.1 Explain the basic principles of a fission reactor (page 101)

☐ ☐ 4.4.2 Gather, process and analyse information to assess the significance of the Manhattan Project to society (page 102)

☐ ☐ 4.4.3 Describe some medical and industrial applications of radioisotopes (page 103)

☐ ☐ 4.4.4 Identify data sources and gather, process and analyse information to describe the use of a named isotope in medicine, agriculture and engineering (page 103)

☐ ☐ 4.4.5 Describe how neutron scattering is used as a probe by referring to the properties of neutrons (page 104)

☐ ☐ 4.4.6 Identify ways in which physicists continue to develop their understanding of matter, using accelerators as a probe to investigate the structure of matter (page 104)

☐ ☐ 4.4.7 Discuss the key features and components of the standard model of matter, including quarks and leptons (page 105)

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