HSC Physics Notes – From Ideas to Implementation

9.3 – 1. Increased understanding of cathode rays led to the development of the television

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

Observations suggesting that cathode rays were **charged particles**:

- **Do not** reflect at **equal angles**
- The rays are **deflected by both magnetic and electric fields**
- Travel **slower than the speed of light** or any other electromagnetic waves
- **Move in straight lines** – evidenced by sharp shadows of opaque objects

Observations suggesting that cathode rays were **waves**:

- Effectively **unaffected by gravity** (the extremely low mass makes it almost undetectable)
- **No** obvious appearance to be **deflected by electric fields**
- Could **travel through certain thin sheets of metal** (and were in fact so small they could travel through the crystal lattice of some metals)
- **Produce florescence**

Such varying characteristics and attributes that the cathode rays were exhibiting led to much confusion and debate to whether they actually should be classed as particles or waves; exhibiting characteristic properties of both.

2. explain that cathode ray tubes allowed the manipulation of a stream of charged particles

Production of Anode Rays
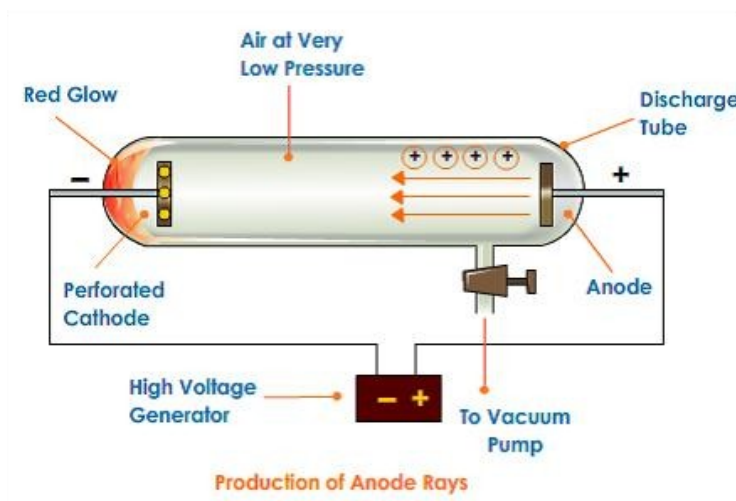
Cathode ray tubes (or discharge tubes) are glass tubes that have near **vacuum** pressures inside. The cathode ray tube is connected in series where a positive anode passes a stream of charged particles (electrons) through to the negative cathode where they are **emitted as a florescent glow.**

Only some of the charged particles return to the anode (because of their fast speed)

The stream of charged particles can be **manipulated by electric and magnetic fields**.

3. identify that moving charged particles in a magnetic field experience a force

Just as a current carrying conductor in a magnetic field will experience a force and resultantly move, so too do charged particles in a magnetic field. A current is simply a stream/flow of electrons (which are charged particles – along with protons) which are affected by a magnetic field. It is important to note **Faraday's field lines** which travel from **positive to negative** particles + same charged particles repel.

Moving charged particles will experience a force in the presence of an external magnetic field

4. identify that charged plates produce an electric field

Uniform electric fields can be produced when two parallel plates are placed a small distance apart and given a certain charge. The magnitude, or intensity, of an electric field is determined by finding the force acting on a unit charge placed at that point.

When a potential difference is applied across the plates, a <u>uniform</u> electric field is produced except where it 'bulges' at the edges accordingly with Faraday's field lines. **[right]** ▶
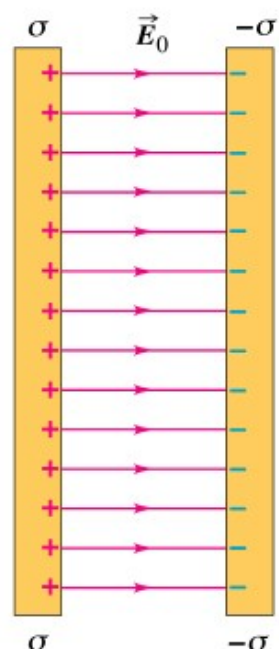
5. <u>describe</u> quantitatively the force acting on a charge moving through a magnetic field

If a particle with charge *q* is moving with velocity *v*, perpendicularly to a magnetic field of strength *B*, the particle will experience a magnetic force, *F*, given by:

$$F = qvB$$

where;
F = force (*N*)
**q** = charge on particle (either *electron* or *proton* – on data sheet)
v = velocity (*m.s⁻¹*)
B = external magnetic field strength (*T*)

The *direction of the force is given by the right hand push rule*. If the charged particle is **positive** (proton), then the flow of current is in the **direction of the velocity.** However, if the charged particle is **negative**, then the current flows in the **opposite direction to that of the velocity.**

If the charged particle moves at an angle θ, to the magnetic field, then we must adapt the formula so that

$$F = qvB\sin\theta$$
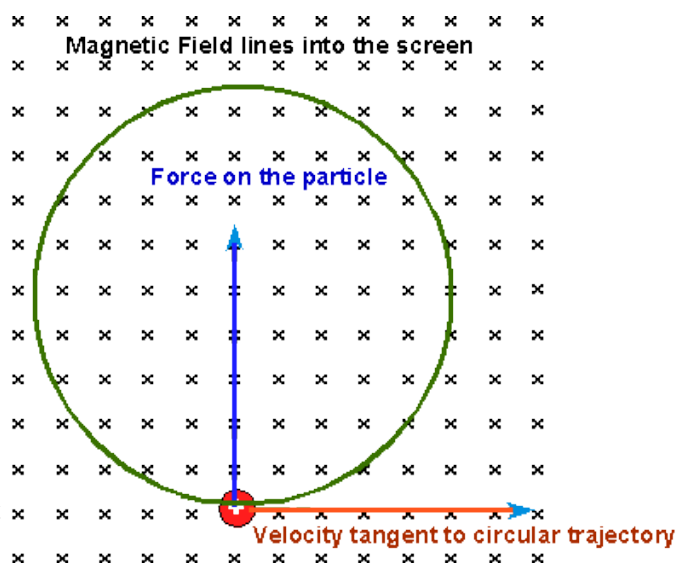
The value for **θ is taken from the line of velocity to the perpendicular to the magnetic field lines**. If the particle moves parallel to the magnetic field lines, then θ = 0 and therefore, F = 0. Since the *force acting on the particle will be changing the trajectory* (or path) of the particle, then the direction of velocity will also change and therefore move in a **circular motion**.

6. <u>discuss qualitatively</u> the electric field strength due to a point charge, positive and negative charges and oppositely charged parallel plates

It is important to know the flow of electrical field lines (by Faraday's work):

- **Positive charge:** field lines away from
- **Negative charge:** field lines into
- **Positive-Negative charge:** a constant electric field is established (bulging at the edges) which flows from the proton to the electron.

From a **point charge** (singular charge) the **electric field strength** that this particle emits becomes **less the further away** you are from it. The strength is also affected by the type of point charge which you are near – whether it is negatively or positively charged.

For **parallel charged plates**, the electric field flows from the positively charged plate to the negatively charged plate. The field is duly affected by the **distance between the plates** and the **strength of the potential difference** (emf) across the individual plates. If the same charged plates are placed near each other, the plates will repel.

7. <u>describe quantitatively</u> the electric field due to oppositely charged parallel plates

The magnitude of the electric field due to oppositely charged parallel plates is given by:

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

where;
E = electric field strength (*Vm⁻¹*)
V = voltage across plates (*V*)
d = distance between plates (*m*)

This equation for the magnitude of the electric field between the two oppositely charged parallel plates can derived with the knowledge that:

$$W = qV = \frac{1}{2}mv^2 \quad \text{and} \quad F = qE \quad \text{and} \quad W = Fd$$

Equating, such that **qV = Fd → qV = qEd**; and therefore **E = V/d**

8. <u>outline</u> Thomson's experiment to measure the charge/mass ratio of an electron

Thompson devised an apparatus to measure the **mass and charge ratio of cathode rays** (electrons) using a cathode ray tube. In his experiment, he verified an earlier hypothesis that **cathode rays could be deflected by an electric field** by placing oppositely charged parallel plates (capacitor plates) in the cathode ray tube where the rays **would travel through the uniform electric field**.

When conducting the experiment, Thompson observed that the stream of **cathode rays** passing through the uniform electric field, produced by the charged parallel plates, were **attracted to the positively charged plate** showing that the cathode rays **acted as electrons**. In Thompson's experiment, he varied two factors:

- **varying electric/magnetic fields:** Thompson conducted this until the two fields cancelled each other's force out (positioned at right angles to each other) so the cathode rays would be undeflected and pass through the fields to show a fluorescent glow. By **equating the magnetic and electric force equations**, he was able to **determine the velocity** and path of the cathode rays.
- **magnetic field alone:** By applying the magnetic field *uniformly* (alone) across the cathode rays, Thompson could **determine the radius of the circle path travelled by the charged particles**.

Thompson combined these two results and thus determined the magnitude of the charge-to-mass ratio of the cathode rays (electrons).

9. <u>outline</u> the role of electrodes in the electron gun, the deflection plates or coils and the fluorescent screen in the cathode ray tube of conventional TV displays and oscilloscopes

Cathode Ray Tubes are used in both conventional **TVs** and old CRT monitors – this also can be applied to **oscilloscopes** which create a green wave showing the variations in AC currents. The operate by *cathode rays being deflected in electron guns and fluorescing on a coated screen that activates phosphors to present the correct colours and image*.

– electrodes in the electron gun
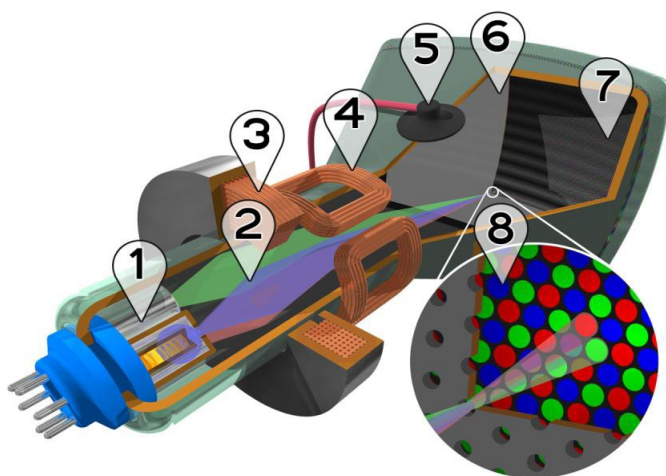
1. Electron guns
2. Electron beams
3. Focusing coils
4. Deflection coils
5. Anode connection
6. Shadow mask
7. Phosphors

The **electrodes** (i.e. the anode and cathode) **allow for a potential difference** to be applied and thus *cathode rays (electrons) can be emitted* from the cathode.

However, cathode rays are travelling at extremely fast speeds and only very few rays go back to the anode, while most continue on towards the screen.
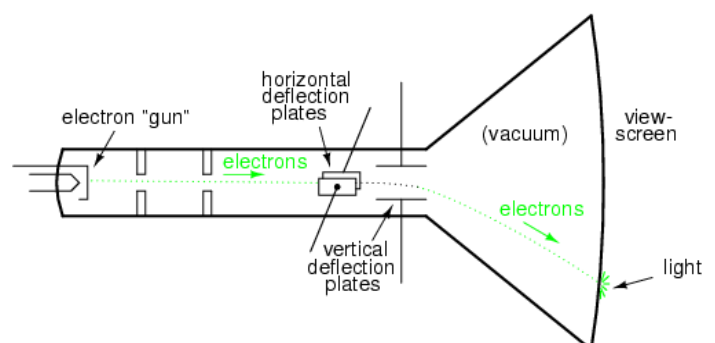
– the deflection plates or coils

Since cathode rays can be deflected because they are negatively charged particles, they are able to be deflected and their path changed. This principle is used by the **deflection plates**/coils in Cathode Ray Tubes to **alter the path of a cathode ray so that it can be directed to a particular part of the phosphor coated screen**.

Deflection plates are **positioned along the x and y axes** and *electric fields* are altered accordingly to change the path of the cathode rays.

– fluorescent screen

The screen of a conventional TV, CRT monitor or oscilloscope is **coated in layers of fluorescent phosphors** which are **activated when cathode rays hit** them. These display one of the primary colours.

Firstly, five discharge tubes were set up so that each had a different internal pressure than all the others and increased from near vacuum pressure (0 mm/Hg) up to approximately 40 mm/Hg. **Discharge tubes require very high voltages.** A power pack was used to achieve voltages of up to 12V, however, we tested potential differences that far exceeded this level to observe the effect this had in each differently pressurised tube – an induction coil was used.

We could conclude from the experiment, *by the observance of colours and striation patterns that the level of pressure in each discharge tube affected the transfer and slow of cathode rays* in each. **Low pressures** displayed a vast, **spread cloud of fluorescent light** while the **highest pressure displayed distinct thin lines** from the cathode to the anode.

If an induction coil is used to increase or decrease the voltage (and therefore the strength of the x-rays emitted), safety and care must taken when using them as high voltages can be sparked – a teacher should assist with the set up.

2. perform an investigation to demonstrate and identify properties of cathode rays using discharge tubes:
    – containing a maltese cross
In this experiment, cathode rays were projected in a discharge tube from the cathode to directly hit a maltese cross anode. It was observed that the **cathode rays created a shadow of this cross** on the end of the tube.

This therefore showed that electrons and *cathode rays are not affected by gravity* and they also therefore *travel in straight lines* – in order to form a shadow.
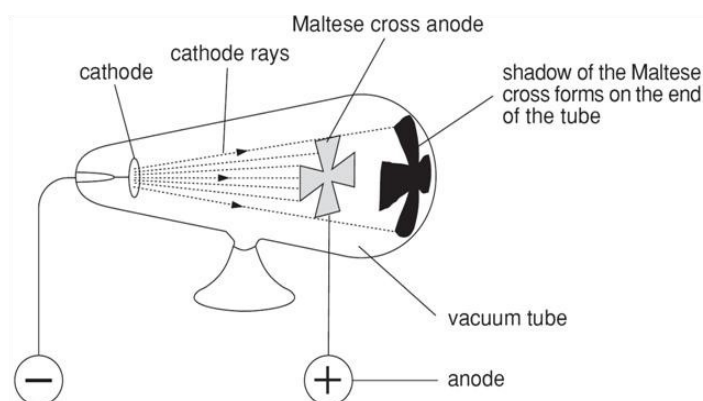
    – containing electric plates
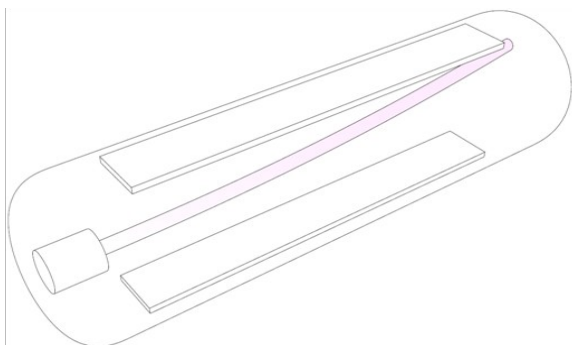
A cathode discharge tube was set up with two oppositely charged electric plates and placed along the y-axis of the cathode ray's path. The cathode rays passed through the electric field and were observed to attract toward the positively charged plate.

This therefore identified that the cathode rays acted like electrons and their velocity could be changed.

    – with a fluorescent display screen
Cathode rays were shone through a discharge tube onto a phosphorus coated screen which when observed, displayed the path of the cathode rays. On this fluorescent screen we were able to observe the effect that a magnetic field had on the cathode rays: when a magnet was placed near the cathode rays, the displayed rays' path was altered and we could conclude that:
    1. *magnetic fields* affected the path of cathode rays
    2. cathode rays *activate phosphors* and display colour.

    – containing a glass wheel
Possibly the most important experiment conducted was when cathode rays were projected toward a glass wheel that was free to move in a low pressure discharge tube.

The **glass wheel moved** as rays were projected from the cathode to the anode **which meant that the cathode rays must have a mass in order to have a momentum** to move the glass wheel. This meant that *cathode rays were particles*, as waves do not have a mass and would not move the wheel.
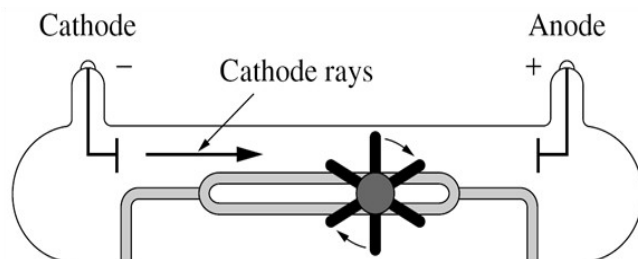
Through the analysis of the charged plates in the discharge tube, we are able to conclude that cathode rays are negatively charged and therefore must have a *negative sign* – acting as electrons do. This is because they were **attracted toward the positively charged plate** and repelled by the negatively charged plate.

3. solve problems and analyse information using:

$$F = qvBsin\,\theta \qquad F = qE \qquad E = \frac{V}{d}$$

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

1. describe Hertz's observation of the effect of a radio wave on a receiver and the photoelectric effect he produced but failed to investigate
The **photoelectric effect** is when **electrons are released from a metal surface**; exposed due to electromagnetic radiation. This is because the quanta of energy from the **electromagnetic radiation give the electrons the energy needed to escape from the metal**.
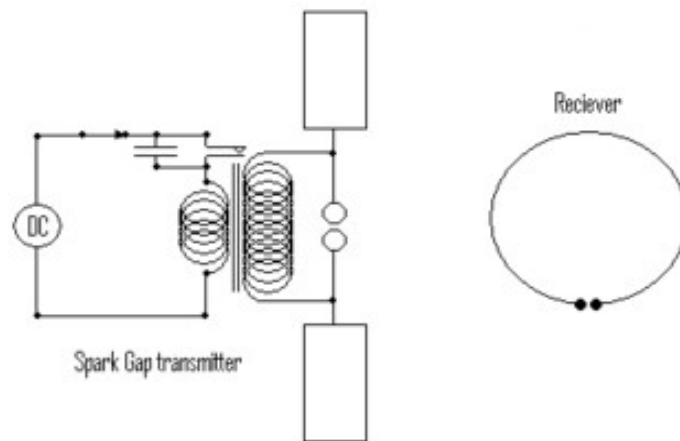
In Hertz's initial apparatus, he used an induction coil to create an oscillating spark from an AC current. From this, Hertz was able to observe that this **spark emitted electromagnetic waves which could be detected using his 'ring receiver'**. Hertz *observed a spark* (emittance of electrons) across the receiving terminals and concluded that these were radio waves.

Hertz was able to measure the speed, refraction, reflection and polarisation of these waves – demonstrating how they displayed similar characteristics of light. This was the first experiment that **showed the existence of electromagnetic waves and also demonstrated the photoelectric effect**; however, Hertz did not pursue and investigate this further.

2. outline qualitatively Hertz's experiments in measuring the speed of radio waves and how they relate to light waves
Hertz showed that these waves behaved like light. He showed that, like light, **radio waves could reflect, refract, interfere, diffract, be polarised** and travelled at the speed of light.

Hertz could infer the speed of radio waves by using the relationship that $c = f\lambda$. The **frequency** of **the emitted waves was determined by the number of windings in the induction coil, and the voltage and current** in the circuit. And the **wavelength** could be **determined by reflecting these waves of metal sheets** which was placed in front of the radio waves; an interference pattern would occur by constructively and destructively superimposing the waves over each other.
This discovery *verified Maxwell's equations* and therefore significant for further scientific research.

Hertz demonstrated that radio waves travel at the speed of light (and in fact, so do all electromagnetic waves).

<u>identify</u> Planck's hypothesis that radiation emitted and absorbed by the walls of a black body cavity is quantised

A ***black body is any object that will absorb 100% of radiation that hits it*** and therefore appears black. The black body theory can be observed and tested against a black, fully sealed <u>**furnace**</u> in which burns a hot fire that can monitored and a small cavity (hole) is drilled in the wall of the furnace.

We know that the furnace will not be able to let any radiation escape, however, the **walls of the furnace will begin to absorb the radiation** of the fire (such as ultraviolet and infra-red electromagnetic radiation). From the small cavity in the wall, some external radiation will be able to enter the furnace and be absorbed by the walls of the black furnace when that radiation hit it – however; ==radiation must also be emitted from the walls and therefore establishes an *equilibrium* state== (input = output).

Old theories had mathematically hypothesised the radiation and therefore appearance of certain bodies in accordance with the radiation emitted. Planck's hypothesis (proved in experimental data) was that **radiation from black bodies could be thought of as small 'packets' of radiation**, known as **quantum** of radiation and this **quanta could be measured**. Planck showed that the energy of each quanta (photon) emitted was proportional to it's frequency → this is shown by:
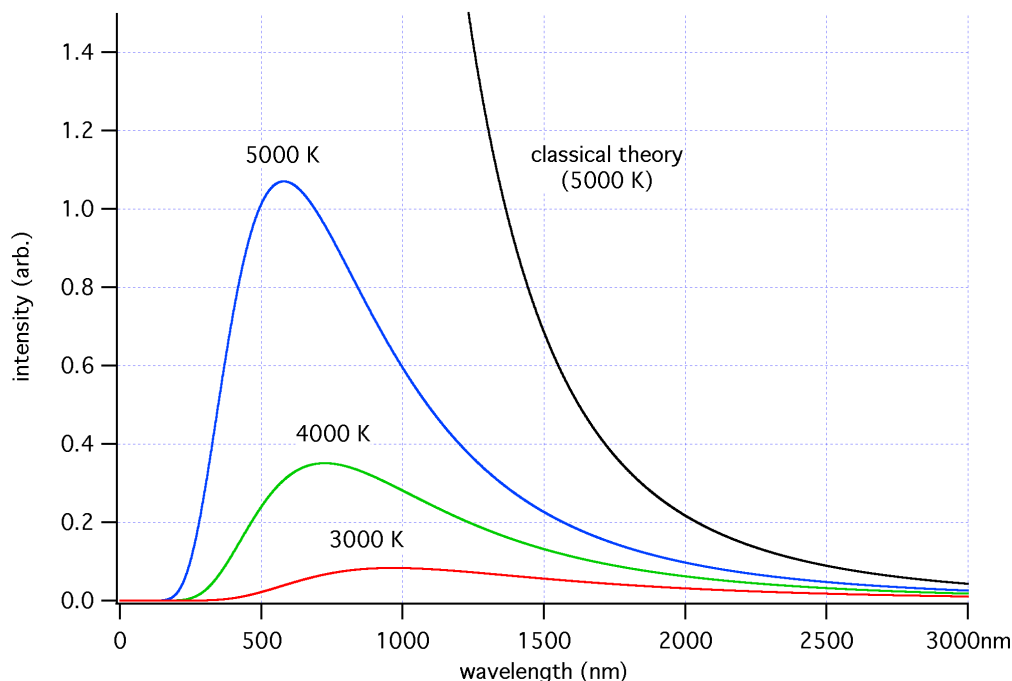
$$E \ = \ hf$$

where;
E = energy of quantum (*J*)
h = Planck's constant (***6.626 x 10^{-34} Js***)
f = frequency of electromagnetic radiation (*m*)

4. <u>identify</u> Einstein's contribution to quantum theory and its relation to black body radiation

Einstein used Planck's theory of the emission of energy from black bodies as quanta (packets) to explain the observations and characteristics of light (and all electromagnetic radiation) that could not be explained under the traditional and classical wave theories of light.

*The classical theory states that the emission of electrons is independent of the frequency, while Quantum particle theory states that the emission is frequency dependent and **have momentum**.*

Einstein stated that "**The simplest conception is that a light quantum transfers its entire energy to a single electron.**" In other words, the light quantum is acting as a particle in a collision with an electron. Einstein's particle theory was **able to explain all the observations of the emission of electrons from black bodies**; including the *threshold at which electrons were no longer emitted* and the intensity of the light emitted. It **explains the photoelectric effect**.

==**The intensity of light depends on the amount of photons, not the energy of the photons**==

5. explain the particle model of light in terms of photons with particular energy and frequency

The particle model of light is that *light energy travels in photons*; and it is that **energy in these photons that activate electrons in a metal.** When a photon strikes the metal, all (or none) of the energy will be passed on to the electron and then be emitted as a spark.

Photons have a particular energy and **particular frequency**

This particle theory was used by Einstein and explains how the intensity of light depends on the rate of photons.

6. identify the relationships between photon energy, frequency, speed of light and wavelength:

$$c(v) = f\lambda$$ → The speed of **light is proportional to a waves' frequency and wavelength**.

$$E = hf$$ → The **energy of a photon is proportional to its frequency**.

These two formulae can be merged in certain situations such that: $f = c/\lambda$ → therefore, **E = (hc)/λ**

1. perform an investigation to demonstrate the production and reception of radio waves

This investigation was simply using a step-up generator and solenoid to create a spark. The spark was generated when the high voltages jumped across the **varying size gap** – independent variable - (that was monitored and changed by the teacher).

With the knowledge that this oscillating spark would emit low frequency (and sometimes, moderate frequency) a normal radio was turned on to the AM setting. We first tested a station that had a reception on that band and during the broadcast, **intermittent cracks could be heard only when the solenoid was turned on**. We then investigated the effect of this EMR emitted on a channel that had no broadcast and it was extremely evident by the **effect on the static that radio waves were in fact being produced**.

Thus we had modelled the reception of radio waves based on Hertz's experiment.

2. 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
refer to orange dot point 4

Einstein's work was of significant contribution to the establishment of the quantum theory of light and establishing quantum physics is general. His discoveries in regard to the nature of photons and light were pivotal in the **development of the particle nature of light in the photoelectric effect**.

Einstein also devised his photoelectric equation which shows the maximum kinetic energy of different frequency photons against different metals. From this, Einstein's significance and impact extends into the **verification of Planck's constant** (*h*) which could be identified in the gradient of Einstein's plotted equation. Thus Einstein's contribution to quantum theory helps to **verify hypotheses of black body radiation and explains the monochromatic photoelectrons emitted from non-black bodies** which define their colours.

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

Photocells are devices which utilise the photoelectric effect to **convert electromagnetic radiation energy into electrical energy** to be used for practical functions.

The negatively charged **cathode will react in the presence of light** (or other electromagnetic radiations); when the *photons collide with electrons they are emitted* (escape) from the cathode sheet – this is the photoelectric effect. The **electrons** emitted from the cathode **travel to the positive anode and are measured by a galvanometer**. This was explained by Einstein using Planck's quanta theory of light.

Photocells are utilised in solar panels and solar cells. The cathode is is a sheet of silicon and gallium arsenide which reacts in the
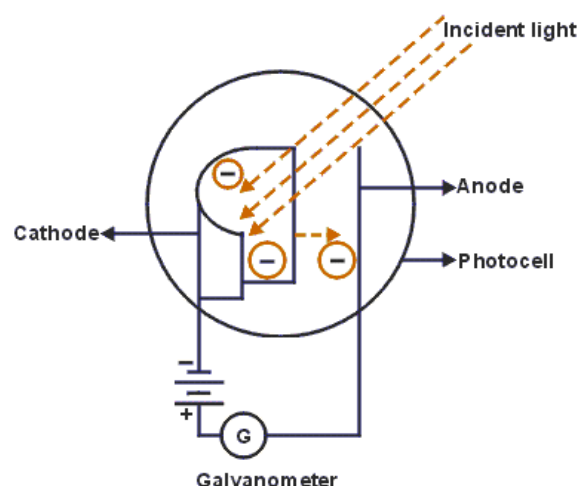
presence of the sun's photons. The **photoelectrons** which are emitted are able to be collected between the two layers and **used as electrical energy to power home appliances and water heating**.

We can apply the following formula:

$$KE_{max} \;=\; hf - \Phi$$

$E_{k\,max}$: maximum kinetic energy emitted by an electron (*eV - electron volt*)
hf: energy of a photon (*J*)
ϕ: minimum work required to remove the electron from the metal [work function]

4. solve problems and analyse information using:

$$c \;=\; f\,\lambda \quad \text{and} \quad E \;=\; hf$$

c = speed of light (*3 x 10^8 ms^{-1}*)
f = frequency of photon (*Hz*)
λ = wavelength (*m*)
E = energy of photon (*J*)
h = Planck's constant (*6.626 x 10^{-34} Js*)

5. process information to discuss Einstein's and Planck's differing views about whether scientific research is removed from social and political forces

Einstein: believed that scientific research and experimentation was integral to the progress and development of scientific theories that would one day affect and benefit society. The *political and social barriers to scientific research should be removed* and conducted regardless of debate and controversy. Scientific research should be conducted separate from these social and political forces.
- **Remained a pacifist**, however may have been compromised by the invention of the **atom bomb**.

Planck: believed that because most science benefited society, it **should comply with political and social regimes and beliefs**. If controversy was stirred in either politics or religion to due scientific experiment, then the research should end as this would appear to have no clear beneficiaries to society.

Despite this, **Plank supported the German war movement (WWI)** and worked as a scientist in the development of nuclear war weaponry for the Second World War. He maintained an **anti-Semitic approach**. This reaffirms Planck's view science should support political and social agendas. *World views affected scientific research*.

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

1. identify that some electrons in solids are shared between atoms and move freely
Metal lattices consist of an orderly **array of positive metal ions** which are bonded to each other. In order to maintain stability, **valence electrons are delocalised and shared between the atoms**. This electron sharing will only occur in metal substances or other solids which are *able to conduct electricity* with a 'cloud' of electrons that are free to move.

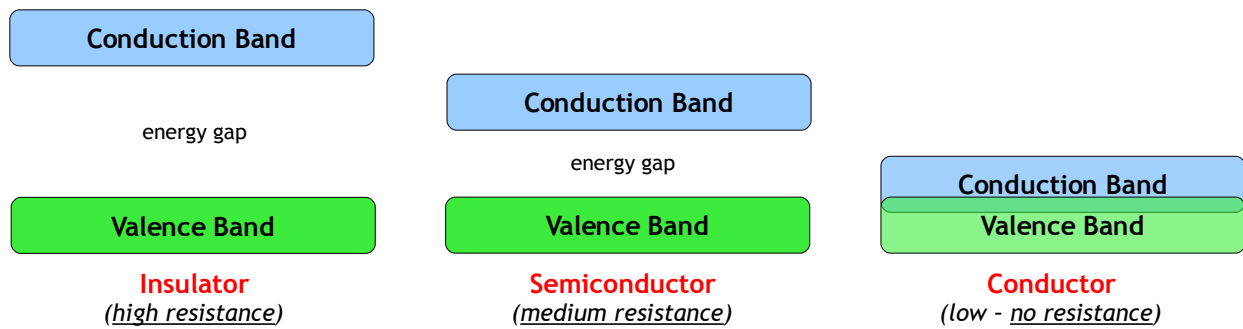Free Eelectrons (- charged)   Metal Ions (+ charged)
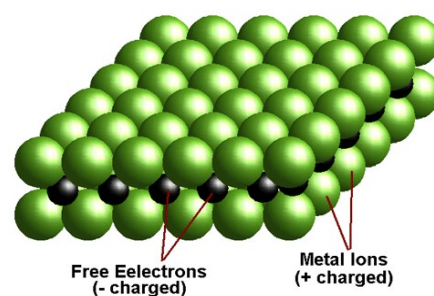
2. describe the difference between conductors, insulators and semiconductors in terms of band structures and relative electrical resistance
The difference between conductors, semiconductors and insulators is their level of electrical resistance or conduction due to the relative distance between their valence and conduction bands. The closer the valence and conduction bands are, the better the substance is at allow electrons from the valence band (shell) to pass onto the conduction band → and therefore conduct electricity.

Valence Band: is the shell, or band, of outermost electrons which are used to determine the reactivity and conductivity and bonding of a substance

Conduction Band: is the band which exists above the valence band and has no electrons in it. It is where electrons jump to if they are to conduct.

Conduction Band		
energy gap		
	Conduction Band	
	energy gap	
		Conduction Band
Valence Band	Valence Band	Valence Band
Insulator *(high resistance)*	**Semiconductor** *(medium resistance)*	**Conductor** *(low - no resistance)*

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

In substances (elements) which have a nearly full outer-valence shell, the **absence of an electron is known as a hole**. These elements, such as Fluorine are often one electron short of completing their valence shell and therefore a slightly positively charged. **When a potential difference is applied, other electrons are attracted to this Fluorine**, but are taken from another → this continues infinitely.

Therefore, *'holes' in valence shells of atoms and electrons help the flow and carry of current*.

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

Due to the nature of conductors, semiconductors and insulators + the distance of the valence and conduction bands in each; comparatively the amount of electrons that drift from atom to atom in descending order is:

conductors → semiconductors → insulators

Depending on temperature and humidity, since *resistivity decreases with increasing temperature*, conductors will allow many electrons to be passed through atoms. Semiconductors will allow less and insulators shall have no sharing of electrons.

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

Transistors are a form of semiconductor and are generally **composed of crystals from Group 4** on the Periodic Table. These elements consist of 4 electrons in the valence shell and will bond through strong *covalent bonding*; however, there is movement between some of the electrons.

In earlier times, **transistors were made from germanium**, despite silicon being a far better and pure substance for transistors. Germanium had to be used as this was the **only substance that could be purified to suitable levels**. Techniques and technologies had not been acquired to purify silicon to the required state.

6. describe how 'doping' a semiconductor can change its electrical properties

The **doping of a semiconductor is the addition of an a different of external atom to the pure crystal lattice** of the semiconductor. This different atom is known as a **dopant** atom and is defined by a *different valence level* which is considered an **impurity**.

Doping assists the conduction of the semiconductor because there is an **energy gap which allows for extra energy levels to be formed** and fill this gap between the valence and conduction gap. This means it is easier for these materials to conduct because the energy *difference between the valence and conduction bands* for such dopant atoms is less.

Conductors which have been **doped** are known as <u>**extrinsic**</u> semiconductors.

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

p-type and n-type semiconductors are those which have been altered in order to have an overall positive or negative charge. Doping will change the charge of a
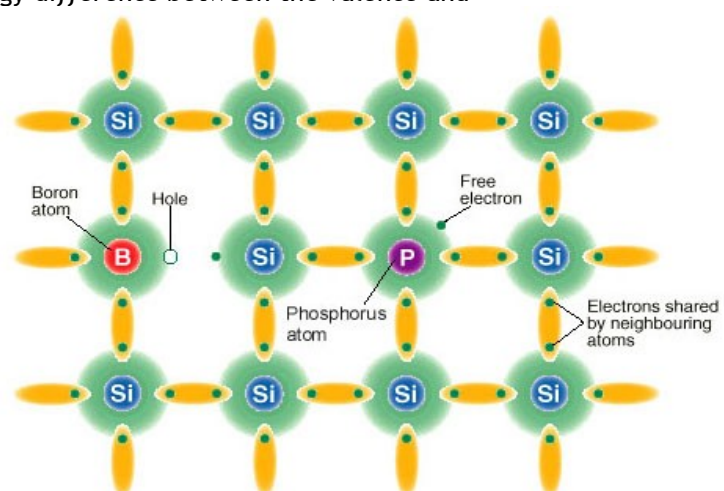
semiconductor since this will either leave holes in the valence shell or a sea of extra electrons.

Positive-type semiconductors arise when (taking silicon for example) silicon is doped with a dopant with a lower valence than silicon. **Silicon has a valence of 4, however, when it is doped with Boron which has 3 electrons in its outer shell and will create holes** in the silicon lattice. P-type = holes (positive).

Negative-type semiconductors occur when silicon is doped with an element with a higher valence, such as Phosphorus. Phosphorus has 5 electrons in its valence shell and when added as a dopant to the crystal lattice structure of the semiconductor, there will be extra electrons → creating an n-type semiconductor.

8. describe differences between solid state and thermionic devices and discuss why solid state devices replaced thermionic devices

Thermionic devices (**valves**) were only used in earlier times due to the lack of expertise and technologies to create the components of the solid state devices that change/alter and switch on/off current. They are employed in a range of devices. Solid state devices are better because:

- use **less energy** than thermionic devices
- run **faster** than thermionic devices
- are **cheaper, lighter and smaller** than their thermionic counterparts
- Solid state devices are **more reliable and stable** than the thermionic comparable devices – this is because *solid states use the solid state diode and transistors*, while *thermionic devices operated on valves* and were made from glass; making them more fragile
- produce **less heat**

Solid state drives replaced the classic thermionic devices because of the aforementioned superior properties and characteristics – there was no obvious need for thermionic devices any more since solid state devices operated better and were cheaper to make.

1. 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

To model a semiconductors behaviour, we analyse students and chairs:

students = electrons, chairs = holes

When a hole is created in an extrinsic semiconductor (that is, with impurities), this can be represented by a chair which is empty in the group of students. Due to the behaviour of holes and electrons (their positive and negative charge) – the *electrons will flow toward the holes in order to fill them* and complete the semiconductor.

Therefore, in the analogy, a person will continue to move to right to fill the chairs until the hole is on the left most side.

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

Before the use of semiconductors in solid state devices, **thermionic values were the main means of radio communication**. However, thermionic devices had many problems and were inefficient for global communication. **Due to this shortcoming in communication technology, research into semiconductors was commenced and therefore it was found that solid state devices could replace the older thermionic devices**.

It was the development of solid state devices that led researchers to the knowledge of and further investigation into the materials required for transistors. Conventional intrinsic transistors had required Germanium as their constituent material, however, testing and observations showed a far better conductivity was achieved when silicon was used. From this, **transistors made from silicon replaced their germanium counterparts and also replaced thermionic devices**.

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

The invention of the transistor has allowed the effective use and implementation of microchips and microprocessors. These microchips and processors have pushed society into a revolutionary

information age; finding practical application in many light, cheap technological devices – including calculators, small computers and *mobile phones*.

Because the transistor is used in any device which needs to monitor and change the current of the entire circuit, then transistors are also used in many other devices (including large computers and televisions) and these impact society in the forms of information, *entertainment and interaction with others* → for instance, without the invention of the transistor, microprocessors could not have been invented and thud mobile phones would not exist/operate as well.

Data Sources: Education DVDs, government and university (Charles Sturt) websites, reliable textbooks from accredited authors and publishers.

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

Light, as defined by the particle theory of light, travels in photons → and it is these photons that are required to affect the photocells and semiconductors in solar cells. Transistors are used in **photovoltaic cells** which are applied in solar panels and solar cells. When **light strikes the cell, some of the photons are absorbed by the silicon semi-conductive coating which is transferred through to the physical semiconductor.** The light *photons knock back the electrons from the valence band into to the conduction band so that they may induce a current between the n and p layers of the photovoltaic cell*.

The electrons which have been activated by the photons colliding with the silicon layer must travel a relatively far distance → so to **minimise energy losses**, a conductive **metallic grid** is placed between the layers to aid energy transfers.

◀[Thus, the effect of light (photons) on solar cells: is the *movement of electrons* into a semiconductor which induces a current and therefore a <u>potential difference is established</u>]▶
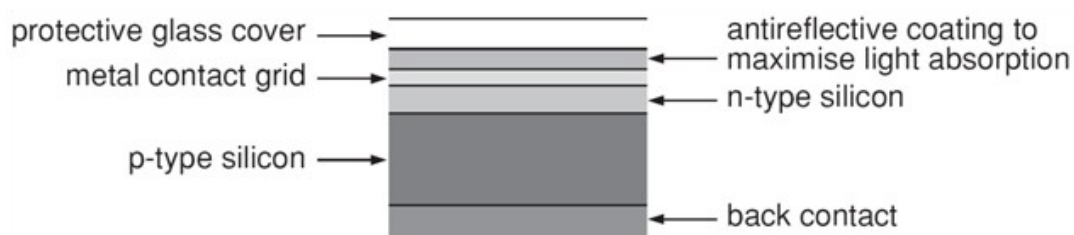

4. Investigations into the electrical properties of particular metals at different temperatures led to the identification of superconductivity and the exploration of possible applications

1. <u>outline</u> the methods used by the Braggs to determine crystal structure
Sir William and Lawrence Bragg studied the crystal structures using **X-rays**.

The Braggs used **parallel beams of x-rays which were shone through the crystal substance** onto a photographic plate which displayed the diffraction and patterns. The *incident rays hit atoms and reflected*, from this, scattered x-rays were observed and their **interference pattern depended on the wavelength** of the x-rays, the *distance between the atoms* in the crystal and the *angle of incidence* of the x-rays on the crystal planes.

Calculation of the angles between the bright spots forming the pattern on the photographic plate allowed the Braggs to determine the internal structure of the crystal.
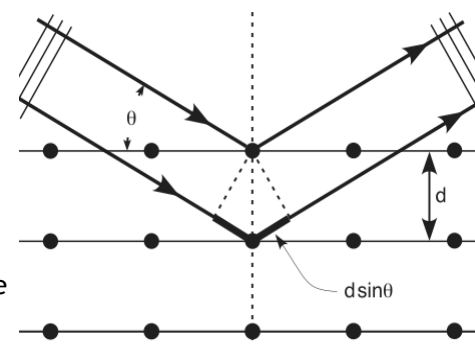
2. <u>identify</u> that metals possess a crystal lattice structure
Metals possess a crystal lattice structure that will alter and change depending on the type(s) of metals that it is composed. The lattice is a dense compaction of **atoms** which all **de-localise their valence electrons** so that a 'cloud' of electrons is free to move about positive ions.

3. <u>describe</u> conduction in metals as a free movement of electrons unimpeded by the lattice
Since metal structures follow that of a solid crystal lattice, then it is a strong substance and structure.
Conduction that occurs in metals is the free (and excited) movement of electrons, which is unimpeded by the crystal lattice.

4. <u>identify</u> that resistance in metals is increased by the presence of impurities and scattering of electrons by lattice vibrations
Generally speaking, there are **impurities** in most metals and these impurities create small breaks and gaps in the metallic crystal structure. These impurities act as barriers against the flow of electrons and impede the electron cloud's movement through the lattice structure.

The **hotter** a metal becomes, the more energised the electrons will become and consequently move about faster and in different directions. As a result, the electrons will scatter and cause the lattice structure to vibrate. The *collisions between electrons and the lattice*, along with the *vibrations* caused as a result, **impede the flow of electrons**.

The **impedance of electrons results in an increased resistance**.

5. <u>describe</u> the occurrence in superconductors below their critical temperature of a population of electron pairs unaffected by electrical resistance
Superconductors are materials (generally metals and ceramic hybrids) that, when in a cooled state, exhibit **near zero resistance and electrons are not impeded by the lattice structure** → thus there is no energy loss. Superconducting materials have a temperature at which they achieve this <u>superconductive state</u> → known as the <u>critical temperature</u> (and any temperature below).
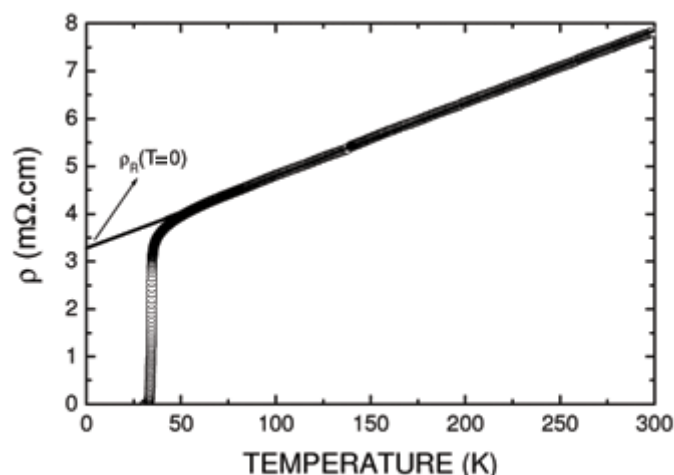

As explained by the BSC theory, **when a superconductor is cooled below its critical temperature electrons begin to pair** (however, are constantly forming and being destroyed) → known as a cooper pair. A **Cooper pair** consists of two electrons that are a considerable distance apart. The *attractive force* between the two electrons is *provided by the exchange of phonons (lattice vibrations)*.

6. <u>discuss</u> the BCS theory
Atoms in a crystal lattice are constantly vibrating. Because they are all connected, **these vibrating atoms create waves throughout the metal called phonons**. The more the atoms are vibrating (i.e. the hotter the material), the larger the phonons. In **superconductors** (at low temperatures) **the phonons are small,** and any distortion caused by the electrons is reflected in phonons. These phonons can attract electrons to form cooper pairs [described above].

Superconducting State
Area of distortion

Cooper Pair

The two electrons, called Cooper Pairs, become locked together and will travel through the lattice.

According to the Barden-Cooper-Schrieffer theory, atoms of metals in the superconducting state will have **electrons that lock and travel together** throughout the lattice. This pair of electrons causes the lattice to distort as the electrons move unimpeded.

This is because their **strong negative charge will repel any positive**
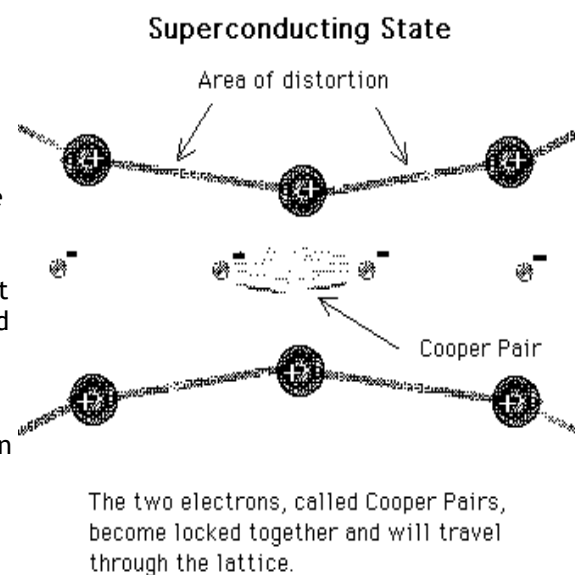
atoms that it gets close to, thus <mark>no collisions</mark> occur and electron flow is not resisted.

7. <u>discuss</u> the advantages of using superconductors and <u>identify</u> limitations to their use
Power Transmission:

Electrical *transmission lines lose an appreciable amount of power when transporting electricity to users because of the heat and energy transformations* it must make as AC power. The AC power Is required to be used so that it can be stepped up and down along its journey.

The application of superconducting materials for the transmission of electricity is a wide and prosperous field and would **eliminate the smallest of energy losses**. However, current *superconductors must be cooled* to extremely low temperatures so that they are below their critical temperature and will assume the superconductive state. <mark>When many materials are cooled so much they become extremely <u>brittle</u></mark> and are hard to manage because of their *size* and *weight*. Because of the temperatures required to achieve superconductivity and the brittleness that comes with this state → they are not employed to <u>replace traditional copper transmission lines</u>.

Electronics:

The *speed and further miniaturisation of computer chips* are <mark>limited by the generation of heat</mark> (due to resistance of the electric current flow required to make them run), and by the speed with which signals can be conducted.

Superconductors or a **superconductive film would have extreme advantageous implications** and revolutionise the digital world. Because superconducting materials have <mark>zero resistance, signals could be transmitted at or near the speed of light</mark> (like *optical fibres*) and there is <mark>no generation of heat</mark>. This would allow transistors and processors of <u>electronic devices to become smaller and faster</u>.

Magnetic Levitation (maglev):

Magnetic levitation is a fundamental characteristic and ability of superconductors and can be used by scientists to <mark>create a frictionless surface</mark> between objects. Maglev-systems are therefore extremely suitable for **trains** which can be magnetically lifted off the tracks, they are able to reach high speeds.

Electrodynamic suspension (EDS) systems are used in Japan to levitate streamlined trains by using superconductive magnets along the train and electrically conductive strips along the guidance track → which need monitoring and computer control.

The superconducting materials used in magnetic levitation are '**high-temperature superconductive**' materials and do not require to be cooled close to zero Kelvin → and therefore are *not as brittle* as the metallic superconductors.

1. 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

	Material	Critical Temperature (°K)
Metals	**Aluminium**	**1.2**
	Tin	**3.73**
Metal alloys	Ni-Al-Ge alloy	21
Compounds	$YBa_2Cu_3O_7$	90

2. perform an investigation to demonstrate magnetic levitation

To be able to produce magnetic levitation we must be able to **create a superconductor** using either a metal (such as Tin) or the Ni-Al-Ge Alloy. Allowing only the teacher to conduct and touch any equipment; the teacher will use temperature-controlled gloves and goggles and pour **liquid nitrogen** (which boils at approximately 77˚K) over the metal/alloy so that it will go below its critical temperature. Once the superconductor has achieved its superconducting state, *place a magnet above the superconductor and let go → it should levitate due to the presence of the magnetic field which will pass around the superconductor.*
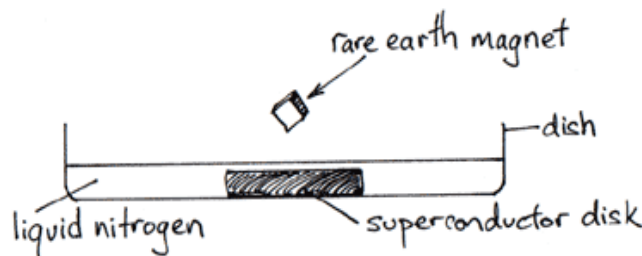

The stronger the magnet, the higher it will levitate. As the superconductor warms back to room temperature and goes above its critical temperature the magnetic will lower and sit back on the material.

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

A magnet is able to levitate/hover above a material that is below its critical temperature because of the Miessner effect. The **Meissner effect** is the **expulsion of a magnetic field from a superconductor during its transition to the superconducting state**.

When a material is cooled to its superconducting state, the Meissner effect applies → in which the magnetic field produced by the permanent magnet will not pass through the superconducting material. As a result, the *magnetic field lines are forced around the material which causes the magnet to lift above the superconductor.*
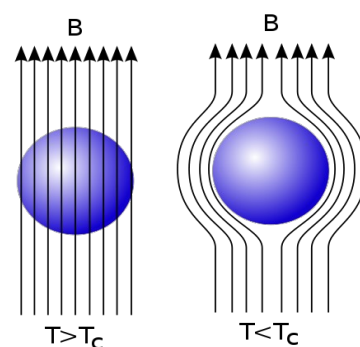
4. gather and process information to describe how superconductors and the effects of magnetic fields have been applied to develop a maglev train
Refer to orange dot point 4.7

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

- **Computer Chips:** Currently computer chips cannot be made smaller because of the *heat generated from resistance*. With **superconductors no heat** is produced and so wires and transistors on a *computer chip could be packed much more closely together* and with no heat produced, making computing power much more faster.

- **Generators and Motors:** The use of superconductors in generators and motors would mean *super strong magnets* and **no energy loss in the coils** of the motor or generator. This means that the generator or motor would be 100% efficient. This has not yet been achieved → however, if this could be achieved the *cost of electricity could be significantly decreased* and also have less impact on the environment as a result.

- **Transmission of electricity through power grids:** When electricity is transmitted through power lines, *energy is lost in heat due to resistance in the wires*. If superconductor materials were used for the wires, there would be **no heat lost from transmission**. The application of superconducting materials in power grids would significantly impact on power generation and use and therefore see an *efficiency increase*.