9.4 From Ideas to Implementation

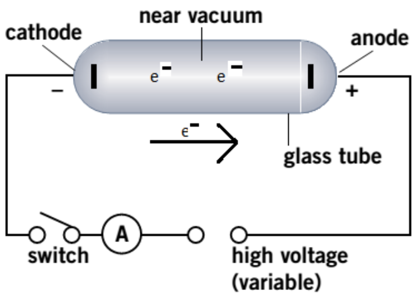
Contextual outline

By the beginning of the twentieth century, many of the pieces of the physics puzzle seemed to be falling into place. The wave model of light had successfully explained interference and diffraction, and wavelengths at the extremes of the visible spectrum had been estimated. The invention of a pump that would evacuate tubes to 10^{-4} atmospheres allowed the investigation of cathode rays. X-rays would soon be confirmed as electromagnetic radiation and patterns in the Periodic Table appeared to be nearly complete. The nature of cathode rays was resolved with the measurement of the charge on the electron soon to follow. There was a small number of experimental observations still unexplained but this, apparently complete, understanding of the world of the atom was about to be challenged.

The exploration of the atom was well and truly inward bound by this time and, as access to greater amounts of energy became available, the journey of physics moved further and further into the study of subatomic particles. Careful observation, analysis, imagination and creativity throughout the early part of the twentieth century developed a more complete picture of the nature of electromagnetic radiation and matter. The journey taken into the world of the atom has not remained isolated in laboratories. The phenomena discovered by physicists have, with increasing speed, been channelled into technologies, such as computers, to which society has ever-increasing access. These technologies have, in turn, often assisted physicists in their search for further knowledge and understanding of natural phenomena at the sub-atomic level.

This module increases students' understanding of the history, nature and practice of physics and the applications and uses of physics, the implications of physics for society and the environment, and the current issues, research and developments in physics.

1. **Increased understandings of cathode rays led to the development of television**	
Students learn to:	*Notes:*
▪ explain why the apparent inconsistent behaviour of cathode rays caused debate as to whether they were charged particles or electromagnetic waves	▪ In the 19th century, scientists experimented a vacuum tube with two electrodes attach to a voltage supply. When turned on, they noticed the presence of glow on the glass in the opposite end of the cathode (negative electrode). ▪ During the experiments, the experiments gave out observation of both electromagnetic waves and charged particles properties. Hence sparked the debates of **German scientists with electromagnetic waves** and **English scientists with charged particles**. ▪ **Charged particles nature:** – Since the ray **could push objects**, it was known to have **momentum and mass**, evident when placing a **paddle wheel** in the tube. This proves that it wasn't a wave as waves have no mass. – The ray was **deflected** when place in **between an electric field and magnetic field**. Hence it was **charged**. (Particle) – The ray emitted was a **straight line**, moreover a perpendicular to the cathode surface. Further proves that it is not a EM wave, since **light would emit everywhere**. – The ray travelled slower than a wave (light). ▪ **Electromagnetic waves nature:** – **Initially at first**, the ray **wasn't deflected** by the **magnetic field**, which backup the properties of a wave for a while. This was because they were an **unnoticeable deflection** due to the **lack of vacuum in the tube**. – The ray could **pass** through **thin sheet of metal without damaging it**. No particle was observed to do this. Hence support the light characteristic. – Travels in **straight lines**. – Causes **florescent (produces light)** ▪ These **inconsistent properties of both particles and wave** on cathode ray caused the **debate**.

▪ explain that cathode ray tubes allowed the manipulation of a stream of charged particles 	▪ **Cathode ray** tubes are evacuated tubes that have **low pressure density**, due the lack of air [vacuum tube]. They are sealed and containing two cathodes. ▪ **Positive charged anode** and **negative charged cathodes** are placed in opposite ends of the tube. ▪ When **potential difference** is supplied to the negative cathodes, it will emit **a steam of charged particles**, commonly known as cathode rays. ▪ Note that **positively charged particle (cations) attract cathode**, and **negative charged particle (anions**) will attract anode. – **Cations:** is when atoms lose electrons, hence becoming positively charged. – **Anions:** is when atoms gain electrons, and becoming negatively charged. ▪ The (negatively) charges particles (electrons) accelerate towards to anodes. ▪ The cathode rays will cause the glass to glow green. ▪ A discharge tube is where a vacuum pump is installed to **variate the air pressure**. Different air pressure can produce **different visible light**. ▪ Also, placing an electric field or a magnetic field surrounding the tube will cause deflection of the steam.
▪ identify that moving charged particles in a magnetic field experience a force	▪ When some current flows in a magnetic field, it will **experience a force**. ▪ Similar a charged particle in motion in a magnetic field, will also experience a force. ▪ Given by the equation: $F = qvb\sin\theta$ $F = \text{Force (N)}$ $q = \text{electron charge } (1.6 \times 10^{-19}\text{ C})$ $b = \text{Magnetic Field Strength (T)}$ $\theta = \text{angle of charge and magnetic field}$
▪ identify that charged plates produce an electric field	▪ **When two sheet of metal plates are placed within a distance and is connected to a power supply, it will produce an electric field when turned on.**
▪ describe quantitatively the force acting on a charge moving through a magnetic field ▪ $F = qvB\sin\theta$	▪ The force is basically the charge particle moving in a magnetic field. $F = qvb\sin\theta$ ▪ The **Right-Hand Palm Rule** is use to determine the direction of force. ▪ Sometimes the force on the changing particle will change, causing the direction of the particle to change, hence follows a **circular path**.

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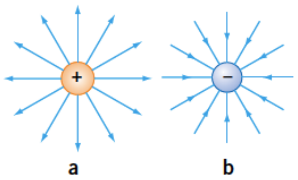
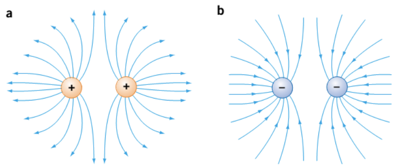
- discuss qualitatively the electric field strength due to a point charge, positive and negative charges and oppositely charged parallel plates





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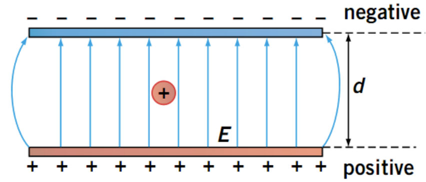
- A positive and negative point charge will create an electric field. Same occurs between oppositely charged parallel plates.
- They are determined by field lines which are radiated out of positives and in by negative.
- In Diagram 1: Shows two the direction of two opposite point charges.
- In Diagram 2: Portrays like charges and the repulsive force.
- In Diagram 3: Simulates an electron within an electric field, produced by parallel plates.
- Within the field lines:
  - All the lines exiting or entering the point charge is perpendicular.
  - Field lines never cross.
  - Having closer field lines means they have stronger fields.
  - Further field denotes a weaker field.
  - In parallel plate the field lines should be equal distance apart, with two out field lines bending (as shown in diagram). This is to shown the uniform electric field strength.



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- describe quantitatively the electric field due to oppositely charged parallel plates

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- **Electric Field Strength** is denoted by the equation:

$$W = F \times d, F = \frac{W}{d}$$

$$\text{Also } E = \frac{F}{q} \text{ and } W = V \times q$$

$$\text{Therefore } E = \frac{V \times q}{d \times q}$$

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

$$E = \text{Eletric Field Strength } (Vm^{-1})$$

$$V = \text{Voltage between plates } (V)$$

$$D = \text{distance between plates } (m)$$

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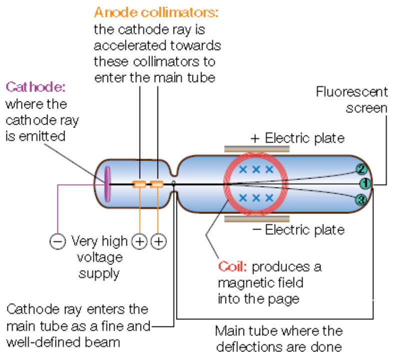
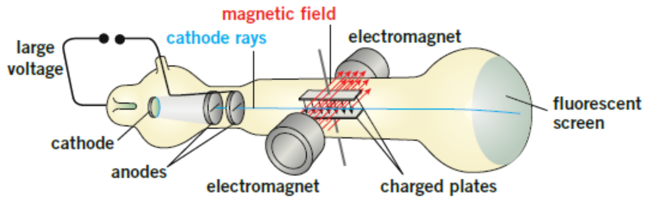
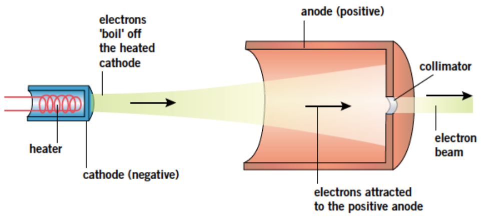
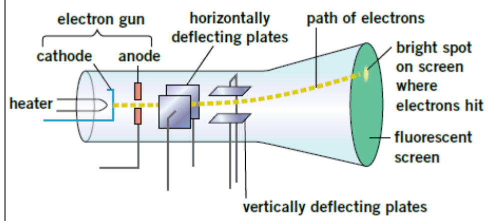
▪ outline Thomson's experiment to measure the charge/mass ratio of an electron
 	

 	
1 When undeflected, the cathode ray travels straight to the mid-point of the fluorescent screen. This happens again when the deflection due to the electric field is balanced out by the deflection along the magnetic field
2 Deflection of the cathode ray due to the electric field
3 Deflection due to the magnetic field
	▪ **JJ Thomson** in **1897**, conducted an experiment that could deduce the **charge/mass ratio** of an **electron**.
	
	
	▪ Thomson's CRT was shown to have a **cathode** and **two anodes**. The anodes were **separated** by **a small distance** and contained **horizontally slits** for the cathode rays to pass. These slitted anodes were known as **anode collimators**, and their purpose was to allow cathode to pass the anode and become a **well-defined beam**.
	▪ As the cathode rays **accelerate** through the tube, it was **subjected to charged plates** which provided an electric field and electromagnets which supplied a **magnetic field**. Note that the electric field and magnetic field was placed in **equal at opposites directions** to each other..
	▪ As it passes it will deflect which proves that they were charged particles and not electromagnetic waves.
	▪ It was noted that the **deflection** moves towards the **positive plates** proving that it was **negatively charged. (Electrons)**
	▪ At the end, it hits the **fluorescent screen**.
	▪ The experiment was conducted in two forms:
	– **Velocity**
	  – It was known that electrons (cathode rays) were affected when subjected to an **electric and magnetic field.**
	  – Hence Thomson varied the electric field and magnetic field until they **cancelled out** and there was **no deflection**. It was not deflectable.
	  – But doing this he could determine the **velocity of the cathode rays**.
	  – The electric field would **equal** with the magnetic field.
	$F_E = F_B$
	$qE = qvB$
	$E = vB$
	$v = \frac{E}{B}$
	$v = \text{Velocity } (ms^{-1})$
	$E = \text{Eletric Field } (Vm^{-1})$
	$B = \text{Magnetic Field Strength } (T)$
	– **Charge/Mass ratio**
	  – By **turning off the Electric plate**, the **magnetic field** provided the turning of the path in a **circular path**. This determines **a centripetal force** acting on the ray.
	  – Hence the centripetal force was **equal** with the moving charge in a magnetic field.

	$$F_c = F_B$$ $$\frac{mv^2}{r} = qvB$$ $$\frac{mv}{r} = qB$$ $$\frac{m}{q} = \frac{rB}{v}$$ $$\text{Substituting}, v = \frac{E}{B}$$ $$\frac{m}{q} = \frac{rB}{\frac{E}{B}}$$ $$\frac{m}{q} = \frac{rB^2}{E}$$ $$\frac{q}{m} = \frac{E}{rB^2}$$ $$\frac{q}{m} = \text{ratio of charge/Mass}$$ $$E = \text{Eletric Field Strength } (V\ m^{-1})$$ $$r = \text{Radius of Curvature in the ray } (m)$$ $$B = \text{Magnetic Field Strength } (T)$$ ▪ **Conclusion:** – Thomson was about to calculate E with the measured distance (D) and the potential difference provide (V). – He also could calculate the B, with the number of coils and the current through the coil. – And finally, carefully measuring the radius he **could calculate the charge/mass ratio**. – When equated, and concluded that the results q/m $$\frac{q}{m} = 1.76 \times 10^{11}\ Ckg^{-1}$$ – The value was the same in any material of the cathode tubes and allowed for the **ending of the debate** that the cathode rays were indeed **negative charged particle known as electrons**. This constant values further proves that all. – The value was relative high for a particle; thousand times smaller than Hydrogen, indicating that they were either **very light** or **very high in charge**.

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





- **CRT** are usually found in **Cathode ray oscilloscopes (CRO)** and **old television** and computers.
- Usually CRT consist of **electron gun, deflection plates or coil and a fluorescent screen**.
  - **Electrodes in electron gun**
    - An **electron gun produces** a **beam of cathode rays (electrons).** They consist of a **heating filament, a cathode and a number of anodes**.
    - This allow helps **accelerate** and put **focus** on the electron beam.
    - When the **heating filament (wire) emits thermal energy** by applying a large current, it will heat the cathode which **releases electrons**. (**Thermal emission**)
    - Positive anodes are placed in front of the cathode so it can accelerate the beam of electrons.
    - A number of anodes are placed for **focusing** and **controlling the brightness**.
  - **The deflection plates or coils**
    - **Deflection plate**s provide an **electric field** which help **deflect** the cathode rays
    - Consist of two sets of parallel plates are connected to a potential difference, creating an electric field.
    - When the parallel deflection plates are placed **horizontally**, the beam could deflect **left or right**.
    - When the plates are placed **vertically**, the beam could deflect **up or down**.
    - The amount of deflection can be controlled with varying the electric field.
    - Deflection plates can also be replaced with coils to create a magnetic field to achieve the same purpose.
  - **The fluorescent screen in the cathode ray tube of conventional TV displays and oscilloscopes**
    - At the **end** of tube is a **fluorescent screen**.
    - It is made by coating fluorescent material on the **glass tube**, which will allow for emission of **light** when high moving **beam of electrons strike the surface**.
    - The screen acts as a **visible detector** for the cathode rays.

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<tr><th>Students:</th><th>Notes:</th></tr>
<tr><td>▪ perform an investigation and gather first-hand information to observe the occurrence of different striation patterns for different pressures in discharge tubes</td><td>▪</td></tr>
<tr><td>▪ 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</td><td>▪ Discharges tubes can pose high level of risks. High voltage can cause electric shock so to minimise the risk, keep a safe distance. Also, the use induction coil, cause X-rays which is harmful to human cells.
– Containing a Maltese cross (Wave/Light)
▪ By having a Maltese cross placed inside the tube near the end of cathode, a shadow of the cross was cast on the fluorescent side.
▪ As the cathode rays beamed onto the cross, it can be determined that the beam was block by the cross, hence a shadow.
▪ Further proves that the beam travel in straight lines like a wave.
– Containing electric plates (Particle)
▪ Parallel plates are insert either horizontally or vertically. These electric plates provide an electric field.
▪ As the cathode rays passes through these electric field, it is observed to be deflected. This deflection was influenced by the air pressure in the tube.
▪ It could be detected by a slope in the fluorescent screen. The path of the beam was tilted to the positive end of the plates, conveying that it is negatively charge.
– With a fluorescent display screen
▪ A fluorescent screen is placed at the end of the CRT.
▪ When the beams hit the screen, it was seen to be glowing, which could be explained by the beam carrying large enough energy to produce reactions on the screen (visible light)
– Containing a glass wheel
▪ A glass paddle wheel for placed in the tube and was able to freely rotate.
▪ As the beam shone on the paddle wheel, it could be moved and rotated.
▪ This observation proves that the beam must have mass as the Law of conversation of momentum, indicates that in order for momentum or motion, there must be mass.</td></tr>
<tr><td>▪ solve problem and analyse information using:</td><td>▪</td></tr>
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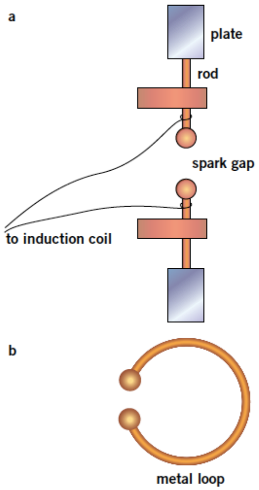
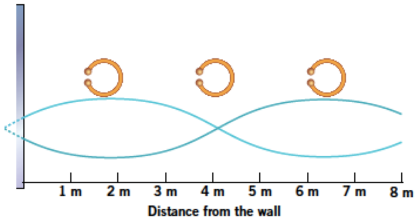
$F = qvB\sin\theta$ $F = qE$ ▪ and $E = \frac{V}{d}$	

2. The reconceptualization of the model of light led to an understanding of the photoelectric effect and black body radiation	
Students learn to:	*Notes:*
▪ describe Hertz's observation of the effect of a radio wave on a receiver and the photoelectric effect he produced but failed to investigate 	▪ Side Note: **Maxwell** was a Scottish Physicist to first derive the **nature of light and E-M waves**. – From his studies about Faraday's electricity and magnetism. He derives fundamental equations that linked the two concepts. – He predicted that oscillating electric charges should produces wave that were able to travel in space at the speed of light. – These waves consist and electric and magnetic waves are oscillating perpendicular to one another and commonly known as electromagnetic waves. – His was able to conclude that EM wave: ▪ **Hertz** was the person to **further verify** that there were **E-M waves other than visible light**. ▪ In **1886**, Henry Hertz conducted an experiment proving Maxell's' prediction. ▪ The experiment was known as the **Hertz spark-gap coil**: – An **induction coil is attach to two rods with plates**. This allowed for high voltages to surge to the sphere at the end, with one being positive and the other being negative. This was his **transmitter** – A coil shaped like a **loop** with a **gap** was his **receiver**. [**loop, detector loop, receiver**]. ▪ **Observation**: – When the induction coil was switched on, and the loop was **held near the transmitter** he notices that secondary spark occurred in the loop, **simultaneously** as when there was an occurrence of spark in hid transmitter. He observed that the spark could occur **without** the need to **connect to any source of electrical current** or any **physical contact** to the transmitter. – He observed that the **AC voltages** supplied to the induction coil, allowed for a **back and forth motion of spark** which **causes a changing electric and magnetic field**. This was just like how **Maxwell purposed EM waves, and Hertz's experiment was the cause of radio waves.** – He also saw that these invisible radiation had light waves properties. ▪ They could be **reflected with metal mirrors.** ▪ **Refracted through different medium.**

	▪ **Interference through different sources**. ▪ **Moved** at the **speed of light**. ▪ Could be **polarised**, by placing the loop **perpendicular to the transmitter**, it causes for **no spark**, whereas placed **parallel gave a full spark**. ▪ He also noticed the spark could **varied** depending on the **distance and placement of angles**. – He further noticed that when **exposed to UV light [Sunlight],** the **spark in the detecting loop was intensified**, but **failed to investigate further**, due to his **demise shortly after.** ▪ This was done by placing the **experiment** in a **dark room [No UV]**, **compared** to one in **the broad sunlight**. There was a **different in the intensity of spark** and the **initial** discovery for **"Photoelectric effect"**. Proved that **light and electricity** had **similarity** in EM waves. ▪ He also compared by placing a **glass** to **prevent ultraviolet transmission**, **reducing** the production of **spark** to a **quartz glass** which **allowed** for **ultraviolet transmission**. This cause the spark to be produced more **easily**.
▪ outline qualitatively Hertz's experiments in measuring the speed of radio waves and how they relate to light waves  Figure 9.1.6 Standing electromagnetic waves produced by reflection from a large zinc plate enabled Hertz to measure the speed of light.	▪ In order to prove his **invisible waves were electromagnetic waves** like light, he conducted another experiment to **measure the speed**. ▪ **Standing Wave experiment:** – This consist of the notion of an **interference pattern** in waves, using **superimposed** waves. **Constructive and destructive waves** an interference in the standing wave using the known **frequency**. With this we can calculate the **wavelength** and hence the **speed of radio waves**. – A **standing wave was two waves that had the same amplitude, frequency but oscillated in different direction.** ▪ When these **two waves combined**, they form a super positioned wave, where they will experience **zero amplitude** and are known as nodes [**destructive**]. ▪ The **crests** of the wave will have **maximum amplitude** and are known as anti-node [**constructive**]. – He formed a standing wave of electromagnetic radiation via, reflecting his waves from a large zinc plate. This allowed for **two paths**; one directly to the **detector loop** and the other **reflecting of the zinc plate at an angle**. This allowed for the interference pattern and determination of the wavelength. – The **spark** on the loop would be **induced at anti-nodes** and **not at nodes**. Hence, **logically, half a wavelength** can be **determined** by **moving the detector loop from a spark to the position on no spark**. Doubling the length will provide a wavelength. – Thus, will the wavelength found and the predetermined **frequency**, using the equation, $v = f\lambda$ – More Research ➔ Wavelength of the wave was measured by setting up the receiver loop at intermediate angles to the transmitter, the interference of currents providing a measure of wavelength of radio waves ▪ **Result**:

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– Hertz' was able to conclude that his **calculation remained** the **same** with the difference value of wavelength.
– More importantly, he measured it to be near **3x10^8**, which was the same to **Maxwell's** predict/theory. This proves that Maxwell's theory, and Hertz experimental provided **evidence** for show light as a form of **transverse electromagnetic waves**.
– He also was able to conduct mini experiment to further identifies properties related to EM waves.
▪ Pitch prism was used to determine that light can be refracted.
▪ Polarisation could be determined by rotating the loop.
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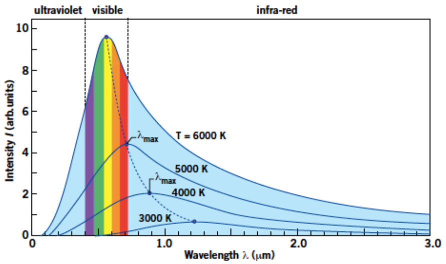
▪ identify Planck's hypothesis that radiation emitted and absorbed by the walls of a black body cavity is quantised


Figure 9.2.2 The intensity of light from a hot object is dependent on wavelength.
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▪ **Black body radiator: General term for an object that has the ability to perfectly absorb and emit radiation on energy. [None of the energy is reflected or passed through]**
▪ Black body absorber and black body emitter.
▪ **Background Notes**:
– Maxwell's theory of electromagnetic waves led to scientist to solve the problem of radiation from hot objects.
– Objects t hat are heat will tend to glow red to yellow and blue and white. [This occurs as the temperature increase without melting]
– This notion of brightness and intensity depends on the wavelength and temperature.
▪ **Black body comes in the amount known as quanta, given by the equation, E=hf.**
▪ Random fact:
– As **frequency increases**, the **wavelength should decrease** and vice versa.
– When the black body has higher frequency, it will have more energy, and hence be hotter.
▪ **Black body diagram**:
– It is shown that as **temperature increases**, the **wavelength** emitted will **decreases** and hence a **higher frequency**.
– This means that the **intensity** of the black body will **increase** and thus become **hotter**.
– Usually temperature heated up will be around wavelengths of visible light, where the spectrum of colours denote for hot the black body is.
– As **temperature increases**, it will start to glow **red**, to **yellow**, **blue** and **white**. If the black body is able to withhold these temperatures, and allow for an increase in temperature, then eventually they will emit harmful waves.
– Although this case is less likely as it will violate the conservation of energy with classic physic.
▪ **The Ultraviolet Catastrophe**
– In **Classic physics**, it predicts that has **wavelength decreases**, the **radiation emitted will increase**.
– Simply as **wavelength** become **shorter**, the **radiation intensity increases without limit**.
– Thus, as **temperature increases**, the **wavelength will approach zero**, and plotted on the intensity vs wavelength, **its intensity is infinity**.
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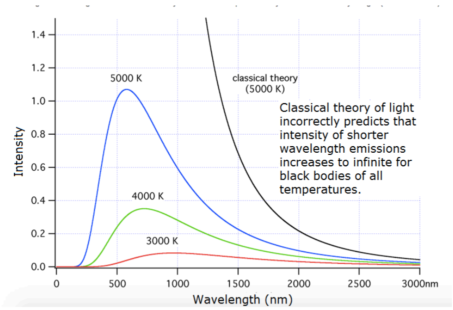


- This notion, **violates** the **law of conservation of energy, as shorter wavelength = higher frequency = more energy.**
- Also, it didn't match the **experimental observation.**

- **Plank's hypothesis**
  - **Max Plank** in 1900, invented **Quantum physic** stating that **all energy is radiated and absorbed into discrete packets [quanta].**
  - Simply states that all **energy** is **quantised**.
  - This can be given by the **equation** showing that not just any value but multiple of value.

$$E = nhf$$
$$\text{where } E = \text{Energy of photon (J)}$$
$$n = \text{Number of quantum (must be interger)}$$
$$h = \text{Plank's constant } (6.63 \times 10^{-34})$$
$$f = \text{frequency of EM radiation (Hz)}$$

  - Also, given the equation, $v = f\lambda$, the energy being emitted and absorb was electromagnetic waves which all travel at c. Hence,

$$v = f\lambda$$
$$f = \frac{v}{\lambda}$$
$$\text{and since } v = c$$
$$f = \frac{c}{\lambda}$$

  - Hence the equation of **quanta** and **photons** could be equated as,

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

  - Energy of each packet of **light** ➔ **Photon**.
  - Plank's hypothesis spark the revolution and the creation of **quantum theory and quantum physics**.

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

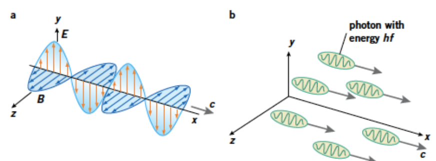
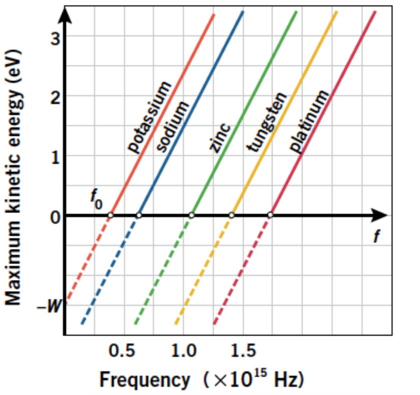


Figure 9.2.5 Light can be shown as (a) an electromagnetic wave and(b) a collection of particles called photons.

- With Plank kind of restricted and disagreed with his theory, denoting that is was a mathematical trick and limited himself.
- However, Einstein help further improve Plank's hypothesis making EMR, mainly light wave a concentrated bundle of energy, known as photon.
- With Einstein being able to extend Plank's theory and applying it to light, he was able to explain the photoelectric effect.
- Photon
  - Photon was discreet packet of energy [quantised].
  - They were proportional to the frequency, given the equation, E=hf.
  - Photons cannot be transfer by parts, only as a whole, or none.
  - With Einstein, insinuating that EMR are form of photon, he proposed that light is a particle and not a wave.



- Wave-particle duality ➔ EMR acts as neither waves or particle but as photon. Einstein believe that EM waves were photons, and a flow of photon is known as a wave.
- Light intensity depends on the number of photon. Increase in photon, higher light intensity.

- Photoelectric Effect
  - Definition One: the photoelectric effect is the liberation of electrons from a metal surface by electromagnetic radiation.
  - Definition Two: the photoelectric effect is the emission of electrons from a polish metal surface when light is shined on it.
  - Require a minimum energy for the emission of electron known as the work function.
  - History ➔ The photoelectric effect was first discovered by Hertz in his Hertz spark gap experiment.
  - Given by the equation,

$$KE = hf - W$$
$$KE = \text{kinetic energy of the photon}$$
$$hf = E = \text{photon}$$
$$W = \text{Work function}$$

  - When KE is plotted on a graph, we see that it is a linear line.

$$KE = hf - W$$
$$y = mx - b$$
$$\text{where the gradient, } m = h = 6.63 \times 10^{-34})$$

  - Determination of the minimum frequency, if we are given the KE and f and W,

$$\text{Using } KE = hf - W$$
$$\text{we work out for } W$$
$$\text{with } W \text{ that is the work function, infering to the minimum energy required to liberate electrons}$$
$$W = E = hf_o$$
$$\text{where now since } W \text{ is the minimum, we can found the minimum frequency, } f_o.$$

- **Classical Physic Vs Quantum Physic**
  - If we applied classical physic to the photoelectric effect, it would violate laws and will not be able to explain some of the phenomenon. [Classical physic statements are wrong].
  - Intensity problem
    - Classical Physic: Classical physics states that when light was more intense (increase in the intensity of light), the energy of light increase. This meant that the amount of photoelectron was dependant of the amount of intensity in the light.
    - Quantum Physic / Experimental data: Quantum physic states that it is not dependant on the intensity but the frequency of light. When experimented, EM waves and light were observed with the change of intensity and some of the light spectrum

	didn't show the photoelectric effect despite having its intensity strengthened. Eg. Red light failed to show the photoelectric effect with on increased intensity. – **Frequency problem** ▪ Classical physic: Classical physics states that the ejection of electrons should come from any frequency of waves because the photoelectric effect stems only from the intensity. ▪ Quantum physic / Experimental data: Quantum physic states like above, that frequency is important for the photoelectric effect. Threshold frequency is the term used to define the minimum frequency of incident light to cause the emission of electron. Experimental data showed that higher frequency tend to have a better liberation then lower frequency despite the intensity of light. Eg. Blue light and purple will liberation more electron then yellow, and will have no liberation on red light. – **Time emission** ▪ Classical physic: Classical physic states that energy could be absorbed until a sufficient amount. Meaning that over time, the energy is absorbed slowly will have energy for even low intensity light to emit. ▪ Quantum physic / Experimental data: Quantum physic states that there is no build up to a sufficient energy, as quantum theory already showed that energy come in discreet packets and not in parts. This means that there is no delay in time and follows the all or nothing principle. If the frequency of photon is less than threshold frequency of the metal than it will be insufficient for electron emission. – **Kinetic energy** ▪ Classical physic: Classical physic states that increasing the intensity in light should increase the energy of electron meaning it would be faster if intensity increased. ▪ Quantum physic / Experimental data: Quantum physic states that as frequency increases, it kinetic energy increases. Having an increase of intensity mean increasing the number electrons and the number of electron will not mean energy. The energy will remain constant. Hence to change the kinetic energy and display the photoelectric effect, the frequency of the light must change to overcome the threshold frequency. – Overall, the problems above relate to distinguishing the relation of intensity and how to doesn't affect the photoelectric effect. – This also will explain the black body radiation, of have short wavelength means larger frequency, and hence more energy being radiated. ▪ Random note on denoting the photon's intensity and energy: – Higher intensity means more photons per unit area. – Think of two lasers. A red laser and a blue laser. The red laser shoots out 20 photons on a area of 1cm2 while the blue shoots out 10 photons – Which one has a higher intensity? the red laser because it has more photons per square cm – Which one has a higher energy? the blue laser because the blue photons have a shorter wave length therefore higher energy

	– Those two are definitely not interchangeable.

▪ explain the particle model of light in terms of photons with particular energy and frequency	▪ **IMPORTANT NOTES: Definitions of key words**
	– **Work function: the minimum energy that is required to release the electrons from the surface of a particular material.**
	  ▪ **The work function varies for the type of material.**
	  ▪ **Overcoming the work function will cause the photoelectric effect.**
	– **Threshold frequency: The minimum frequency at which light causes the photoelectric effect for a particular substance.**
	  ▪ **Refers to the work function as it relates.**
	– **Minimum frequency (cut-off frequency): I think it's another word for threshold frequency, stating it as the minimum frequency of light just before the electrons are being emitted.**
	  ▪ **The minimum frequency required for the photoelectric effect.**
	– **The photoelectric effect:**
	– **Photon: The fundamental element of light.**
	  ▪ **Comes in discreet packets known as quanta.**
	– **Photocell: Light sensors**
	– **Photoelectrons: When a photon collide with an electron on the surface of a material and emits something known as photoelectrons.**
	  ▪ **Basically, when photons overcome the work function and has the force to liberation electrons, they turn and emit as photoelectrons.**
	– **Einstein's postulates of photoelectric effect:**
	  ▪ **Energy of light is quantised.**
	  ▪ **Energy of each photon is e=hf. They follow the all or nothing principle.**
	– **Quanta: A quanta is the smallest amount of energy.**
	▪ Particle light

▪ identify the relationships between photon energy, frequency, speed of light and wavelength: $E = hf$ and ▪ $c = f\lambda$	$\mathrm{E = nhf}$ where E = Energy of photon (J) n = Number of quantum (must be interger) h = Plank's constant (6.63×10^{-34}) f = frequency of EM radiation (Hz) – Also, given the equation, $v = f\lambda$, the energy being emitted and absorb was electromagnetic waves which all travel at c. Hence, $v = f\lambda$ $f = \frac{v}{\lambda}$

	$$\text{and since } v = c$$ $$f = \frac{c}{\lambda}$$ – Hence the equation of quanta and photons could be equated as, $$E = \frac{hc}{\lambda}$$

Students:	*Notes:*
▪ perform an investigation to demonstrate the production and reception of radio waves	▪
▪ 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	▪ Einstein was able to expand on the idea of Plank's quantum theory, with the idea that **light energy was distributed as packets.** ▪ Einstein's analysis on the photoelectric effect suggests the notion of photons and how they are quantised, proving that Plank's hypothesis was correct in terms of radiation in black body was quantised ▪ Basically, Einstein played a crucial role in **supporting quantum theory, remodelling the model of light and founding evidence to explain the Ultraviolet Catastrophe** with his photoelectric effect on black body. ▪ Provide an explanation for Plank's Hypothesis.
▪ identify data sources, gather, process and present information to summarise the use of the photoelectric effect in photocells	▪ Photocells are solar cells that **converts light energy into electrical energy**. ▪ They used **P-N junction** and **photoelectric effect** to function. ▪ As light hit the N-type, the **electrons** get **liberated** and thus move and **migrate** to **fill** the **holes** in the P type. This causes the **N-type** to now become **positively** charged and the **P-type negatively** charge hence form an electric field or a **depletion zone**. ▪ At this point the **remaining electrons** that are liberated by the light in the **N-type** can **no longer** migrate across, hence they are jumped into the **conduction band** where they are **freely move** through an external **circuit** and hence provide **electric conductivity** for the load before joining up in the other end to **fill** the **holes**.
▪ solve problems and analyse information using: $E = hf$	▪

and $c = f\lambda$	
▪ process information to discuss Einstein's and Planck's differing views about whether science research is removed from social and political forces	▪ Initially, **Einstein** and **Plank** has **differing view**s on between how **science** contributed to **politics** and how their discoveries were going to be used. ▪ Einstein at first **refused to support** the use science to help governments fight the war, believing that science should be removed from social and political forces. His views were those of a pacifist and believed that science should not be a tool of governments in waging war. ▪ However, with the extreme persecution of the Jews in Nazi Germany, Einstein emigrated to the US where he assisted with the **Manhattan Project** in developing the **world's first atomic weapons**. Einstein's contribution to the Manhattan Project may be seen as his change in views, as scientific contributions led to the development of a weapon that surely ended the war. ▪ Planck clearly **believed (support)** that science is not separate from political and social forces. Planck believed in the German cause during the war, but at the same time, he protected many of his Jewish colleagues from Nazi persecution. Planck was one of the first German intellectuals to sign a document supporting the role of Germany in the war. ▪ During the war, he devoted his work and research to whatever the war effort required of him. Although he eventually came to resent and oppose the Nazi regime, he still believed that science is not separate from political and social forces.

3. Limitations of past technologies and increased research into the structure of the atom resulted in the invention of transistors	
Students learn to:	*Notes:*

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

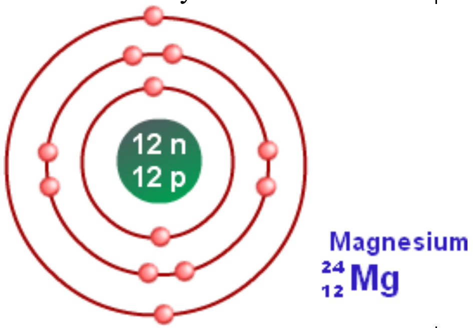


Figure 10.1.1 An abstract energy level diagram helps visualise the ionisation energy of an atom, which would produce free charges for an electrical current.

- **Lattice: The term given to describe the 3D arrangement of atoms, ions, and molecules in a metal or crystalline solid.**
- Ion: an atom that is positively charged (cation) or negatively charged (anions).
- **Cation** ➔ More protons than electrons

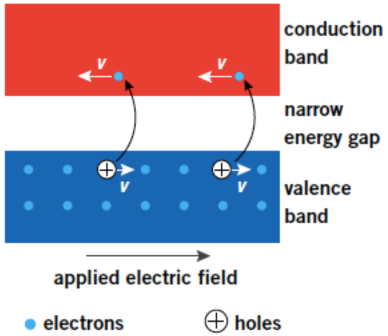
  Anion ➔ More electrons than protons

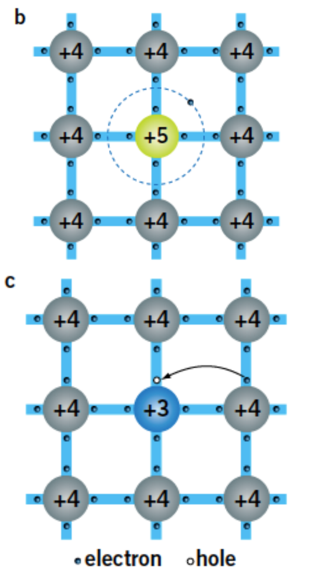
  Atoms and their energy bands [Example: **Magnesium**]
  - Each **outer shell** will have **more energy** than the inner shell.
  - Each **energy** (shell) can only hold a **maximum allowable electron**.
  - **Last shell** is commonly known as **valence shell** [outermost electron shell].
  - The **electrons** on the **valence shell** is known as **valence electrons**.
  - The **gaps** in between the shell are **forbidden band**. **No electrons** can be **located** or **had** that **energy** in the energy gap. This means that electrons will have a **fixed**.
  - A **shell above** of the **valence** can be created and is known as the **conduction shell**.
  - **Conduction shells** with have **no electrons**, but **electrons** are move to the conduction shell, and when in the conduction shell, they can **move freely**.
  - When these electrons move freely they can **conduct electricity**.
- **Diagram**:
  - Portrays the **energy level** and a diagrammatic representation of how electrons are able to move freely.
  - **The Y-axis** shows the **amount of energy and is increasing.**
  - **The yellow lines show the shells.**
    - Bottom line is the valence shell where the electrons can jump from and to the conductor shell.
    - It portrays the
    - [Valance band]
    - The top line is the conductor shell where the electrons are located from the valence shell and in here, the electron can freely move.
    - [Conductor band]
    - The gap in between denotes the forbidden band.

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

Figure 10.1.4 Energy band diagrams for (a) a conductor, (b) a semiconductor and (c) an insulator

- **Different materials vary** greatly in their ability to **conduct electricity**.
- This lets us classify materials as either conductors or insulators.
- The **conductivity** of a material **depends** on it **crystal lattice structure**.
- Electron band structure are energy levels possessed in electrons within an atom.
  - **Valance band** is the outermost electron energy band containing electrons.
    - Has the **highest energy**.
    - The electrons in the valance shell is known as the valance electrons.
  - **Conduction band** is the shell above the valance shell.
    - Allows the **free transfer** of electrons with neighbouring atoms.
    - They will initially contain no electrons. But as this is where electrons would jump to if it were to conduct.
  - The **forbidden gap** is the area where electrons **cannot be occupied**, since they are **quantized**.
    - It consists of the energy value between the valance and the conduction band.
- **Conductor**
  - The valance band and conduction band usually **overlap each other**.
  - Hence this provide the electrons in the valance shell to easier jump to the conduction band.
  - This overlapping notion give the material a **low relative electrical resistance**.
  - The overlap of the band also means that there is **no need any extra energy input**, since already some of the electrons had been placed in the conduction band.
  - The **valance band** will **be partially full** due to some the of the electrons in the **conduction band**.
- **Insulator**
  - The valance band and conduction band usually contain an **energy large gap**.
  - The valance band is usually **full** due to the lack of electron moving into the conduction band.
  - This is because a lot of energy will be required to jump over the large gap. Hence making them mainly in the valance band and leaving an **empty conduction band**.
  - Thus, there will be **less free electrons** carrier to apply current flow.
  - This property of **difficulty** in **transferring electrons is known as high electrical resistance.**
- **Semiconductors**
  - The distance between the valance band and the conduction band is a **relative small gap**.
  - This places them as better electrically conductive material than insulators but less conductive than conductors.
  - **Semiconductors require thermal emission** and **energy** for electrons to leap into the conduction band. At **zero temperature, basically semiconductors will act like insulators**.
  - They have the property that an **increase in temperature will mean a decrease in resistivity**.

▪ identify absences of electrons in a nearly full band as holes, and recognise that both electrons and holes help to carry current  Figure 10.2.1 Holes are created in the valence band of a semiconductor when electrons are excited up to the conduction band.	▪ The absences of electrons in a **nearly full band** is due to the **excited electrons moving into the conduction band as freely flowing current.** ▪ The position of those electron are now **vacant** what remains is known as a **hole**. ▪ **Hole** – A hole is where the excited electrons place was, and now they behave like **positively charged part**icles. – In reality, other **electrons will take over** and **flow** into those positions but will leave the **position empty and the process infinity goes.** – Thus, it will be easier to treat them as positively charge particles. – The magnitude of both the electrons and the holes are **1.6 x 10 ^-19, but holes will have a positive sign. [They are in different signs].** – **Holes in the valance shell essentially helps the flow and carry of currents.** – Holes tend to move in the direction that opposes the electrons. [**conventional current**] ▪ **Electrons are negative charged carriers and holes are positively charged carriers.**
▪ compare qualitatively the relative number of free electrons that can drift from atom to atom in conductors, semiconductors and insulators	▪ **Conductors**: In each atom, they contain **loosely bounded electrons** hence require **less energy** for them **to leave their valence band into the conduction band**. They can **freely move** due to little energy required, they are **low in resistivity** and **high in conductivity**. ▪ **Semi-conductor**s: In each atom, the electrons are **less tightly bound than insulators** and **more tightly bounded than conductors**, hence will require **some more energy** in order to move freely in the conduction band. In semi-conductors, the **resistivity and conductivity** will **depend on the temperature.** ▪ **Insulators**: In each atom, the electrons are **held tightly to its atoms**, hence will require a **lot more energy** to move freely, in fact most of the time, the **conduction band is empty** hence they are **unable to conduct electricity**. Since they take a lot of energy to move, they **have high resistivity and low conductivity**.
▪ identify that the use of germanium in early transistors is related to lack of ability to produce other materials of suitable purity	▪ **Germanium** was the **first** element to be used in **transistors** as it was the only element that could be **purified** at a **sufficient high level**. ▪ Germanium was classified as a relative **rare** element. ▪ Germanium was used as **semi-conductors** as it was the only **group 4** element that could. However, at **high temperatures, it couldn't retain it semi-conductors.** ▪ Hence germanium was soon replaced by **silicon** due to it retainment as a semi-conductor at high temperature. ▪ It was **more abundant** and **thus cheaper.** ▪ **More reliable at high temperatures**.

▪ describe how ‘doping’ a semiconductor can change its electrical properties  	▪ **Doping a semi-conductor is to introduce an impurity to the lattice structure**. This is done to **manipulate the electrical property. [It increases the conductivity of the semi-conductor]** ▪ **Intrinsic semi-conductors** – **Pure**, and **undoped** semi-conductors. – The **properties will occur naturally**. – No doping is need to the lattice structure. – Eg. **Silicon and Germanium**. ▪ **Extrinsic semi-conductors** – **Impure**, and **doped with an impurity**. – Manufactured to behave in the required manner, **enhancing it’s electrical property**. – Generally, it had a natural lattice structure acting like a semi-conductor, however, it had it property modified by a dopant atom. – Small impurities like, **Phosphorus and Boron**. ▪ When semi-conductors are doped, they either become: – **N-type → More electrons.** – **P-type → More holes.**
▪ identify differences in p and n-type semiconductors in terms of the relative number of negative charge carriers and positive holes	▪ Example used → **Silicon** as it has **4 valence electrons** and can covalently bond with other silicon atoms to form a crystal lattice structure. ▪ **N-type:** – N-type semi-conductors are doped with **Group 5 elements**. – E.g. of Group 5 elements are **Phosphorus and Arsenic**. – Meaning that an element with **5 electrons** in its **valence band** is introduced and doped onto the Silicon. – **4 out of the 5 electrons** will **fill** the valance band just like Silicon would bond with its 4 electrons. – It **leaves one electron** in the dopant that can’t participate in the bonding hence, it will **move freely in the conduction band as a charge carrier.** – Impurities that produce unbounded electrons are called **donor impurities**. – This **enhances the conductivity** and **reduces the resistance** of the material. – Hence negative charged [N-type].

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- **P-type:**
  - P-type semi-conductors are doped with **Group 3 elements**
  - E.g. of Group 3 elements are **Boron**.
  - Meaning that an element with **3 electrons** in the **valence band** is introduced and doped onto the Silicon.
  - **Having all 3 of the electrons** able to bond with the **3 out 4 valence electrons** in Silicon, this leaves **one hole** that Is **positively charged** and are **mobile**.
  - Impurities that produce a **charge vacancy** are called **acceptor impurities**.
  - When one **electron** comes to **occupied** that **hole**, it will **leave** a hole in its **original position** and this process will repeat for the next electron.
  - This **increase positive charge density**, hence **increasing the conductivity**.
- **Note** that both p and n types are **electrically neutral**, even through that all **uneven amount of electrons**. Since a **neutral impurity** is doped with a **neutral solid**, the **net charge remains zero**.

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- describe differences between solid state and thermionic devices and discuss why solid state devices

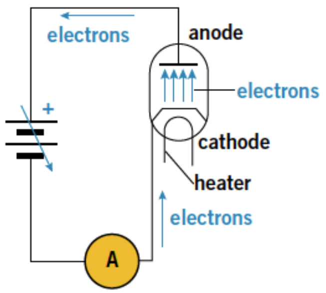

Figure 10.4.2 A thermionic diode enables current to flow in one direction.

replaced thermionic devices

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- Both **Solid State Device's** and **Transistor's** purpose is to **amplifies and manipulate electrical signals**. They also allow to **control the flow of electrical**, **converting AC to DC** and or act as **switch to turn on and off electrical current.**
- **Solid State Devices:**
  - Solid State Devices are devices that are **made from semiconductors** material. Devices usually consist of a **p-n junction** or a combination of **extrinsic semiconductors** to **control** the **flow of current** in on direction.
  - A p-type semiconductor attached to a n-type semiconductor (p-n junction) acts as a **diode**.
  - Application of Solid State Devices are **transistors** and **integrated circuits**.
- **Thermionic Devices:**
  - Thermionic Devices are devices that uses **thermionic emission** to **produce electrons** and **control** them in a **flow of one direction**.
  - They consist of a **vacuum tube**, containing a **heating filament (cathode)** where electrons are liberated and accelerated towards the anode on the other end. This however was **very power hungry** and **unreliable.**

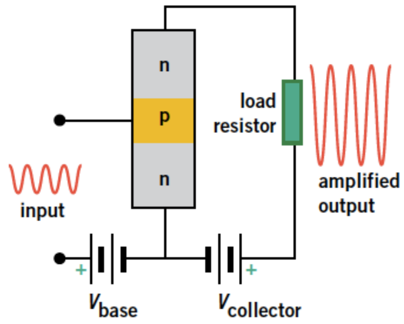

Figure 10.4.7 This small signal amplifier uses an n–p–n transistor.

- Solid state devices have **advantages** which outweigh Thermionic devices and hence over time transistors require extrinsic silicon material to create diodes that were **near sizes of atoms**.
- **Reasons why Solid State Devices replaced Thermionic:**

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– Solid state devices were very small, lighter and cheaper then Thermionic devices which were bulky and require complex circuitry. This meant they were more versatile and could be incorporated in laptops and phones.
– They were more reliable and longer lasting due to semi-conductors, whereas Thermionic devices were made from glass encased in vacuum which meant they were very fragile and heating caused problems.
– Can operates at low voltage will thermionic requiring large amount of voltage to heat up the liberation of electrons. Consume less energy.
– Efficiency was a major advantage as solid state didn't need any heating and time to produce current. Thermionic however, need time for the filament to heat up and electrons to be liberated.
– Due, to silicon be abundant, semiconductors could be mass produced meaning they were cheaper and a could process faster than thermionic devices. More economical.

▪ Advantages of Thermionic over Solid state devices:

– The knowledge of understand semiconductors and how p-n junction work were not required.
– They were immune to EMR such as EM shockwaves.

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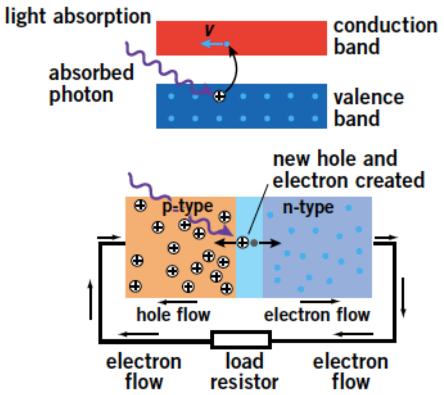
Students:	*Notes:*
▪ perform an investigation to model the behaviour of semiconductors, including the creation of a hole or positive charge on the atom that has lost the electron and the movement of electrons and holes in opposite directions when an electric field is applied across the semiconductor	▪
▪ gather, process and present secondary information to discuss how shortcomings in available communication technology lead to	▪ **Throughout the history, scientist have advanced technology such as communication technology by implementation new materials into circuitry and thus into device which nowadays allow for global communication.** ▪ **The need for sensitive radar and radio technology allowed for the research of semiconductors. Thermionic values and diodes were already, but they were fragile, bulky, inefficient, noisy, unreliable and insensitive. They were used in electronics to amplify signals in radio, loudspeakers and audio devices but they were easier burnt out due to their heating filament overheating.**

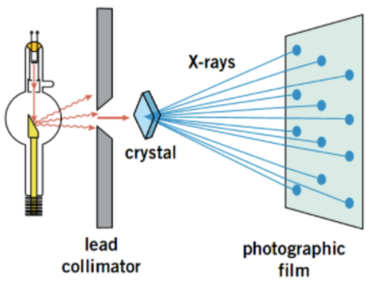
an increased knowledge of the properties of materials with particular reference to the invention of the transistor	▪ **This shortcoming in available technology spark germanium as a semiconducting material to be used as solid state device which achieve the same purpose as thermionic device. They were much smaller, lighter, faster, efficient and didn't require heat. They were made into transistors** ▪ **Over the year, silicon soon replaced germanium as they were more abundant and better. Making them a invention for communication technology and replacing thermionic devices.**
▪ 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	▪ **Advantages**: – **The development of hundreds of transistors made from tiny slices of impurities of silicon and germanium, lead to the inventions of microchips and integrate circuits which are extensively used to power electronics and maintain fast processing of storage and information.** – **With transistors integrated on circuits accompanied with advance capacitors and resistors, they can come in compact and portable sizes such as in mobile phones, tablets and laptops, which enable for easy and effective communication world-wide with little discrepancy.** – **Microprocessors, have significantly advance the living standard in society, as they are incorporated in almost everyone household appliance to make life simpler and difficult task achievable. Advanced computers, television, rice cookers, allow for leisure time and entertainment to be provided.** – **Finally, in industries, these microchips and processors allows automation of hazardous and repetitive tasks to be accomplished in matter of seconds yet producing efficient and reliable production, reducing the cost of paying worker.** ▪ **Disadvantages:** – **With electronic surveillance, individual is given the lack of privacy and can cause major issues concerning invasion of privacy of information.** – **Less personal contact with friends and family.** – **With advanced computer capturing leisure time, individual lack physical activities and thus, degrade of wellbeing.** – **Due to redundancy of automated machines, unemployment rates will increase and job lose will rises, making workers with insufficient income for their daily living.**

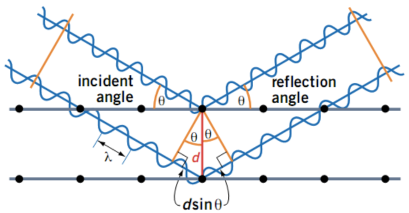
▪ identify data sources, gather, process and present information to summarise the effect of light on semiconductors in solar cells 	▪ **Solar Cells (Convert Sun's light energy ➔ electrical chemical energy using the p-n junction)** – Solar cells are based of the **function of p-n junction** with the use of its **depletion zone**. – Also, the **photoelectric effect** is used to convert **light energy (photons) directly to electricity. This is known as the photovoltaic cell.** ▪ When the **sunlight beams** onto the p-type semiconductors, it experiences the **photoelectric effect**, where **the light's threshold frequency liberates electrons** and are send to **fill the holes in the n-type**. As this process occurs the **p-type become negatively charges** and **n-type, positively charge**. As a result, this **forms an electric field**, where further liberated electrons can **no long flow freely** into the n-type to fill the hole, instead **must travel through a provided circuit and into the n-type where they migrate and balance out.**

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

Students:

- outline the methods used by the Braggs to determine crystal structure





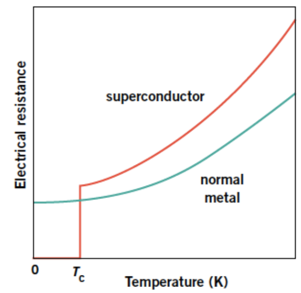
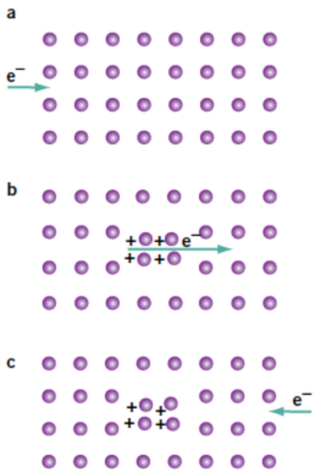
Notes:

- In waves, when **two or more waves are combined** they are undergoing **superposition**, either constructive or destructive.
- This is now known as an **interference**, where the **waves travel in the same medium at the same time.**
- An **interference pattern** is when waves are either **in phase** or **out phrase**.
- **Diffraction** is the process of shadows being displayed as light is **spreaded out** from the object in a blurry state.
- Diffraction is associated with waves, especially light.
- **X-ray Crystallography:**
  - Was known to be the **study of crystal structure** and lattice using **X-ray** to determine the **interference pattern of the wave.**
  - To determine the crystal structure, **X-ray waves was beamed** on a lead collimator to form a well-defined beam of X-ray wave to **struck the metal surface**.
  - It was done as it allowed to **hit a single crystal of the metal.**
  - In doing so the waves will **hit the electrons** and thus **diffract of them** and are **sent off in a diffracted direction. Scattering of in different direction to form an interference pattern.**
  - **X-ray wave was used because it had sufficient wavelengths to be diffracted and comparable with the spacing of atoms in metals.**
  - This was then **detected by a photographic film** where the waves that met in the **same phase (in phase)** were **constructive waves** and **formed white spots.**
  - **Out phases waves** were **destructive** and shows **black spots.**
  - With this pattern and diffraction of X-rays the internal crystal structure could be determine will the information.
- **William Henry Bragg and William Laurence Bragg** both further conducted research and on the structures of crystalline solids using this method.
- They modified it by implementing their **Bragg Spectrometer** which consist of producing **X-rays**.
  - The spectrometer made X-rays by heating up the anode with very high energy.
  - This allowed for a **beam parallel to the surface** of the metal and as they **struck the atoms**, the X-ray would **scatter of hitting and diffracting other atoms forming** an **interference pattern**.
  - A layer of **photographic film** was placed behind to **visualise** that **pattern**.
  - By knowing the **X-ray's wavelength** and the **angle between the spacing** they and wave, they could **determine** the **internal crystal** with the relationship: [**Bragg's Equation**]

$$2d\sin\theta = n\lambda$$

  - From this they **concluded**:

	▪ Revealed the **arrangement of atom** in a crystal are **repeated** to **form a crystal lattice.** ▪ They have **electron density**. ▪ The metals have a **3D lattice-structure**.
▪ identify that metals possess a crystal lattice structure	▪ Bragg also established that **metals have crystal lattice crystal** and are formed by **positive ions** which are **loosely bonded** with a **cloud 'sea' of delocalised electrons**. ▪ The **cloud of electrons surround** the **positive ions** and are **free to move around the lattice** which makes them **good electrical conductors.** ▪ They are **binded** by the **attraction force of positive ions** and the **electron gas**.
▪ describe conduction in metals as a free movement of electrons unimpeded by the lattice	▪ Since metals are **formed** by **positive ions** with **freely moving electrons**, when **under an electric field**, a **current** may **flow** through. ▪ Since they are freely move, they are **unimpeded** by the **ions** giving metal a **low resistivity property**. ▪ When a present of **potential difference**, electrons also **drift** and move along the conductor metal unimpeded. This is known as **drift velocity behaving like a wave propagating through the crystal lattice.** ▪ **Drift velocity: The average velocity at which the electrons in crystal lattice are moving.**
▪ identify that resistance in metals is increased by the presence of impurities and scattering of electrons by lattice vibrations	▪ In most metal, they have some **degree of impurity**, and if not are, there crystal lattices are subject to some **irregularities**, **small gaps** and **break**. These acts as **barriers** to hinder the **straight and free movement of electrons** and hence metals will have **electrical resistance**. ▪ **Electrical resistance** in metal can be affected by [preliminary]: ▪ **Cross Sectional Area** ▪ **Temperature** ▪ **Length of Conductor** ▪ **Type** ▪ With **lattice vibration**, electrical resistance can be studied at atomic level. When electrons collide with the lattice, they **lose energy** and **hence velocity** and will travel **disrupted**. Hence a **voltage drop** can be observed. ▪ **Deformations** of the **lattice structure**. [**Defects or imperfection**] ▪ **Impurities added to a metal [Alloy] changes it lattice structure.** ▪ **Above 0K [Absolute Zero]** ▪ As **temperature increases**, the **vibration** in the **positive ions** start **rapidly increasing** it amplitude in movement and **hence increases** the **chance** of **collision** with the moving **electrons**. Hence, we can say, **electrical conductivity** will **increase** if there is a **decrease in temperature**. [**Superconductors**]. ▪ Compared to semiconductors, **good conductors** have **resistant decrease** as **temperature decrease**. **Semiconductors** have a **resistant increase** as **temperature decreases.**

▪ describe the occurrence in superconductors below their critical temperature of a population of electron pairs unaffected by electrical resistance	▪ **Superconductors: A metal that has the ability to conduct electricity will zero resistant. ➔ No energy loss.** ▪ This ability can come in effect depending on the type of conductor and it **Critical Temperature (T_c).** ▪ **Above** the **critical temperature**, the **thermal vibration** of the lattice will sufficient to cause **collision with electron**, hence containing **electrical resistance**. ▪ **Critical Temperature: The temperature at which the atoms in the lattice experience zero vibrations hence providing zero resistant for electrons to flow.** ▪ This phenomenon can be explained by the **BCS Theory** stating that they **electrons** in superconductors become a **pair. [Cooper pair]**  Figure 11.6.2 The resistance of a normal conductor and a superconductor
discuss the BCS theory  Figure 11.10.1 Classical description of the coupling of a Cooper pair. (a) The first electron approaches a section of the lattice and (b) deforms part of the lattice electrostatically. (c) A second electron is attracted to the net positive charge of this deformation.	▪ **BCS Theory**: John **Bardeen**, Leon **Cooper**, John **Schrieffer**. This theory attempts to **explain** the concept of **superconductors** using **quantum mechanics** and observe the behaviour of electrons moving between the positive ions. ▪ **Superconductors have zero resistant** due to the **pairing of electrons travelling** together, **Cooper Pair**. ▪ Two **like charges** should **repel** each and **not travel together**, but the **attractive force** on the **positive ions** allow for a **binding energy** of **two electrons travelling in cooper pair**. The action of the **phonons** creating a **positive region** allows for that attraction. ▪ An **initiating electron**, or the first electron that **enters the lattice** will allow the **surrounding positive ions** of the lattice to be **distorted** and **attracted** to each other. ▪ This attraction makes the **area very positively charged** and hence the **second electron** will **become attracted** to the **displaced ions** which are **moving back to its equilibrium** state. However, **before** it can go back to that state, that **second electron** being **attracted** will acts **like** the **first electron** and **attract** the **positive ions** and hence with the first electron **work together** and form a **cooper pair**, that **travels unimpededly through the lattice**. ▪ This **chain effect** happens to third electron and so on, making **no collisions** and that electrons flows through **efficiency** with **no resistant**. ▪ **As a phonon is the movement of vibrations in positive ions, the movements of positive ions in superconductors are known as virtual phonon.** ▪ **Cooper pairs** are continually **formed**, **broken** and then **reformed** between different electrons allowing them to move through the lattice coherently **without collision** and **without resistance**. ▪ At **low temperature**, the **lattice attractive doesn't have the energy** to **break** the **bonds of the cooper pair**. However, as the **temperature increases**, the **phonons** become **more violent** and increases the chance to break the cooper pair and ultimately the **superconductor diminishes its properties**.

- discuss the advantages of using superconductors and identify limitations to their use

- **BCS Theory: The idea that lattice distortions at low temperatures lead to the formation of Cooper pairs.**
- Main important limitation → BCS theory successfully conveys **Type 1 superconductors**, however **failed** to explain **Type 2 superconductors** (ceramic based materials).
- **Advantages:**
  - **MAIN: Able to carry large currents with zero electrical resistant and therefore no heat loss or energy loss. Transfer of electricity over long distance can be made more efficient.**
  - **100 % efficiency.**
  - **Can be used to produce very strong magnetic fields.**
  - **Economically advantageous, for powering and transmission of electrical energy, as we can change the source of fossil fuel.**
  - **With such efficiency, power plants and station cost can be lower, meaning consumer's electrical bills can be less.**
  - **Supercomputers and advance electronics are be made using superconductors for high and fast process of information and storage.**
- **Limitation (Disadvantage):**
  - **MAIN: Since superconductors needs to be at below critical temperature to function, it makes them difficult to maintain at such low temperature.**
  - **Maintain them would be costly.**
  - **A little bit above the critical temperature can diminish the superconductivity of ceramic base material or metal.**
  - **Very sensitive to magnetic fields, meaning AC appliance will require DC.**
  - **Since most superconductor function with ceramic base materials, it makes them very brittle and hard to form wires for transmission and cables. Prone to cracking and breaking at cold temperatures.**

Students:

Notes:

- 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

- **Type I superconductors are pure metals.**
- **Type II superconductors are ones where they exhibits two or more metals (ceramics**).

Type I	Critical Temperature	Type II	Critical Temperature
Aluminium	1.2	$Hg_{12}Tl_3Ba_{30}Ca_{30}Cu_{45}O_{127}$	138
Lead	7	$Bi_2Sr_2CuO_6$ (BSSCO)	110

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Mercury	4	$YBa_2Cu_3O_7$ (YBCO)	92
Zinc	0.85	SmFeAs	43

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- perform an investigation to demonstrate magnetic levitation

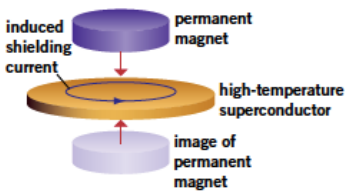

Figure 11.9.2 Eddy currents on the surface of the superconductor essentially create a mirror image of the magnet resulting in repulsion and levitation.

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- **Magnetic levitation** is based on **cool object subjected** on very **strong magnets** and follow the concept of **Meissner Effect** and **Quantum Locking**.
- This demonstrates and investigate magnetic levitation by the **repulsion** of **magnetic field** by superconductors and thus making the magnet levitation.
- When a superconductor is **exposed** in a **magnetic field**, it produces **eddy currents** on the **surface** and **creates** a **magnetic field opposing the magnetic field. [Lenz's Law]**

Magnetic Levitation

- **Steps:**
  - **Have the superconductor placed under it critical temperature by using liquid nitrogen.**
  - **At this state the superconductor should have no resist and hence when placed on top of a magnet, it induced eddy current that repel or mirrors its magnetic field.**
  - **Thus, this allows for the suspension of the superconductor located anywhere and at any angle within the magnets.**

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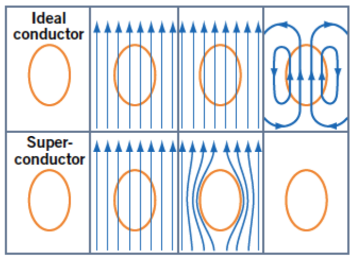
- analyse information to explain why a magnet is able to hover above a superconducting material that has reached the temperature at which it is superconducting



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- **Meissner Effect: the phenomenon of expulsion of magnetic field in an interior superconductor.**
- **Superconductors can resist magnetic field** in them.
- As **conducting materials**, when they are **exposed in magnetic field**, they **produced eddy currents** which flow **in the direction of the provided magnetic fields** and hence **pushes back** on the magnets.
- Since **superconductors have no resistance**, they can **induce current** that is **equal, opposite and permanent field lines** that suspension them within the magnet.
- As a different interpretation, as magnetic field lines, cannot pass through the superconductors, they are **forced to thread around the superconductors holding in place** and allowing it to **hover suspended**.

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

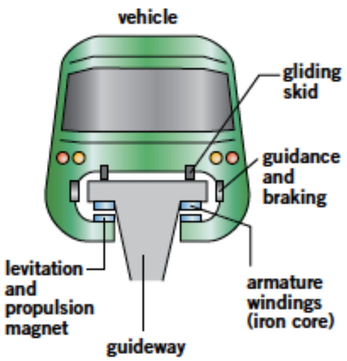
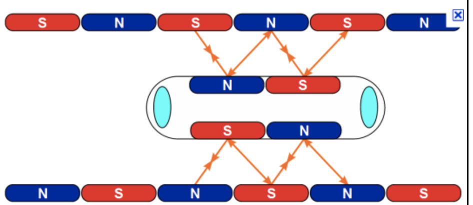


Figure 11.11.3 Levitation of a train using onboard superconducting magnets on a guideway that propels it with conventional electromagnets



- **Maglev Trains are an application for superconductors and requires two uses of magnetic field and superconductors:**
- **Levitation: [DC]**
  – This part of superconductors requires the **lifting** of trains using the **repulsion** or **Meissner Effect**.
  – The **guardrails** consist and **strong conventional electromagnets** and on the **train**, contains **superconductors with induced magnetic fields**.
  – **On the train**, they contain **cooling agent [liquid nitrogen]** that **cool** the s**uperconductors** to **below critical temperature** as thus when exposed in those magnetic rails create a **repulsion force** that **levitates** the train to **near frictionless motion**. This enables mag lev trains to **travel at very high speed**.
  – This **however only** allows for the **hover** of trains; the propulsion phase is where electromagnets are used as **alternating poles** make the **train propel** in the **forward direction**.
- Lateral Guidance:
  –
- **Propulsion: [AC]**
  – **The propulsion coils are placed at the sides of the train and on the side of the rail.** The two **interaction** of **AC electrical magnets** allow for a **constant attraction/repelusion motion** to the train, **pushing** it **forward**.
  – By controlling the **frequency** of **AC**, it allows for the **acceleration** of train.
  – The **magnets on the train have the same polarity** throughout the course of the track, while the **electromagnets on the rails constant change.**
  – **In diagram:**
    - The trains magnets with the north is exposed to a south in the front and a north in the back. Both these three magnets interaction to push the train forward. North/South attract which pushed it towards, and North/North would repel, yet again pushing the train forward.
    - At the train reaches move forth, the North magnet will yet again experience this same attraction/repulsion force, because those magnets on the rail change polarity. Meaning the concept is applied the same, but at a forward direction.
- **Advantages**:
  – **With the ability to hover above the tracks and**
  – **Compared to conventional trains, mag lev trains do not require a lot of maintenance.**
  – **Frictionless motion of train makes rides more smooth and more efficient energy consumption. [conversion to sound and heat on conventional trains]**
  – **Safe and effective braking system with electromagnets braking system.**
  –
- **Disadvantages:**

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– **The powered conventional electromagnets on guardrails, the constant cooling of superconductors make mag lev trains very expensive to apply and maintain.**
– **The equilibrium state [position] must be keep maintain to function sufficiently.**
– **The high magnetism in and around the train, makes electronics and magnetic storages very ineffective.**

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▪ 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

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▪ **Power Transmission:**
– Superconductors can **generate** and **transmit electrical energy efficiency** with **little or no energy loss**. **[Power loss]**
– Energy loss like **heat** and **sound** and **resistance** can be a minor **issue in transformers** if they use superconductors.
– This means that energy **consumption is lowered** and is **cheaper** for consumers and electrical industries.
– With superconductors as a means for power transmission allow means it is **safely**, as **less voltage** is required to power up or down in order to maintain electrical current through civilastion.

▪ **Power Generation:**
– Power generation is done through **radiation** and **coal burning**. With this method, it r**elease**s a lot of **greenhouse gases**. Not only that, they are needed to be **located** at **long distance** from cities and hence **lose** of **habitats** to locate the power stations.
– These generators with the use of superconductors can be much **smaller** in **size** and **mass**, compared to present generators, **creating powerful magnets**.
– To **minimise** these negative effects power generation can be done with the use of superconductors acts as **no resistance** wire to **transmit energy on home**.

▪ **Power Storage:**
– **SMES [Superconducting Magnetic Energy Storage]** is device that allows for the **immediate access** to electrical energy. They are constructed of **superconducting rings** that uses **DC** to **indefinitely** store energy around in **loops**. **DC is used due to the energy loss provided in AC**.
– This is effective because it means that machinery and electronics can occur at its **peak efficiency** at any given **time**, even when there is **minimum power** or a **failure** in the **power generators**.
– SMES can be used to **store electrical energy** of **solar cells** can be used for **night-time**.

▪ **Electronics:**
– **Quantum computers** can be of use, using superconductors as for **fast** and **reliable** access to **information**. **Requiring little cooling** of computer making them run more faster and **cheaper**.
– Advanced technology means **computer chips** and **microprocessors** can be made **smaller** and create fast switches that send **powerful signals** at fast rates.
– Also, highly **sensitive measuring equipment** can be used to measure units at **atomic scale**.

▪ **Medical Dialogistic (MRI Instruments):**

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	– **MRI [Magnetic Resonance scanning]** require intense magnetic field to be created and hence will the mere use of **solenoid**, requires **thick** and **large** coils wounded together. – With superconductors, electromagnets can be created by alloys that can easier provide an intense magnetic field. – As MRI rely heavily on it current in the solenoid, with superconductors it means that little energy loss is implemented hence making them a future application to **replace thick copper wires**. ▪ **Magnetically Levitated Train:** – As mentioned above they are much more effective compared to **conventional steam trains** that require a **bad braking system**. ▪ **Particle Accelerator:** – With superconductors, particle can now be **accelerated** at **fast velocities** and **little resistance** in the cabling. This can **replace conventional electromagnets**.