HSC 2010 Physics

Summary Notes

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Last Updated:

31/10/2010

Contents

SPACE

The Earth has a gravitational field that exerts a force on objects both on it and around it

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

Weight: The force of gravity on any mass $W = mg$ or more commonly known as $F = ma$

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

A gravitational field surrounds anybody of mass and acts on all other masses in the universe.

Gravity is a relatively weak force but has enormous range.

It is not noticeable in a classroom; your gravitational attraction is minimal

It is noticeable in an interstellar scale. The solar system is held together by gravity.

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.

$$E_p = -G\frac{m_1 m_2}{r}$$

The potential energy given to any mass due to its distance from another mass. The universal gravitational constant is used to determine the gravitational field of any mass where:

$$G = 6.67 \times 10^{-11} Nm^2kg^{-2}$$

Many factors have to be taken into account to achieve a successful rocket launch, maintain a stable orbit and return to Earth

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

Projectile motion is made up of two components:

- horizontal (x)
- vertical (y)

And follows a parabolic path

Maximum Height:

- The maximum height reached by a projectile:

Vertical velocity = 0

- $v_y = 0$

Range:

- The horizontal distance that is travelled by a projectile in flight

Gravity:

- The only force we consider in projectile motion
- Always taken to be negative
- $a_g = -g$

Time of flight:

- The time taken from initial release (t_0 or t = 0) to time of impact (t_f)

Solve problems and analyse information to calculate the actual velocity of a projectile from its horizontal and vertical components using:

$$v_x^2 = u_x^2$$

$$v = u + at$$

$$v_y^2 = u_y^2 + 2a_y\Delta y$$

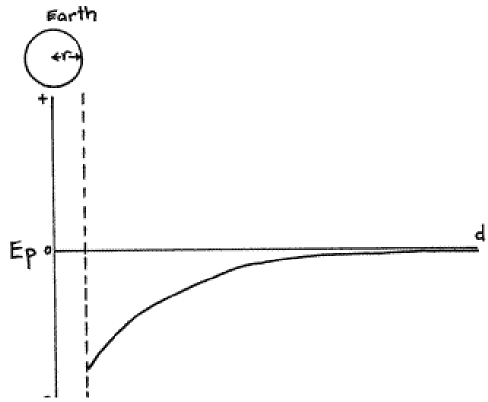
$$\Delta x = u_x t$$

$$\Delta y = u_y t + \frac{1}{2}a_y t$$

Describe Galileo's analysis of projectile motion

Aristotle believed that projectiles followed a straight line until it ran out of impetus and fell straight to the ground. Galileo challenged this belief by describing projectile motion as comprising of two components (x and y) and following a parabolic path

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



$$E_p = -G\frac{m_1 m_2}{r}$$

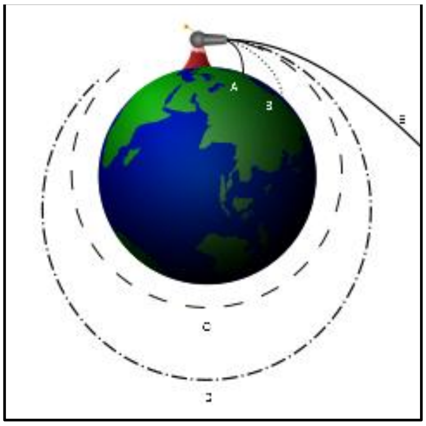
$$E_k = \frac{1}{2}mv^2$$

For escape velocity:

$$E_k \geq -E_p$$

$$v = \sqrt{\frac{2Gm}{r}}$$

Outline Newton's concept of escape velocity.



Isaac Newton's analysis of escape velocity. Projectiles A and B fall back to earth. Projectile C achieves a circular orbit, D an elliptical one. Projectile E escapes.

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

When an astronaut is launched into space, s/he feels significant changes to his/her apparent weight. It is convenient to describe the forces as g-forces to gain a concrete reference to his/her experience. We can also gauge the potential danger using an approximate scale.

G-Forces	Effect
0-6G's	Minimal damage
6-10G's	Moderate danger
10-20G's	Difficult to endure
>20G's	Extreme danger

Breaking a rocket launch into stages has a few advantages. Most importantly, it decreases the g-force on astronauts by spreading the forces out over a greater time period.

Another advantage is by increasing the distance from Earth we decrease the required escape velocity

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

For local launches (satellites into space, space station, moon missions) rotational momentum from the Earth can be used to give launches more velocity (KE). When launching a rocket, it is best to launch it east i.e.: the direction of the Earth's rotation. This relative velocity will result in a higher orbit velocity.

For extra planetary launches, the orbital momentum can be used to good advantage to propel a rocket (spacecraft) towards other planets. Engineers can plan to launch a rocket during a time of the year when the direction of the Earth's velocity matches that of the direction required.

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

Rockets work because of Newton's Third Law

$$Force\ on\ rocket = Force\ on\ Gas$$

$$-F_{rocket} = F_{gas}\ and;$$

$$-\Delta p_{rocket} = \Delta p_{gas}$$

$$-\Delta(mv)_{rocket} = \Delta p_{gas}$$

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

- Russian mathematician.
- "Father" of astronautics.
- Proposed to escape Earth's gravity through launching from top of tower reaching from Earth to geostationary orbit (36,000 km high). Wrote book called "Beyond the Planet Earth" about life in a spindle-shaped spacecraft at this position.
- Conceived idea of the rocket - continuous, propellant driven vehicle to escape the Earth, giving precise control of acceleration and orbit.
- Conceived of fundamental formula for rocket motion, essentially applying Newton's Third Law to derive the quantity of "specific impulse" (impulse is $\frac{F}{\Delta t}$).
- However his work was virtually unknown outside even his home town (Kaluga) - Oberth and Goddard developed similar principles independently.

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

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

The motion of an object in a circular path is called uniform circular motion. Although the speed remains the same it follows that an object travelling in a circular path must be accelerating since the velocity is constantly changing.

So: $v_1 \neq v_2$ however $speed_1 = speed_2$

The change in velocity is given by $\Delta v = v_2 - v_1$

When the change in velocity is placed in the average position between v_1 and v_2, it is directed towards the centre of the circle. When an object is moving with uniform circular motion, the acceleration (centripetal acceleration) is directed towards the centre of the circle. So for an object moving in a circle of radius r with an orbital velocity of v, the centripetal acceleration a is given by:

$$a_c = \frac{v^2}{r}$$

When some mass, m undergoes centripetal acceleration, the centripetal force F_c is given by:

$$F_c = \frac{mv^2}{r} \; (F = ma)$$

So if an object m_1 is in orbit, we can equate our two expressions for the force acting on it:

$$F_c = F_g$$

$$\frac{m_1 v^2}{r} = \frac{G m_1 m_2}{r^2}$$ (r is the radius of the orbit, not the height above the planet)

Compare qualitatively low Earth and geo stationary orbits

Low Earth Orbits	**Geostationary Orbits**
Between 250-1000kms high	Altitude = 38 800km
Above atmosphere to reduce drag	Always same spot above the Earth
Orbital period = 90mins, v=27900km/h	Orbital period = 24 hours, v = 10600km/h
Stronger signal for satellite phones	Useful for communication satellites because we don't have to move a dish (AUSTAR etc.)

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 radius of the orbit using Kepler's Law of Periods

Kepler's Third Law relates to the period of orbiting satellites to their orbital radius

$$F_g = G\frac{m_1 m_2}{r^2}$$

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

$$a_g = \frac{G m_1}{r^2}$$

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

$$a_c = \frac{v^2}{r}$$

$$a_c = \frac{\left(\frac{(2\pi)^2 r^2}{T^2}\right)}{r}$$

$$= \frac{\left(\frac{(2\pi)^2 r^2}{T^2}\right)}{r} \times \frac{1}{r}$$

$$= \frac{(2\pi)^2 r}{T^2} = \frac{G m_1}{r^2}$$

$$\frac{r^3}{T^2} = \frac{G m_1}{4\pi^2}$$

$$\frac{r^3}{T^2} = constant\ for\ satellites\ orbitting$$

Solve problems and analyse information to calculate the centripetal force acting on a satellite undergoing uniform circular motion about the Earth using:

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

Account for the orbital decay of satellites in low Earth orbit

For satellites in orbit around the Earth there is still some atmosphere drag which causes the satellite to lose altitude. This drag is more significant for satellites in LEO (Low Earth Orbit) and becomes more significant as altitude decreases. Solar wind activity can also affect the orbital path of satellites.

Discuss issues associated with safe re-entry into the Earth's atmosphere and landing on the Earth's surface

A space craft in orbit carries significant KE and GPE. During re-entry, the space craft experiences friction with the molecules in the atmosphere. The KE and GPE are converted into heat causing the space craft to reach extreme temperatures.

To disperse this energy, a blunt shape is best used to carry the energy away. However, there is still a significant amount of heat that needs to be dealt with. This is addressed by using special tiles on the nose of the spacecraft that are composed of 90% air. Air is a very good insulator and the use of the tiles allows for the use of "ablation". During re-entry the ceramic tiles are ablated (vaporised) which also helps to disperse the heat.

When re-entering the Earths' atmosphere, the angle of approach must be taken into consideration. When the space shuttle is re-entering the atmosphere, the approach angle must be correct. There is a 2° optimum window of entry. If the approach angle is too shallow there is a risk that the shuttle will "bounce" off the atmosphere. If the approach angle is too steep, the heat generated may be so great that is causes the shuttle to burn up on re-entry.

As well, the human occupants must also be taken into consideration. If the angle is too steep, acceleration will be high and therefore astronauts will experience higher g-forces. The human body can only withstand a certain amount ($\sim 8g$) of g-forces. This tolerance can be increased through the astronaut lying flat so that the g-forces do not force the blood away from the brain.

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

If the angle you re-enter the atmosphere is:

- too shallow: you may bounce off the atmosphere
- too steep: you burn up in the intense heat of re-entry

The solar system is held together by gravity

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

A gravitational field is a zone around celestial objects within which gravitational forces will act on a mass. All objects possess this field but it is only significant around very large masses.

$$W = mg \text{ } so$$

$$g = \frac{W}{m}$$

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

A gravitational field surrounds any mass, becoming significant with planetary-sized masses. It is strong close to the mass and weakens quickly with increasing distance. Despite this, its influence extends to very great distances in space.

Define Newton's Law of Universal Gravitation [Solve and analyse information using]:

$$F = G\frac{m_1 m_2}{d^2}$$

This is the force that any gravitational field applies to any mass at any position in it

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

A satellite orbiting Earth in a circular motion must therefore have some form of centripetal force acting up it to maintain the circular motion. Newton's first law states that "an object in motion will remain in motion unless acted upon by a net external force". This net external force (centripetal force) is provided by the Earth's gravitational field.

By equating Newton's Law of Universal Gravitation and the equation for centripetal force, we can figure out the velocity required for a satellite to remain in orbit. From the equation we see that the only variable that changes the motion of a satellite is the radius. The greater the radius the lower the orbital velocity required.

$$G\frac{m_E m_S}{r^2} = \frac{m_S v^2}{r}$$

$$G_E m_S = m_S v^2 r$$

$$G m_E = v^2 r$$

$$v = \sqrt{\frac{G m_E}{r}}$$

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

A spacecraft passes by a planet at close range and gains momentum from the elastic collision (gravitational interaction) between them.

The spacecraft gains a significant amount of velocity with very little effort.

Initially:

$$KE_s = mv^2$$

$$KE_p = Mv^2$$

$$Total\ Energy = KE_s + KE_p$$

$$\Delta KE_s = mv_2^2 - mv_1^2 = k$$

$$= m\Delta v^2 = k$$

$$\Delta KE_p = MV_2^2 - MV_2^2 = -k$$

$$= M\Delta V^2 = -k$$

Finally:

$$KE_s = mv_2^2 + k = mv_2^2$$

$$KE_p = MV_1^2 - k = MV_2^2$$

So:

$$M\Delta V^2 = -k$$

$$M\Delta v^2 = k$$

$$M \gg m$$

$$but\ |M\Delta V^2| = |m\Delta v^2|$$

$$so\ \Delta v^2 \gg \Delta V^2$$

Current and emerging understanding about time and space has been dependent upon earlier models of the transmission of light

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

In the 19^{th} century and early 20^{th} century, there was some support in the scientific community for the "aether" model of the transmission of light. This basically said that light needed to propagate through an invisible medium called the "aether". The aether was said to be reasonably fluid and all matter was said to be moving through it.

This was at odds with Einstein's premise that light always travels at the same speed regardless of the frame of reference. Michelson-Morley set out to prove the existence of the aether.

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

If the aether existed, the Earth would be moving through the aether and we would be able to experience the "aether wind". Many experiments before Michelson-Morley were designed and performed however it was always though that the equipment was too insensitive to measure and detect the aether wind.

The Michelson-Morley experiment was highly sensitive and used the effect of the interference of light waves to measure relative velocity on Earth through the aether. A light wave was split into two perpendicular beams, one travelling across the aether and one into it. Mirrors reflected the light rays back where calculations were performed. If the aether did exist, then the light would travel at different speeds and when the apparatus was rotated, the aether interference would be seen to shift.

However, the experiment provided a null result despite Michelson-Morley repeating the experiment many times during the day and the year. No evidence of the aether was found.

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

The results of the Michelson-Morley experiment concluded that no aether existed however many attempts were made to try and adapt and explain the model of the aether such as the movement of the planet dragged the aether with it however the alternative models proposed did not withstand scrutiny.

Einstein realised that if the principle of relativity (all steady motion if relative and cannot be detected with reference to an outside point) were to be held true, then light must move at a constant speed for all observers $3.0 \times 10^8 ms^{-1}$. If this is the case, then space and time become relative to each other. The Michelson-Morley experiment was an observational proof of Einstein's Special Theory of Relativity.

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

Use a boat race as an analogy. One boat is travelling across the current and the other boat is travelling with the current.

Outline the nature of inertial frames of reference

Einstein's Theory of Special Relativity specifically defines situations that occur between inertial reference frames. An inertial reference frame is one that is undergoing constant acceleration with respect to the other. This includes zero acceleration. In an inertial reference frame, Newton's Law are obeyed.

This notable excludes:

- Things travelling a curved path
- Things in orbital motion

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

The pendulum experiment: the pendulum is an accelerometer. In a non-inertial frame of reference the mass will swing in the opposite direction to the acceleration. In an inertial frame of reference the mass will hang vertically.

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

Discuss the principle of relativity

The principle of relativity states that all steady motion is relative and cannot be detected without reference to an outside point. The principal of relativity only applies for inertial reference frames. For example, in a car, you cannot tell if you are moving at a constant velocity or standing still unless you look out the window (the reference to an outside point).

The principle also states that you cannot perform any mechanical experiments or observations within an inertial reference frame that would reveal to you whether you are moving with uniform velocity (the pendulum experiment)

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

Einstein said that "light always travels at the speed of light from any reference frame". The consequences of this are that:

- If observers at relative motion to each other both observe the speed of light to be constant then due to $speed = \frac{distance}{time}$, the distance and time witnesses by the two observers must be different.

- An object moving with relative velocity to an outside observer will experience time dilation, length contraction (in the direction of motion) and mass dilation.
- Space and time become relative so simultaneous events in one frame of reference do not necessarily appear to be simultaneous in a different frame of reference. Any event has the three dimensions of space and one of time.

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

Einstein's theory states that the speed of light is constant from any frame of reference. This means that an observer moving at relative motion to another observer both see the speed of light to be the same. If the speed of light is constant and space and time must be different.

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

Length is a fundamental physical property. The SI unit is "one ten millionth of the distance from the equator to the geographic North Pole". The standard platinum bar is kept in Paris.

In 1961, the atomic standard was adopted. Length = 1650763.73λ of orange red light from Krypton-86

Since 1983, length has been redefined in terms of *c* in a vacuum i.e.: *"The distance light travels in $\frac{1}{299792458}$ of a second measured by a Cesium clock".* The speed of light is constant so this method gives incredible precision. A crazy fraction arises from the traditional definition of a metre (the gold bar) so current standard of length is defined in terms of time rather than length.

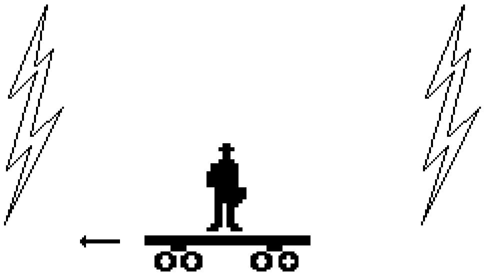
Explain qualitatively and quantitatively the consequence of special relativity in relation to: the relativity of simultaneity; the equivalence between mass and energy; length contraction; time dilation; mass dilation[1]

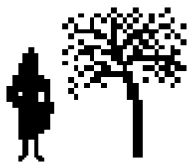
Relativity of Simultaneity:

We cannot consider time to be constant as a consequence of Einstein's Special Theory of Relativity. This means that the time interval between two events depends on the observer's frame of reference **even if the two events appear to be simultaneous**.

For example: Alice is standing in a field and she sees two simultaneous flashes of lightning. Rodger is on a railroad car moving to the left with velocity v.

[1] http://aether.lbl.gov/www/classes/p139/exp/gedanken.html





Question: What will Rodger see?

Answer: Rodger will see the light flash on the left first since he is moving toward that light and away from the flash on the right. Thus, he will not agree that the flashes of light occurred at the same time. In fact, from his perspective, Alice is the one that is moving, and he will say that it is only because of her movement that she happened to perceive both flashes of light as happening simultaneously.

Equivalence between mass and energy

When an object is accelerated, we apply a force and in the process work is done:

$$W = Fs$$

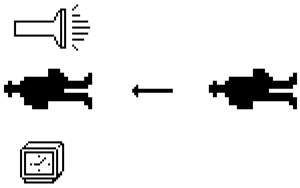
However an object cannot accelerate indefinitely as no object may travel faster than the speed of light. When work is done on an object, KE is increased as the object speeds up. As the object approaches c due to $E = mc^2$ that energy is changed into mass reducing the amount of energy that is speeding up the object.

When an object is stationary, it has no KE but will have energy due to its mass.

Length Contraction

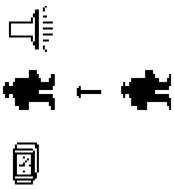
As a consequence of perceiving time differently, observers in different frames of reference will also perceive length differently.

For example: Super Einstein is flying through space with his twin brother, Murray, who is 186,000 miles behind him. Every time he wants to make an acceleration of 10 mph, he uses a flashlight to signal his brother so that they will accelerate together and stay the same distance apart.



From Einstein's perspective, he and his brother are 186,000 miles apart, and by letting 1 second pass on his clock before accelerating, he allows the light to reach his brother right at the moment of acceleration. As a result, from Einstein's point of view he and his brother accelerate together and remain a constant 186,000 miles apart. This is what Einstein sees, but if we are standing still with respect to Einstein and his brother, then what will we see?

Answer: From our perspective, two things happen. First, we say that the beam of light has less than 186,000 miles to travel since his brother is traveling toward it. Second, we are going to see Einstein's clock as running slow. Thus, for two reasons we are going to see Einstein's brother get the signal to accelerate before a full second has passed on Einstein's clock and he begins his own acceleration. Hence, the distance between Einstein and his brother gets shorter. However, if we stop our analysis at this point, then we are going to wind up with a contradiction, because if Einstein and his brother keep accelerating and if we keep seeing his brother accelerate first, then eventually distance between them will become so small that Murray will run into Einstein. However, from Einstein's perspective, he and his brother stay a constant 186,000 miles apart! How can we resolve this seeming contradiction? Only by making a very bizarre assumption. In order to keep Murray from running into his brother the shortening of the distance between Einstein and his brother must be compensated for by a contraction of length in a direction parallel to the direction in which Einstein and his brother are moving! In other words, from our point of view, Einstein and his brother are getting shorter so that some distance always remains between them in spite of their accelerations.



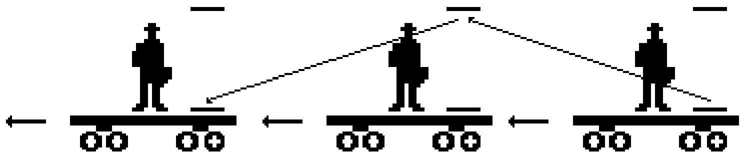
In the next experiment we will derive a formula that will show us by just how much lengths contract.

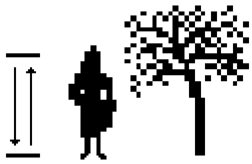
Time Dilation

Time is perceived differently by observers in relative motion.

For example: Alice is standing in a field. Next to her is a light clock. That is, two mirrors that are reflecting a beam of light back and forth, and the journey from one mirror to the other and back again counts as one tick of the clock. Also, Alice is wearing a watch that is synchronized with her light clock.

Standing on a railroad car is Rodger. He also has a light clock, and his clock is synchronized with Alice's and his own wristwatch. The railroad car is moving to the left with a velocity v.





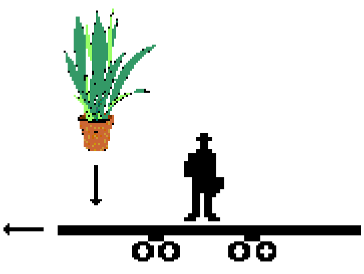
Question: What happens?

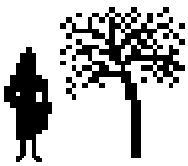
Answer: From Rodgers's perspective, the beam of light keeps going up and down between the mirrors, but from Alice's perspective, the light now has to travel a diagonal path from one mirror to the other. Since Alice still measures the speed of light as **c**, she is now going to observe Rodgers's light clock as ticking slower than hers since the light now has a longer distance to travel. However, since Rodger still experiences his watch as being synchronized with his clock, Alice will see his watch slow down along with his clock!

Conclusion: If someone moves in a straight line with velocity v with respect to you, then you will observe time passing more slowly for them.

Mass Dilation

For example: Rodger drops his wife's favourite potted plant while traveling at a high velocity. It shatters. Meanwhile, his wife is standing in the field watching.





Question: What will they each observe?

Answer: They both agree that the pot shatters when it hits the surface and that Rodger is in BIG trouble. However, from Alice's point of view, Rodger's time slows down and she sees the plant fall in slow motion. This raises the question of why the pot shatters if it seems to gently float to the surface of Rodger's railroad car. The answer has to do with momentum. Momentum is the amount of "punch" something has. Physicists define momentum as the product of mass and velocity ($p = mv$). For instance, a car hitting you at 1 mph will do a lot more damage than a feather hitting you at 1 mph because it has more "punch". This extra punch or momentum is a consequence of the car's greater mass. Likewise, if both Rodger and Alice agree that the dropped pot shatters, then this is because the momentum of the pot has remained unchanged. However, since Alice sees the pot falling with less velocity, this also means that its mass must have increased in order for momentum to be conserved.

Conclusion: When an object goes fast with respect to us, not only do we see its clocks slow down and its length shortens, we also see an increase in its mass!

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

During a space mission, acceleration is always the most costly phase (in terms of energy required). The effect of mass dilation (the acceleration is decreased for a given thrust) and time dilation (there is less time in which to accelerate) means that accelerations beyond 0.9c will be impractical as greater and greater amounts of forces will be required for minimal gain.

If humans are to reach locations outside our solar system in a reasonable amount of time, these speeds will be required however we do not yet have the technology to produce this much amount of energy.

The effect of time dilation and length contraction may make is possible for humans to undergo extremely long space journeys in a reasonable amount of time for the travellers. The distance appears to be shortened due to length contraction and the journey will take less time (time dilation). When the astronauts return to Earth, they will have aged less compared to the amount of time that has passed on Earth.

However, the energy requirements necessary to propel a spacecraft to speeds those close to *c* are not within the abilities of modern science.

Analyse information to discuss the relationships 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

Scientists have verified time dilation through the use of very accurate atomic clocks. Both clocks were synchronised, one stayed on the ground while another was flown around over a long distance. When compared, the clocks that were flown around did in fact slow down compared to the clocks on the ground.

Mesons are particles created in the upper atmosphere by incoming cosmic rays. Their life span is so short that they should not live long enough to hit the Earth yet they do. This is because of the fact they travel at 0.996c and due to time dilation, they have a dilated lifetime allowing them to reach the Earth

Solve problems and analyse information using:

$$E = mc^2$$

$$l_v = l_o\sqrt{1-\frac{v^2}{c^2}}$$

$$t_v = \frac{t_o}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$m_v = \frac{m_o}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$Let\ \gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$l_v = \frac{l_o}{\gamma}$$

$$t_v = t_o\gamma$$

$$m_v = m_o\gamma$$

MOTORS AND GENERATORS

Motors use the effect of forces on current carrying conductors in magnetic fields

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; the angle between the direction of the external magnetic field and the direction of the length of the conductor.

Strength of the magnetic field

$$F \propto B\ (Strength\ of\ magnetic\ field)$$

Magnitude of the current in the conductor

$$F \propto I\ (current\ in\ the\ conductor)$$

Length of the conductor

$$F \propto L\ (length\ of\ the\ conductor)$$

Angle between the direction of the external magnetic field

Maximum force when the conductor is at right angles to the field i.e. when $sin\theta = 90$

$$F \propto sin\theta$$

$$\therefore F = BILsin\theta$$

Describe qualitatively and quantitatively the force between long parallel current-carrying conductors [and solve problems using]:

$$\frac{F}{l} = k\frac{I_1 I_2}{d}$$

Refers to the force exerted by two lengths of parallel charge carrying-conductors on each other.

- $F\ =\ force\ (N)$
- $l = length(m)$
- $k = magnetic\ force\ constant$
- $I_1 I_2 = currents\ in\ wires\ (A)$
- $d = distance\ between\ wires\ (m)$

If the currents are in the **same** direction, they will **attract**

If the currents are in the **opposite** direction they will **repel**

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

The DC motor prac

Solve problems and analyse information about the force on current-carrying conductors in magnetic fields using:

$$F = BIlsin\theta$$

- $B = strength\ of\ magnetic\ field\ (T)$
- $I = current\ through\ wire\ (Amps\ of\ Cs^{-1})$
- $L = length\ of\ conductor\ (m)$

Define torque as the turning moment of a force using:

A twisting force is called a torque

$$\tau = Fd$$

- $\tau = Torque$
- $F = Force\ applied$
- $d = perpendicular\ distance\ of\ force\ from\ axis$

Solve problems and analyse information about simple motors using:

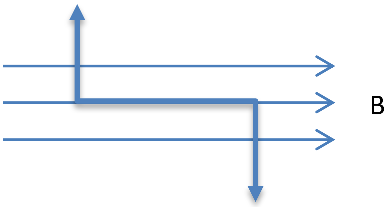
$$\tau = nIABcos\theta\ OR\ \tau = InABcos\theta$$

- $\tau = Torque$
- $n = number\ of\ coils$
- $I = current\ (Amps)$
- $A = Area\ (m^2)$
- $B = Strength\ of\ magnetic\ field\ (Tesla)$
- $\theta = Angle\ between\ coil\ and\ field$

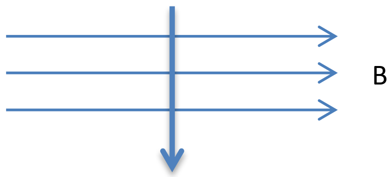
Identify that the motor effect is due to the force acting on a current-carrying conductor in a magnetic field.

A conductor which carries a current through a magnetic field will experience a force. This is caused by the movement of charged particles (current) through the field. This is known as the motor effect. The force causing the movement of the conductor results from the interaction between the magnetic field due to the magnet and the electromagnetic field produced simply because of the relative movement of charges in the conductor through the magnet's field

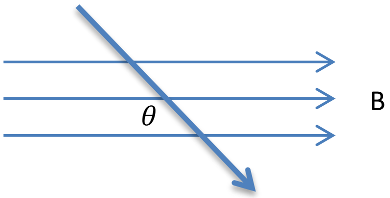
Describe the forces experienced by a current-carrying loop in a magnetic field and describe the net result of the forces.



Max $\tau = nIAB$

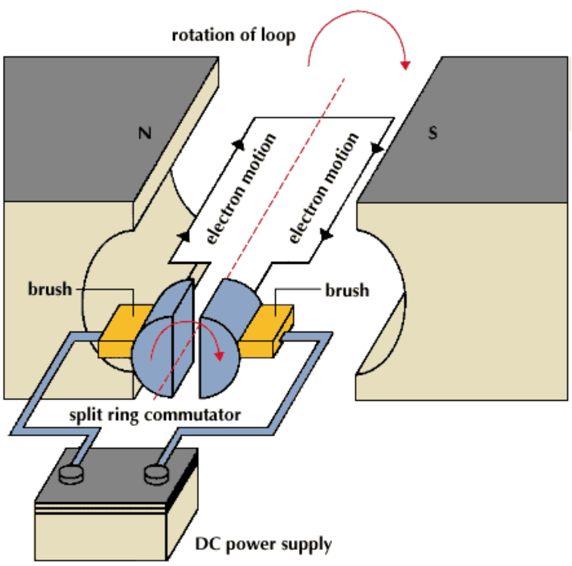


$\tau = 0$



$\tau = nIABcos\theta$

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



Magnets (permanent or current carrying coils): The magnets create a magnetic field. This magnetic field interacts with a current-carrying coil causing the coil to experience a force and move.

Coil: The coil carries a direct current which interacts with the magnetic field producing a torque

Brushes: maintain electrical contact with the coils and the rest of the circuit

Commutators: The split ring commutator switches the current off when the coil is in a vertical position. This allows the momentum of the coil to continue turning before the current switches back on again and the coil once again experiences a force acting on it. This continues until the current is removed.

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

The magnetic field in a DC motor can be provided by a permanent magnet as well as an electromagnet. Permanent magnets are usually used in small toys as the strength of even the most powerful permanent magnet is not near as powerful as electromagnets can reach. Also, electromagnets allow us to turn the magnetic field on and off as we desire.

Identify data sources, gather and process information to qualitatively describe the application of the motor effect in: the galvanometer; the loudspeaker.

The galvanometer makes use of the fact that an electric current flowing through a wire sets up a magnetic field around the wire. In the galvanometer, the wire is wound into a coil. When current flows through the coil, one end of the coil becomes a north magnetic pole, the other a south magnetic pole. When a permanent magnet is placed near the coil, the two fields—the one from the coil and the one from the magnet—interact. The like poles will repulse each other and the unlike poles will attract. The amount of attraction and repulsion increases as the strength of the current increases.

How does the fluctuation make the speaker coil move back and forth? The electromagnet is positioned in a constant magnetic field created by a permanent magnet. These two magnets -- the electromagnet and the permanent magnet -- interact with each other as any two magnets do. The positive end of the electromagnet is attracted to the negative pole of the permanent magnetic field, and the negative pole of the electromagnet is repelled by the permanent magnet's negative pole. When the electromagnet's polar orientation switches, so does the direction of repulsion and attraction. In this way, the alternating current constantly reverses the magnetic forces between the voice coil and the permanent magnet. This pushes the coil back and forth rapidly, like a piston. When the coil moves, it pushes and pulls on the speaker cone. This vibrates the air in front of the speaker, creating sound waves.

The relative motion between a conductor and magnetic field is used to generate an electrical voltage

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

Faraday discovered that three things were necessary for the production of an electric current:

- A magnetic field
- A conductor
- Relative motion

If the conductor is in a closed circuit, then a current will be produced. As long as there is relative motion of the magnet then a current and emf will be produced.

$$\varepsilon = n\frac{\Delta\Phi}{\Delta t}$$

- $\varepsilon = induced\ emf\ (V)$
- $n = number\ of\ coils$
- $\Delta\Phi = change\ in\ magnetic\ flux\ (Webers)$
- $\quad = BA\ where\ B = magnetic\ flux\ density\ (T), A = Area\ of\ coil$
- $t = time\ taken\ for\ \Delta\Phi\ to\ occur$

The induced emf can be increased by:

- Increasing n, the number of coils
- Increasing B, use stronger magnets
- Increasing A, get a bigger coil
- Decrease t, go faster

Define magnetic field strength B as magnetic flux density

Magnetic flux density is the magnetic flux per unit of area (such as per $meter^2$). It is a measure of the strength of the magnetic field.

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

$\Phi = BAsin\theta$

$where\ B = magnetic\ density\ (T)$

$A = Area\ (m^2)$

$\Phi = magnetic\ flux\ (Wb)$

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

Potential difference = Voltage or induced emf. As per Faraday's law, the induced emf is proportional to the rate of change of magnetic flux through the circuit.

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

$$\varepsilon = -n\frac{\Delta\Phi}{t}$$

Lenz's Law simply adds a negative to Faraday's law. It says that any induced current will have a direction that opposes the change that caused it. Similar to the law of conservation of energy because the induced electrical energy has to come from the thing that causes the original motion.

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

Back emf is generated in any coil that experiences changing B fields even though it is producing them. Back emf is produced in the rotating coil of a motor.

Back emf	Unloaded motor	Loaded motor
None	Stationary	Stationary
Increases	Speeding up	Speeding up
Almost equal to input emf	Operating speed	-
Significantly reduced to allow motor to do work	-	Operating speed

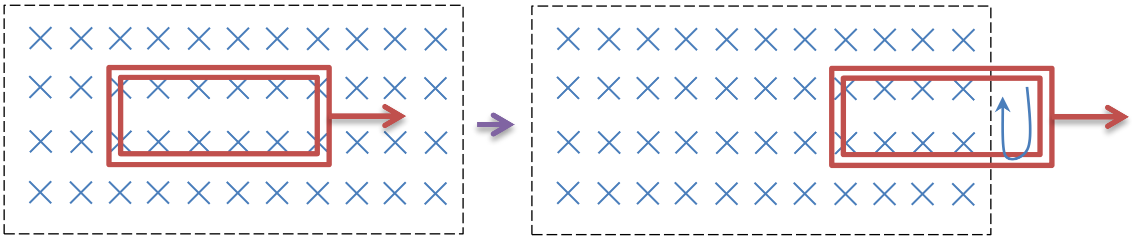
When the motor is spinning at its operating speed, back emf will have its max value, but when the motor is just turned on it isn't spinning yet so there is no back emf.

This can lead to excessive current so the motor may be protected by using a "starting resistance" that limits current. When up to speed the resistor is taken out of the circuit.

This is not needed in an AC motor as it constantly produces its own back emf

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

If we have a magnetic field moving through a coil of wire, electrical current will be induced. This current will flow in circles and resemble "eddies" in rough flowing water. The eddy currents can be used to create stored electrical energy or heat. They can occur in 2D objects (sheet of metal) or a 3D object (block of steel).



The conducting coil experiences a change in magnetic field. Faraday's law says a current is induced. Lenz's law says that the induced magnetic field opposes the change in the external magnetic field.

Perform an investigation to model the generation of an electric current by moving a magnet in a coil or a coil near a magnet

Swinging the wire around and moving the magnet back and forth towards the coil.

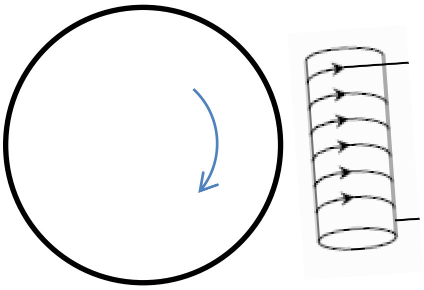
Plan, choose equipment or resources for, and perform a first-hand investigation to predict and verify the effect on a generated electric current when: the distance between the coil and magnet is varied; the strength of the magnet is varied; the relative motion between the coil and the magnet is varied.

As per $F = BIlsin\theta$

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

Instead of a heating element, this cooktop contains a set of coils with alternating current passing through them. This produces a changing magnetic field above the cooktop. A metal saucepan placed on the cooktop is a conductor in the changing magnetic field and therefore an electric current is induced in the base of the pan. The current heats the pan, and this heat cooks the food. Induction cooktops are approximately twice as efficient as a gas cooktop, have less of a burning risk and provide more control than a conventional cooktop. However, they are expensive to purchase and require cookware with high iron content.

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



Lenz's law says that the induced eddy currents oppose the motion – braking. The faster the spinning of the wheel, the greater the resistance. This leads to very smooth braking as the resistance decreases with speed. Less contact means that there are less maintenance costs. Such brakes are used in free fall rises in amusement parks, roller coasters, fast trains

Generators are used to provide large scale power production

Describe the main components of a generator

An electric generator (dynamo) is a device that includes all of the elements necessary to convert KE to electricity using Faraday's law.

- A magnetic field (e.g.: permanent magnets)
- A conductor (e.g.: coil on axis)
- Relative motion (The coil is made to spin by some form of energy such as Hydro)

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

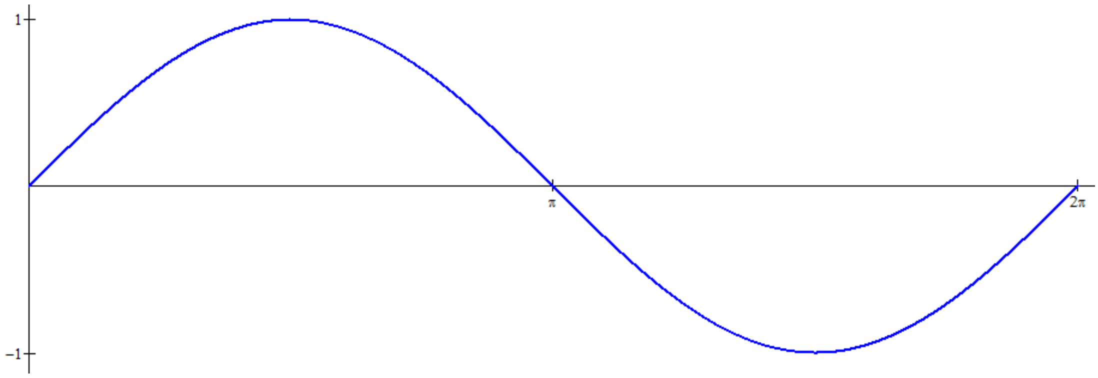
Most generators are constructed just like a motor; however the flow of energy through them is different.

- Motor: $electrial\ E \rightarrow KE$
- Generator: $KE \rightarrow electrical\ E$

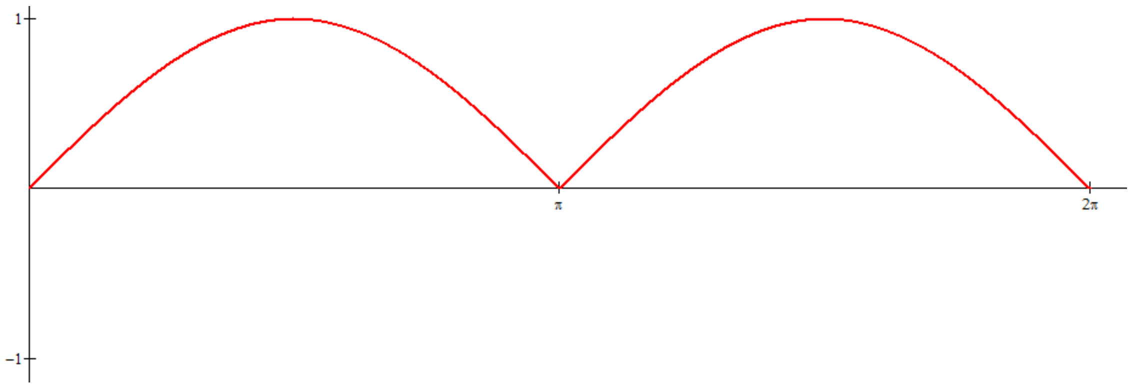
Describe the differences between AC and DC generators

emf is generated in the coil and a circuit is completed to the outside world using ring connectors just like motors.

If standard slip rings are used then a dynamo naturally produces an alternating current



A split ring commutator is used in a DC generator so the current is reversed every half cycle



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

Even good conductors (like copper) generate substantial resistance due to their length. This is particularly relevant when transmitting electricity around towns and across the country. To minimise energy losses we need to minimise current as $Heat\ Loss \propto I^2$. This is achieved by increasing voltage.

Remember: $E = VIt$

For example:

- Transfer 1000J @ 100V → $I = 10A$
- Transfer 1000J @ 500V → $I = 2A$

Assess the effects of the development of AC generators on society and the environment

	Positive	Negative
Society	Improved lifestyle	Cancer risk for people living near transmission lines
	Street lighting	Longer working hours
	Electric trains	Possible over reliance on electricity
	Communication	
	Computerisation of systems e.g.: banking	
	Industrial development → more jobs	
Environment	Electric trains have reduced pollution caused by steam trains	Burning coal in power stations produces smoke and CO_2 emissions (greenhouse gases)
	Electricity production is becoming cleaner than old technology	Nuclear power stations produce radioactive water and risk of a nuclear accident
		Hydroelectric schemes redirect natural waterways
		Mining impacts heavily on local ecosystems
		Visual pollution of cables

Plan, choose equipment or resources for, and perform a first-hand investigation to demonstrate the production of an alternating current

The generator with the light bulb prac

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

	Advantages	Disadvantages
AC	Is easy to transform	Back emf due to eddy currents lowers power
	Can be transmitted at high voltage, low current and then transformed	Emitted electromagnetic radiation interferes with other electronic equipment
	Energy losses in transmission can be minimised by high voltage transmission	Requires thicker insulation to minimise interference from other cables
	Motors and generators have fewer moving parts and are easier to maintain	
	Three phase motors powerful enough for industry use	
DC	Does not need as much insulation as it has not electromagnetic radiation output	Cannot be transformed
	Significantly lower back emf	More difficult to supply to houses by line distribution
	No high frequency radiation to cause interference in other equipment or signals	Equipment not as reliable due to sparking and wear across split ring commutator
	Transmission has no energy loss due to induction in adjacent lines and metal structures	Sparking causes interference

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

Edison and Westinghouse were both businessmen. Edison was also a prodigious inventor holding more patents than anyone in history. Westinghouse built his empire on the back of this railroad network.

Tesla brought some new electricity ideas to Westinghouse for financial backing. Tesla designed motors that used AC electricity. Most of Edison's devices used DC.

Edison started to distribute DC electricity:

- Hundreds of generators (power stations) across New York
- Generators about 1km apart
- Transmission distance limited because DC can't be transformed → more pollution due to generators

Edison plays dirty:

- Lobbies politicians
- Takes AC electric chair "road show"

- Lobbied for 240V max for AC and 800V max for DC
- Bought European patents for transformers
- Recommended name for electric chair as "Westinghouse" chair

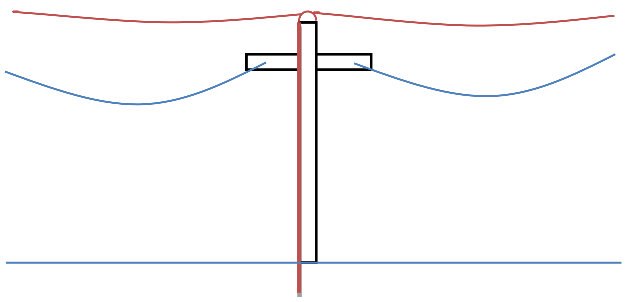
Westinghouse develops AC:

- Set up AC generating system invested by Nikolai Tesla
- Westinghouse won the contract to power the World Fair in 1892. His bid was half the price of Edison's.
- At the fair, 100000 lights were powered by 12 AC generators
- After then, 80 of appliances were AC
- After harnessing Niagara Falls to generate AC electricity, DC was dead
- By 1896, 10 generators supplied electricity to New York

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

Transmission lines are insulated from supporting structures with special ceramic insulators or ceramic insulating stacks. These are placed some distance from the metal towers that carry them as electricity can jump a significant distance at high voltages. There has been a trend towards using newer rubber insulators instead of ceramic ones.

High voltage lines have a lightning umbrella or a ground wire to attract lightning.



As well, the ceramic insulation chains protect the lines from lighting strike if the metal towers are hit. Furthermore, the distance between each tower is significant enough to protect each adjacent tower in case one is hit.

Transformers allow generated voltage to be either increased or decreased before it is used.

Describe the purpose of transformers in electrical circuits

Transformers change the voltage in an AC current. A transformer consists of two overlapping coils. The coils do not need to be physically connected because they use electromagnetic induction to transfer energy.

Compare step-up and step-down transformers

Step up transformers: increase voltage

Step down transformer: decrease voltage

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

$$\frac{V_p}{V_s} = \frac{n_p}{n_s}$$

- $V_p = Primary\ voltage\ (voltage\ in)$
- $V_s = Secondary\ voltge\ (coltage\ out)$
- $n_p = number\ of\ turns\ in\ primary\ coil$
- $n_s = number\ of\ turns\ in\ seconary\ coil$

Explain why voltage transformations are related to conservation of energy

In an ideal transformer, there is no energy lost and we can't create energy either. So the power in the primary coil is equal to the power in the secondary coil.

$$P_p = P_s$$

$$V_p I_p = V_s I_s$$

So if a step up transformer gives a greater voltage at the output, its current must be decreased

Explain the role of transformers in electricity sub-stations

NSW power stations produce electricity with a voltage of about 23,000 V and a current of about 30,000A. Unfortunately, this amount is too high to be sent through a cable. To reduce heat loss, the voltage is increased as high as possible to reduce the current and heat loss.

Along the way, step down transformers gradually reduce the voltage, at town substations for distribution across the town and then at individual transformers before being distributed to houses at 240V

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

Many household appliances operate at low DC voltages (iPods, laptops and phone chargers) therefore theses appliances will have inline or inbuilt transformers to step down domestic 240V as well as a rectifier to convert AC to DC. TV's also have step-up transformers for producing voltages needed for CRT's and Plasmas.

Discuss the impact of the development of transformers on society

The development of transformers in conjunction with AC current has allow for nationwide distribution grids allowing the transfer of electricity from on power station to a large area compared to the use of multiple, high voltage DC generators. Using transformers to step up and down voltage, we can make distribution and transportation as efficient as possible.

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

The one with the washers, audio oscilloscope and the CRO

Solve problems and analyse information about transformers using:

$$\frac{V_p}{V_s} = \frac{n_p}{n_s}$$

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

Laminations, reducing surface area, cooling down the coils using oil

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

Motors are used in industries and the home usually to convert electrical energy into more useful forms of energy

Describe the main features of an AC electric motor

The rotor: end rings short circuit non-ferrous rotor bars, that is sealed i.e. no external connections at all (usually a “squirrel cage”). Encased in a laminated iron armature.

The stator: surrounding electromagnet.

Connection to stator: the surrounding electromagnet receives the AC.

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

The one with the plastic cup, magnets as well as the one with the washing machine motor.

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

IDEAS TO IMPLEMENTATION

Increased understandings of cathode rays led to the development of television

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

Early experiments produced inconsistent evidence as cathode rays appeared to behave as both waves and a stream of particles

Hertz performed an experiment that seemed to show that cathode rays were not deflected by electric fields (this is incorrect). This was used as evidence to support the fact that cathode rays were EM waves just like light (which is not deflected by an electric field)

JJ Thompson performed an experiment which showed that cathode rays were visibly affected by an electric field. This indicated that cathode rays charged particles.

Hertz showed that cathode rays penetrated thin metal foil indicated that it must be an EM wave.

Due to the lack of the knowledge about the nature of atoms, conflicting results arose from these experiments.

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

Cathode ray tubes allow the manipulation of a stream of charged particles.

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

Charged particles in a magnetic field experience a force. This force is given by the equation:

$$F_B = qvB$$

- $F_B = Magnetic\ Force\ (N)$
- $q = charge\ (C)$
- $v = velocity\ of\ of\ charge\ (ms^{-1})$
- $B = strength\ of\ magnetic\ field\ (T)$

Identify that charged plates produce an electric field

Two metal plates, placed at a distance attached to a current will produce an electric field.

$$\epsilon = \frac{V}{d}$$

- $\epsilon = Electric\ Field$
- $V = Voltage$
- $d = distance$

Describe quantitatively the force acting on a charge moving through a magnetic field

$$F_E = q\epsilon$$

- $Where\ F_E = electric\ force\ (N)$
- $q = Charge\ (C)$
- $\epsilon = Electric\ Field\ Strength\ (NC^{-1})$

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

An electric field surrounds any point in a radial direction. The stronger the charge, the stronger the field.

$$\frac{d_1}{d_2} = \frac{q_1}{q_2}\ calculates\ the\ null\ point$$

If a positive charge is placed near another positive charge it will experience a repulsive force

A positive charge placed in a field will experience a force in the direction of the arrow

A negative charge placed in a field will experience a force opposite to the arrow

Describe quantitatively the electric field due to oppositely charged parallel plates

Parallel charged plates produce a uniform electric field. The position of the charge in the field does not matter as the field is uniform. Hence,

$$\epsilon = \frac{V}{d}$$

$$Electric\ Field = \frac{Voltage}{Distance}$$

- $\epsilon = strength\ of\ magnetic\ field (NC^{-1})$
- $V = Voltage\ or\ potential\ difference\ between\ the\ plates\ (V)$
- $d = distance\ between\ plates\ (m)$

Outline Thomson's experiment to measure the charge/mass ratio of an electron.

Used a cathode ray tube with fluorescent screen at the end to measure deflection of beam

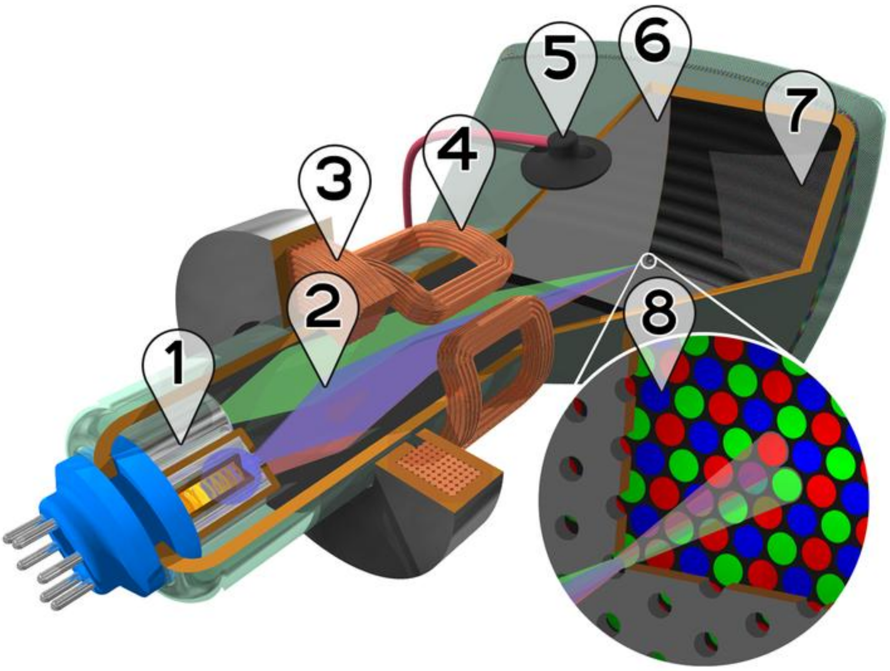
Equated B to E to determine the velocity of the particle ($F_E = qE, F_B = qvB$)

Applied projectile motion principles after turning off B to find expression for $\frac{m}{q}$, ie: the charge/mass ratio

Experiment showed either very small mass or very high charge

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

A TV monitor consists of a large vacuum tube with a fluorescent screen. The electron gun is surrounded by two electromagnets which work to focus the electron beam into a dot on the screen. The beam performs a very fast “sweep” of the screen at a constant rate. A vertical pair of electromagnets varies the vertical position and a horizontal paid of electromagnets varies the vertical position.



1. Three Electron guns (for red, green, and blue phosphor dots)
2. Electron beams
3. Focusing coils
4. Deflection coils
5. Anode connection
6. Mask for separating beams for red, green, and blue part of displayed image
7. Phosphor layer with red, green, and blue zones
8. Close-up of the phosphor-coated inner side of the screen

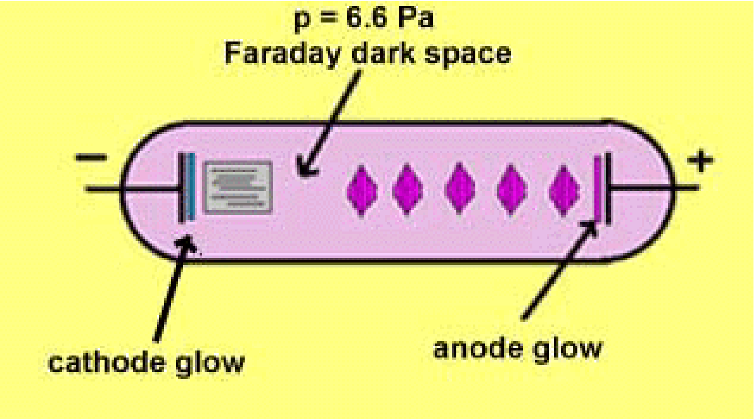
When we tune into a TV station, we are aligning the sweep rate with the station’s signal frequency. The signal varies in intensity to make blue, green and red spots on the screen, which resolve into a picture.

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

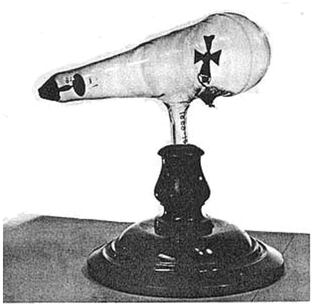
The tubes with the different pressures glowed different colours and brightness.

Striation patterns appeared depending on the pressure inside each tube.

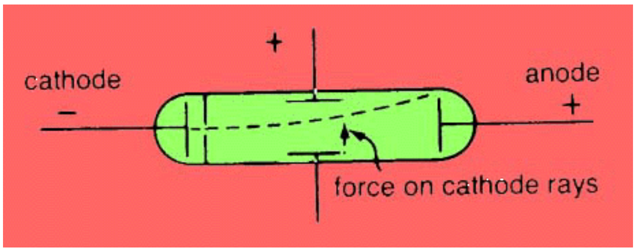
Moderately low pressure streams appear to flow along the outer edge of the tube. Green glow around the cathode and anode.



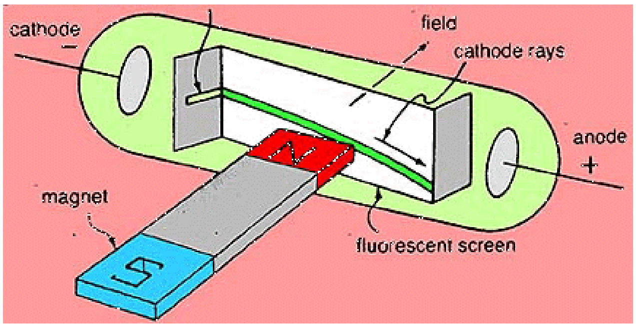
Perform an investigation to demonstrate and identify properties of cathode rays using discharge tubes: containing a Maltese cross, containing electric plates, with a fluorescent display screen, containing a glass wheel.



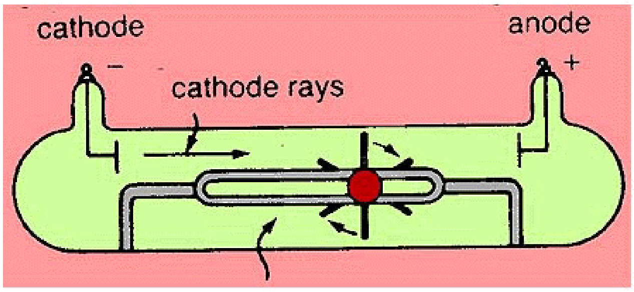
Produced a shadow which showed that cathode rays travel in straight lines



Deflected by electric field as a negative charge should be.



Cathode rays are deflected in a circular path by a magnetic field. Use of fluorescent screen allows the cathode ray to be seen.



Paddle wheel moves showing cathode rays have energy and momentum

Analyse the information gathered to determine the sign of the charge on cathode rays

Solve problems and analyse information using:

$$F = qvBsin\theta$$

$$F = qE$$

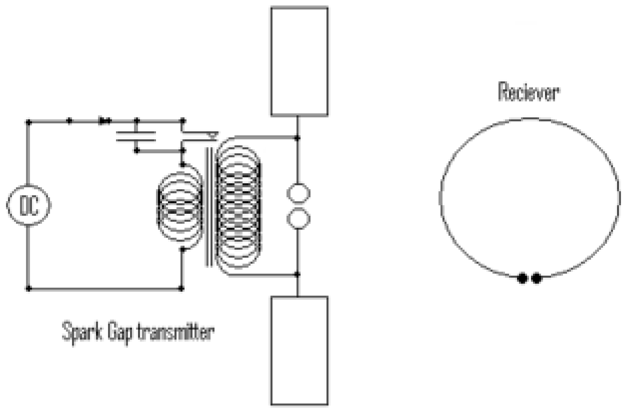
$$E = \frac{V}{d}$$

The reconceptualisation of the model of light led to an understanding of the photoelectric effect and black body radiation

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

In 1865, James Maxwell produced his equations that predicted EM waves

In 1887, Hertz conducted an experiment that produced his waves. He showed the rays produced have wave properties: They could be reflected and refracted, could be diffracted, could be polarised, had their speed measured to be the same as light (as predicted by Maxwell)



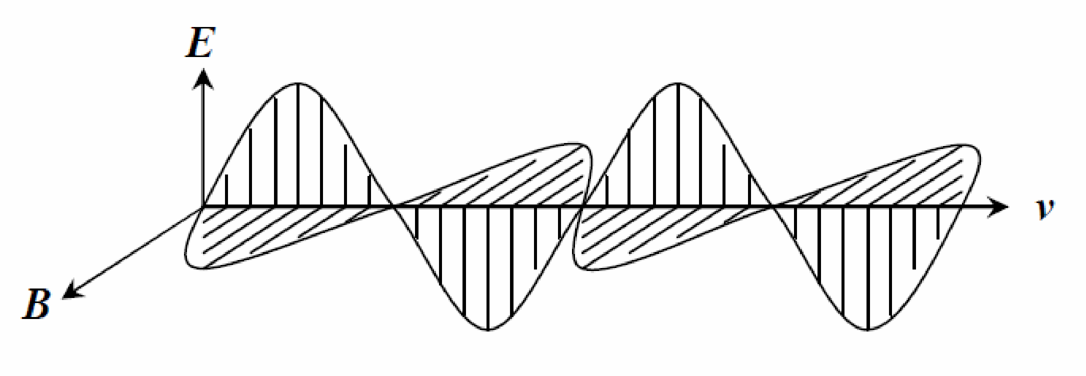
The speed of the waves was calculated using $v = f\lambda$. The frequency and wavelength were measured by observing interference patterns.

Hertz then shone a UV light on his brass plates and observed an increased intensity of the signal. This is the first observation of the photoelectric effect. Hertz did not investigate further

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

Waves can be diffracted when it passes through a small opening. The spreading waves are called dispersion. This can occur with light using a prism or diffraction grating. Dispersion can also separate waves of different frequency and wavelength because they are refracted or diffracted to a different degree. If we add more than one split we can create interference patterns. Changes in interference patterns can indicate a change in frequency or wavelength of the wave.

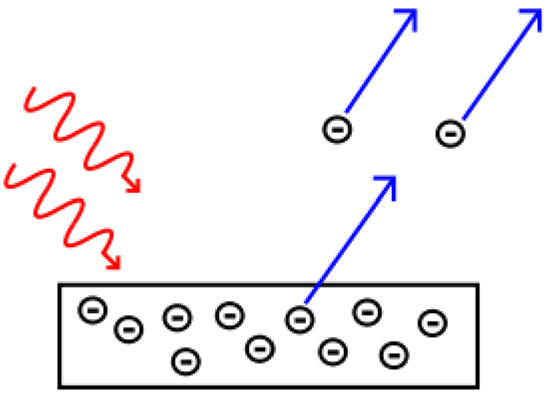
Henrich Hertz used interference patterns to measure the speed of radio waves in his experiment. Amazing, the velocity turned out to be c (the speed of light) verifying Maxwell's equations.



Radio waves are formed when an oscillating electric charge produces and oscillating electric field which in turn induces an oscillating magnetic field. These two field combine to form EM waves.

The Photoelectric Effect

The photoelectric effect is: the ejection of an atomic electron by the absorption of a photon.



$$KE_e = E_p - Binding\ Energy$$

There is a minimum energy that a photo must have to eject an election. This energy is different for all atoms and we use special compounds in photocell to take advantage of this.

1900-1902: Lenard investigation showed the charges emitted were elections. He investigated the relationship between the energy of the emitted photoelectrons and the intensity and frequency of light.

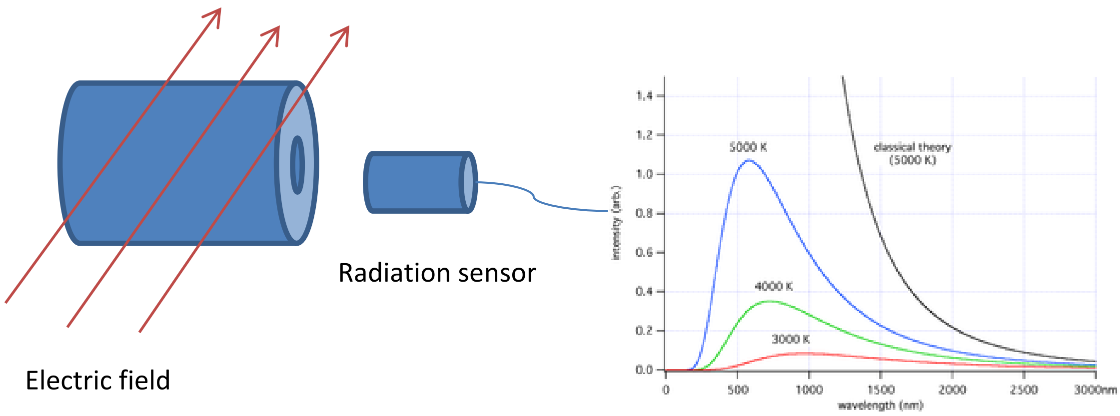
By varying the voltage, Lenard was about to find the amount of energy required to stop the current that inferred that this must be the KE of the photoelectron.

The results he obtained contradicted classical physics:

- Photoelectrons were only emitted once a certain frequency was exceeded (classical physics stated that as light intensity increased, the energy of the photons would increase)
- Photoelectrons were emitted instantly when the threshold frequency was exceeded.
- As frequency increased, KE increased, there was no increase in current (classical physics said the frequency of the light should have no effect on the energy of the photoelectrons)
- As intensity increased, current increased, KE remained constant.

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

A "black body" absorbs all incident radiation, and won't emit radiation due to its own temperature. An ideal black body can be thought of as a black tungsten cylinder with a small hole drilled into it to emit radiation



Results:

- As temperature rises, the energy peaks moves to shorter wavelengths
- As temperature rises, total energy emitted (area under curve) increases
- Classical physics could not explain the peaks at longer wavelengths

The predictions of classical physics are known as the ultraviolet catastrophe meaning that at shorter wavelength, energy increased. These curves have infinite areas under them showing they give off infinite energy. This would destroy the universe, and that is not cool.

Max Planck came along and explained it mathematically. The solution was to describe energy as increasing by little steps which he related to his constant. Planck said **energy was quantised.**

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

Einstein's contribution: "A single photo is required to eject a single photoelectron". Basically he quantised light into photons. He came up with the equation $E = hf$. He got a Nobel Prize for that?

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

Light exists as photons, each with an energy represented as E = hf.

Light intensity depends on the number of photons.

Photons with the highest energy correspond to light of the highest frequency.

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

$$E = hf$$

$$c = f\lambda$$

$$f = \frac{c}{\lambda}$$

$$\therefore E = \frac{hc}{\lambda}$$

The *energy of a light photon* of any known wavelength of light can be determined as they all travel with the same velocity (speed of light).

At this energy level we use electron volts which the energy required to raise one electron to 1 volt.

Perform an investigation to demonstrate the production and reception of radio waves

Equipment: DC source, induction coil, AM Radio

Production of radio waves:

- Charges hitting metal plate gives off EMR → radio waves
- Related to photoelectric effect

Reception of radio waves:

- Use AM Radio not tuned → signal is soft
- Turn on induction coil and static becomes much louder indicating a higher amplitude radio wave has been produced.
- Aerial of radio would be approximately the same as the wavelength

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

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

Solar cells are an important application of the photoelectric effect. Photocells are cells in which light incident upon a cathode causes the emission of an electron - the greater the intensity of light, the greater the current.

Modern solar cells use silicon and gallium arsenide. They also use focusing devices such as lenses to increase intensity and achieve greater efficiency

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

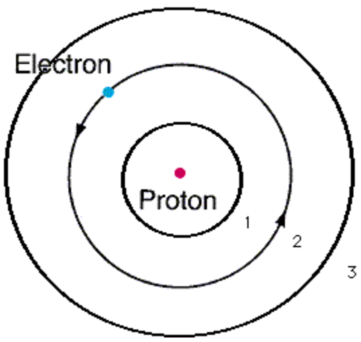
Einstein and Planck were contemporaries. Planck believed that science was a pure form of study and could be completely removed from politics.

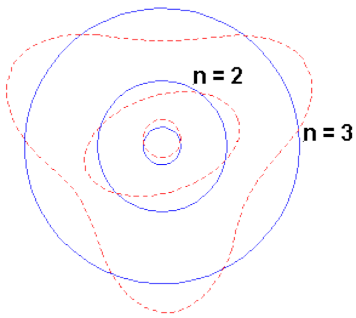
Einstein believed that scientific development and politics were inextricably linked. He was concerned that the new physics of the time would be used to develop the atomic bomb. He wrote to President Eisenhower to express concern about Germany's nuclear weapons program hence starting the Manhattan project and building the first bomb.

Limitations of past technologies and increased research into the structure of the atom resulted in the invention of transistors

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

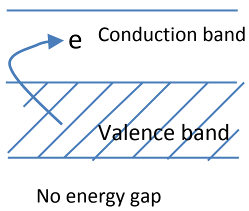
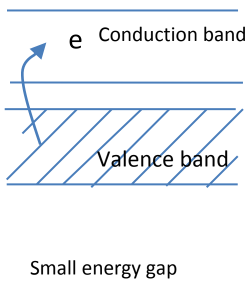
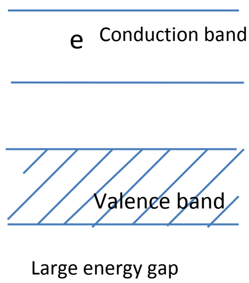
A good conductor is metal because a metal can be thought of as a big positive lattice in a sea of electrons. The electrons move freely and easily between atoms to conduct electricity.





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

In an isolated atom, electrons occupy a series of energy states around the nucleus. An isolated atom has a certain amount of energy to distribute to its elements. We represent this distribution in bands

	Conductor	Semiconductor	Insulator
			
Resistance	Low	Variable	High

Valence Band: contains valence electrons and is partly or completely filled. The highest level of an electron when the atom is "ground"

Conduction band: upper energy band and corresponds to the higher energy levels in an isolated atom – it is empty ☺

Forbidden zone: the gap between energy levels

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

Semiconductors don't conduct without help. They have four valence electrons. Silicon and germanium are the two common examples. They are both photoconductors meaning they are stimulated by the right frequency (energy) of into conducting electricity.

So light ejects a valence electron which produces a free electron. This leaves a positive "hole" in the valence shell which effectively acts as a positive charge.

Semiconductors have much less conductivity than conductors. A conductor's valence electrons are all free to move. This means that in semiconductors, currents can be carried by the movement of electrons or the formation of holes.

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

	Conductor	Semiconductor	Insulator
Free electrons	1 per atom	1 per million atoms	None

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

Early transistors were made from Germanium (Ge) because the technology at the time was not sufficiently developed to produce other materials of sufficient purity. Today, we use Silicon (Si) because it is far more abundant in the Earth's crust whereas Germanium is quite rare

Describe how 'doping' a semiconductor can change its electrical properties

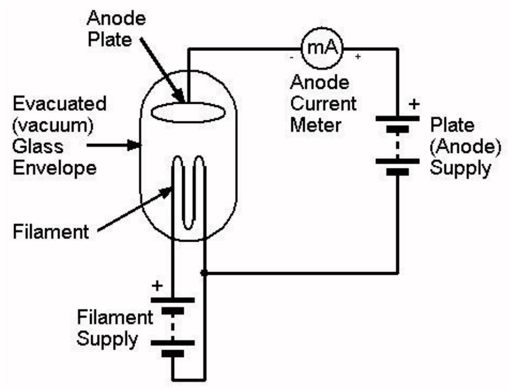
We can further reduce the energy gap between valence and conduction bands by pre-introducing a hole or free electron. This is done by placing an atom with three or five valence electrons in the centre of the lattice.

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

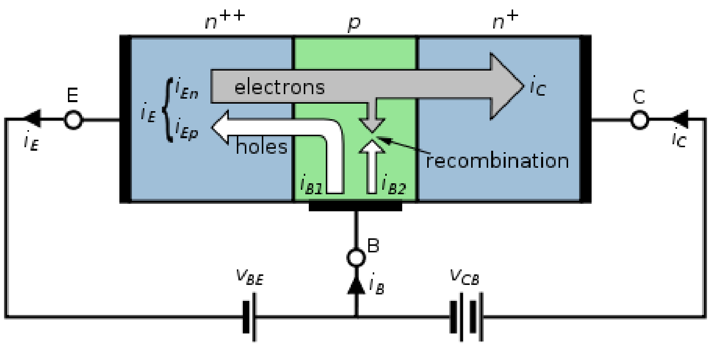
P-type	N-type
Doping with an atom with three valence electrons	Doping with an atom with five valence electrons
Eg: doped with Gallium	Eg: doped with Arsenic
Adds a (positive) hole	Adds a (negative) free electron

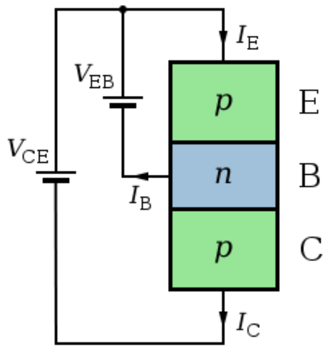
Describe differences between solid state and thermionic devices and discuss why solid state devices replaced thermionic devices

We make transistors out of semiconductors. Before transistors we had valves which are small thermionic devices in an evacuated tube which allows or disallows current flow.



Both circuits need to be on for the current to flow. Filament needs considerable energy to gain enough heat to eject electrons





	Thermionic Device (Valve)	Solid State Device (Transistor)
Function	Can switch on/off and amplify	Can switch on/off and amplify
Structure	Evacuated tube with filament and another at either end	Three layers of semiconductors joined together
Energy	Filament is heated until electrons are ejected	Base or bridge is switched on to give electrons enough energy to allow current to flow
Ad/Dis	Really big Lots of Energy Unreliable Energy inefficient	Really small Not much energy needed Very reliable Energy efficient

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

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

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

Good	Bad
• Miniaturised communications devices	• More disposable communication devices (e-waste)
• Greater reliability	• Mobile communication (always at work)
• Multifunction devices	
• Remote communication	
• Mobile communication (safety)	
• Faster access to large amounts of info	
• Storage of information	

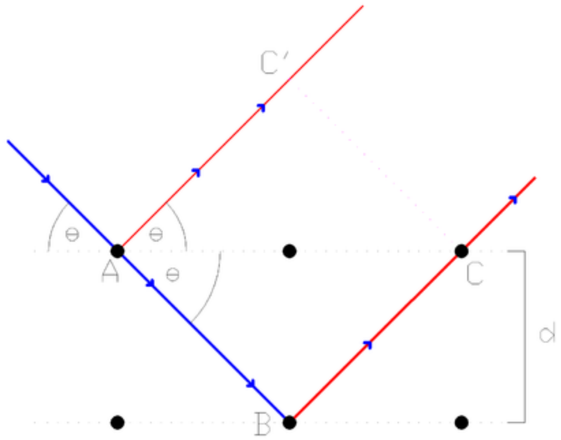
Greater computing power has led to:

- Advances in biotechnology (human genome project)
- Globalisation in the economy
- Internet and availability of information
- Improvements in transport (eg: GPS)

Identify data sources, gather, process and present information to summarise the effect of light on semiconductors in solar cells

Investigations into the electrical properties of particular metals at different temperatures led to the identification of superconductivity and the exploration of possible applications

Outline the methods used by the Braggs to determine crystal structure



In 1915, the Bragg's used the principle of x-ray diffraction to investigate crystal structure and measure the distance between atoms. This is useful for crystals because they are so ordered.

Identify that metals possess a crystal lattice structure

Bragg's established that metals possess a crystal lattice structure.

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

Conduction in metals occurs as single valence electrons drift between atoms in the lattice. We know that metals, in general, have only one, two or three electrons in their outer energy shells. These electrons are only loosely bound to the positive ions, causing a lattice of positive ions to be surrounded by a 'sea' of electrons.

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

Resistance in metals increases with:

- Impurities in the lattice. Electrons are less able to drift between atoms and may be captured by a different atom
- Temperature increases. This Is because the lattice vibrates more and electrons are more easily deviated from their A to B path

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

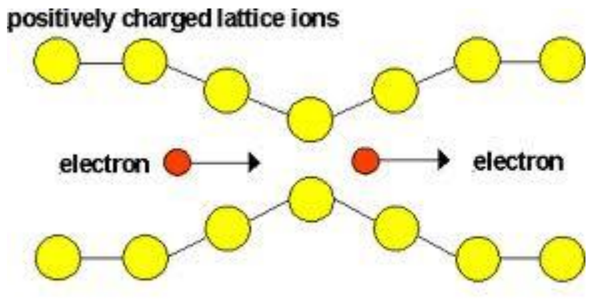
Superconductors have zero resistance!

In 1911, Dutch physicist Kammerlingh Onnes made liquid helium. He used it to conduct experiments at super low temperatures . He discovered that the resistance of mercury disappeared below 4K. This means that a superconductor can carry a current with no thermal loss. This is very cool…

Discuss the BCS theory

Superconductors have no resistance. A current can flow with not thermal loss. In a normal conductor a current is passed by the flow of single electrons being "passed" from atom to atom within the lattice.

The prevailing theory of superconductivity is called "BCS theory". It describes the current in a conductor as being passed by pairs of electrons (cooper pairs) moving between layers of lattice.



Cooper pair moving through lattice

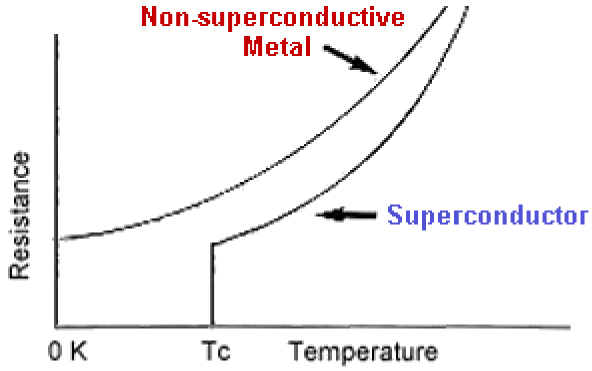
BCS theory is names after Barden, Cooper and Schrieffer who were jointly awards the 1972 Nobel Prize. There are no agreements on how the pairs are formed.

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

Advantages	Limitations
Can carry large currents for long periods with little or no loss of energy	Become active at extremely low temperatures – everyday use limited
Can be used to generate large magnetic field	Ceramics are unstable and brittle and they cannot be drawn into a wire

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

Kammerlingh Onnes discovered the superconducting properties of Hg in 1911 after cooling it to below 4K. This is the "critical temperature" of mercury. When any superconducting material reaches it's critical temperature, its resistance suddenly falls to zero.



Material	Type	Tc(K)
Zinc	metal	0.88
Aluminium	metal	1.19
Tin	metal	3.72
Mercury	metal	4.15
$YBa_2Cu_3O_7$	ceramic	90
TiBaCaCuO	ceramic	125

Perform an investigation to demonstrate magnetic levitation

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

Meissener effect?

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

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

One future application for super conductors would be the creation of motors and generators. Because of the zero resistance in a super conductor, motors can be created that have greater energy efficiency and torque than conventional motors. As well, super conductor generators have as little has half the electrical losses of a conventional machine at full power. Due to the high density and efficiency of both motors and generators, the size and weight can be reduced.

With research into high temperature superconductors, it may be possible to transmit electricity and develop a power grid which contains next to zero resistance minimising energy waste and removing the need to transmit electricity at high voltages. However, currently high temperature superconductors are made of brittle ceramics which means they are very difficult to turn into wire or other useful shapes.

As well, due to the fact that there is not resistance in a superconductor, it is possible to store energy within a superconducting coil. Energy can be stored in a superconducting “battery” and retrieved instantaneously when there is a need to stabilise the power grid.

Superconductors also have computing applications, the Josephson junctions associated with super conductors allow for significant speed developments such as the development of quantum computers which would reach speeds far greater than those of today’s computers.

Superconductor’s greatest limitation at the moment is the need for cryogenic cooling of materials to enter a superconductive state. Even high temperature superconductors need to be cooling to 70K. If room temperature superconductors (such as 0C) could be found, superconductors would become more accessible and practical.

QUANTA TO QUARKS

Problems with the Rutherford model of the atom led to the search for a model that would better explain the observed phenomena

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

Rutherford discovered the nucleus using his "gold foil" experiment.

Rutherford found:

- Nearly 100% of particles detected had passed straight through or deviated slightly
- A very small amount were reflected straight back

He knew that:

- Alpha particles had low penetration
- Alpha particles were positively charged

So he thought:

- There must be a lot of space in an atom for an alpha particle to pass through
- There must be a very small concentration of positive charge in the atom to reflect alpha-particles
- Electrons must orbit the nucleus with their motion caused by the electrostatic attraction

Rutherford's model had a positive nucleus with electrons in separate orbitals. In 1920, Rutherford proposed the existence of a neutrally charged counterpart to the proton within the nucleus. Chadwick discovered the neutron in 1932.

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

Any sort of range can be considered a spectrum. There are three main types:

- Continuous: black body or incandescent such as the sun
- Emission: An excited atom returning to ground state emits energy of characteristic frequencies
- Absorption: EMR passing through a gas absorbs a particular frequencies (used in astronomy)

All evidence at this stage regarding the hydrogen spectra and other elements was experimental (empirical knowledge).

Absorption and emission go hand in hand. For electrons to move from their ground state to an excited state, they must absorb the corresponding energy so we have to put energy in. The electrons very quickly return to their ground state and emit the corresponding energy.

As the hydrogen emission spectra showed only that energy was emitted in characteristic amounts and never in between, Bohr reasoned that there must be discrete levels of energy. That is, electron shells were at a specific distance from the nucleus. His model showed quantised energy levels and allowed electrons to move between these discreet levels by absorbing or emitting energy.

Define Bohr's postulates

1. Electrons exists in stable (or stationary), circular orbits
2. Electrons in stable orbits do not emit radiation
3. Electrons absorb or emit specific quanta or energy when they move from one orbit to another

Discuss Planck's contribution to the concept of quantised energy

Planck said that energy was quantised in discrete packets given by the formula $E = hf$ (h being Planck's constant). This differs from the classical interpretation that energy was a continuous wave. This theory was derived from Planck's work on black body radiation.

Describe how Bohr's postulates led to the development of a mathematical model to account for the existence of the hydrogen spectrum [Solve problems and analyse information using]:

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

A success of Bohr's model was that an equation for predicting the wavelengths of hydrogen spectrum lines could be derived, confirming Balmer's trial and error and Rydberg's general equation. It also correctly predicted the ionisation energy for hydrogen as well as other series in the hydrogen spectrum.

Discuss the limitations of the Bohr model of the hydrogen atom

The Bohr model of the hydrogen atom predicts well the distribution of spectral lines in hydrogen and is described by the Rydberg equation. However it does not predict the following well:

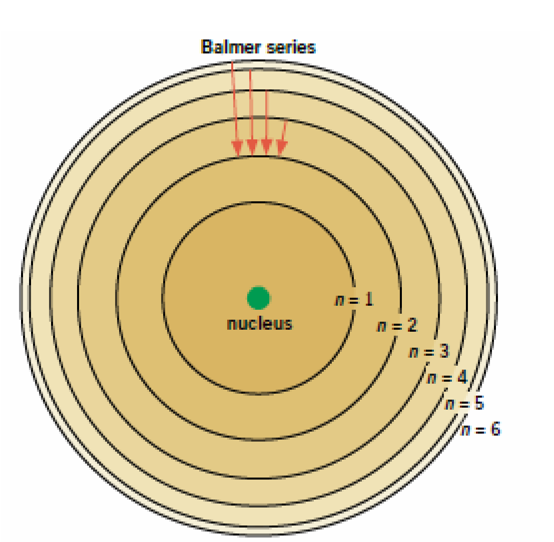
- Distribution of spectral lines in other elements aside from hydrogen
- Varying intensity and thickness of spectral lines
- "Splitting" of spectral lines (Zeeman effect) – when a B field is applied
- Hyperfine lines
- The model is an "untidy" mix of classical and quantum physics

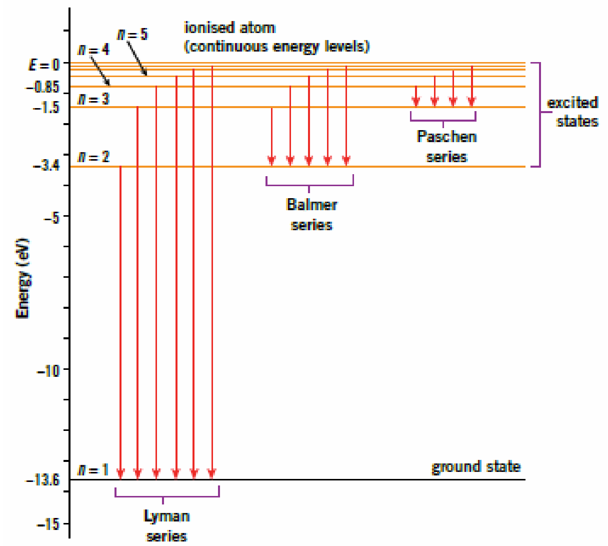
Perform a first-hand investigation to observe the visible components of the hydrogen spectrum

Use of a rotating spectroscope…

- Apply a large potential difference across the discharge tube. This will excite the electrons in the gas!
- As the excited atoms ground themselves, they emit characteristic bands of light.
- The diffraction grating splits these bands
- Rotate the eyepiece of the spectroscope and note the angle of diffraction for each band. This can be used to calculate the wavelength
- Note qualitatively the thickness and intensity for each spectral line

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





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, the Zeeman Effect

See above – Limitations of the Bohr model

The limitations of classical physics gave birth to quantum physics

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

De Broglie stated that any kind of particle can have both wave and particle properties! He wanted to try and explain orbital stability and discrete energy levels in a new way. He compared stable energy levels to standing waves (eg: resonance). There is not "half resonance" state just as there are forbidden energy levels for particular atoms. He extended this analogy to say that electrons are waves – indeed, that all particles are waves! OMG!

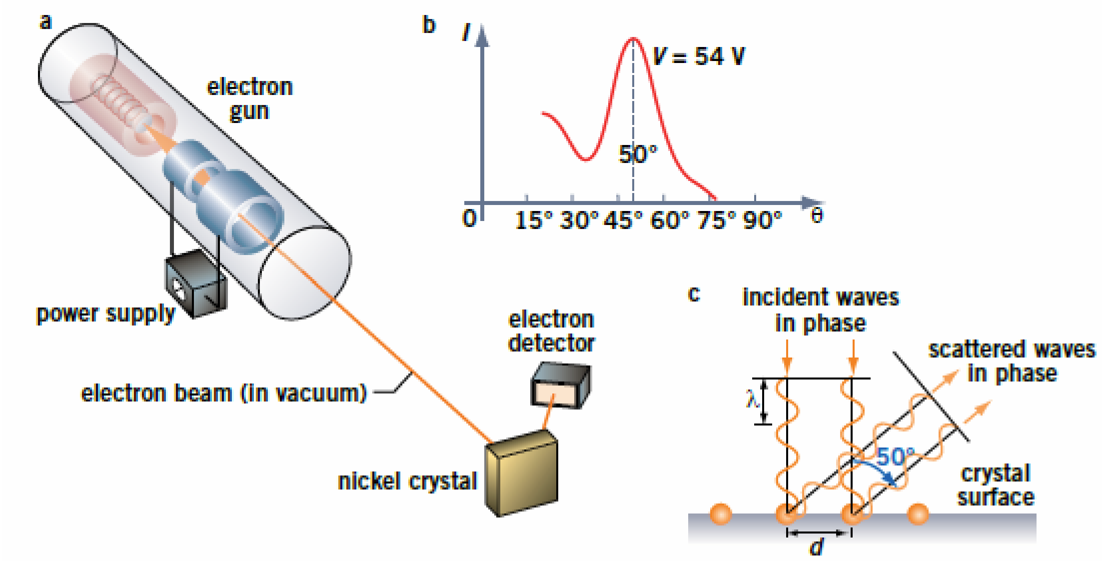
The equivalence of energy and mass had already been identified by Einstein (E=mc^2) so it was a small leap to say that as particles carry energy and waves carry energy, particles are waves.

De Broglie developed a formula to calculate the wavelength of a particle.

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

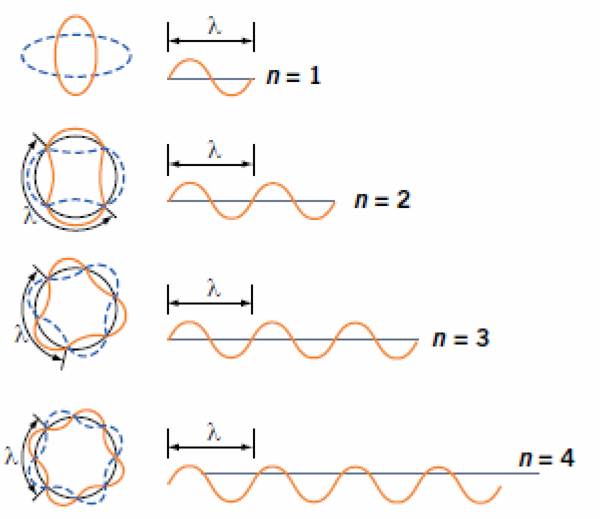
Describe the confirmation of de Broglie's proposal by Davisson and Germer

Davisson and Germer were studying "reflection" of electrons off a nickel surface. They noticed that the surface had oxidised. To remove this, they heated up the nickel and annealed the surface coating it with large crystals. They continued to notice anomalies in the reflection pattern and chose a large crystal and fired electrons at it. They noticed that maxima and minima indicated different diffractions of electrons and that the patterns were similar to x-rays which definitely are waves.



Significance: first experimental evidence that a particle could be a wave.

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



We can imagine the standing wave as being a rope which obeys $n\lambda$ with n being 1, 2, 3 etc. If we shake the rope we can produce standing wave patterns that contain whole wavelengths. We then take these standing waves and wrap them end-to-end to form a standing wave that corresponds to Bohr's orbit. The values of n are called the principal quantum numbers and they tell the number of wavelengths that fit into the Bohr orbit.

Solve problems and analyse information using:

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

- $h = Planck's\ Constant$
- $m = mass$
- $v = velocity\ (ms^{-1})$

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

Pauli developed quite separate principles, each having an impact on the way we understand the distribution of energy of electrons in atoms. Pauli's exclusion principle says that no two electrons can occupy the same quantum state.

The quantum state includes:

- Energy level
- Orbital shape
- Magnetic quantum number
- Spin

Electrons "pair up" with electrons of opposite spin. This adds stability as the spin's balance. Exclusion helps explain emission spectra, intensity of lines and thickness of lines.

Heisenberg said that: “we cannot know the position and momentum of a particle without some degree of uncertainty”.

This is only relevant at the quantum level because the uncertainty is of a similar order to the size of small particles. Our measurements of large particles are not done with devices of similar momentum. Eg: we don’t measure the speed of a car by bouncing another car off it.

Our best tools for measuring small particles still have a significant impact on either momentum or position, so in measuring one we impact heavily on the physical state of the particle.

This acceptance of uncertainty supports the idea of electron “clouds” instead of orbits. The question of “what is the quantum state of the electron” becomes “What is the state of the electron most likely to be”. Probability underpins many items in Quantum physics contrary to Einstein’s dissenting comment “I cannot believe that God plays dice”

The work of Chadwick and Fermi in producing artificial transmutations led to practical applications of nuclear physics

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

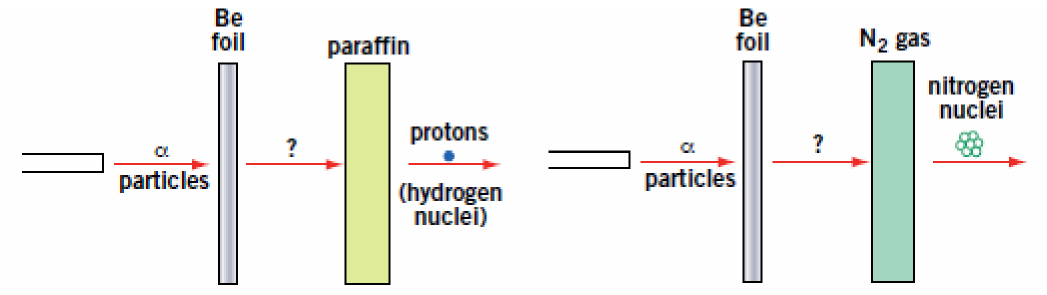
Nucleons:

Protons	Neutrons
$m_p = 1.675 \times 10^{-22}$	$m_n = 1.675 \times 10^{-22}$
$q_p = +1.602 \times 10^{19}$	$q_n = 0$

Lack of charge makes neutrons harder to observe. It wasn't long before scientists figured out there was a big difference between the expected mass of a neutron and its measured mass. Rutherford predicted the existence of another particle but it was Chadwick who isolated it.

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

Chadwick used conservation of momentum laws to calculate properties of the neutron. He set up two experiments and used simultaneous equations and data gathered from each experiment to determine the likely mass of the neutron.



Define the term 'transmutation'

Transmutation: the conversion of one element into another.

There are two types:

- Natural Transmutations:
  - Fusion: occurs in stars (proton-proton chain, H->He)
  - Fission: radioactive decay
- Artificial Transmutations:
  - Fusion: cold fusion does not happen yet with our current technology
  - Fission: used in nuclear reactors
  - Nuclear Bombardment: Bombarding a nucleus to stimulate decay

Describe nuclear transmutations due to natural radioactivity

In certain unstable atoms, the repulsive electrical forces overcome the strong nuclear forces. The two most common decay processes are the emission of alpha and beta particles.

Alpha-decay:

- Usually happens in large unstable nuclei
- Alpha particle is identical to ${}^{4}_{2}He$
- General equation:
  - ${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$
  - ${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$

Describe Fermi's initial experimental observation of nuclear fission

Between 1934 and 1938, Fermi:

- Bombarded a variety of targets with neutrons and created many "new" unstable isotopes
- He noticed many targets absorbed a neutron then emitted a beta particle. This increased the atomic number by one.
- He predicted that he could create transuranic elements by the process.

Then he did it! He created ${}^{A}_{Z}Np$ $(z = 93)$. Further investigation shows the subsequent decay products to be rather unstable isotopes like Barium $(z = 56)$, Radium $(z = 88)$ and Lanthium $(z = 57)$. This indicated a significant splitting of the nucleus – FISSION!!

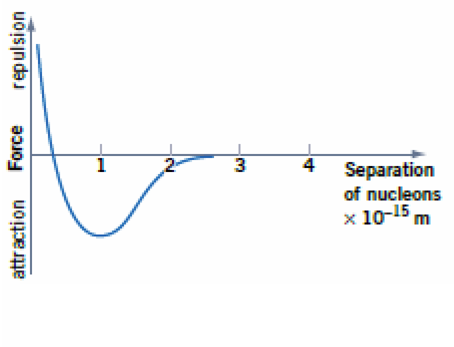
Discuss Pauli's suggestion of the existence of neutrino and relate it to the need to account for the energy distribution of electrons emitted in β-decay

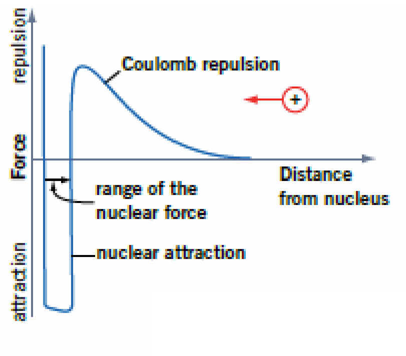
In beta decay, the particles have a broad spectrum of kinetic energies unlike alpha decay. Pauli proposed that a new particle was emitted during the beta-decay process and that this particle had no charge and could only weakly interact with matter. This explained the distribution of energy as the energy released during the decay could be shared between the beta particle and neutrino in any ratio. Thus, the spectrum of energies was explained.

Evaluate the relative contributions of electrostatic and gravitational forces between nucleons

$$F_{elec}\ between\ two\ protons\ in\ the\ nucleus\ \approx\ 230N$$

$$F_{grav}\ between\ two\ protons\ in\ the\ nucleus \approx\ 5.6 \times 10^{-34}N$$





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

If we ask the question, "what prevents transmutation" we enter the domain of the nuclear force. There are two: weak and strong. It we left the atom to be held together by gravity and electrostatics, protons would shoot all over the place.

The nuclear force is:

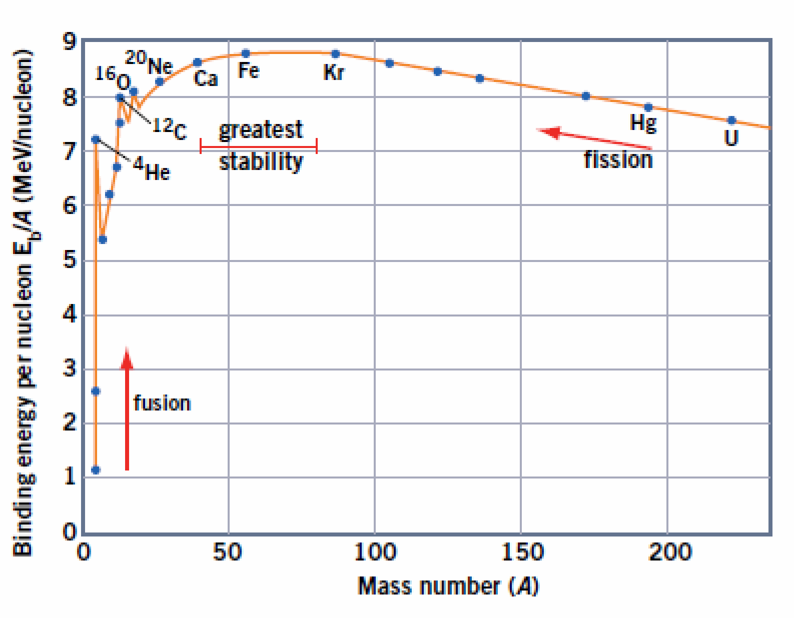
- Incredibly strong (to exceed electrostatic repulsion)
- Extremely short ranged ($\sim 10^{-15} m$)
- Independent of charge
- Independent of mass

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

The total mass of a stable nucleus is less than the total sum of the masses of the protons and neutrons that it contains. But conservation of mass must hold. This mass is converted into energy (the binding energy which holds the atom together given by E=mc^2) and this loss of energy reduces the mass of the nucleus.

The difference in the total original mass and the total final mass is called the mass defect.

Another way to look at the mass defect is through binding energy. The binding energy tells us how much energy you would need to separate the nucleus of the atom back into separate protons and neutrons.



ΔE_b gives energy released ($E = mc^2$)

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

- Fermi determined that a fission chain reaction could be achieved using naturally occurring uranium.
- Fermi designed his reactor so that the uranium fuel blocks were spread evenly through a pile of very high purity carbon blocks which would slow (moderate) the speed of the neutrons ejected from the uranium nuclei
- Cadmium rods were inserted throughout the pile to capture neutrons and control the reaction.
- On December 2nd 1942, the cadmium rods were partially withdrawn from the pile with the amount of radiation produced in agreement with Fermi's calculations.
- The control rods were removed to a certain point and by Fermi's calculations, the reactor reached criticality – sustaining a chian fission reaction that could be controlled.

Compare requirements for controlled and uncontrolled nuclear chain reactions

Leo Szilard realised that if a neutron caused one nuclear event and in that event, more than one neutron is realised then those neutrons in turn will cause more fission events.

A chain reaction, therefore, requires:

- Fuel that is capable of fission (fissile material)
- An amount of fuel to produce enough neutrons to cause new fission (critical mass)
- Neutrons with the right energy to be absorbed by fuel nuclei

Uncontrolled reactions:

- Production of neutrons is unregulated

- Fission reactions increase at an accelerating rate (exponential)
- Energy increases exponentially
- Eg: reactor meltdown, atomic bomb

Controlled reactions:

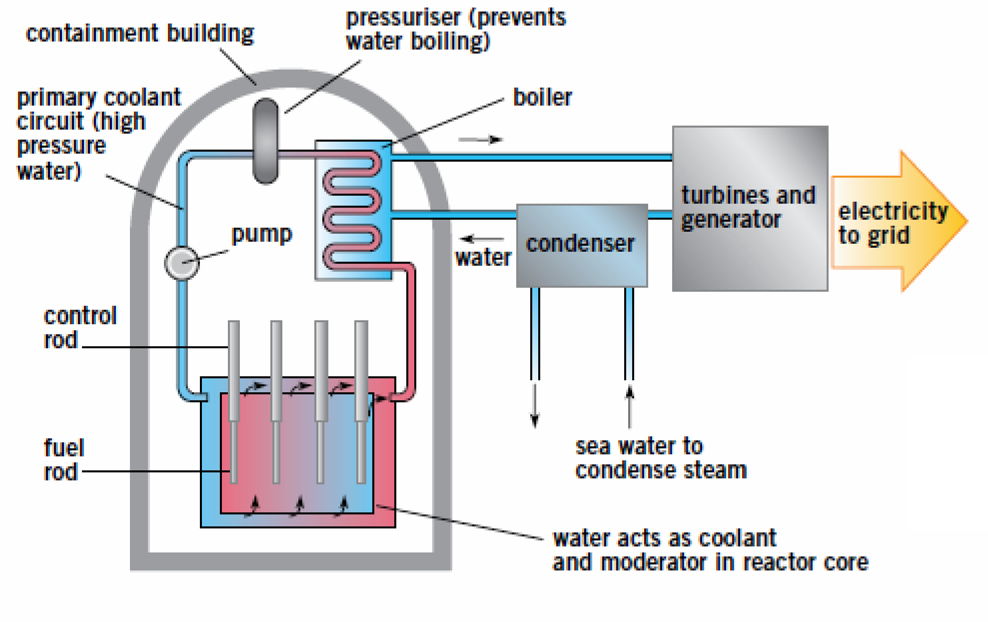
- Available neutrons are regulated
- Fission reactors use absorption materials (cadmium) and manipulate control rods (graphite) to control the production of neutrons
- Energy increases exponentially until it is capped by the effects of the moderator
- Eg: nuclear reactor

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

Solve problems and analyse information to calculate the mass defect and energy released in natural transmutation and fission reactions

An understanding of the nucleus has led to large science projects and many applications

Explain the basic principles of a fission reactor



In a basic Pressurised Water Reactor

Components:

- Fuel Rods:
  - Filled with uranium Oxide Pellets
  - Required for "controlled chain reactions"
  - Located in the "core" of the reactor
- Core:
  - House fuel rods, control rods, coolant system and a moderator (which can also act as a coolant)
  - Moderator:
  - These act to slow neutrons, which improves the chances of neutron capture.
  - Eg: Heavy water (Deuterium $D_2O \rightarrow H_2O + {}_1^2H$)
  - Graphite (regularity of cross-sectional area helps control neutrons speed and path)
- Control Rods:
  - Usually boron or cadmium
  - Located between fuel rods
  - Absorb neutrons ("excess" neutrons) to control chain reaction
  - Can be adjusted to absorb more or less
  - A constant rate is achieved when, for each fission, one ejected neutrons is allowed to initiate another fission (all others are captured by control rods)
  - For shutdown, control rods need to be "fully inserted"

- Coolant:
  - Usually water or heavy water
  - In electrical power stations, the coolant drives the turbine
  - Takes heat from the core
- Radiation Shielding:
  - Cores emit large quantities of gamma-particles and neutrons
  - Lead and graphite are used
  - The containment building is high density concrete

Describe some medical and industrial applications of radio-isotopes

Medicine:

- Technetium-99
- A product of Molybdenum decay
- Delivered in meta-stable form. One triggered, ${}^{99m}Tc$ has a half-life of 67 hours
- ${}^{99}Tc$ has a half-life of a few hours so it doesn't stay in your body too long
- Gamma-source
- Used in imaging (diagnostic)
- Detected by a gamma camera and used with SECT (Single Emission Computer Topography)
- Medical Radioisotopes (Therapeutic) target diseased organ and tumours

Industrial:

- ${}^{241}Am$ (Americium-241)
- Alpha source
- Used in smoke detectors. Smoke is attracted to the ionised trails (like the Wilson Cloud Chamber)

Agricultural:

- ${}^{32}P$ (Phosphorus-32)
- Beta source
- Used for tagging and tracing fertilizer to monitor
- Added to soil water. Half-life of 14 days
- Detected by Geiger-Muller tubes

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

- $q_n = 0$
- $m_n \approx m_p$ (a significant mass)
- de Broglie says it acts like a wave (It was a wavelength)
- has a "spin"

- has magnetic properties due to its spin

This makes neutrons excellent for probing nuclei.

There are four main applications:

1. Spacing: The de Broglie wavelength of slow (thermal) neutrons is in the same order as the structure/spacing of solids/liquids
2. Motion: E_k of slow neutrons is similar to atomic vibrations in solids/liquids allowing the investigation of forces between atoms
3. Magnetic structure: The neutrons acts like a "subatomic" magnet and is used to investigate the magnetic structure of semiconductors and magnetic materials
4. Inner Structure (nuclear structure): x-rays and electrons are scattered by atomic electrons. Neutrons are scattered by nuclei and are not affected by electrostatic forces. This means they can penetrate to depths of several centimetres and study large equipment (like aircraft engines) and vessels of varying conditions of pressure, temperature and environment.

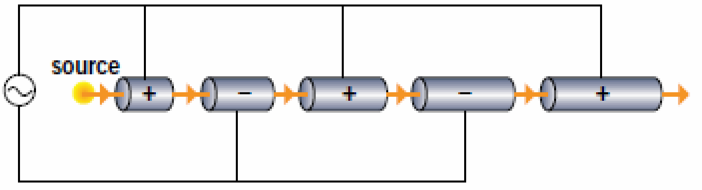
The first neutron diffraction experiment was conducted in 1945 using a graphite pile reactor. Today, neutron diffraction is combined with x-ray diffraction a la Braggs Institute at ANSTO. It is useful in engineering, pharmaceutical, mining, plastics, biology etc.

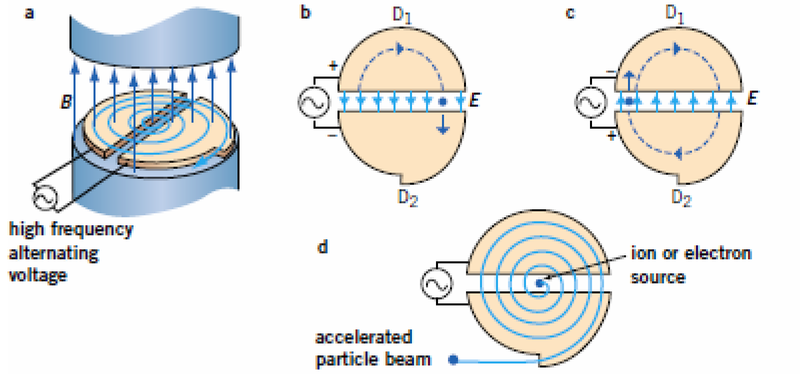
Identify ways by which physicists continue to develop their understanding of matter, using accelerators as a probe to investigate the structure of matter

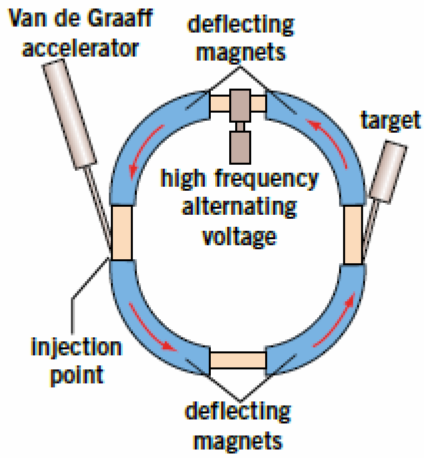
Particle accelerators accelerate charged particles to high speeds to generate high energy collisions.

Before accelerators:

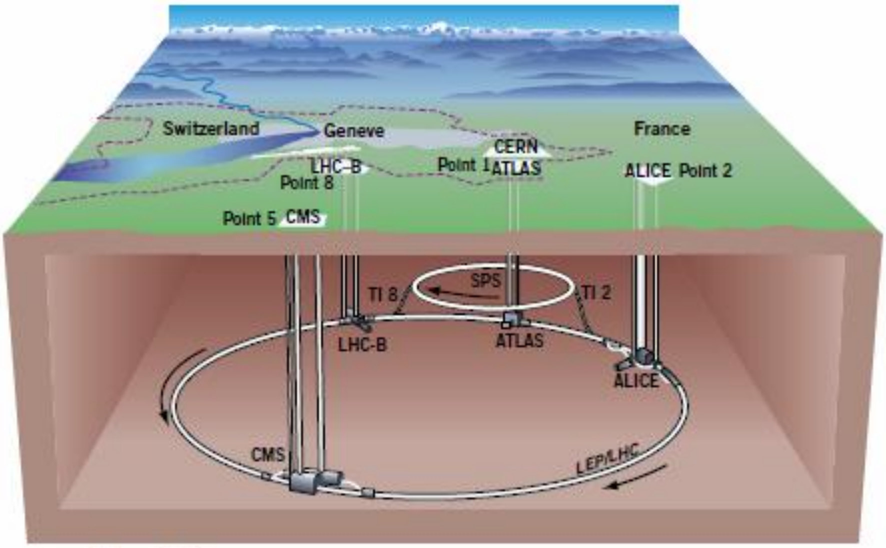
- Physicists observed collisions caused by cosmic rays in the atmosphere. This was not very convenient, not very controlled and required high energies.
- Basic accelerators have: a source of charge particles, accelerating mechanism and an evacuated tube to travel through.
- Common Types:
  - Electrostatic accelerators (eg: Van de Graaff)
    - School = 200kV
    - Early = 1.5MV
    - Now = 20MW
  - Linear Accelerator (eg: Stanford Linear Accelerator Collider, 3.2km)
    - Tubes of alternating polarity accelerate electrons to 50GeV



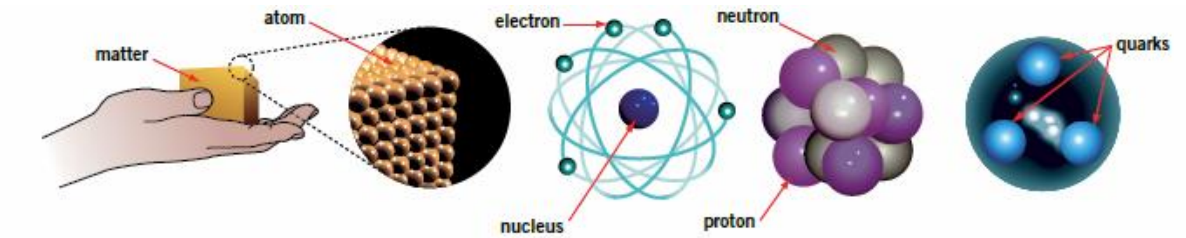
-
    - Cyclotron (RPA Hospital)
        - Accelerates ions in a spiral path
        - 

        - More compact to build but limited to 20 MeV by realistic effects
    - Synchrotron (Large Hadron Collider – 27km circumference)
        - Produce highest energy collision
        - Use superconducting magnets to accelerate ions along a circular path
        - 

        - Can reach 10TeV



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



Physicists in the 20th century made incredible advances in our knowledge of sub-atomic particles. It is often referred to as the "golden age" of physics.

The standard model aims to list fundamental particles and explain the fundamental forces of nature.

	Leptons		Quarks	
1st family	Electron [light, $q = -1$]	Electron Neutrino	UP [$q = +\frac{2}{3}$]	DOWN [$q = -\frac{1}{3}$]
2nd family	Muon [heavy, $q = -1$]	Muon Neutrino	CHARM	STRANGE
3rd family	Tau [heavier, $q = -1$]	Tau Neutrino	TOP	BOTTOM

Force Carriers (Gauge Bosons)

- Gluons: carry strong force (felt by quarks)
- Photons: carry electromagnetic force (felt by quarks and leptons)
- Intermediate Vector Bosons: weak force (quarks and leptons)
- Gravitons: gravity (all particles with mass)

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

"The Manhattan Project left a legacy that shaped the 20th century in ways that few could have imagined. The project led to the post-World War II nuclear arms race between the Soviet Union and the West. After the test detonation of the Soviet Union's first bomb in 1949, relations between the Soviet Union and the West deteriorated. This tension became known as the Cold War and continued until the early 1990s; it ended with the dissolution of the Soviet Union. The United States of America, Britain and the Soviet Union developed fusion bomb technology, known as the thermonuclear bomb, the H-bomb or the hydrogen bomb. By the mid-1960s France and China had tested atomic weapons, and today Israel, India, Pakistan and North Korea also possess atomic weapons. Despite the Nuclear Non-proliferation Treaty, which pursued a reduction in weapon stockpiles, today there is a worldwide arsenal of approximately 20 000 nuclear weapons.

In tandem with the military developments, civil projects using nuclear energy have also proliferated. Today there are 440 nuclear power plants worldwide, which supply 15% of the world's electricity demand, and there are more than 200 research reactors. The use of reactors for nuclear medicine, neutron scattering and other industry-based applications highlights the peaceful endeavours pursued by scientists and engineers today."

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