Physics HSC Revision Notes

Topic 1: Space

	Students learn to/Students:
1. 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 is the force on an object due to a gravitational field. Mathematically, $W = mg$. This is measured in Newtons, and varies with the distance in the field from the point source of gravity.
▪ explain that a change in gravitational potential energy is related to work done	When a force is applied to an object, so that it moves, work has been done to the object. Thus work done to move an object on the ground to a height changes kinetic energy into potential via the <u>Law of Conservation of Energy</u>. This work is stored as Gravitational Potential Energy where: $E_p = mgh$ (Joules)
▪ 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 $E_p = -G\frac{m_1 m_2}{r}$	Gravitational potential energy is defined as the work done for an object to move from a point in infinity (or some point very far away) to a point in a gravitational field. To change the GPE, work must be done to move the object. **<u>NB</u>:** A point (x) has a negative value. The Ep is zero at infinity (from Earth). $E_p = -G\frac{m_1 m_2}{r}$ (Joules) Where: • m_1 = object 1 • m_2 = object 2 • r = (radius + altitude) • G = gravitational constant (6.67×10^{-11}) • E_P = gravitational potential energy (negative)
▪ *perform an investigation and gather information to determine a value for acceleration due to gravity using pendulum motion or computer-assisted technology and identify reason for possible variations from the value 9.8 ms^{-2}*	<u>Aim:</u> To determine the rate of acceleration due to gravity using the motion of the pendulum <u>Hypothesis:</u> The acceleration of pendulum will be calculated within 10% of 9.8ms^{-2} <u>Apparatus:</u> Retort stand, boss-head and clamp, 120cm of string, 100g mass, stopwatch, 1m ruler, protractor <u>Method:</u> The pendulum was set up with the string 20cm and mass at 30° degrees. A stopwatch timed 10 complete oscillations that were recorded and the period calculated using: $T = 2\pi\sqrt{\frac{L}{G}}$. This was repeated 3 times. Then lengths 0.4m, 0.6m, 0.8m and 1m were tested in a similar way. <u>Result:</u> Gravity was 9.87 ms^{-2} <u>Conclusion:</u> Aim & Hypothesis proved. (<u>NB</u>: Variation/Trial/Accuracy?)
▪ *gather secondary information to predict the value of acceleration due to gravity on other planets*	Using tables (with altitude, gravity, radius, mass of planet), and the formula: $g = G\frac{m_{planet}}{r^2}$ (ms^{-2}) [Predict the value of acceleration due to gravity on other planets]

▪ *analyse information using the expression: $F = mg$ to determine the weight force for a body on Earth and for the same body on other planets*	The mass of a person stays constant. Expression is derived from (F=ma) where "a" is the gravitational acceleration of a planet. Therefore, a change in gravity (per planet) will result in varying forces, creating a direct proportionality "F ∝ g".
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	When a ball is thrown the observations are: • The only force acting is gravity, creating a projectile • Parabolic path, where the trajectory makes up a whole curve or a part of the curve • No parabolic path when thrown perpendicular to ground • Horizontal and vertical components are independent of each other • The horizontal component is constant velocity (ie. No acceleration) • The vertical component is constant acceleration
▪ describe Galileo's analysis of projectile motion	Galileo postulated that a projectile would travel in projectile motion. It was made up of 2 components: a constant horizontal velocity and a constant vertical acceleration. Also, all masses fall towards the centre of the earth at the same rate.
▪ explain the concept of escape velocity in terms of the: – gravitational constant – mass and radius of the planet	Isaac Newton theorised that it is possible to launch a <u>projectile</u> fast enough so that it achieves an orbit around the Earth. He used the idea that if a stone is thrown fast enough, at a certain velocity, it will fall, but with the curve of the Earth's surface, thus never reaching the ground. When a stone is thrown directly above, the faster it is thrown, the further it will travel before falling back to Earth. However at a certain velocity, the stone will only come to a rest when it has completely escaped the Earth's gravitational field. This initial velocity is known as <u>escape velocity</u>. This can be shown mathematically below: $Escape\ Velocity = \sqrt{\frac{2Gm_{earth}}{r_{earth}}}$ Thus the escape velocity is a relationship between the gravitational constant (G), the Earth's mass (m) and the radius of the planet (r). Note that the <u>mass of the object</u> does not affect the Escape Velocity.
▪ outline Newton's concept of escape velocity	Newton was the first to propose that an artificial satellite may be launched to orbit the Earth. An object launched off a hypothetical mountain with enough velocity may fall with the Earth's curvature, leading to orbit. A velocity higher than this will result in the object escaping the Earth's gravitational field.
▪ identify why the term 'g forces' is used to explain the forces acting on an astronaut during launch	G-forces is a term which measures multiples of gravitational acceleration. ie. 1g is when a person stands on the ground (they exert a force downwards, and the ground exerts and equal and opposite force up) Therefore, during a launch, the rocket accelerates upwards. This force (F=ma) can

be measured in g-forces, because an astronaut would experience acceleration upwards. This can be identified in the formula:

$$g = \frac{Apparent\ Weight}{Real\ Weight}$$

NB: Vertical G-forces are calculated by adding the coefficient of gravity and the thrust force.

$$g - forces = \frac{a+g}{g}$$

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

Eg. When a bowler runs up to bowl, the ball receives a boost, since:
Ball Velocity = Ball $V_{\text{to bowler}}$ + Bowler $V_{\text{to ground}}$ (these are relative velocities)

This also applies to rockets launched from the Earth. The Earth is a moving platform with 2 moving motions (rotational velocity around sun and axis rotational velocity). Engineers take advantage of this in a rocket launch by using favourable periods known as "launch windows" at specific times of the year. When a rocket is launched into orbit, it is launched to the East (as close as possible to the equator where orbital motion is at maximum) and is then pushed into orbit when orbital velocity corresponds to desired heading. Using this conserves fuel and minimises energy needed to achieve a successful launch.

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

The total change in momentum = 0 (momentum before burn is 0. Therefore, momentum after is 0)
ie. The change in momentum of the gases being expelled through the back of the rocket is equal and opposite to the forward change in momentum of the rocket. This relationship is maintained because the gases have a much smaller total mass, but a much large velocity than the rocket. However since the mass of the rocket is decreasing, acceleration occurs.

Prior to lift-off, a rocket experiences no acceleration due to a balance between weight, and reaction force + thrust. This translates to 1g for the astronaut.

The rocket will only achieve lift off, if there is a net force upwards. (Building thrust > weight force). The g-force is slightly greater than 1, and as the mass of the rocket decreases, g-force increases until the maximum value just before all the fuel has been used (usually peaks at 4g).

At this point, the rocket becomes a projectile. However, a multi-stage rocket drops the spent stage, leaving 0g momentarily as there is no thrust. When the second rocket fires, thrust quickly begins to develop and when it overtakes the net force in space, acceleration occurs again. This g-force gradually builds until the second stage fuel supply is exhausted. (and for every stage after) (peaks around 2g).

The engine is sometimes throttled to reduce excess g-force loads on the astronauts. This leads to jagged peaks of g-forces on a graph.

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

Circular motion is a 2 dimensional velocity. Uniform circular motion is the motion of an object with a constant speed.

However, for an object to travel in a circular path, its velocity must be constantly changing in magnitude and direction. This means that the object's velocity is changing over time, and is accelerating. This is known as centripetal acceleration.
[**NB:** Circular motion is only possible if a centripetal force is present]

$$F_c = \frac{mv^2}{r} \quad \& \quad a_c = \frac{v^2}{r}$$

If there is (centripetal) acceleration, there must be a (centripetal) force ie.$f_{g}=ma$

But since Fc=Fg, equating the formulae gives:

$$V = \sqrt{\frac{Gm_{earth}}{r}}$$

*Not in syllabus, but relates V, R and M

- compare qualitatively low Earth and geo-stationary orbits

	Low Earth Orbit	Geo-stationary orbit
Similarities	• Both under the influence of 1 force: gravity	
	• Both satellites, moving and orbiting the Earth	
Differences	• Closer to the Earth, – Allows for cleaner, clearer targets	• Further from Earth - its period is exactly the period of the Earth's rotation (fixed position)
	• Useful for detailed coverage, but has small span of coverage	• Fewer needed for total global coverage
	• 90 minute orbital period	• 23hr 56min 4sec orbital period
	• Experiences orbital decay	• No negligible friction
	• Under Van Allen's belt	• Over Van Allen's belt

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

Kepler was able to relate the Period (T) <u>the time taken to complete one revolution</u> in orbit and the radius of different satellites/moons that orbited a mass/planet/sun.

{He realised that these ratios were a constant for a central body.

ie. $\left(\frac{r^3}{t^2}\right) = k$ *k = constant for all orbits around a common central mass}*

[**<u>NB</u>:** The constant can be changed, by changing the mass of the central body]
When this is related to Newton's Law of Universal Gravitation,
A relationship between Velocity, Mass of central body, Radius and Period can be related.

ie. $\left(\frac{r^3}{t^2}\right) = \frac{GM}{4\pi^2}$ (**<u>NB</u>:** Can also be used to derive orbital velocity equation)

This is known as <u>Kepler's Law of Periods</u>.

- account for the orbital decay of satellites in low Earth orbit

If a low-orbital satellite loses altitude, it drops mechanical energy.

Friction due to the atmosphere causes this – but the satellite speeds up as it is in lower orbit, through a gain in kinetic energy and a loss in GPE.

ie. $V_{orbital} = \sqrt{\frac{GM_{earth}}{r}}$ *Not in syllabus

Thus, faster and lower orbit (more air) means more friction. The process repeats and accelerates, leading to a spiral of orbital decay.

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

Re-entry or de-orbiting is a deliberate orbital manoeuvre resulting in an elliptical path down to the Earth. Issues associated with re-entry include:

1) <u>Angle of re-entry</u> – To prevent "burning up" or "bouncing off", optimum re-entry is 5.2 ~ 7.2 degrees
2) <u>Extreme heating</u> – The friction with the atmosphere creates extreme and dangerous heating. A blunt nose produces a shockwave of compressed air that absorbs most of the heat

3) High G-forces – The steeper the angle of descent, the greater the G-forces.
    - Astronauts lying down at re-entry and take off with an "eyeballs in" application
    - Supporting the by using specially moulded seats
4) Ionisation blackout – On re-entry, atoms in the air around the spacecraft become ionised, preventing outside communication for a few minutes.
5) Landing – Space capsules have ejection seats or splash into the ocean. Space shuttles use their wings to control descent and apply speed braking, to reduce the G-forces on the astronauts.

- 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

For manned spacecraft attempting re-entry, there is an optimal angle for safe re-entry. This is usually between 5.2 ~ 7.2 degrees.

If this angle is too shallow, the spacecraft may skip off the atmosphere and not penetrate it. If the angle is too steep, re-entry will be too dangerous with extreme heating and g-forces, putting astronauts' lives at risk.

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

$$v_x^2 = u_x^2$$
$$v = u + at$$
$$v_y^2 = u_y^2 + 2a_y\Delta y$$
$$\Delta x = u_x t$$
$$\Delta y = u_y t + \frac{1}{2}a_y t^2$$

Horizontal (X Component)		(Vertical – Y Component)	
1)	$u_x = u\cos\theta$	5)	$u_y = u\sin\theta$
2)	$v_x = u_x$	6)	$v_y = u_y + at$
3)	$v_x{}^2 = u_x{}^2$	7)	$v_y{}^2 = u_y{}^2 + 2ar$
4)	$r = v_x t$	8)	$r = u_y t + \frac{1}{2}at^2$

However, the only equations necessary are:
X = Horizontal (1, 2)
Y = Vertical (5, 6, 7)

NB:
- To solve problems:
    - Write down what is known
    - Make the initial direction positive
    - Opposite direction is always negative (eg. Gravity)
    - Substitute data into equation and then solve.
- To calculate half trajectories, use the last formula to work out *t*. Then solve.
- To calculate projectiles that are elevated off the ground, find the maximum of the parabola, then find the maximum displacement *r*. Since $V_y = 0$ at the maximum, the last formula can be used to work out *t*. Then solve.

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

Aim: To analyse the motion of a projectile by using video capture and computer analysis
Hypothesis: The horizontal initial velocity should be constant while the vertical velocity is changing. The error should be less than 20%.
Apparatus: Camera, ball, ruler, white screen
Method:
i. Capture a video of a ball being thrown
ii. By using Multilab, track the ball's path and then analyse by using excel
iii. Calculate the initial velocity (by Pythagoras of horizontal and vertical components), the range and time of flight.

Results: All of the calculations were within the 20% error limit. When the velocity is broken down, the horizontal component is constant (or no acceleration) while the vertical component is constant acceleration.

▪ *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*	1) Robert Goddard is known as the father of modern rocketry. 2) He created 214 patents, and of these are two important patents: a. The liquid-fuel rocket design (1915) – By using liquid oxygen and fuels. Unlike solid based fuels, liquid-fuel's rate of combustion could be controlled, and is still used today. b. Multi-staged rockets (1915) – Thus, he theorised space flight is possible, by combining these 2 patents together. 3) He also proved that rockets work in vacuums due to the Law of Conservation of Momentum 4) Lastly, he suggested that man could reach the moon. Goddard's inventions are considered revolutionary for modern space flight.

▪ *solve problems and analyse information to calculate the centripetal force acting on a satellite undergoing uniform circular motion about the Earth using:* $F = \frac{mv^2}{r}$	Skill.

▪ *solve problems and analyse information using:* $\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$	Skill. Remember <u>**units**</u>.

3. 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 vector is used to describe the magnitude and direction of a gravitational field. A large mass exerts a gravitational field that is strong enough to affect other masses. When two objects are near, their gravitational fields combine and interact like an electric field. The result is that each mass exerts a force on the other. There is a point between the two where the force is exactly equal and opposite in direction, where the field strength is 0.

▪ define Newton's Law of Universal Gravitation: $F = G\frac{m_1 m_2}{d^2}$	Newton proposed that <u>every point mass attracts every other point mass</u>. The force of attraction is determined by: $F \propto m_1 m_2$ and $F \propto \frac{1}{d^2}$ m_1 = Larger mass m_2 = Smaller mass d = Distance between G = Gravitational constant

▪ discuss the importance of Newton's Law of Universal Gravitation in understanding and calculating the motion of satellites	The force of gravity serves as a centripetal force that keeps a smaller mass (eg satellite) in the orbit of a larger mass. However, on a planetary scale, centripetal force = gravitational force, allowing for smaller masses to orbit the Earth. Therefore when these expressions are equated, the motion of satellites can be calculated:

	ie. $V_{orbital} = \sqrt{\frac{GM_{earth}}{r}}$ Newton's law of universal gravitation is vital for calculating satellite motion.
▪ identify that a slingshot effect can be provided by planets for space probes	The slingshot effect is a deliberate manoeuvre to pass close to a large mass so that its gravity pulls the spacecraft towards it. By Newton's Third Law (and the Law of Conservation of Energy), as the probe's speed relative to the planet increases, the planet's speed decreases (slightly). This causes the spacecraft to accelerate and depart in a different direction. The <u>non-contact elastic collision</u> uses very little expenditure of fuel to increase final velocity and change direction.
▪ *present information and use available evidence to discuss the factors affecting the strength of the gravitational force*	The strength of a gravitational field is shown graphically by the number of vectors or field lines from a mass. From Newton's Law of Universal Gravitation: $F = G\frac{m_1 m_2}{d^2} \rightarrow g(field) \propto m_1 m_2$ and $g(field) \propto \frac{1}{d^2}$ Variations in mass distribution affects gravity distribution. Eg. metal and ore distribution, gas and natural resources, affect the strength of the field.
▪ *solve problems and analyse information using:* $F = G\frac{m_1 m_2}{d^2}$	Skill.
4. 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	The Aether Model supported the wave theory through the following properties: • Filling all space and be stationary in space • Permeating all matter – while all objects are permeable to it • Elastic yet still • Be transparent • Low in density • Be an absolute frame of reference (in terms of light transmission) [**<u>NB</u>:** Many of these characteristics were conflicting]
▪ describe and evaluate the Michelson-Morley attempt to measure the relative velocity of the Earth through the aether	During the 18th century, physicists believed in wave theory, and that light (like other physical waves) must have a medium to propagate within. The "Luminiferous Aether" model was developed. In 1887, Albert Michelson and Edward Morley devised an experiment to test the aether, as the Earth's motion relative to the aether would cause interference patterns, due to the different speeds of light. However, it was unsuccessful. A marble surface floating in mercury was used. Light was sent from a source and split into two perpendicular beams by a half-silvered mirror. These two beams reflected back from two equidistant mirrors towards an observer's eye. The experiment results in interference patterns as the beams return at different times. One beam travelled across and the other against the aether, with a reversed effect when the block was turned 90°. The Michelson-Morley experiment produced negligible results even after further

	tweaking and testing at different times of the year and altitudes. They concluded that no movement of Earth relative to the aether was detectable. Therefore, the experiment's attempt failed to prove the hypothesis of the aether.
▪ discuss the role of the Michelson-Morley experiments in making determinations about competing theories	The Michelson-Morley produced a null result which showed that the "Aether Hypothesis" was invalid. Each new modification resulted in new predictions and further null results. This lead to the introduction of competing theories. ie. In 1905, Einstein postulated "Special Relativity Theory", oblivious to the Aether failure. Even though the experiment did not refer to Einstein's theory, it supported it, by enhancing it as a better means of justifying the qualities of light.
▪ outline the nature of inertial frames of reference	<u>Any inertial frame of reference holds true for Newton's Law of Motion</u>. This is the <u>Principle of Relativity</u>. An inertial frame of reference is one that is either stationary or moving at a constant velocity (and not accelerating). It is therefore impossible to tell within this frame whether in fact you are moving or stationary without looking at some point outside the system. A frame is a non-inertial frame of reference if the system is accelerating.
▪ discuss the principle of relativity	Galileo developed this, known as the "Principle of Relativity", which states that the laws of mechanics are the same for a body at rest and a body moving with constant velocity. This principle also incorporates Newton's First Law of Motion. There are 2 important factors to consider: 1) The Principle of Relativity only applies to non-accelerated motion, known as an inertial frame of reference 2) No mechanical experiment can ever detect if you are either moving at a steady velocity or stationary (Newton's idea). Thus, the only way motion can be detected, is by referring to another inertial frame of reference. Einstein extends the idea of relativity to the "Principle of the Constancy of the Speed of Light", where light is the only absolute reference point.
▪ describe the significance of Einstein's assumption of the constancy of the speed of light	Einstein's second postulate *"light travels through empty space with a definite speed c independent of the speed of the source or observer"*. This assumption has many consequences: ➢ Relativity became an internally consistent model that holds the two ideas of light and Newtonian Physics. ➢ It explained the null result in the "Michelson-Morley experiment" ➢ It contrasted Newtonian Physics, by theorising that time, length and mass are relative. ➢ It suggested that the speed of light is the only absolute value.
▪ identify that if c is constant then space and time become relative	Using the formula: $v = r/t$, if the velocity is constant, then r and t need to be relative to satisfy Newtonian physics. Therefore, with an absolute (c), space and time become relative, depending on the inertial frame of the observer.

▪ discuss the concept that length standards are defined in terms of time in contrast to the original metre standard	The metre was first defined as $1x10^{-8}$ times the meridian distance from the equation to Paris to the North-Pole. The metre was based on length intervals. Since the speed of light in a vacuum is constant, the metre can be defined as the length travelled by light in 1/(distance in a second) ie. 1 wavelength. The metre is now based on time intervals.
▪ 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	Special Relativity has a consequence on: A) The relativity of simultaneity – Special Relativity suggests that 2 events can occur simultaneously. Einstein discussed this in his thought experiments with moving trains and an observer on a platform. Ie. Two observers in different inertial frames will experience different events. B) Mass and energy – Einstein's theory is that when there is work done to an object, its speed increases. However as this approaches "c", work is no longer converted into speed, but into mass. Thus, mass is a form of energy. This is known as the Law of Conservation of Mass-Energy. The relationship between this is: $$KE = \Delta MC^2$$ C) Length contraction – As an object's speed approaches "c", the distance travelled becomes relative. That is, the length of space contracts in size as viewed by an observer. At "c", there is no space. The relationship is: $$l_v = l_0\sqrt{1-\frac{v^2}{c^2}}$$ D) Time dilation – As an object's speed approaches "c", the time of travel dilates as viewed by an observer. This is shown by moving clocks running slower than stationary clocks. The relationship is: $$t_v = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$$ E) Mass dilation – As an object's speed approaches "c", the mass of the object dilates as inertia and resistance must increase. But inertia is a measure of mass, so mass increases. The relationship is: $$m_v = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$$
▪ discuss the implications of mass increase, time dilation and length contraction for space travel	Relative mass, time and length affect space travel inevitably. Increasing the velocity of space travel to approach "c" would require considerable energy costs, due to the inevitable conversion of some energy into mass. Other implications: i. Twin Paradox – The twin travelling at relativistic speeds has experienced acceleration, and so the rules don't apply to him. The twin on Earth however ages considerably, relative to the other twin. ii. Relativistic speeds for extended periods can reduce your rate of ageing compared to those on Earth, as time moves slower relative to Earth iii. Time travel to distant stars is possible in one lifetime due to the properties of length contraction and time dilation (but not into the past), however generations would have passed by the time you returned.
▪ *gather and process information to interpret the results of the Michelson-Morley experiment*	The essence of the experiment can be compared to two swimmers in a lake's current. In this analogy, a square is drawn with two swimmers start at one corner. One swims up the leading edge and the other across the side, both returning to the start. By calculating the lap times (the lap of the swimmer parallel to the current is simple, but the other swimmer needs Pythagoras), it is clear they arrive back at

	different times. This analogy is used in the experiment to test the "aether".

▪ *perform an investigation to help distinguish between non-inertial and inertial frames of reference*	A string attached to the ceiling of a moving object, with a pendulum hanging down acts as a simple accelerometer. This experiment can be used to test for a net force. If the frame of reference is inertial, the pendulum will not move and be at normal to the ground. If the frame of reference is non-inertial, the pendulum will experience a force and move.

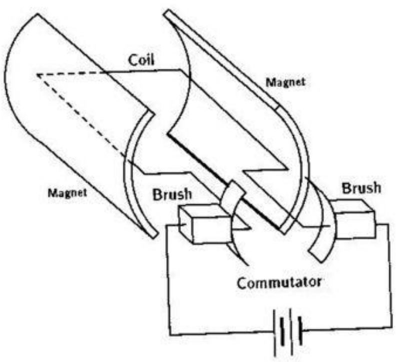
▪ *analyse and interpret some of Einstein's thought experiments involving mirrors and trains and discuss the relationship between thought and reality*	A. A train is moving at a constant velocity past an embankment, and a passenger shines a torch in the direction of travel – In this thought experiment, because of the constancy of the speed of light, both see the speed of light move from the flashlight at the same speed. Thus, the speed of light is independent of the frame of reference. Even at relativistic speeds, the speed of light remains constant. B. A train is moving at a constant velocity past an embankment when an observer sees two simultaneous flashes of lightning at both ends of the train – Since the train is moving away from the rear flash, the passenger would see the lightning strikes occur at different times. He can justify this by saying the observer is moving away from the train with a constant velocity (different frame of reference). This paradox relates to the concept of <u>simultaneity</u>. C. A light clock is used on a train travelling at a constant velocity past an embankment, where a beam is projected perpendicular to the direction of travel, reflects off the mirror on the ceiling and back down, measuring one unit of time – Since the train is moving when the beam is projected, the light has to travel a longer distance to cover the trains velocity, and takes a diagonal path. This longer distance translates to a slower time relative to an observer on the embankment. Thus, at relativistic speeds, moving clocks travel slower and time appears to dilate. D. A passenger sits on a train travelling at "c" and holds in front of him a mirror. The problems lies with – If he can see his reflection, light is travelling faster than its constancy speed. If he can't, this can be used as a measure for an inertial frame. In reality, different frames of references yield different observations depending on the relative motion compared to the other inertial frame of reference. However, no frame is more correct than another.

▪ *analyse information to discuss the relationship between theory and the evidence supporting it, using Einstein's predictions based on relativity that were made many years before evidence was available to support it*	Every theory in science will undergo the scientific method before becoming commonly accepted. The steps in relation to Einstein are: 1) <u>An observation is made</u> – The mysterious properties of light were observed with no current explanation. The attempts of the aether were inconclusive, and invalid. Thus, the theory of General Relativity did not be applied to light. 2) <u>Developing ideas</u> – Einstein postulated "Special Relativity Theory" and the constancy of the velocity of light. 3) <u>Experiments to test idea</u> – Einstein's Theory in 1905 was unsupportable with the current level of technology. However, he devised a series of thought experiments and to test his hypothesis. 4) <u>Prediction of experiments</u> – Einstein's thought experiments were predicted with mathematical formulas describing relative length, time and mass. 5) <u>Observe what actually happens</u> – Over the decades, physicists applied Einstein's theory to practical experiments, and supported his theory. They include: • Flying of atomic clocks to determine time dilation • Dilated lifetimes of mesons penetrating the Earth's atmosphere • The conversion of energy into mass at high speeds in nuclear reactions As a result of the continual success of the theory, and the failure of experiments to test the aether, Einstein's theory is commonly accepted today.

▪ *solve problems and analyse information using:* $E = mc^2$ $l_v = l_0\sqrt{1-\frac{v^2}{c^2}}$ $t_v = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$ $m_v = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$	Skill. Where: $L/T/M_o$ = Measurement inside the inertial frame of reference $L/T/M_v$ = Measurement in another inertial frame of reference ΔM = Final mass – Rest Mass (rarely used for calculations) C = Speed of light $(3 \times 10^8\ ms^{-1})$

Topic 2: Motors and Generators

	Students learn to/Students:
1. 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	The force acting on a current-carrying conductor depends upon: ○ The magnetic field – The force on a current carrying conductor (due to force on charged particles) is proportional to the strength of the magnetic field (B) ○ Current – Greater current means more electrons are moving, generating greater force on the conductor. ○ Length of conductor – The greater the length, the more electrons experience a force and so the greater the total force. ○ The angle – Charged particles experience a maximum force when they move at right angles to a field. Parallel movement = no force. Thus, the force on the conductor varies with the angle between the conductor and the field. Thus, the relationship describing the force on the wire is shown in the equation: $F = (n)BIl\sin\theta$
▪ describe qualitatively and quantitatively the force between long parallel current-carrying conductors: $\frac{F}{l} = k\frac{I_1 I_2}{d}$	When two long parallel wires are near each other, they experience a force on each other. When the current flow is in the same direction, there is an attraction and when the current flow is in the opposite direction, the force is repulsive. (ie. Like currents attract, unlike currents repel) The magnetic field generated by each coil can be found by using the right hand grip rule. The Force is proportional to the currents in each coil, and the length, while being inversely proportional the distance. Thus, the force on 2 wires in a vacuum is: $\frac{F}{l} = k\frac{I_1 I_2}{d}$ Where, $k = 2\times10^{-7}$ **<u>NB</u>:** "k" Represents the constant when one ampere flows in 2 indefinitely long

	wires separate by one metre, in a vacuum.
▪ define torque as the turning moment of a force using: $\tau = Fd$	Torque is the turning effect of a force. It is defined as the product of force and the perpendicular distance from the axis. It is measured in Nm. ie. $\tau = Fd$
▪ identify that the motor effect is due to the force acting on a current-carrying conductor in a magnetic field	The motor effect occurs when a current-carrying wire in a magnetic field experiences a force. The direction of the force is determined by using the right hand palm rule: All axis are perpendicular to each other, where the thumb points in the direction of current, fingers point in the direction of magnetic field lines and the palm points in the direction of force.
▪ describe the forces experienced by a current-carrying loop in a magnetic field and describe the net result of the forces	There are 2 forces experience by a current-carrying loop in a magnetic field. The two perpendicular sides to the field experience an equal but opposite force, producing torque. The parallel sides to the field experience no force. Depending on the direction of the current, there will be a net force either causing the coil to rotate clockwise or anticlockwise. A commutator ensures the motor is always rotating in the same direction. The torque produced is shown in the equation: $\tau = nBIA\cos\theta$
▪ describe the main features of a DC electric motor and the role of each feature	The main features of a DC motor are: ➢ Rotor – This consists of the armature (soft iron-core) and coils (where the coils are sometimes wrapped around the armature). It is the rotating part. ➢ Field structure – The stationary part, consisting of permanent magnets (field magnets) or electromagnets (field coils). ➢ Split-ring commutator – This consists of a copper cylinder divided into 2 halves. Each half is connected to one side of the armature and changes the direction of the current every half a turn. ➢ Brushes – Made of graphite, and contain springs to minimise sparking. This supplies current to the commutator. 
▪ identify that the required magnetic fields in DC motors can be produced either by current-carrying coils or permanent magnets	The field structure (stator) can be made up of electromagnets (field coils) where coils are wrapped around a motor's iron core casing to produce a north and south pole. It can also be made up of permanent magnets.
▪ *solve problems using:*	Skill. Where: • F = Force (N) • L = Length of shortest coil (m)

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

- I = Current in each wire (A)
- D = Distance between wires (m)
- K = Constant (2×10^{-7})

NB: When calculating force per metre, let L=1.

- *perform a first-hand investigation to demonstrate the motor effect*

Aim: To investigate the motor effect.
Apparatus: Variable power supply, connecting wires, 2 magnets, metal strip.
Method: Connect the power supply to metal strip using the connecting wires. Place the north side of one magnet on one side of the strip, and the south side of the other, on the other side, so that the strip's length is perpendicular to the magnetic field. Turn on the DC supply quickly, and then turn it off. Observe what happens to the strip.
Results: When no current flows, there is no movement. When the current flows, the strip is pushed out of the field, using the right-hand push rule.
Conclusion: A force acts on a current-carrying conductor, where the direction of the force depends on the direction of current. The force is perpendicular to both the magnetic field lines and the direction of current.

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

$$F = BIl\sin\theta$$

Skill. Where:
F = Force (N)
B = Magnetic field strength (T)
I = Current (A)
L = Length (m)
Sinθ = Angle measured from a field line

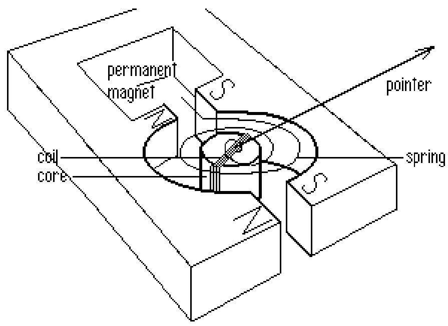
- *solve problems and analyse information about simple motors using:*

$$\tau = nBIA\cos\theta$$

Skill. Where:
τ = Torque (Nm)
n = Number of coils
B = Magnetic field strength (T)
I = Current (A)
A = Area of coil (m^2)
Cosθ = Angle measured from field line. A parallel coil has maximum torque.
NB: *Indicate direction of force by using the Right Hand Palm rule.*

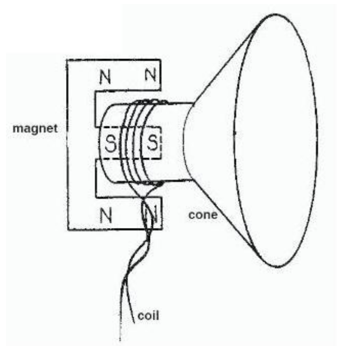
- *identify data sources, gather and process information to qualitatively describe the application of the motor effect in:*
  - *the galvanometer*
  - *the loudspeaker*

Galvanometer



Electric meters experience a force that is proportional to the size of the current in the conductor. A galvanometer consists of a fine wire wrapped around an iron core, attached to a spring. A split magnet surrounds the wire. As current flows, the coil experience torque and rotates the pointer. This is balanced by the restoring torque of the spring, which is proportional to the angle of rotation and the current. Therefore, the amount of rotation indicates the amount of current flowing.

The Loudspeaker



In a loudspeaker, a coil is attached to a speaker cone and wrapped around a central pole piece, with a South polarity in the centre and a North polarity around the coil. As current flows, a changing magnetic flux induces an emf in the coil that opposes the change that caused it (Faraday's Law and Lenz's Law). So, the interaction between

	the field and the coil makes the cone vibrate. Alternate currents cause the coil to vibrate, where electric energy is converted into sound.

2. 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 <u>electromagnetic induction</u>, which involves converting mechanical energy into electrical energy. He noticed that a <u>changing</u> magnetic field was needed to produce electricity. His initial experiment involved the induction ring, where 2 separate coils were wrapped on either side of an iron ring. The 1^{st} coil was connected to a battery, and he observed that a current was induced in the 2^{nd}. He then verified this induced current by experimenting with moving a magnet in and out of a coil of wire.

▪ define magnetic field strength B as magnetic flux density	Magnetic flux (φ) refers to the number of lines emerging through an imagery area in a magnetic field. <u>Magnetic flux density is a measure of magnetic field intensity</u> (ie. Larger flux = more intensity). Measured: $B = \varphi/A$

▪ describe the concept of magnetic flux in terms of magnetic flux density and surface area	Magnetic flux is given by: $\varphi = BA$, where A is a perpendicular area to the magnetic field.

▪ describe generated potential difference as the rate of change of magnetic flux through a circuit	The relationship between these variables is stated in <u>Faraday's Law</u>: The induced emf is proportional to the rate of change of magnetic flux through the circuit. $$\varepsilon mf = -\frac{\Delta\Phi}{\Delta t}$$ The potential difference generated depends on: value of B, speed the conductor cuts flux lines and the number of conductors.

▪ account for Lenz's Law in terms of conservation of energy and relate it to the production of back emf in motors	<u>Lenz's Law</u> states that the direction of the induced emf is such that the current it produces creates a magnetic field opposing the change that produced the emf. The direction of induced current can be found by using the right-hand palm rule. It is a consequence of the law of conservation of energy. If the current produced aided the motion, the conductor would accelerate, producing more current, creating greater acceleration, resulting in perpetual motion. This is impossible, thus the direction must be reversed, signalled by the negative sign in Faraday's Law. In a motor, emf is induced in the coil, the direction which is opposite the motion of the motor. This opposing emf is called <u>back emf</u>.

▪ explain that, in electric motors, back emf opposes the supply emf	Back emf is a consequence of Lenz's Law, and is produced in a motor when it is operating. This helps to limit current and hence speed. Electric motors use applied emf to produce a current to cause the rotor to move. As applied emf increases, current increases and the motor speeds up. However, an increasing speed increases the induced emf, opposing the applied voltage. Thus, ***net emf = supply emf – back emf***. At high speeds, the motor will reach a steady

speed when supply emf can just overcome back emf.

- explain the production of eddy currents in terms of Lenz's Law

Eddy currents are produced when a solid conductor is in the presence of changing magnetic flux (or a conductor is moving in a magnetic field). These circular currents induced oppose the change that caused them (Lenz's Law). To calculate the direction of an eddy current flow, use the rule:
More Crosses = Clockwise
More Dots = Anti-clockwise

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

Aim: To generate an electric current
Method: Connect an air-cored solenoid to a galvanometer. Observe what happens when a magnet is:

1) pushed into the solenoid
2) stationary
3) moved away from the solenoid
4) stationary while the solenoid moves

Results:

1) The needle deflects, indicating a current is produced
2) The galvanometer doesn't move
3) The needle deflects in the opposite direction to (1)
4) Current is also produced.

Conclusion: An electric current is produced when there is relative motion between a magnet and coil. [**NB:** Was there constant relative distance & speed?]

- *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*

Aim: To observe various factors affecting the size of the current generated between a magnet and a coil.
Method: Connect a solenoid to a galvanometer. Conduct various trials by changing one variable and moving the magnet. Observe what happens when only the distance between the magnet and the coil changes. Observe what happens when only the strength of the magnet changes (number of magnets held together). Observe what happens when only the speed of the magnet changes.
Results:

- The closer the coil and magnet, the larger the induced current
- The stronger the magnet, the larger the current
- The faster the relative motion the larger the induced current.

Conclusion: The size of the electric current produced through relative motion between a magnet and coil increases when: the distance between the 2 decreases, the strength of the magnet increases and the relative motion increases.
[**NB:** Was there constant distance & speed in the trials?]

- *gather, analyse and present information to explain how induction is used in cooktops in electric ranges*

Induction cookers use coil inductors beneath a glass cook top. Alternating current creates oscillating magnetic fields (Faraday's Law: $\varepsilon mf = -\frac{\Delta\Phi}{\Delta t}$) that produce eddy currents when a conductor (pot/pan) is present. This causes the metal above to resist the change that caused it (Lenz's Law), resulting in heat production, heating the pot.

Advantages of induction cook-tops include:

- Up to 80% efficiency, and almost all heat, heating the pan
- Cheaper to operate, easy to clean and very safe

Disadvantages include:

- Must use a metal pot
- Is more expensive than traditional cook-tops

- *gather secondary information to identify how eddy currents have been utilised in electromagnetic braking*

Eddy currents are used in electromagnetic braking as the direction of the induced current flow opposes change that caused them (Lenz's Law).

When the wheel spins on the axle and a magnetic field is placed so that it rotates in the field, there is relative motion, inducing circular eddy currents that oppose the motion of the disk. A dampening effect occurs, creating smooth braking.

3. Generators are used to provide large scale power production

- describe the main components of a generator

The main components of a generator are:

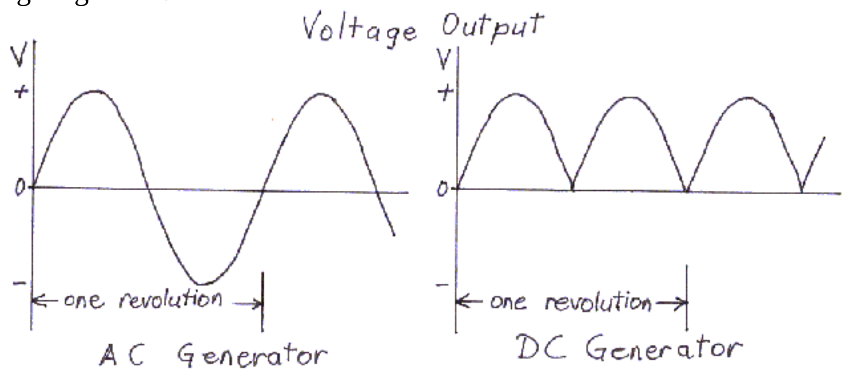
- Rotor – Consisting of an armature and coils
- Field structure (stator) – Can be an electromagnet or permanent magnet
- Brushes – Which allows current to flow out of generator
- Commutator for DC generators and slip rings for AC generators

- compare the structure and function of a generator to an electric motor

Generator	Electric Motor
▪ Both have the same rotor and stator	
▪ The field structures in both can be permanent magnets or electromagnets	
▪ DC Generators and Motors both have a commutator	
▪ Converts mechanical energy into electrical energy	▪ Converts electrical energy into mechanical energy

- describe the differences between AC and DC generators

The definitive difference lies in the connection to the brushes. <u>AC generators</u> use slip rings connected to brushes that produces a <u>sinusoidal</u> output. <u>DC Generators</u> however use a commutator, which reverses the direction of the induced current every half revolution. Thus, the current only flows in 1 direction, however with varying magnitude.



***<u>NB</u>:** When a generator is starts parallel to the magnetic field and is rotated, the magnetic flux produces a sine curve and the emf produces a cosine curve.*

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

Some mechanical energy used in a generator is converted into heat, and so energy is lost before transmission. Also, energy loss occurs in transmission due to:

- Resistive power lines – Even good conductors generate resistance over long distances (as resistance is proportional to the length of the conductor). This can be reduced, by decreasing current through transformers. Power loss is calculated by:

$$P_{loss} = I^2 R$$

- Inductive energy loss – Eddy currents are produced in the iron cores of transformers representing energy loss.

Nevertheless, generators have an efficiency of as high as 97%.

- assess the effects of the development of AC generators on society and the environment

AC generators have had a very significant impact being positive on society but negative on the environment. These impacts include:

- Efficient power – The use of coal is the most efficient energy source
- Domestic electricity – AC generators allow for the use of transformers, which allows electricity to be transmitted to remote and far areas
- Electrical appliances – Edison's incandescent light-bulb, and electrical appliances have improved our standard of living and increased efficiency.
- Environmental costs – Non-renewable resources produces environmental pollution that contributes to global warming and acid rain.
- The transmission lines that carry the generated AC current requires significant land clearing

Overall, they have had a positive impact on society but not the environment.

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

Aim: To demonstrate the production of an Alternating Current (AC).

Method:

a) Connect a solenoid to a galvanometer. Move a bar magnet in and out of the coil and observe.
b) OR, observe a demonstration of an AC generator with a rotating handle, and a galvanometer.

Results:

a) When the magnet is moved back and forth, the galvanometer's needle moves back and forth indicating an AC current.
b) The continuous rotation of a handle inside a pair of magnets moved the needle inside a galvanometer back and forth, producing an AC current. As the handle's rotation increased, the size of the AC current increased.

Conclusion: When there is continuous relative motion between a coil and magnet, AC current is generated.

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

	DC Generators	AC Generators
Advantages	• Output can be smoothed, useful for some appliances	• Requires less maintenance, and is more reliable than DC • Can produce 3 phase power
Disadv.	• There is added friction due to the leading edge • Commutator can wear out	• Transforming current loses energy • Slip rings can also wear out

- *analyse secondary information on the competition between Westinghouse and Edison to supply electricity to cities*

Thomas Edison used a direct current (DC) system to establish electricity supply in 1882. He used commutators, where power stations could only supply to areas a few kilometres away, due to power loss.

George Westinghouse obtained the patent rights to AC generations (From Tesla) as he saw the advantages of using AC for supplying cities. Edison saw this as a threat and tried to discredit it by publishing "A Warning" and holding public demonstrations to kill animals, through AC generators.

(Edison also developed the electric chair by acquiring a 1000-volt Westinghouse Generator. Death by electrocution was then enabled, but soon banned)

In 1887, Westinghouse won the contract for AC generation in Niagara Falls, after tests showed that only 23% of power was lost after transmitting 180km away.

- *gather and analyse information to identify how*

Transmission lines transmit high voltages that need to be insulated from the towers, as the high voltages can easily jump through air to the tower (path of least

<table>
<tr><td>transmission lines are:
– insulated from supporting structures
– protected from lightning strikes</td><td>resistance). Insulators prevent this path, achieved by stacking saucer-shaped insulators made from porcelain or glass. This shape prevents the build up of moisture and dust while increasing the surface area between the tower and line.

Transmission lines are protected from lightning strikes through an overhead earth wire that hangs next to the live wire. It is designed to intercept a lightning strike and divert it to the ground, preventing damage to the transmission lines.</td></tr>
</table>

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

<table>
<tr><td>▪ describe the purpose of transformers in electrical circuits</td><td>Household power points are 240V while Commercial supply is 415V. Many appliances require smaller voltages, and require a “step down” transformer to lower voltage. Older analogue TV’s require a “step up” transformer to increase the voltage to 1500V.

Transformers transfer electrical energy by changing the size of the alternating voltage (<u>NB</u>: They cannot operate on DC). They consist of primary and secondary coils of wire, wrapped around a soft-iron core. A change in magnetic field induces a voltage in the secondary wire. Thus transformers enable voltages to be altered to be used in electrical circuits.</td></tr>
<tr><td>▪ compare step-up and step-down transformers</td><td><table>
<tr><th>Step-up Transformer</th><th>Step-down Transformer</th></tr>
<tr><td colspan="2">▪ Two coils wrapped around a laminated soft iron core</td></tr>
<tr><td colspan="2">▪ Both transfer current from one circuit to another</td></tr>
<tr><td>▪ More turns in secondary coil</td><td>▪ Less turns in secondary coil</td></tr>
<tr><td>▪ Higher voltage in secondary</td><td>▪ Lower voltage in secondary</td></tr>
<tr><td>▪ Less current in secondary</td><td>▪ Higher current in secondary</td></tr>
<tr><td>▪ Used for more efficient transmission/ Analogue TVs</td><td>▪ Used for smaller appliances</td></tr>
</table></td></tr>
<tr><td>▪ 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</td><td>The ratios are identified in the formula below:
$$\frac{V_p}{V_s} = \frac{n_p}{n_s} = \frac{I_s}{I_p}$$
Thus, the number of coils and voltage is directly proportional, while current is inversely proportional.</td></tr>
<tr><td>▪ explain why voltage transformations are related to conservation of energy</td><td>The law of conservation of energy states that energy cannot be created or destroyed. It can only be transformed.

In an ideal transformer, Power In must equal Power Out, as energy is conserved.
$P_{in} = P_{out} \quad \therefore V_p I_p = V_s I_s$
Therefore, if the number of coils increases, voltage increases and current must decrease to conserve the energy. The vice versa is also true.</td></tr>
<tr><td>▪ explain the role of transformers in electricity sub-stations</td><td>Transformers are used in substations, to “step-down” the voltage. This is sensible, as it lowers the voltage to safer and more practical levels, while also increasing the current for household and commercial use.</td></tr>
</table>

▪ discuss why some electrical appliances in the home that are connected to the mains domestic power supply use a transformer	Some home electrical appliances require a transformer to: a) "Step-Up" the voltage – This is use in analogue TVs to power the cathode ray tubes (240V to 1500V) b) "Step-Down" the voltage – Smaller electrical appliances need lower voltages, and use a transformer-cube. Eg. laptops, phone chargers, printers. c) Change the current – Rectifiers are used to supply DC to the appliance.
▪ discuss the impact of the development of transformers on society	Impacts of transformers on society include: • Reduction in energy losses during transmission – By stepping up the voltage, electricity can be carried over longer distances to a greater area, and with lower power loss. • Power stations and generators can be built away from towns and cities and closer to natural resources. • Less pollution entering cities from generators • Land clearing for cabling networks which disturbs ecosystems and aesthetics
▪ *perform an investigation to model the structure of a transformer to demonstrate how secondary voltage is produced*	<u>Aim:</u> To model the structure of a transformer <u>Method:</u> Connect a 300 coil wire (primary) to a soft-iron core, and a smaller (secondary) coil wire to the other side. Connect the ends of the secondary coil to a galvanometer, and a DC battery to the primary. Observe what happens when the battery is connected. <u>Results:</u> When the battery is connected, the needle moves for an instant before returning back to 0. When it's disconnected, the needle flicks in the opposite direction before returning to 0. <u>Conclusion:</u> A changing current in a primary coil will induce a changing current in a secondary adjacent coil.
▪ *solve problems and analyse information about transformers using:* $\frac{V_p}{V_s}=\frac{n_p}{n_s}$	V = Voltage (V) n = Number of coils I = Current (A) $\frac{V_p}{V_s}=\frac{n_p}{n_s}=\frac{I_s}{I_p}$ ***<u>NB</u>**: Only a ratio is needed to calculate the other values.*

▪ *gather, analyse and use available evidence to discuss how difficulties of heating caused by eddy currents in transformers may be overcome*	Transformers are conductors that through a changing magnetic field *(Faraday's Law)* create eddy currents (Lenz's Law). These currents circulate in the conductor, perpendicular to the magnetic field, producing heat and causing energy loss.
	• To minimise losses, the soft-metal is divided into sheets, stacked perpendicular to the magnetic field and laminated on each side to prevent contact from other sheets. This reduces the size of the eddy currents, heat production, and energy loss.
	• Transformers still get quite hot, and are cooled by:
	  ○ Cooling fins
	  ○ Fans that circulate air
	  ○ Coolants
	  ○ Dark colours to quickly absorb heat
	  ○ Placing transformer in the open

▪ *gather and analyse secondary information to discuss the need for transformers in the transfer of electrical energy from a*	At a generator, mechanical energy is transformed into electrical, generating large amounts of current. A step-up transformer is needed to reduce this current for transmission over long distances. This enables electrical energy to be transmitted far away with minimal power loss. Closer to cities, "step-down" transformers are needed to decrease the voltage to make transmitting safer for households and

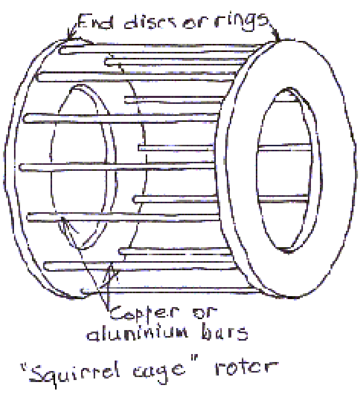
power station to its point of use	commercial use. Also, transformers can be used in electrical appliances to adjust the main's voltage to a more appropriate voltage.

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

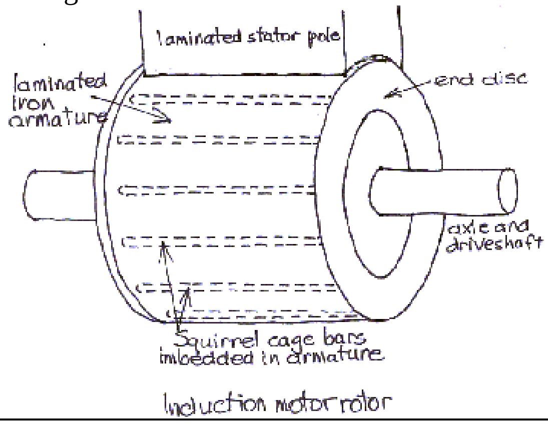
- describe the main features of an AC electric motor

AC Motors consist of:

- ➢ A field structure (stator) – Several iron cores wound with coils circulate the rotor. They are connected in such a way that the polarity of the magnetic field switches at a constant rate around that stator.
- ➢ An armature (rotor) – This looks like a squirrel-cage of iron cores, embedded in the armature, with both ends closed off by discs of copper. The armature "chases" the stator's changing magnetic field.
- ➢ No Slip Rings or Commutator – Current is fed directly to the Stator.
- ➢ A fixed maximum speed, but the speed reduces if a load is applied. Gears can also be used to create speed changes.



"Squirrel cage" rotor



Induction motor rotor

- *perform an investigation to demonstrate the principle of an AC induction motor*

In electromagnetic braking, two magnets set up a magnetic field, where eddy currents are produced in a spinning disc, causing the disc to smoothly brake. The converse of this technique can be used to mimic an AC motor. For a stationary disc, when two magnets are manually rotated above the centre, this motion causes the disc to follow, thus creating torque. The converse of electromagnetic braking demonstrates the principle of an AC induction motor.
[**NB:** Universal AC induction motors can operate on AC or DC (they are simple DC motors with electromagnets), as the electromagnets in the stator changes ensuring a constant torque direction]
An Induction motor has pairs of stator windings that rotate the polarities of the magnetic field around the rotor. This creates relative motion between the field and squirrel cage bars, inducing an emf in each end ring. This current flow experiences the motor effect, resulting in torque, and a "chasing effect".

- *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*

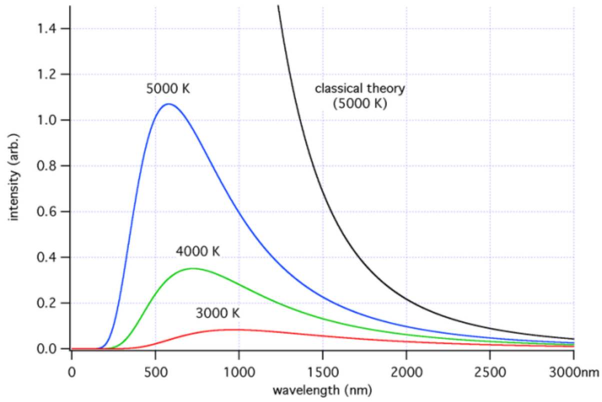
Electrical Energy
→ Heat Energy (eg. kettles, ovens)
→ Light Energy (eg. Light bulbs, TVs)
→ Microwave Energy (eg. Microwave ovens)
→ Kinetic (eg. fans, blenders / industrial motors)
→ Sound (eg. Speakers)
→ Chemical (eg. / car batteries, electroplating)
NB: "/" means industry

Topic 3: From Ideas to Implementation

	Students learn to/Students:
1. 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	The timeline of the development of the cathode ray is as follows: 1858 – Plucker shows that magnets deflect the discharge path 1869 – Hittorf shows solid objects cut off the glow. 1875 – Crookes creates the maltese cross, paddle wheel and bent tube experiments 1883 – <u>Hertz incorrectly shows cathode rays are not deflected by electric fields</u> 1892 – Hertz shows that cathode rays could penetrate a thin metal foil 1894 – Thomson shows cathode rays travelled 200 times slower than light 1895 – Perrin showed that cathode rays left a negative charge on collision.
▪ explain that cathode ray tubes allowed the manipulation of a stream of charged particles	Under normal conditions of temperature and pressure, air is an insulator. However, at reduced pressure, air conducts electricity. By placing metal electrodes inside a Geissler tube (glass tube with 0.01% normal air pressure), and joining the electrodes to a high voltage source, the large potential difference allows electricity to flow through the tube. The colour of the flow determines the type of gas, and the striations & patterns determine the gas's pressure.
▪ identify that moving charged particles in a magnetic field experience a force	Stationary electric charges exert an electric force on each other, and a current carrying wire has a magnetic field. Hence, a moving charge sets up a magnetic field that interacts with an external magnetic field to experience a force. (This can be demonstrated by placing a magnet near a pc monitor, which distorts the screen)
▪ identify that charged plates produce an electric field	Two charged parallel plates with one being negative and the other positive, will produce a uniform electric field (ie. Field lines from +ve to –ve), except at the edges.
▪ describe quantitatively the force acting on a charge moving through a magnetic field $F = qvB\sin\theta$	The force "F" acting on a charge "q" moving with a velocity "v" at an angle θ to the magnetic field B is given by: $F = qvB\sin\theta$ The direction of movement can be found from using the right-hand palm rule.
▪ discuss qualitatively the electric field strength due to a point charge, positive and negative charges and oppositely charged parallel plates	For electric field lines around isolated charges, the field lines/strength: • Move out from a positive charge • Move into a negative charge • Strength decreases with increasing distance from an isolated charge • Unlike charges attract, like charges repel For two oppositely charged plates, the electric field strength is uniform, except near the edges. When a positive charge is place in this field, it will be attracted to the negative plate.
▪ describe quantitatively the electric field due to oppositely	If the potential difference between two plates is "V" and the separation of the plates is "d", then the electric field "E" is given by:

charged parallel plates	$$E = \frac{V}{d}$$ Also, a charge moving in this field will experience a force causing it to move in a parabolic curve. The force "F" acting on a charge "q" is given by: $$F = Eq \text{ or } E = \frac{F}{q}$$
▪ outline Thomson's experiment to measure the charge/mass ratio of an electron	In 1897, J.J. Thomson, while assuming cathode rays were negatively charged proved their particle nature and charge to mass ratio. His experiment was as follows: 1) Cathode rays pass through slots, making a near parallel beam 2) An electric field causes the beam to deflect towards the positive plate 3) A magnetic field is then arrange to deflect the beam in the opposite direction 4) By calculating displacement, B and current, the strengths of the two forces could be equated so that the beam could pass through undeflected 5) When the two forces are balanced, v could be calculated: Hence, the q/m ratio could be calculated. 6) Thomson concluded that the mass of a cathode rays is about 1/1800 the mass of a hydrogen ion.
▪ 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 cathode ray tube consists of: A. Electron gun – This produces a narrow beam of electrons from a cathode. Two open-cylinder anodes help accelerate and focus the electrons. A ring-shaped electrode controls the brightness, by controlling the number of electrons emitted. B. Deflection plates/coils – Consists of 2 sets of parallel plates connected to a potential difference. These produce electric fields, with the Y-plates controlling vertical deflection and X-plates controlling horizontal deflection. The greater the voltage, the greater the deflection. By alternating the charge of each plate with frequency, the spot can move up and down faster enough to appear as a vertical line. C. Fluorescent Screen – At the end of the tube, a screen contains numerous "pixels" with a fluorescent coating. When an electron beam hits the screen, a pixel glows and is shown on a screen. A Cathode-Ray Oscilloscope (CRO) views electrical signals by graphing the relationship between time (horizontal axis) and voltage (vertical axis through an input). An amplifier allows for the adjusting of the CRO's scale. A conventional TV display has pixels with 3 colours (Red, Green, Blue) and uses a magnetic field to deflect the electron beam. The high AC voltage results in the electron beam zig-zagging down the screen, with each scan 1/50th of a second.
▪ *perform an investigation and gather first-hand information to observe the occurrence of different striation patterns for different pressures in discharge tubes*	<u>Aim:</u> To investigate the effect of different gas pressures on an electric discharge in a discharge tube <u>Apparatus:</u> Power supply, induction coil, discharge tubes of varying pressures <u>Method:</u> The induction coil produced a continuous spark, with the negative terminal connected to the top (cathode) and positive terminal to the bottom (anode). Effects on different pressured tubes was observed. <u>Results:</u> The anode and cathode are surrounded by a glow. The lower the pressure, the lower the glow and colour. The tube also contained faraday's dark space, and bigger striations with lower pressures. <u>Conclusion:</u> As the pressure of the gas reduced, the discharge changed. At low pressures, the tube's glow was minimal but the anode glowed brightly.

▪ *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* *analyse the information gathered to determine the sign of the charge on cathode rays*	The experiments to test the properties of cathode rays and their results included: i. Maltese Cross – The metal cross in the discharge tube produced a shadow. It showed that the cathode rays travelled in straight lines towards the anode ii. Electric Plates – The presence of an electric plate deflected the cathode ray towards the positive plate, indicating a negatively charged ray. iii. Fluorescent Screen – A small opening at the cathode with a fluorescent screen proved that cathode rays only travelled from cathode to anode. A magnetic field deflected the ray using the left-hand palm rule. iv. Paddle Wheel – When the rays collided with the wheel, the wheel moved, suggesting a particle nature as the rays were proved to have a mass. These experiments proved that the cathode ray was negatively charged.
▪ *solve problem and analyse information using:* $F = qvB\sin\theta$ $F = qE$ *and* $E = \frac{V}{d}$	Skill. Remember si units: • $E = vm^{-1} \ or \ NC^{-1}$ • $q\ (electron) = -1.6 \times 10^{-19} C = -(proton)$ • $\theta = 90°\ (when\ moving\ perpendicular\ to\ the\ field)$ **NB:** Remember that F and E can be equated to find the other parameters!
2. The reconcept-ualisation 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	Hertz (1886) tested Maxwell's mathematical equations, by producing radio waves. A spark in the transmitter across a room induced a spark in a detector. Further observations include: • The wave could be reflected and refracted • The waves could be polarized (by rotating the receiver or transmitter) • Shining UV onto the receiver booster the spark, known as the photoelectric effect. When he placed a sheet of glass in the gap, no spark was induced
▪ outline qualitatively Hertz's experiments in measuring the speed of radio waves and how they relate to light waves	In Hertz's experiment (1886), he tested the speed of an electromagnetic wave. A bent wire into a loop with a gap will produce a spark that jumps the gap when connected to a high AC voltage. These waves were subject to: reflection, refraction, interference, diffraction and polarisation. Hertz measured the frequency, and through interference, set up constructive crests and destructive troughs allowing the wavelength to be measured, and thus the speed of light. He confirmed Maxwell's theory, and that shining UV increased the photoelectric effect. Unfortunately, he did not investigate this further.
▪ identify Planck's hypothesis that radiation emitted and absorbed by the walls of a black body cavity is quantised	A blackbody is hypothetically, a perfect emitter/absorber of energy. Classical Physics predicted the "Ultraviolet Catastrophe", in which blackbodies will radiate infinite power. It states that decreasing the wavelength increased energy and intensity exponentially. However, this was inconsistent with experiments.



Planck proposed that radiation is not emitted/absorbed by a blackbody continuously, but in "packets of energy" known as quanta or photons. Thus, there is a quantum amount of energy for each frequency. Mathematically:

$$E = hf$$

He deduced that as the wavelength of radiation shortens, its harder for the blackbody to emit that radiation frequency as more energy is needed. Therefore, the shorter the wavelength, the fewer the photons emitted.

<u>NB</u>: *This is only an "identify" DP, but it's important that you understand his hypothesis*

▪ identify Einstein's contribution to quantum theory and its relation to black body radiation	Albert Einstein extended blackbody radiation to all forms of electromagnetic radiation with the following proposals: a) Blackbody radiation is concentrated into small packets of energy known as photons b) A photon is the smallest packet of radiation possible. It <u>can transfer all of its energy or none of it</u> c) The energy of a photon is proportional to its frequency d) The intensity of light is proportional to the number of photons. The <u>intensity does not affect the energy of a photon</u>, only frequency does e) Excess energy after the work function is the kinetic energy of the electron f) All electromagnetic waves travel at the same speed and contain photons He also explained that the wave and particle nature could coexist.
▪ explain the particle model of light in terms of photons with particular energy and frequency	The Photoelectric Effect investigated Maxwell's electromagnetic waves. Philipp Lenard (1900) investigated this in his **<u>Photoelectric Experiment</u>**. Briefly: ➢ He first determined the energy level of electrons (ie. The electrons with the highest energy or shortest wavelength in the light, when it hit the emitter) ➢ A backing voltage "retarded" the electron's motion, just until current=0 ➢ Thus, the kinetic energy from the electrons could be found, from the work done to stop them His experiment showed that increasing the frequency of light increased the kinetic energy of photoelectrons. Also, a threshold frequency for the photoelectric effect (varies between emitters) existed. Lastly, as energy (light intensity) increased, the maximum kinetic energy remained constant.
▪ identify the relationships between photon energy, frequency, speed of light and wavelength: $E = hf$	These equations can be combined to find a relationship between energy and wavelength. $$E = \frac{h \times c}{\lambda}$$ Remember: • E is the energy of the photons (Joules) • h is Planck's constant (6.63×10^{-34})

and $c = f\lambda$	• f is the frequency (Hz) • c is the speed of light ($3 \times 10^8\ ms^{-1}$) • λ is the wavelength (m)

▪ *perform an investigation to demonstrate the production and reception of radio waves*	Set up an induction coil to produce sparks. Then tune in a radio receiver and note the effect of the radio waves. The effect on the AM station is more obvious than the FM stations. ***<u>NB</u>:** Aerials can be used to produce radio waves by applying AC voltage. The aerial induces a radio wave whose wavelength is half the length of the aerial.*

▪ *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*	*(On top DP 3.2.4):* Einstein had a significant impact in shaping quantum theory and explaining black body radiation. i. He explained Planck's theory by proposing the "Photoelectric Effect"; that light energy is transmitted in discrete packets of energy rather than a spreading wave. His theory proposed that the smallest quantity of light energy of a particular frequency was a quanta, or photon. It also showed why classical physics failed to predict the experimental results. ii. He also explained the duality of light: When light is described in terms of propagation it is a wave, and when as a matter, it is a stream of particles These two discoveries increased the credibility of Planck's idea and gave a deeper understanding of the nature of light

▪ *identify data sources, gather, process and present information to summarise the use of the photoelectric effect in photocells*	Photocells use the photoelectric effect by coating the cathode with photosensitive material. When light falls on it, photoelectrons are accelerated to the anode with the photocurrent being proportional to the intensity of light. Photocells are used as electric eyes, radiation detectors and light meters. ***<u>NB</u>:** These are usually thermionic and require an external potential difference*

▪ *solve problems and analyse information using:* $E = hf$ *And* $c = f\lambda$	Skill. Remember: • "f" can be substituted between both equations • h = 6.63×10^{-34} • f = Frequency (Hz) • λ = Wavelength (m) ***<u>NB</u>:*** $hf = W_k + KE$ (ie. Work Function) *By graphing this function, the y-intercept = work function, x-intercept = threshold frequency and gradient = Planck's constant (h).* ***<u>NB 2</u>:** There are 2 types of work functions. The <u>photoelectric effect</u>, and <u>thermionic emissions</u>.*

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

Einstein's Views	**Planck's Views**
❖ Jewish parents, studied in Germany, pacifist ❖ Fled Germany, Swiss citizenship then immigrated to USA ❖ Signed anti-manifesto ❖ Opposed Nazi tyranny	❖ Avowed nationalist ❖ Believed in respecting German science ❖ Anti-Nazi Views ❖ Signed Manifesto – to support the Germany military
❖ Warned Roosevelt of atomic bomb, opposed Manhattan project, later life dedicated to eliminating atomic war threat ❖ <u>Strongly believed science should be independent of social/political forces</u>	❖ Even though he supported German survival, he opposed Hitler's Laws ❖ <u>Strongly believed science should be used by all of society, especially to advance Germany</u>

NB: *The context **must** show how it has influenced the social/political forces.*

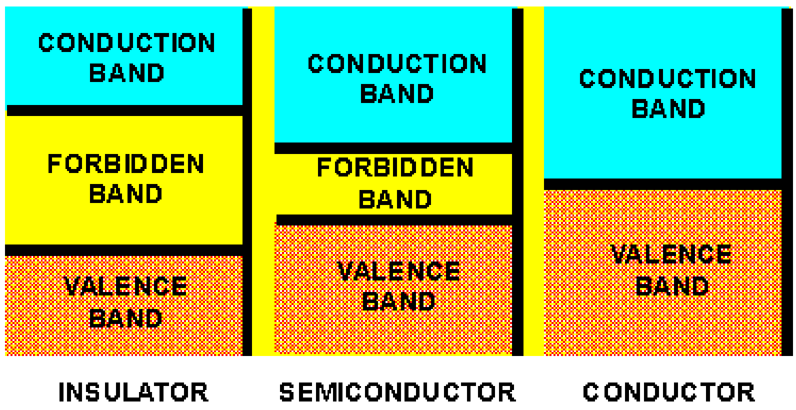
3. Limitations of past technologies and increased research into the structure of the atom resulted in the invention of transistors

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

Conductivity refers to the ease of movement of the solid's electrons. In some solids, the outer electrons are very loosely bound and are free to move through a solid's crystal lattice between positive ions.

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

	Band Structures	**Relative Electrical Resistance**
Conductors	Overlap of conduction and valance band (Partially filled valence)	Low; *But resistance increases with temperature/energy*
Semiconductors	Small forbidden energy band (Almost filled valence)	Medium; *resistance reduces with temperature/energy*
Insulators	Large forbidden electric band (Completely filled valence)	High



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

When an electron is removed from the valence shell, or a nearly full band, this absence is called a "positive hole". The movement of electrons and holes helps to carry electric current, as the movement of electrons one-way results in the movement of holes in the other. When an electric field is connected, the net electron movement is towards the positive terminal, with the holes appearing to drift towards the negative, attracting more electrons and allowing current to flow.

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

The relative resistance is dependent on the number of free electrons that can drift in the conduction band. Conductors have large numbers of electrons that can drift from atom to atom. Semiconductors have some electrons that can drift, and by adding energy, this number can be increased. Insulators have almost no electrons available to drift.
Nevertheless, conductors, semiconductors and insulators contain electrons.
NB: Increasing the potential in all materials can break down the resistance

- identify that the use of

Germanium is a rare element (1.5 parts per million in the Earth's crust) but the recognition of its semiconducting properties lead to early purification techniques germanium in early transistors is related to lack of ability to produce other materials of suitable purity

(1940s). However purification methods were developed for silicon in the 1950s, superseding germanium as the preferred semiconductor material due to:

- More abundance (second most abundant element in the crust)
- Retains its semi-conductive properties at high temperatures unlike germanium
- It forms an oxide that can be doped and made into thin layers
- However, silicon is harder to purify than Germanium

▪ describe how 'doping' a semiconductor can change its electrical properties

There are two types of semiconductors:
Intrinsic – These occur naturally eg. silicon and germanium
Extrinsic – These are manufactured, by adding dopant atoms to make the material semi-conductive. The two extrinsic semiconductors are: P-type and N-type

Doping involves changing a medium's pure state to increase conductivity. When a Group 3 atom replaces/dopes a Group 4 atom, this creates a mobile hole in the valence band. When an electric field is applied, the movement of electrons to fill this hole conducts current, known as a P-type semiconductor. When a Group 5 atom replaces a Group 4 atom, there is an excess of electrons, which moves under the influence of an electric field. This is known as an N-type semiconductor.

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

In P-type semiconductors, positive holes constitute the majority carriers and electrons the minority carriers.

In N-type semiconductors, negative electrons constitute the majority carriers and holes the minority carriers.

▪ describe differences between solid state and thermionic devices and discuss why solid state devices replaced thermionic devices

Thermionic Devices	Solid State devices
• Uses a cathode & anode to accelerate electrons at high temps • Consumes a lot of energy • Fragile and inefficient • Cannot start-up as fast	• Uses semiconductors to generate a flow of electrons • Less power, heat • Miniature and efficiency • Works immediately

A diode is the interaction of P and N type conductors. The adjacent side neutralises some positive holes and free electrons, creating a depletion zone (region). Connecting an electric field creates a unidirectional current flow (P to P)

The combined advantages of smaller size, cheaper construction, lower power, and higher efficiency in solid states lead to the replacement of thermionic devices.

▪ *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*

Aim: To model the behaviour of semiconductors
Apparatus: 24xMarbles, 2xWell tiles
NB: *There are no significant risks or hazards in this experiment*
Method: The wells represent holes, with the marbles representing free or valence shell electrons. Firstly, move electrons into holes and observe the apparent movements. Then apply an electric field to the P and N type well tiles. Next, join the P section and N section, create the depletion zone, and apply a potential difference in forward bias and reverse bias and observe.
Results: Current can only flow if there is an imperfect valence shell with either free electrons on an absence (holes). When a potential is applied, the electrons drift to the positive terminal and the holes towards the negative. A p-n junction only allows current to flow when the P section is joined to the positive terminal.

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

The need to control current flow through rectifying and amplification lead to the creation of thermionic devices. The heating of a filament lead to unidirectional conduction, and the introduction of a "grid" or triode amplified a carrier wave to produce sound.

However, this bulky size, high heat production, fragility and short life lead to the invention of transistors, which relied on p-n junctions known as diodes. *(As mentioned in DP3.3.9)*, when the positive terminal is connected to the P-type, the depletion region is decreased, resulting in current flow, known as <u>forward bias</u>. When the positive terminal is connected to the N-type, the depletion zone widens as both semiconductors sides experience an increase in neutralised atoms. This shuts off current flow, known as <u>reverse bias</u>.

Also, <u>thermionic triodes</u> were replaced by transistors consisting of an emitter, base and collector. The two types are: PNP and NPN with the base being "sandwiched" and very thin. Since the base is effectively neutralised, when the emitter is forward biased and the base reverse biased, current flows. By varying the emitter's base voltage, the circuit's collector current is amplified. Transistors are still used today because they provide the best sound quality as amplifiers.

Transistors require a fraction of the energy and size to do the same thing.

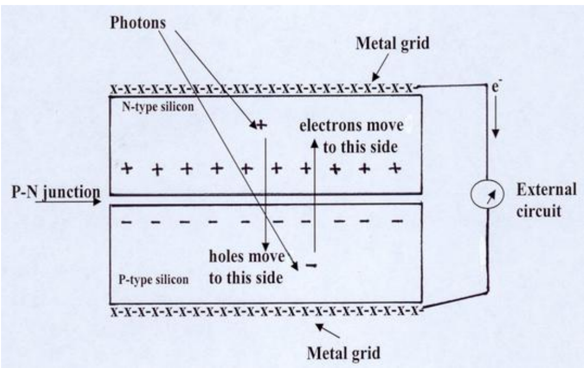
- *identify data sources, gather, process, analyse information and use available evidence to assess the impact of the invention of transistors on society with particular reference to their use in microchips and microprocessors*

Transistors have had a positive impact on society by:

- The miniaturisation of electronic circuits, to make amplification possible without complex drawbacks eg. heat, size, fragility
- Microchips have made computers run faster and increased portability from room-sized computers to hand-held devices. Micro-technology can also be developed and evolved quickly
- Microchips are prevalent in almost all household goods that improve our quality of life eg. computers, tvs, mobiles, clocks, cameras, etc.
- Power consumption is reduced to maximise efficiency and minimise the impact on the environment/resources
- Also, one could argue it has lead to mass consumerism and has discriminated against those who can afford it, increasing inequality

Overall, transistors especially microchips and microprocessors have had a positive impact on society by improving our quality of life.

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



Solar cells (or photovoltaic cells) form a p-n junction so that as light hits the n-side cell, this causes the separation of the electron-hole pairs. As the free electrons are pushed to the N-side and holes to the P-side, this set up a potential barrier and emf (which is dependent on the intensity of light). Metal contacts on both sides conduct electrons away from the n-side towards the p-side when connected in a circuit, doing work in the process. This <u>converts</u> light energy directly into electrical energy.

Solar cells consist of the layers: glass covering→ anti-reflection coating→ contact grid→ n-type silicon→ p-n junction→ p-type silicon→ back contact.
***<u>NB</u>:** Solar cells are always solid state, and can use <u>doping</u>*

4. 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	Diffraction is a wave characteristic and can be observed only with waves. This can produce constructive interference (maximum amplitude) or destructive interference (minimum amplitude). Sir William Bragg and his son Lawrence, applied X-ray diffraction to crystals, and showed that short wavelengths such as X-rays, could penetrate and reflect from the atomic planes. In some directions, constructive interference occurred and in others, destructive interference occurred. The difference in path lengths indicated that the waves were out of phase. He used this to deduce the wavelength, and the inter-atomic spacing of the crystal's structure.
▪ identify that metals possess a crystal lattice structure	Metals' are composed of 3-dimensional arrangements of a polyhedral structure. This is known as a crystal lattice structure, and repeats indefinitely for each unit cell.
▪ describe conduction in metals as a free movement of electrons unimpeded by the lattice	Metals consist of a lattice structure where electrons are free to move under the influence of an electric field. Therefore, when a potential difference is connected to a metal wire, this exerts a force on the electrons creating drift velocity. This influence is close to the speed of light, and allows electrons to move unimpeded by the lattice.
▪ identify that resistance in metals is increased by the presence of impurities and scattering of electrons by lattice vibrations	2 factors that will increase a metal's resistance are: i. Impurity ions or imperfections, affect the purity of the metal and increase the chance of electron collisions, leading to higher resistance ii. As a lattice vibrates more, this increases the probability of electron collision, increasing the resistance. Vibrations are caused by increases in temperature/heat.
▪ describe the occurrence in superconductors below their critical temperature of a population of electron pairs unaffected by electrical resistance	Superconductivity is the phenomenon exhibited by certain conductors where they have no resistance to current. The transition from resistance to no resistance is called the critical temperature (T_c). At or below this temperature, electron pairs are not affected by electrical resistance as described in the BCS theory *(see below)*.
▪ discuss the BCS theory	In 1957, John Bardeen, Leon Cooper and J. Robert Schrieffer developed a BCS model to explain superconductivity. In a superconductor, electrons pass unimpeded with the lattice. They lose no energy, as resistance is 0. According to BCS theory, the interaction of a vibrating lattice and moving electrons produces phonons, which are packets of sound energy. A moving electron causes the lattice to distort, emitting a phonon, and increasing the positive charge density around that electron. Before the lattice rebounds back to normal, a second electron is attracted to this region and accelerates towards the first electron. Effectively, 2 electrons are "paired up".

	This is called a Cooper pair, as one electron emits a phonon, while the other absorbs it, keeping them in a pair. Phonons are continually being formed and broken, until a rise in temperature causes a lattice vibration that breaks up the Cooper pair, stopping superconductivity.
▪ discuss the advantages of using superconductors and identify limitations to their use	Advantages of using superconductors include: ➢ Minimising energy loss, due to a lack of resistive heating ➢ Allows for the generation of intense magnetic fields However, significant limitations exist, including: ➢ Metal superconductors require significant energy to cool them to the critical temperature ➢ Ceramic superconductors are brittle, difficult to manufacture and mould into cables. They are also chemically unstable in some environments.
▪ *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*	Some of the metals, metal alloys and compounds that exhibit superconductivity at their critical temperatures include: • Mercury • Lead • Tin • Certain alloys, and man-made compounds (eg, ceramic)
▪ *perform an investigation to demonstrate magnetic levitation*	Aim: To demonstrate magnetic levitation Apparatus: Foam holder, Type 2 semiconductor, small magnet, liquid nitrogen Safety: Wear eyeglasses and a lab coat to prevent accidents from the nitrogen Method: Cool the superconductor by pouring nitrogen into the foam holder. Once it has reached equilibrium, place a magnet on the superconductor and observe.`
▪ *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*	W.Meissner and R.Ochsenfeld discovered that an external magnetic field could not penetrate a superconductor's interior. This exclusion of a magnetic field is called the Meissner effect. Therefore, when a magnet is placed above a superconductor, the superconductor generates and expels a magnetic field that balances this external field, causing the magnet to levitate. (When the magnet's field strength is above a certain value, it penetrates the metal) ***NB:*** *At absolute 0, conductors also conduct current with no resistance, however, they do not demonstrate the Meissner effect!*
▪ *gather and process information to describe how superconductors and the effects of magnetic fields have been applied to develop a maglev train*	Superconductivity can be applied to magnetically levitated vehicles (Maglev). They can achieve very high speeds, are safe and require low maintenance. Superconductor magnets can be: a) Electromagnetic Suspension System (EMS), Germany - Wrapped around the guide-way attracts the train the iron rail b) Electrodynamic Suspension System (EDS), Japan - Used to achieve levitation through repulsion. Coils in the superconducting magnets interact with coils in the guide-way to cause the train to lift off Both systems use a magnetic wave (Meissner effect) to propel the suspended vehicle. The first commercial Maglev train operates in Shanghai, in 2004.
▪ *process information to discuss*	Possible applications of superconductivity include:

possible applications of superconductivity and the effects of those applications on computers, generators and motors and transmission of electricity through power grids	a) Power Transmission – The conduction of electricity through power lines without power loss. If the sufficient materials can be developed, very large current densities could be conducted in relatively thin wires. Transmission must be in DC however, as AC causes energy losses and heating. b) Power storage – DC current can circulate in a SMES system indefinitely, allowing power to be stored. AC cannot be stored, as its oscillations produce energy loss. c) Electronics – This could allow for the future speed and miniaturisation of electronics. Superconductor chips can achieve switching times much faster than any conventional circuits. d) Maglev – Magnets suspend an object so that it is frictionless from the ground. By continuously changing the polarity of electromagnets on the track, this provides the force to accelerate the Maglev train. However, the enormous electrical power needed is an obstacle to its use. e) Particle Accelerators – Most high energy particle accelerators now use dipole superconducting magnets. The Large Hadron Collider (LHC) at CERN is 27km in circumference. It has been estimated if conventional electromagnets had been used; a 120km circumference is needed to produce the equivalent energy.

Option: Medical Physics

	Students learn to/Students:
1. The properties of ultrasound waves can be used as diagnostic tools	
▪ identify the differences between ultrasound and sound in normal hearing range	Sound is a longitudinal mechanical wave that needs a medium to be propagated. It consists of a series of compressions and rarefactions. A human's normal hearing range is 20Hz~20,000Hz. However, Ultrasound has frequencies greater than 20,000HZ, whose frequency is inaudible to humans.
▪ describe the piezoelectric effect and the effect of using an alternating potential difference with a piezoelectric crystal	Ultrasound is commonly produced by electromechanical transducers through Piezoelectric Crystals and an AC input. Piezoelectric Crystals produce tiny mechanical deformations when subject to a potential difference. They convert electrical energy into mechanical vibrations (and mechanical vibrations back into electric energy), and act as transducers over all ultrasound frequencies and outputs.
▪ define acoustic impedance: $Z = \rho v$ and identify that different materials have different acoustic impedances	The Acoustic Impedance (Z) of a medium measures how easily ultrasound transmits through a medium. The larger the difference in acoustic impedance, the greater the reflection, of sound waves and vice versa. It depends on the speed of the wave and the density of the medium. $Z = \rho v$ Since speed and density varies between different materials, different acoustic impedances exist.
▪ describe how the principles of acoustic impedance and reflection and refraction are applied to ultrasound	Ultrasound works on the principles that different bodily tissues have different acoustic impedances. A gel provides air free contact with a transducer, to avoid pulses being reflected from the skin. Similar to light, pulses of ultrasound undergo reflection and refraction, whose echoes can be detected by the transducer. By measuring the time and distance of an echo, the location of organ/tissue structures can be determined. Thus, time is proportional to distance. ***NB:*** *It must be stressed that the higher the ultrasound frequency, the clearer the*

	image. However, higher frequency waves have shorter wavelengths, and cannot penetrate as far into the body. Therefore, the frequency must suit the depth and size of the tissue to be examined.

▪ define the ratio of reflected to initial intensity as: $\frac{I_r}{I_0} = \frac{[Z_2 - Z_1]^2}{[Z_2 + Z_1]^2}$	If Z_1 is the acoustic impedance in medium 1 and Z_2 is the acoustic impedance in medium 2: $\frac{I_r}{I_0} = \frac{[Z_2 - Z_1]^2}{[Z_2 + Z_1]^2}$ Is the ratio of reflected energy to the original energy ie. $I_r : I_o$

▪ identify that the greater the difference in acoustic impedance between two materials, the greater is the reflected proportion of the incident pulse	The greater the difference in acoustic impedance between two materials, the greater the reflected proportion of the incident pulse. *(The large difference in acoustic impedance between air and the skin, results in a majority of the waves being reflected. This is why a gel with a similar acoustic impedance to the skin, is applied to the skin)*

▪ describe situations in which A scans, B scans and sector scans would be used and the reasons for the use of each	<u>A scans</u> An A scan is 1 dimensional and uses a single transducer to scan a line in the body. The ultrasound echoes are plotted as a function of time. It can be used for measuring eye length and possible deformations. <u>B Scans</u> This 2 dimensional scan uses several transducers to scan a plane (slice) of the body. Each echo is plotted as a dot, whose brightness depends on the signal strength (ie. Brightest/white dot = largest amplitude). The signal strength depends on the acoustic impedance of the material. They can be used to scan for retinal detachments. <u>Sector Scans</u> A Sector scan is built from a number of B scans, to build a sector shaped image. An <u>array of multiple transducers</u> produces a 2 dimensional image. It can be used to scan an infant's brain, or be used during pregnancy.

▪ describe the Doppler effect in sound waves and how it is used in ultrasonics to obtain flow characteristics of blood moving through the heart	Ultrasonics utilises the Doppler Effect, which is the apparent frequency change, when there is relative motion between a wave's source and an observer (ie. When a source is approaching an observer, the frequency increases because the waves "bunch up"). Ultrasound uses this effect to examine liquid flow in arteries and veins. Two ultrasound transducers are used: one transmits and one detects a return signal. Colour can be attributed to the echoes to indicate the speed and volume of blood flow, which can provide information on the narrowing of arties, blockages etc.

▪ outline some cardiac problems that can be detected through the use of the Doppler effect	Some cardiac problems that can be detected by using the Doppler Effect include: i. Narrowing of the arties – When an artery narrows, the blood's velocity increases, which can be detected through "false colour" ii. Leaking Valves – This is indicated when blood flows the "wrong way" iii. Blockages – A mixture of colours in the echoes can indicate partial blockage or rough walls.

▪ *solve problems and analyse information to calculate the acoustic impedance of a range of materials, including bone, muscle, soft tissue, fat, blood and air and explain the types of tissues that ultrasound can be used to examine*	Acoustic Impedance : $Z = \rho\upsilon$ Remember units! Ie: ➢ Acoustic Impedance = $Z\ (kgm^{-2}s^{-1})$ ➢ Density = $p\ (kgm^{-3})$ ➢ Velocity = $v\ (ms^{-1})$ Different body materials respond differently to ultrasound. It is not feasible to scan tissue around bone, as almost all ultrasound is reflected off the bone. Tissues such as fat, muscle and blood, will have multiple transmissions and reflections, due to lower acoustic impedances, allowing these tissues to be examined.

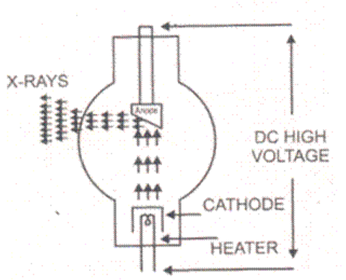
▪ *gather secondary information to observe at least two ultrasound images of body organs*	Examples include: Foetus, Gall Bladder, Brain Notice that bone appears lighter in colour compared with other bodily materials (eg. fluid is the darkest).

▪ *identify data sources and gather information to observe the flow of blood through the heart from a Doppler ultrasound video image*	By analysing a video, false colour will reveal information about the Doppler Ultrasound, including: direction, volume and velocity of blood flow. Different colours may also reveal problems related to blood flow in the heart.

▪ *identify data sources, gather, process and analyse information to describe how ultrasound is used to measure bone density*	Traditional X-rays cannot detect early loss of bone density. Therefore, bone density can be measured by 2 methods: a) Ultrasound – A transducer can be directed through the heel, with the attenuation (absorption) measured. High-density bone has a large attenuation. b) DEXA – This uses X-rays to detect small changes in bone density, usually on the hips or spine. DEXA uses very low levels of radiation to measure bone density with high accuracy and precision. Osteoporosis is a bone disease characterised by decreased bone density, bone strength and an increased chance of fractures. Early detection through the 2 methods above is important for stopping, or even partially reversing the disease.

▪ *solve problems and analyse information using:* $Z = \rho\upsilon$ *and* $\frac{I_r}{I_0} = \frac{[Z_2 - Z_1]^2}{[Z_2 + Z_1]^2}$	Skill. **<u>NB</u>:** ➢ It does not matter which is medium 1 and which is medium 2! ➢ The reflected intensity is always expressed as a percentage (eg. 0.01=1%)

2. The physical properties of electromagnetic radiation can be used as diagnostic tools	
▪ describe how X-rays are currently produced	X-rays are produced in an X-ray tube (similar to a cathode ray tube). A cathode accelerates electrons towards a high temperature metal anode (eg. Tungsten) that is tilted 45° so that the electron beam passes through the wall of the tube. When the electrons rapidly decelerate upon impact, they produce X-rays (1%) and heat

	(99%). *[A Bremsstrahlung Graph depicts the intensity of the braking radiation from a frequency range. Spikes at the top of the spectrum are characteristic rays.]*
▪ compare the differences between ‘soft’ and ‘hard’ X-rays	Hard X-rays have shorter wavelengths, high frequency, higher penetration, and are used for imaging bones. Soft X-rays have longer wavelengths, lower frequency and lower penetration. They have no use in the human body and are usually filtered out.
▪ explain how a computed axial tomography (CAT) scan is produced	A Computed Axial Tomography (CAT) Scan uses X-rays to obtain a cross-section of the body. A table of the patient passes through a circular scanning machine (gantry) to produce a 3-dimensional image. A narrow beam of X-rays is fired at the body and the degree of absorption or <u>attenuation</u> is measured. As the gantry rotates, a computer logs the slices which are superimposed to build a picture of the body. Greyness pixels represent varying attenuations. To improve contrast, contrast solutions (eg. Iodine) can be used.
▪ describe circumstances where a CAT scan would be a superior diagnostic tool compared to either X-rays or ultrasound	➢ Conventional X-rays show an image of all structure in its path. CAT scans allow for some structures to be digitally removed (eg. Ribs) to diagnose tumours ➢ CAT scans are more sensitive than X-rays, allowing better discrimination and identification of tissue ➢ CAT scans can also penetrate structures such as bone, that Ultrasound cannot Thus, the greater accuracy, detail and sophistication make CAT scans more suitable in diagnosing the brain, internal organs and growth abnormalities.
▪ explain how an endoscope works in relation to total internal reflection	Endoscopy refers to the inserting of an optical tube through an opening in the body. It consists of bundles of glass-fibres that transmit light. When light travels from a denser material to a less dense material, the light bends away from the normal *(Snell’s Law)*. When this angle of refraction is perpendicular to the normal, it is known as the <u>critical angle</u>. Exceeding this critical angle results in the light being totally reflected internally. Therefore, by cladding the fibre with a material of lower refractive index, all of the light passes through the fibre.
▪ discuss differences between the role of coherent and incoherent bundles of fibres in an endoscope	A coherent bundle is one in which the individual optic fibres are in the same relative positions at both ends. They are used for recreating a clear copy of the image by transmitting the light received. They are however expensive to manufacture. An incoherent bundle has optical fibres that are arranged randomly. They are mainly used for transmitting light and illuminating an organ. They are cheaper to manufacture but cannot produce clear images.
▪ explain how an endoscope is used in: – observing internal organs	Endoscopes have a number of uses. They contain illumination lenses, an objective lens, an air-water nozzle and a biopsy channel to allow for multiple-uses. a) An endoscope can be used to examine damage to internal organs by using coherent fibre bundles. Such as in Arthroscopy, joints can be examined.

– obtaining tissue samples of internal organs for further testing	b) Endoscopes can also be used to carry out minor operations by installing surgical instruments such as biopsy forceps and snares. In Colonoscopy, polyps, tumours and ulcerations once detected in the anus, can be surgically removed.

▪ gather information to observe at least one image of a fracture on an X-ray film and X-ray images of other body parts	An X-ray image is made by passing a radiograph through a patient and falling on a photographic film. The clear, white areas show dense tissue such as bone, and the dark areas show soft tissue. X-ray films can detect fractures easily upon observation.

▪ gather secondary information to observe a CAT scan image and compare the information provided by CAT scans to that provided by an X-ray image for the same body part	By comparing different CAT and X-ray images, CAT scans show much greater contrast and clarity in the imaging. Also, internal organs such as airways and the heart are clearly visible, which are indistinguishable in standard radiography. CAT scans also take a cross-section of the body, while X-rays give a 3rd person view.

▪ perform a first-hand investigation to demonstrate the transfer of light by optical fibres	<u>Aim:</u> To demonstrate the transfer of light by optical fibres <u>Apparatus:</u> Torch, Optical Fibre strand <u>Method:</u> By shining a torch into an optical fibre strand, observe the way the light enters and exits the fibre. <u>Results:</u> Light passes through the fibre even with bending.

▪ gather secondary information to observe internal organs from images produced by an endoscope	Endoscopes show circular images of the internal organs. The clarity is lower than in standard cameras.

3. Radioactivity can be used as a diagnostic tool

▪ outline properties of radioactive isotopes and their half lives that are used to obtain scans of organs

Radioactive isotopes are isotopes (elements with differing number of neutrons) that are unstable and potentially radioactive. They undergo radioactivity, which is the spontaneous breakdown into new elements by emitting alpha, beta or gamma radiation.

Radiation Type	Nature	Ionising Effect	Absorbed by
Alpha (α)	Positive, proton mass	Strong	Paper
Beta (β)	Negative, electron mass	Weak	Skin
Gamma (γ)	Electromagnetic wave, zero mass	Very weak	Several cm of lead

The "half-life" is the time taken for half the given mass of an element to decay. The radioactivity associated with this decay makes it useful in tracking internal organs through radio-imaging. It is important that the half-life is short, so that the potentially dangerous radiation is minimal.

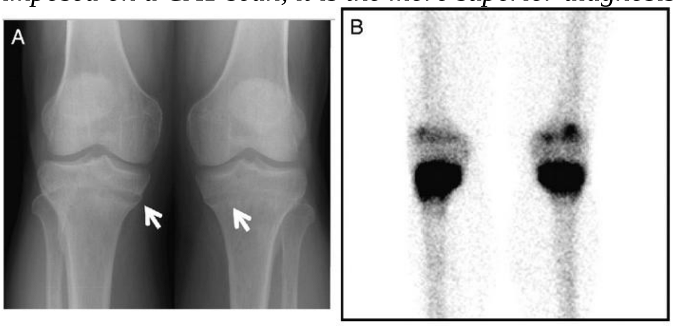
▪ describe how radioactive	Many organs utilise specific chemicals eg. Iodine accumulates in the Thyroid. <u>Radiopharmaceuticals</u> or radioisotopes of similar chemical structures are injected

isotopes may be metabolised by the body to bind or accumulate in the target organ	into the body, utilised in normal metabolic processes and excreted. As these specific radioisotopes accumulate in the target organ, they can be used to diagnose problems in that area.

▪ identify that during decay of specific radioactive nuclei positrons are given off	Positrons are produced when an unstable radioisotope decays. Protons in the nucleus decay to become neutrons, emitting a positron, an electron's antiparticle. Eg. ${}^{11}_{6}C \rightarrow {}^{6}_{5}B + {}^{0}_{+1}e$ ***NB:*** *${}^{A}_{Z}X$ - A is the mass number and Z is the atomic number*

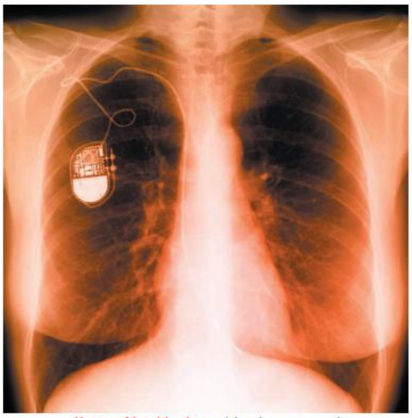
▪ discuss the interaction of electrons and positrons resulting in the production of gamma rays	When a moving positron collides with an electron, they "annihilate" each other. However, the Law of Conservation of Energy states that this energy must be conserved, and so 2 gamma rays are produced. They have the same energy level, but travel in opposite directions. The production of gamma rays allows a computer to construct an image of gamma radiation.

▪ describe how the positron emission tomography (PET) technique is used for diagnosis	Positron Emission Tomography (PET) is a non-invasive technique for imaging the presence of short-lived radioisotopes in the human body. PET scans follow these steps: 1) A patient absorbs a radioisotope (eg. orally, by inhaling or injection), which closely resembles a natural substance (eg. glucose, iodine) in the body and has a relatively short half-life. This ensures the patient receives minimal radiation exposure. 2) The decay of radioisotopes produces positrons that travel a few millimetres before colliding with an electron in the body. This produces 2 gamma rays that travel in the opposite directions 3) A PET scan uses a large-donut shaped ring (gantry) of gamma detectors to absorb the gamma radiation from a patient. The circular gantry detects both of the gamma rays, and analyses this on a computer to produce an image. 4) By taking many slices perpendicular to the body, a 3D image can be created. PET scans are useful for functional imaging, and the diagnosis of diseases in their early stages. They can be superimposed with CAT scans to clarify the location of the PET signal, since they cannot display structural images well.

▪ *perform an investigation to compare an image of bone scan with an X-ray image*	A bone scan is similar to a PET scan, where a radioisotope is absorbed by the bone, resulting in hot spots or cold-spots (eg. to find stress fractures, arthritis). This is used for functional diagnosis. This differs from normal X-rays, which measures the attenuation of X-rays and produces a structural image. It is clearer than a bone scan. *(However, when a bone scan is superimposed on a CAT scan, it is the more superior diagnosis)*  A) X-Ray Image B) Bone Scan

- *gather and process secondary information to compare a scanned image of at least one healthy body part or organ with a scanned image of its diseased counterpart*

Similar to CAT scans, a greyness scale identifies the level of organ activity (ie. Black=0 Activity) in PET scans. A PET scan of a healthy brain should show a symmetrical pattern consisting of a fair spread in greyness. However, a brain with Alzheimer's disease has a very patchy appearance, with distinct black areas indicating loss of brain activity. A PET scan of a diseased brain tends to depict an asymmetrical image.



X-ray of healthy lungs (showing a pacemaker at the heart)

X-ray of lungs showing damage to the right and left tuberculosis

4. The magnetic field produced by nuclear particles can be used as a diagnostic tool

- identify that the nuclei of certain atoms and molecules behave as small magnets

In certain atoms, the nuclei of these atoms can act as small magnets by exhibiting a magnetic field. In quantum physics, these nuclei have a property of net spin, and this property allows the nuclei to behave as small magnets. [As the proton spins, it acts as a small electric current loop, similar to a solenoid]
***NB**: Hydrogen produces the strongest magnetic field and is the most easily detected.*

- identify that protons and neutrons in the nucleus have properties of spin and describe how net spin is obtained

Spin is a measure of the intrinsic angular momentum. The angular momentum of protons and neutrons is found by using the Right-Hand Grip Rule and is known as "spin".

  - Quantum theory gives spin discrete values expressed in multiples of ½
  - Spin can have an orientation of "up" or "down"
  - When two protons/neutrons are paired, they give zero net spin
  - A proton cannot pair with a neutron
  - Net Spin can be either: 0, ½ or 1

- explain that the behaviour of nuclei with a net spin, particularly hydrogen, is related to the magnetic field they produce

A proton (hydrogen) has a net spin of ½. This can be either "up" or "down", and produces a small magnetic field. Similar to the magnetic field created by a moving charge in a current carrying conductor, a spinning hydrogen atom produces a magnetic field.
***NB**: Only proton spin generates a magnetic field. Neutrons do not (but add to the total net spin of the nucleus)*

- describe the changes that occur in the orientation of the magnetic axis of nuclei before and after the application of a strong magnetic field

The magnetic field produced by a spinning charge lies on its axis of rotation. The orientation is random in normal nuclei. When an external magnetic field is applied, the nuclei experience a force and tend to align in either parallel or anti-parallel to the field. Parallel corresponds to a low-energy state while anti-parallel is a high-energy state. As the external field strength increases, the energy difference increases, and there is more alignment.

▪ define precessing and relate the frequency of the precessing to the composition of the nuclei and the strength of the applied external magnetic field	Precession occurs when there is a change in rotational axis from the original axis of rotation. When an external field is applied to a spinning charge, the field will cause the charge to spin in a conical path. Ie. Precession rate $\propto$ applied field (and the nucleus composition). This precession rate is known as the Lamor Frequency, and a photon of equivalent energy can cause the charge to move from a low-energy state to a high-energy state.

▪ discuss the effect of subjecting precessing nuclei to pulses of radio waves	In MRI, pulses of radio waves are superimposed on the strong, steady external magnetic field. If the frequency of the pulse is different from the nuclei's Lamor frequency, it will precess more. If the frequency of the pulse equals the Larmor frequency, the energy is absorbed and the nuclei are "knocked over" into a higher energy state. The nuclei are now rotating in a higher energy state and over time will relax. When they return back to the low-energy state, the Law of Conservation of Energy states energy is conserved, and so the equivalent pulse is released from the nuclei and can be detected.

▪ explain that the amplitude of the signal given out when precessing nuclei relax is related to the number of nuclei present	When a proton enters a high-energy state, it will inevitably relax *(see below)*. Those nuclei with the largest magnetic moment will have the highest net spin, and give out the strongest signal when relaxing. For example, hydrogen, phosphorus and fluorine

▪ explain that large differences would occur in the relaxation time between tissue containing hydrogen bound water molecules and tissues containing other molecules	Hydrogen bound in different mediums will relax at different rates. Relaxation occurs when nuclei return back to their original precession and emit the pulse previously absorbed. There are 2 main relaxation types: 1. T1 (Spin-Lattice Relaxation) – This occurs when the relaxation energy transfers to surrounding molecules. Mediums such as fat/large molecules release the energy quickly, making T1 short. An image emphasising T1 is said to be T1 weighted. (ie. Bigger molecules appear white, fluids appear dark). 2. T2 (Spin-Spin Relaxation) – This occurs when the relaxation energy transfers within a molecular lattice. This occurs in watery tissues, and the energy is released very slowly. An image emphasising T2 is said to be T2 weighted.

▪ *perform an investigation to observe images from magnetic resonance image (MRI) scans, including a comparison of healthy and damaged tissue*	An MRI of a healthy brain depicts a relative consistent scale of greyness. Damaged tissue, such as benign tumours are significantly lighter in colour (due to a higher concentration of blood), and stand out in the MRI image.

▪ *identify data sources, gather, process and present information using available evidence to explain why MRI scans can be used to:* – *detect cancerous tissues* – *identify areas of high blood flow* – *distinguish between grey and white matter in the*	MRI is considered one of the best imaging techniques. They can be used to: a) Detect cancerous tissues – Because cancer is uncontrolled in its growth, it is associated with increased blood flow and an accumulation of water. This water, containing hydrogen, is readily detected by the MRI scanner. b) Identify areas of high blood flow – Similarly, high blood flow is full of hydrogen and easily detected. c) Distinguish between grey and white matter in the brain – Grey matter contains more water than white matter due more non-myelinated nerve cells. They can be readily distinguished in MRI scans. This is possible, because of MRI's ability providing detailed anatomical

brain

information. Developments in functional MRI are leading to very precise and effective, structural and functional scans of the aforementioned uses.

- *gather and process secondary information to identify the function of the electromagnet, radio frequency oscillator, radio receiver and computer in the MRI equipment*

MRI consists of many parts:

- Radio Frequency Oscillator **-** This produce radio wave pulses of a particular frequency, amplitude, duration. When this pulse corresponds with the Lamor frequency of a nuclei, the nuclei absorbs this pulse and enters a higher-energy state.
- Radio Receiver – This detects the radio frequency of the nuclei when they relax. Since the signal is usually very weak, it is also amplified.
- Computer – This plays a key role in converting received radio signals and controlling the gradient magnetic field and pulse sequences.

- *identify data sources, gather and process information to compare the advantages and disadvantages of X-rays, CAT scans, PET scans and MRI scans*

The follow table depicts the comparison:

Procedure	Advantages	Disadvantages
X-rays – A Beam is directed towards the patient, image formed through shadows	➢ Cheap and simple ➢ Shows structural bone images well	➢ Not functional ➢ Resolution not good ➢ Radiation used
CAT Scan – X-rays are directed from around, to a patient and a slice is built up	➢ Better resolution than X-rays ➢ 3D image possible ➢ Good for tumours	➢ Not functional ➢ More expensive than X-rays ➢ Radiation used
PET Scan – Positrons emitted, gamma rays detected by a camera	➢ Structural + Functional ➢ Good for strokes	➢ Expensive to use eg. radioisotopes ➢ Radiation used
MRI Scan – Interaction of external magnetic fields and molecular spin	➢ No radiation used ➢ Provides the clearest picture (for brain MRI) ➢ Structural + Functional	➢ Requires a long scan ➢ Some cannot use eg. Pacemakers, metal ➢ Most expensive scan

- *gather, analyse information and use available evidence to assess the impact of medical applications of physics on society*

Medical applications of physics have had a significant impact on society:

➢ Health – Current medical applications provide more accurate and earlier diagnosis of numerous diseases and conditions. This has lead to a higher standard of living in society.

➢ Economic – Some medical applications are expensive to install and operate. MRI machines cost over $1 million each. This can be a large economic burden, including a need for more equitable access; however some see this as a vital long-term investment for eradicating diseases and illnesses in mankind.

➢ Moral – Current technology allows for the diagnosis of unborn babies and this may raise ethical and moral problems concerning termination.

➢ Knowledge – Medical applications have contributed to a better understanding of the structural and functional components of the human body. This has improved overall health, and development into more efficient health provisions.

On the whole, medical applications of physics have positively impacted society.

NB: *Structural refers to scans of the anatomical structure of the human body/organs. Functional refers to scans of real-time movement of bodily functions.*

Final NB Ever: *Check the Physics Formula Sheet for a complete summary of the Physics Formulae.*

Footnote: Many thanks to Louis Penna, Roger Kong, Aaron Goh and several others for their invaluable individual contributions. These notes are intended for educational use only and have been drawn from various un-cited sources. All merit resides and must reside with these sources. No rights reserved 2011.

Good Luck Boys!