Contents

9.4 From ideas to implementation: 1. Cathode rays

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

- Any moving charged particles that move in a magnetic field will experience a force.

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

- You may be **performing** an investigation that has been planned by your teacher. One suitable investigation is described below. Take note of the safe work practices required when any discharge apparatus is operating.

- **Gather** information by observing and recording observations in accurate summary form. Simple diagrams can assist your recollection of phenomena observed.

Using discharge tubes

A common piece of apparatus used for this investigation is a set of glass discharge tubes at different pressures, arranged side-by-side on a board. The tubes have been sealed after having had varying amounts of air pumped out of them (the more air pumped out, the lower the air pressure).

Each tube contains an electrode at each end to allow the application of a large voltage, which is provided by an induction coil. The high voltage causes an electrical discharge through the air in the tube, causing the air to glow. Different discharge patterns are formed at different pressures.

Sample observations

- At 5% of atmospheric pressure, long, thin red-purple streamers appear between the two electrodes.
- At lower pressure, these streamers give way to a soft red glow.
- Upon further pressure reduction, the glow is broken into striations, bands of light and dark. The amount of dark space between the glowing bands increases with further reductions.
- At 0.01% of atmospheric pressure, the dark space extends throughout the tube. At this very low pressure, the glass near the anode glows a yellow-green colour.

The following web site has some simple diagrams showing various striation patterns and also provides information on the properties of cathode rays.

Investigating new rays Dr. E.P. Scarlett High School, Calgary Board of Education, Canada

The following web site has an example of alternative apparatus that can be used to show the above effects.

Gases that emit light Chemical of the week, Science is Fun in the Lab of Shakhashiri

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

- A cathode ray tube is a highly evacuated glass tube containing two electrodes. A high voltage applied across the electrodes causes cathode rays, streams of negatively charged particles (electrons), to flow from the cathode towards the anode, with little obstruction from the few remaining gas particles.

- Structures built into or around the cathode ray tube allow the cathode rays to be manipulated. Further electrodes can be built into the cathode ray tube to create an electric field to change the path of the cathode rays. Magnetic fields can be applied to the cathode rays through the glass from outside the tube. Solid objects can also be placed inside the tube to block the path of the rays.

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**

and analyse the information gathered to determine the sign of the charge on cathode rays

- You may be **performing** an investigation that has been planned by your teacher. Make sure you identify and use safe work practices with induction coils and discharge tubes during this investigation.

  A table would be a suitable format for recording your observations. List each feature of the various cathode ray tubes you use and describe how each demonstrates a property of cathode rays.
- **Analyse** the information gathered by using your observations to justify inferences and conclusions about the sign of the charge on cathode rays.

The cathode ray tubes used to demonstrate the properties of cathode rays are fairly standard across schools and below are some web sites that outline common procedures you may follow:

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INVESTIGATING NEW RAYS

- Dalton, in 1808 proposed that matter is made of atoms. All substances were either made of single atoms or combinations of atoms (molecules).
- He thought that atoms were indivisible.
- In the 19th century, experiments showed that atoms were divisible**.** As a result, new particles and forces were found.

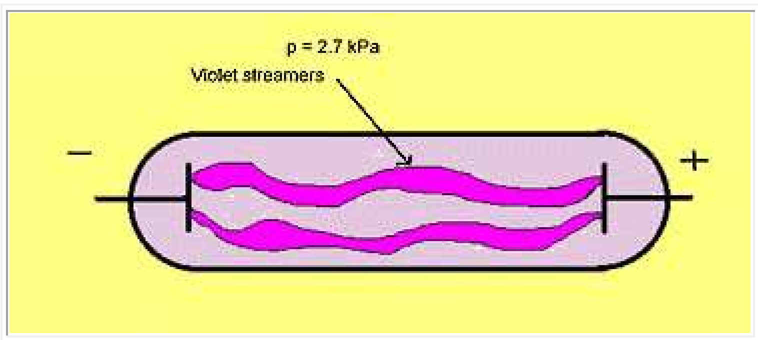
CATHODE RAYS

- Geissler in the 19th century, Invented a new vacuum pump.
- He produced discharges of electricity in evacuated tubes of varying shape. He also produced difference colors of discharge by placing different gases in the tubes.

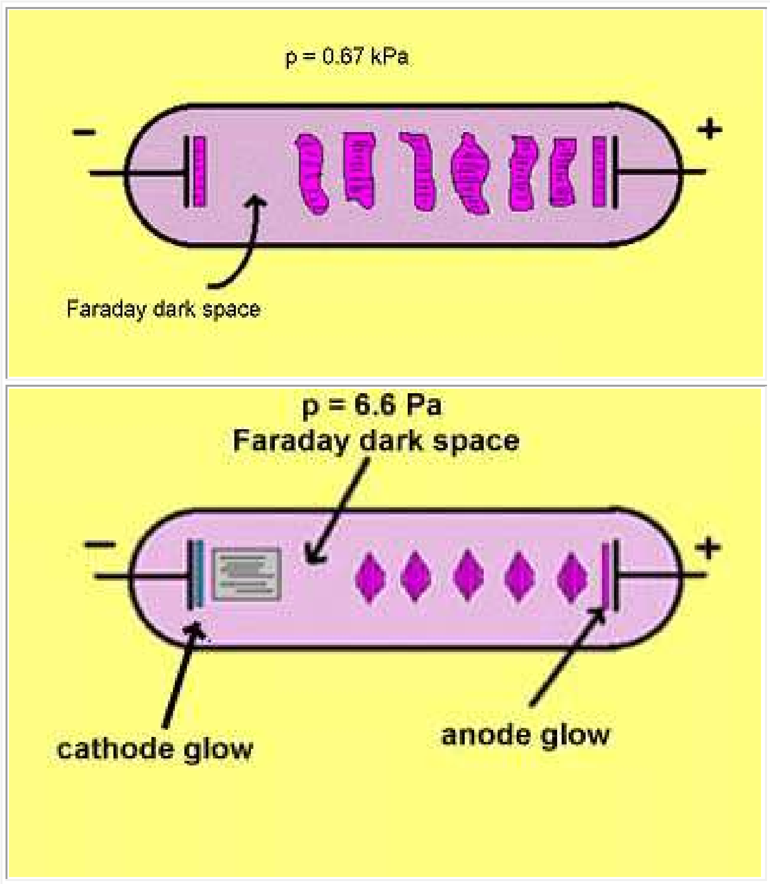
GAS DISCHARGE TUBE - A tube that allows an electric current to pass through a gas at low pressure.

ELECTRODES - Metal plates sealed in the ends of a gas discharge tube. (+ is the anode and - is the cathode.)

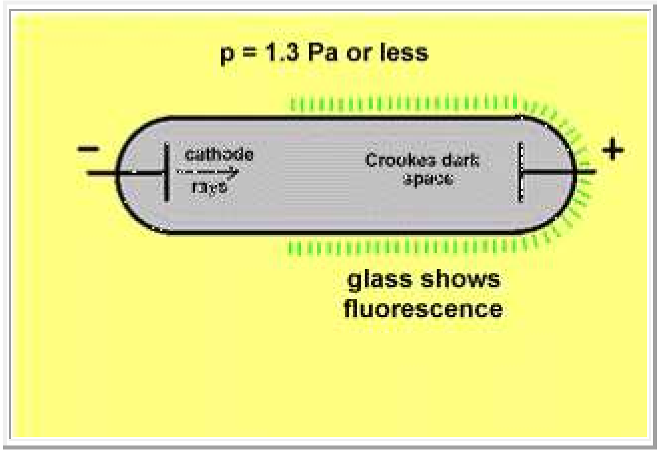
- When air is pumped out of the tube, the discharge across an induction coil stops, and the electrodes in the tube are connected by one or more violet streamers.



- At low enough pressure, a pink glow fills the entire tube. Continued decreases in pressure cause the pink glow to concentrate around the anode and a blue glow around the cathode. The space between the glows is dark (called Faraday's dark space).

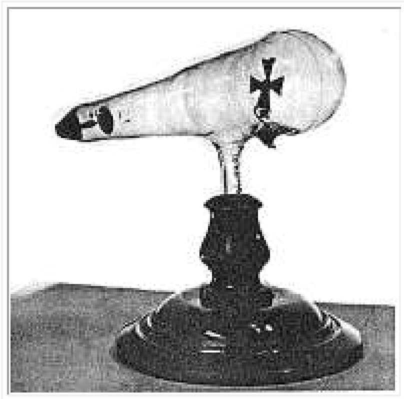


- Continued reduction in pressure causes the dark space to expand, and the color at the electrodes to fade until the tube is dark, except for a faint green or violet glow around the anode. The sides of the tube fluoresce (usually green). The dark region is now called Crookes' dark space.



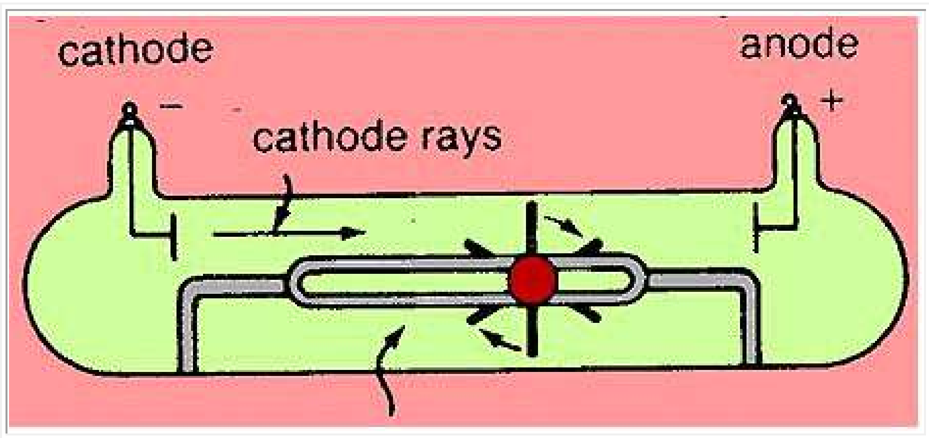
- Investigations centered on what was happening in the dark space. Early researchers decided that the glow in the gas originated at the cathode. For this reason, the discharge was called CATHODE RAYS, and the tube a CATHODE RAY TUBE (CRT).

MALTESE CROSS TUBE



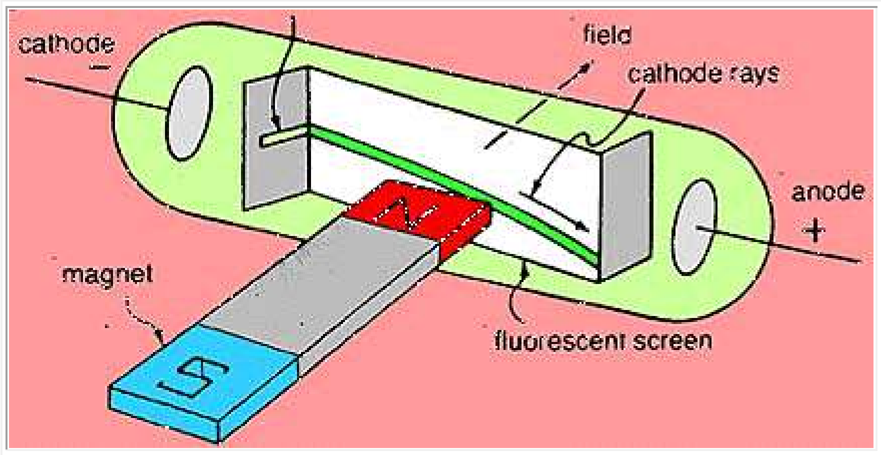
- Plucker made an anode into a Maltese cross, and this produced a shadow in the glow at the end of the tube. This showed that the cathode rays traveled in straight lines.

PADDLE-WHEEL DISCHARGE TUBE



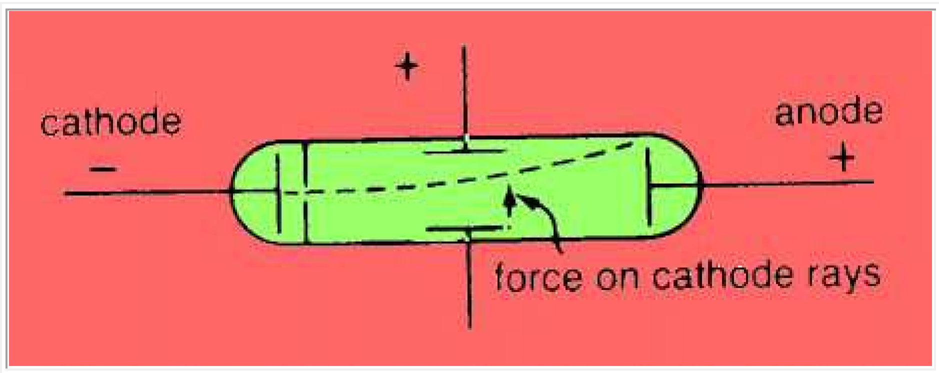
- Crookes reported that a paddle wheel placed in the path of the cathode rays turned. This proved that the cathode rays carried energy, and that they might be made of particles.
- This also indicates that the rays (particles) moved from the cathode to the anode.

CATHODE RAYS IN A MAGNETIC FIELD



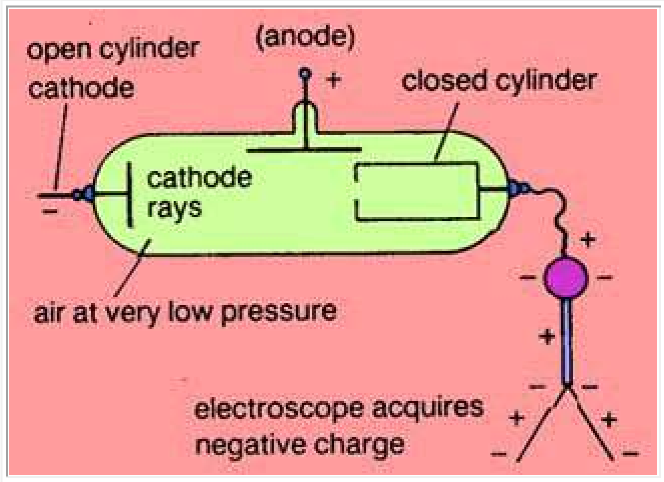
- Crookes showed that the rays were deflected by a magnetic field.
- Crookes noted that charged particles in a magnetic field experience a force. Cathode rays behaved as if they were negatively charged particles.

CATHODE RAYS IN ELECTRIC FIELDS



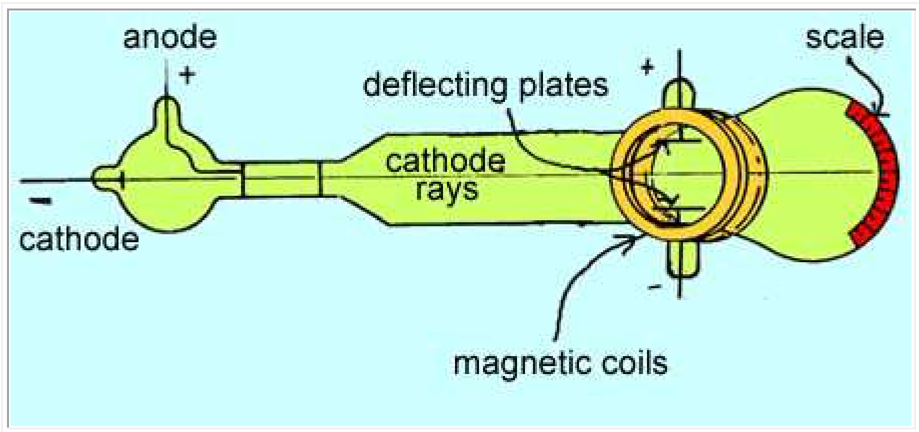
- Arthur Schuster noticed that the particles were repelled from a negative plate and attracted to a positive plate.
- This is further proof that cathode rays are negatively charged particles.

CATHODE RAYS CARRY A NEGATIVE CHARGE



- Jean Perrin constructed an apparatus that had an anode made of a hollow aluminum cylinder that was open at both ends. At the end opposite to the cathode, was a cylinder that was closed at one end.
- The closed cylinder collected the cathode rays and was connected to an electroscope, which was used to determine the charge on the cathode rays.
- The electroscope showed that the cathode rays were negatively charged.

THOMSON'S TUBE



- The deflecting plates deflected the particles in one direction.
- Magnetic coils deflected the particles in the other direction.
- BY adjusting the relative strength of the electric and magnetic fields, the particles went straight.
- From measurements and equations for deflecting particles by magnetic and electric fields, the charge to mass ratio was determined (1.76×10^{11} C/kg).
- The charge to mass ratio (Q/M) was the same regardless of the potential difference used to accelerate particles.
- Q/M was the same for different cathode materials. This indicates that there must be a similarity between particles making up different cathode materials.
- Similar experiments with hydrogen ions, showed that the hydrogen Ion's charge to mass ratio was 1836 times smaller than for cathode rays.
- If we assumed that equal charges were present on the hydrogen ions and cathode ray particles, then the mass of the cathode ray particles was 1/1836 of the mass for the hydrogen ion.
- The hydrogen atom is the smallest atom, yet these particles were smaller. This meant that the atom was not the smallest particle.
- Thomson concluded that cathode rays were light, fast moving, negative particles, that were a part of an atom.

- Thomson called the cathode ray particle, the **ELECTRON.**

PROPERTIES OF CATHODE RAYS

- They are produced by the negative electrode, or cathode, in an evacuated tube, and travel towards the anode.
- They travel in straight lines and cast sharp shadows.
- They have energy and can do work.
- They are deflected by electric and magnetic fields and have a negative charge.
- They are beams of tiny, negatively charged particles called electrons.

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Cathode Ray Tube is a link that leads to virtual cathode ray experiments.

Sample information

The Maltese cross is placed in the path of the cathode rays, causing a clearly defined shadow at the end of the tube. This effect is used to infer that cathode rays travel in straight lines and are blocked by solid objects.

Pairs of electric plates cause the cathode rays to bend towards the positive plate. This shows that cathode rays are associated with negative charges.

A fluorescent screen shows that cathode rays can cause fluorescence. This demonstrates that cathode rays have energy. A fluorescent screen can also be used to trace the path of cathode rays being manipulated by other means.

A lightweight glass paddle wheel, able to rotate freely, is placed in the path of the cathode rays so that the rays strike one edge of the wheel at a tangent. The cathode rays cause the wheel to spin and move away from the cathode. This demonstrates that the cathode rays must have momentum, and therefore mass, and that they are emitted from the cathode.

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

- Early experiments with cathode rays provided apparently inconsistent evidence about the nature of cathode rays, which seemed to behave both as waves and as streams of particles.

- Heinrich Hertz performed an experiment in 1883 that appeared to show that cathode rays were not deflected by electric fields. His experimental results were incorrect, however his result was used as evidence that cathode rays were electromagnetic waves, just like light which is not deflected by electric fields.

- J. J. Thomson performed an experiment that showed that a cathode ray beam was visibly deflected by an electric field. This was interpreted as indicating that cathode rays were charged particles.

- In 1892, Hertz also showed that cathode rays penetrated thin metal foils. This was interpreted to mean that cathode rays were electromagnetic waves.

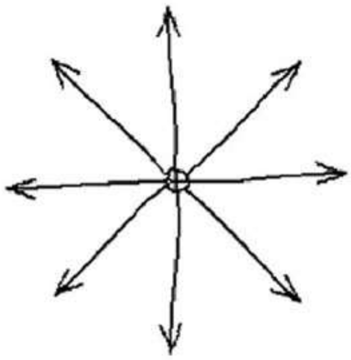
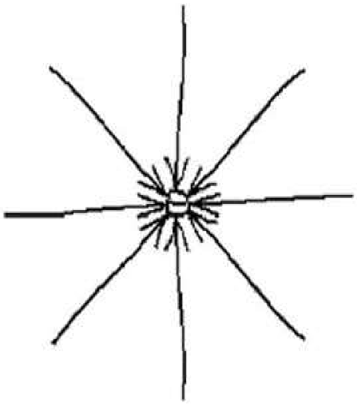
- These apparently conflicting results arose from inadequacies in experimental design and the then current state of knowledge about the nature of atoms. The properties of cathode rays were clarified by later experiments.

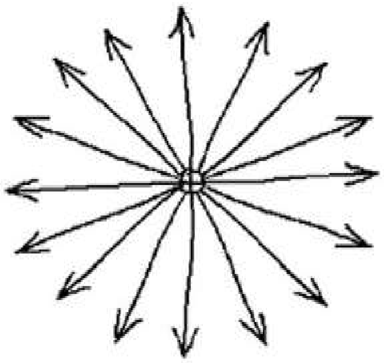
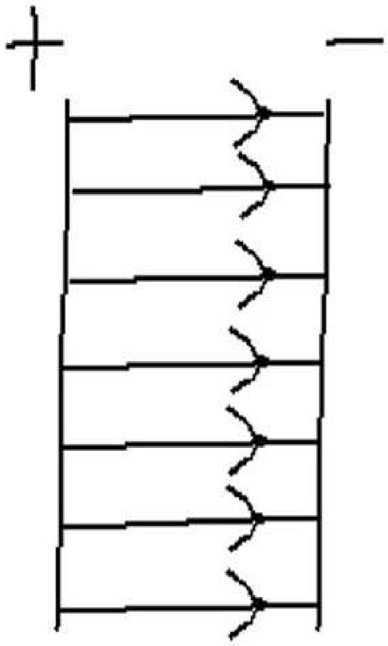
identify that charged plates produce an electric field

- An electric field exists in any region in which an electrically charged object experiences a force. The observation that charged plates exert a force on other charged objects brought close to them indicates that an electric field is associated with charged plates.

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

- An electric field has both strength and direction.

The strength of the electric field due to a positive point charge diminishes with distance from the object. The direction of the field is defined as pointing radially away from a positive point charge.	
The strength of the electric field due to a negative point charge diminishes with distance from the object. The direction of the field is defined as pointing radially towards a negative point charge.	

The electric field between two oppositely charged parallel plates is uniform in strength and direction. The field direction is defined as at right angles to the plates and away from the positive plate.	
The number of the lines drawn to represent a field at any point indicates the electric field strength at that point. The stronger the field, the more lines are drawn in a given space.	

The following web sites have simple interactive examples of electric field strength. You may need to be patient if you are using an early version computer.

Electric Force Fields University of Colorado, Boulder, Colorado, USA.

Electric Field Shapes David Hoult, Open Door Web Site, Ecole Active Bilingue Jeannine Manuel in Paris, France.

Electricity and Magnetism

Electric Field Shapes

Electric fields are often represented by electric lines of force.

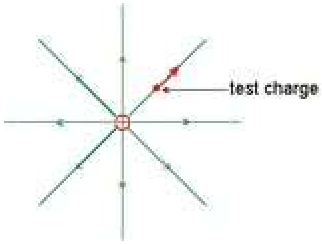
A line of force is a line showing the direction of the force acting on a positive charge placed in the field.

The "density" of the lines represents the magnitude of the field strength.

To draw a diagram showing the shape of an electric field, imagine a small positive charge (a test charge) to be placed in the field at different points.

Field due to a single charge

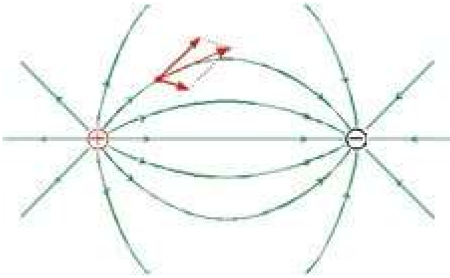
Wherever the test charge is placed, the force will be directed away from the charge (or towards the charge if it is negative). Therefore, in this case, the shape of the field is radial.



Field due to two opposite point charges of equal magnitude

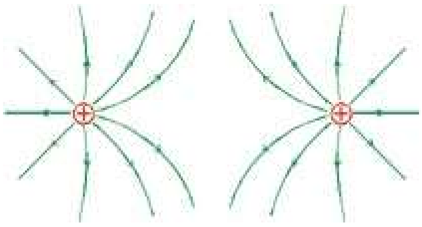
In this slightly more complicated case, a vector addition is needed to predict the direction of the line of force at the point considered.

By considering a number of such additions, we obtain the following shape.



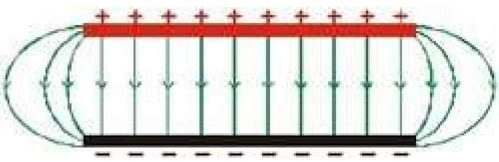
Field due to two similar point charges of equal magnitude

The same process gives the following result.



At the centre of this field is a place where the magnitude of the electric field strength is zero. This is called a neutral point.

Field between two oppositely charged parallel plates



In between the plates the field is uniform except near the ends.

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

- ***E = V/d***, where
  - ***E*** is electric field strength between two oppositely charged parallel plates,
  - ***V*** is the potential difference between the plates in volts, and
  - ***d*** is the distance between the plates in metres.

- Electric field strength, ***E***, between two oppositely charged parallel plates is:
  - proportional to the potential difference, ***V***, between the plates;
  - inversely proportional to the separation, ***d***, between the plates;
  - the same at all points in the region between the plates; and
  - at right angles to the plates everywhere in the region between the plates.

describe *quantitatively the force acting on a charge moving through a magnetic field* $F = qvB \sin \theta$

- $F = qvB \sin \theta$, where
  - ***F*** is the force on the charged object,
  - ***q*** is the charge in coulombs,
  - ***v*** is the velocity of the charged object in m s^{-1},
  - ***B*** is the magnetic field flux density (or magnetic induction) in teslas, and
  - θ is the angle between the velocity and the magnetic induction.

- Force, ***F***, on a charge moving through a magnetic field is:
  - proportional to the size of the charge, ***q***;
  - proportional to the velocity of the charge, ***v***;
  - proportional to the magnetic induction, ***B***; and
  - proportional to the sine of the angle, θ, between the velocity and the magnetic induction, being a maximum when θ is 90° (that is, when the velocity is at right angles to the field), and zero when θ is zero (that is, when the velocity is parallel to the field).

solve problems and analyse information using $F = qvB \sin \theta$ **F="qE " and** $E = \frac{V}{d}$

- **Solve** problems by selecting the appropriate equation, rearranging the equation where necessary, substituting known data for the variables, and computing the answer.

A sample problem:

A proton travelling at 5.0 x 10^3 m s^{-1} enters a magnetic field of strength 1.0 Tesla at 90°. Determine the magnitude of the force experienced by the proton.

Solution:

$$F = q\,v\,B\sin\theta$$
$$= (+1.6 \times 10^{-19}\ C) \times (5.0 \times 10^{3}\ m\ s^{-1}) \times 1.0\ T \times 1.0$$
$$= 8.0 \times 10^{-15}\ N$$

Another sample problem, requiring rearrangement of the equation:

The path of a helium nucleus, travelling at 3.0 x 10^{3} m s^{-1}, makes an angle of 90° to a magnetic field. The electron experiences a force of 1.2 x 10^{-15} N while in the field. Calculate the strength of the field.

Solution:

$$F = q\,v\,B\sin\theta$$

$$B = \frac{F}{qv\sin\theta}$$

$$= \frac{1.2x10^{-15}N}{(2x1.6x10^{-19}C)x(3.0x10^{3}ms^{-1})x1.0}$$

$$= 1.25\ T$$

Here is a sample problem for you to try:

Two parallel plates, placed 0.1 m apart, are connected to a 6-volt battery. Determine the electric field strength between the plates.

Solution:

E = 6 V ÷ 0.1m

E = 60 V m^{-1}

- **Analyse** information by examining relationships between the variables in the equations given.

  Sample analysis questions:

  1. If the potential difference between two charged parallel plates is kept the same, while the plates are moved closer together, how will this affect the electric field strength between the plates?

     Analysis: E = V / d. Since E is inversely proportional to d, if d is reduced E will be increased. For example, if the separation is halved, the field strength will be doubled.

  2. A proton and an alpha particle are travelling parallel to each other with the same speed in the same magnetic field. Which will experience the greater force?

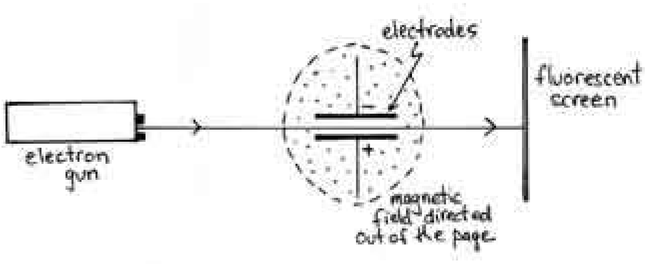
     Analysis: $F = q\,v\,B\sin\theta$. Since F is directly proportional to q, and v and B are equal for both particles, the alpha particle, with two protons, will experience a greater force than the proton alone.

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

- Cathode rays were passed through two narrow slits to make a thin parallel beam aimed at the centre of a fluorescent screen. Electrodes were placed to create a uniform electric field that exerted a downward force on the beam. Electromagnets were placed to produce a uniform magnetic field that exerted an upward force on the beam.

- Thomson manipulated the strengths of the two fields until the beam passed through both fields undeflected. This showed that the two forces on the particles (electrons) in the beam were equal and opposite. By equating the expressions for these two forces, Thomson calculated the velocity of the particles.

- Thomson removed the electric field and calculated the radius of the circular path followed by the particles in the uniform magnetic field alone. By equating the force due to the magnetic field to the centripetal force, he was able to calculate that all cathode ray particles (electrons) had the same *charge / mass* ratio of 1.76×10^{11} C kg^{-1}.



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

- The electron gun produces a narrow beam of electrons. The electrodes in the gun accelerate the electrons.

- The deflection plates or coils establish an electric field that controls the deflection of the electron beam from side to side and up and down.

- The fluorescent screen is coated with a material that emits light when struck by electrons in the cathode ray. This allows the position of the beam to be seen where it strikes the screen.

9.4 From ideas to implementation: 2. The photoelectric effect and black body radiation

Syllabus reference (October 2002 version)

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

- **Perform** the investigation by selecting a procedure like that described below and carrying it out, recognising where and when modifications are needed and analysing the effect of any adjustments that you make. Write an account to explain how this investigation demonstrates the production and reception of radio waves. Note particularly any scientific controls that help you demonstrate this.

Sample procedure

1. Turn on a radio and tune it to your favourite AM or FM (500 - 1600 k Hz) station. Note any "noise" or interference that is heard in the signal.
2. Turn on a signal generator that produces an AM modulated radio frequency (RF) signal and adjust the output signal frequency from 500 - 2000 k Hz. Note any effect on reception of your favourite station.
3. Take a length of copper wire and bend it into a shape that you think will make a good transmitter. Try various shapes in turn, including straight, a loop and a coil.
4. Turn off the signal generator and connect the transmitter to the *output* terminals.
5. Repeat as for step 2. Adjust the output frequency slowly until "noise" or interference is heard on your favourite station. Compare this frequency with the known frequency of the radio stationn when the noise or interference is at a maximum.
6. Repeat the previous step using different transmitter aerials and after tuning the radio to a different station. (Do this in a systematic way.)

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

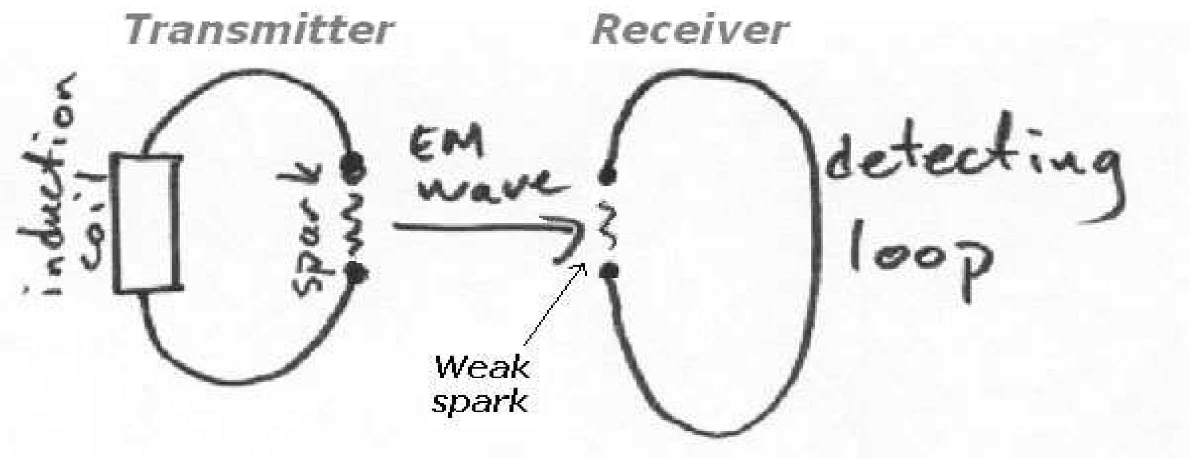
- Hertz observed that the spark between the gap in the transmitter loop caused an electrical disturbance between the gaps in the detecting loop.

- Hertz observed that the gap in the detector could be made larger and still generate sparks when the radiation from the transmitting spark shone directly into the gap in the detecting loop. Hertz did not recognise that the UV component in the transmitter spark removed free electrons from the surface of the metal, thus allowing the discharge (spark) to occur across a wider gap.

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

- In 1887 Hertz produced experimental evidence for the existence of electromagnetic waves, theoretically predicted by Maxwell in 1864.

- Hertz set up an induction coil. As sparks were generated across a small gap they induced sparks in a detecting loop a small distance away. This spark was evidence for electromagnetic waves travelling through space from the induction coil to the detecting loop.

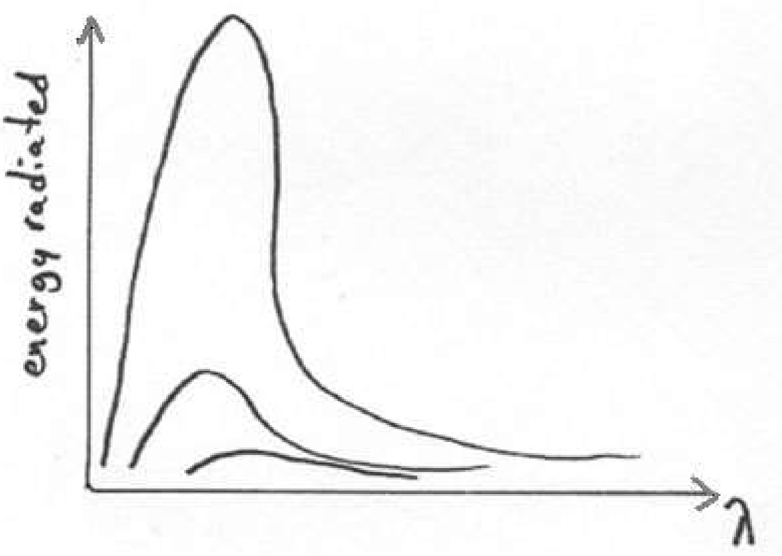


- Hertz was able to calculate the velocity of the waves by reflecting the generated waves off a metal sheet and measuring the wavelength of the standing wave set up by interference. Substituting this wavelength and the known frequency of the wave generator into the general wave equation, v = ? x f, Hertz calculated the wave speed at 3×10^8 ms^{-1}, very close to the values for the speed of light earlier estimated by Maxwell and measured by Fizeau.

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

Background information

It was thought that the energy absorbed and emitted by a black body should be continuous, that is, could occur in any amount, and should increase as the wavelength became shorter. This was not supported by the experimental data as shown in the sketch. The amount of energy radiated reaches a maximum at a wavelength that depends on the temperature of the black body.



- Planck's explanation for the observations involved the radical idea that energy could only be radiated or absorbed in small discrete amounts, later called quanta, now identified as photons. The size of each quantum of energy is characteristic of the frequency of light emitted.

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

This investigation can be conducted by **gathering** a range of resources including scientific journals, CD-ROM resources and the Internet.

- In deciding the **type of data** necessary for this investigation, you need to:
  - consider the type of information about quanta and black body radiation that needs to be collected
  - select data sources.

- To **process** the information in the sources you find, assess its reliability by comparing the information provided. Look for consistency of information.

- **Analyse** the information to make a generalisation regarding Einstein's use of quantum ideas to explain the properties of black body radiation.

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

- Einstein explained Planck's work in the following way:

  The energy associated with the radiation from a black body is concentrated in packets of energy called photons. A photon is the smallest amount of radiation energy possible at a particular frequency. A photon cannot transfer part of its energy: it can only transfer all of its energy or none of it. The amount of energy carried by a photon is proportional to its frequency. The intensity of light is proportional to the number of photons. The energy possessed by a photon is proportional to its frequency, hence the observation, in relation to black body radiation, that the shorter the wavelength (thus the higher the frequency) the greater the total energy radiated (for a given temperature).

- Einstein also explained that wave and particle behaviour can coexist.

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

- Some of the properties of light are best explained if light is considered to consist of a stream of particles, or discrete bundles of energy, called photons.

- A photon carries an amount of energy that is proportional to the frequency of the radiation (light). All photons of light of a particular frequency have precisely the same amount of energy. The higher the frequency of the light, the more energy the photon possesses, thus photons of ultraviolet light have higher energy than those of blue light, which in turn have higher energy than photons of red light.

- All photons, regardless of their frequency, have zero rest mass and travel at 3×10^8 m s^{-1} in a vacuum.

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

- Decide what **data** you need to gather and in what form you will gather it so that it can be efficiently processed. It might be useful to work with a group to collect information to produce a set of annotated diagrams. You will need to decide on the format of the diagrams and the language to be used.

- Try to **gather** information from a range of resources, including popular scientific journals, digital technologies like CD-ROMs and the Internet. Focus on collecting explanations of how the function of each device depends on the photoelectric effect.

- **Present** the information to other students. You may use visual aids such as overhead transparency graphics or a *Power Point* presentation. Keep the information simple with just the summary asked for in the syllabus point.

- Your **summary** could include a brief statement on some or all of the following:
  - How are the design and construction of the device related to its photoelectric function?
  - How are the output voltage and/or current related to the intensity and/or the frequency of incident light?
  - What industrial, scientific, commercial or domestic technologies use this device?
  - What are the advantages or limitations of the device?

Sample information

Photocells are common in electric eyes, radiation detectors and light meters. Many utilise the photoelectric effect to detect the presence of light or radiation at particular wavelengths. For example, a photoelectric photometer is used by astronomers to analyse the frequencies of light received from a star. Others respond to a change in light intensity by detecting a particular photocurrent, such as in an alarm circuit where an intruder cuts a beam of light falling on a photocell.

Photovoltaic devices, use a silicon semiconductor to convert sunlight, or any visible light, into electrical energy. When sunlight falls on a junction between n-type and p-type semiconductor material, electrons are ejected from atoms. These electrons are collected to form a direct electric current (DC).

identify ***the relationships between photon energy, frequency, speed of light and wavelength:*** $E = hf$ ***and*** $c = f\lambda$

- The energy of a photon is given by the relationship **E = h** x **f**, where:
  - **E** is the energy of the photon in joules (or electron volts)
  - **h** is Plank's constant: 6.6 X 10^{-34} J s
  - **f** is the frequency of the light in hertz (seconds^{-1}).

- The speed of light is given by the relationship $c = f \times \lambda$, where
  - **c** is the speed of light: 3 x 10^8 m s^{-1}
  - **f** is the frequency of the wave
  - λ is the wavelength of the wave.

- By combining the two equations we can get a relationship between energy and wavelength, $E = h \times c / \lambda$

solve problems and analyse information using: $E = hf$ **and** $c = f\lambda$

- **Solve** problems by selecting the appropriate equation, rearranging the equation where necessary, substituting known data for the variables, and computing the answer.

  A sample problem:

  Calculate the wavelength and the energy of a photon of light with frequency equal to 1.984 x 10^{14} Hz.

  Calculating the wavelength, from $c = f \times \lambda$:

  $c = f\lambda$ $\quad 3 \times 10^8 = 1.984 \times 10^{14}$ x λ
  =" " 1.51 x 10^{-6} m

  Calculating the energy of the photon: ***E = hf***

  E = 6.628 x 10^{-34} x 1.984 x 10^{14}
  = 1.31 x 10^{-19} J

- **Analyse** information by examining relationships between the variables in the equations given.

  Sample analysis question:

  Two of the lines in the emission spectrum of mercury represent violet light of wavelength 4.05 x 10^{-9} m and red light of wavelength 6.90 x 10^{-9} m. Which of these wavelengths would have the more energetic photons?

  Answer:

  Photons of the violet light would have more energy. From the wave equation *c* = *f* x λ we can see that, as violet light has a shorter wavelength than red light, its frequency is higher. From Planck's equation $E = h \times f$, therefore the energy of violet photons is greater than the energy of red photons.

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

- **Gather information** by looking in encyclopaedias, scientific and popular journals, magazines and text books, as well as searching the Internet , including Wikipedia. Use search strings such as "Political views of Albert Einstein" and "Life of Max Planck".
- **Process** your information by assessing its relevance to your topic and assessing its reliability by comparing information from various sources.
- Summarise your information to describe the social and political influences on both Einstein and Planck at the time, and to describe the views held and actions taken by each of them.
- This is a website about the science more than the philosophy but it is worth having a look at. On Truth and Reality

References

Heilbron, J., 2000, *The dilemmas of an upright man*. Max Planck and the fortunes of German science. With a new afterword. Cambridge (MA), London. This biography of Planck lays out the two sides of the issue.

Rosenthal-Schneider, I., 1980, *Reality and scientific truth.* Wayne State University Press, Detroit, ISBN 0-81-431650-6. This is an engaging collection of essays about and correspondence with Einstein, Planck and von Laue, by Ilse Rosenthal-Schneider, who was taught by these three in Germany before she emigrated to Australia. She spent the second half of her life at the University of Sydney, where she taught the history and philosophy of science.

Walker, M., 1995, *Nazi science: Myth, truth and the German atomic bomb*. Plenum, New York, ISBN 0-306-44941-2.

American Institute of Physics (AIP), June 2001, *Albert Einstein: image and impact,* in ***Public concerns*** American Institute of Physics web site, USA. The following is a relevant quotation from their AIP web site:

"*The outbreak of the First World War brought Einstein's pacifist sympathies into public view. Ninety-three leading German intellectuals, including physicists such as Planck, signed a manifesto defending Germany's war conduct; Einstein and three others signed an anti-war counter manifesto. He helped form a non-partisan coalition that fought for a just peace and for a supranational organisation to prevent future wars. As a Swiss citizen, Einstein could feel free to spend his time on theoretical physics, but he kept looking for ways to reconcile the opposing sides. "My pacifism is an instinctive feeling," he said, "a feeling that possesses me because the murder of men is disgusting. My attitude is not derived from any intellectual theory but is based on my deepest antipathy to every kind of cruelty and hatred*".

Sample information

Although there was no direct debate between Einstein and Planck on this issue, it seems that Einstein and Planck took different views about scientists remaining in Germany during the Nazi era and continuing to do scientific research.

Planck stayed on and directed the Kaiser Wilhelm Institute. Einstein and others left Germany. Although there was no direct correspondence between Einstein and Planck, consideration of the actions of each provides a case study of the complexity of evaluating the moral responsibility of science to social orders.

9.4 From ideas to implementation: 3. Transistors

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

- In some solids, the outer electrons are very loosely bound to particular atoms. These electrons can therefore move across the entirety of the solid.

perform an investigation to model the difference between conductors, insulators and semiconductors in terms of band structures

- **Perform** the investigation by:
  - selecting a procedure, like that described below
  - carrying it out, recognising where and when modifications are needed
  - analysing the effect of any adjustments that you make.

- Write an account to explain how changing the distance between the two halves of the egg carton before tilting the valence band half of the carton models the difference between conductors, insulators and semiconductors.

A procedure to model the difference between conductors, insulators and semiconductors

1. Open an empty egg carton (keep sides joined together) and place a ball bearing into each of the egg holders for ONE side. This represents the VALENCE band. The half of the carton WITHOUT the egg holders filled represents the CONDUCTION BAND.

2. Now slowly tilt the half of the carton with ball bearings towards the empty half.

3. Repeat the above steps EXCEPT separate the two halves of the carton and place them side-by-side and 15 cm apart. This will represent the forbidden energy gap of an insulator.

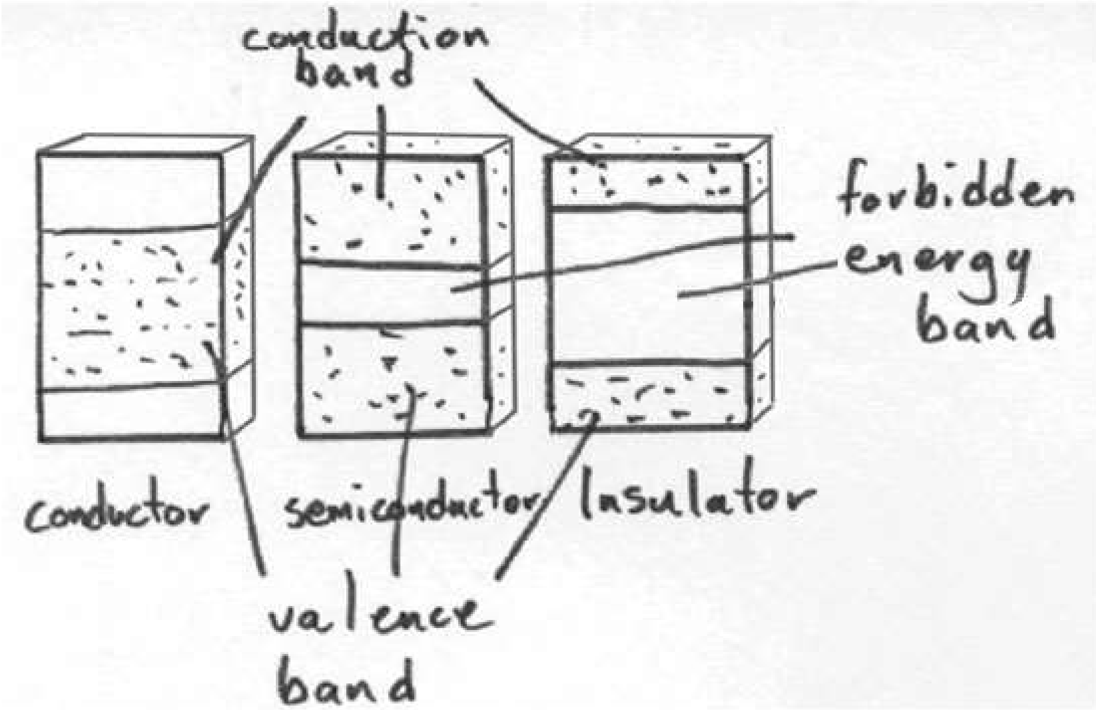
4. Repeat the above steps EXCEPT separate the two halves of the carton and place them side-by-side and 5 cm apart. This will represent the reduced forbidden energy gap of a semiconductor.

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

Background

When two atoms are close enough to interact with each other the allowed energy levels that the electrons can occupy splits into two distinct, but closely spaced, energy levels. In a three atom system there are three energy levels, and so on. In a crystalline solid there are so many atoms interacting that the energy levels are very close to each other. The electrons in the structure are restricted to one or other of these energy levels. Depending on the nature of the chemical bonding, electrons at particular energy levels can be grouped into bands. There are several types of bands, including:

- the conduction band where the electrons are free to move
- the valence band, which contains electrons that, given the right conditions, can be induced to move into the conduction band
- between these two bands is often a third bans or region which prevents electrons moving between the conduction and valence bands (forbidden energy band).



- In a conductor, the conduction and valence bands overlap. This allows the valence electrons to easily move along the conduction band giving the material low electrical resistance.
- In insulators, there is a large forbidden energy band, which makes it difficult for valence electrons to move into the conduction band giving the material a high electrical resistance.
- In semiconductors, the forbidden energy band is not too wide. Under certain conditions, electrons in the valence band can gain sufficient energy to cross the gap. This reduces the electrical resistance of the material.

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

- **Perform** the investigation for whatever aspect you decide to test (elecrton and or whole movement). You may need to make modifications to your procedures as you go. Write an account of your experiment to explain how the model demonstrates the behaviour of electrons and holes in a semiconductor.

A procedure to model the behaviour of semiconductors

1. Place two separated halves of an egg carton side-by-side and 5 cm apart.
2. Place a ball bearing into each of the egg holders in one side of the egg carton. The ball bearing represents an electron. This side will be the VALENCE BAND.
3. Now remove ONE ball bearing from an egg holder in each row. This represents doping a semiconductor to create a "hole".
4. Raise ONE end of the half of the egg carton containing the ball bearings until a ball bearing falls into the space left by removing the first ball. Raising the carton represents the applied potential difference. The movement of the ball bearing represents the electron movement and the apparent movement of the empty egg holder represents hole movement.
5. Repeat the first two steps EXCEPT place extra ball bearings (electrons) between the egg holders. This represents doping a semiconductor to create an n-type.

6. Slowly tilt the half of the egg carton containing ball bearings TOWARDS the empty half.

7. Stop tilting when ANY of the extra ball bearings make it across.

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

- When an electron in a semiconductor moves into the conduction band it leaves a "hole", that is, an atom with one less valence electron than normal. An electron from a nearby atom in the valence band can move and fill the hole. This then creates another hole, and so on.

- The creation of holes and the movement of electrons to fill them is equivalent to an electric current in the semiconductor. Electrons flow in one direction. The apparent movement of holes in the opposite direction can be considered as a flow of positive charge.

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

- Conductors contain high numbers of free electrons in the conduction band. Under normal conditions, insulators and semiconductors have far fewer free electrons than conductors.

- Raising the temperature, using certain lighting conditions or applying a potential difference, can induce electrons in some semiconductors to move into the conduction band.

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

- This investigation can be conducted by **gathering** a range of resources including scientific journals and Internet sites, like the one given below. Focus on collecting information about the shortcomings of vacuum tube technology and the development and strengths of transistor technology.

  Transistorized The American Institute of Physics, USA.

  How does a transistor work? PhysLink.com

- To **process** the sources you find, assess their reliability by comparing the information provided. Look for consistency of information.

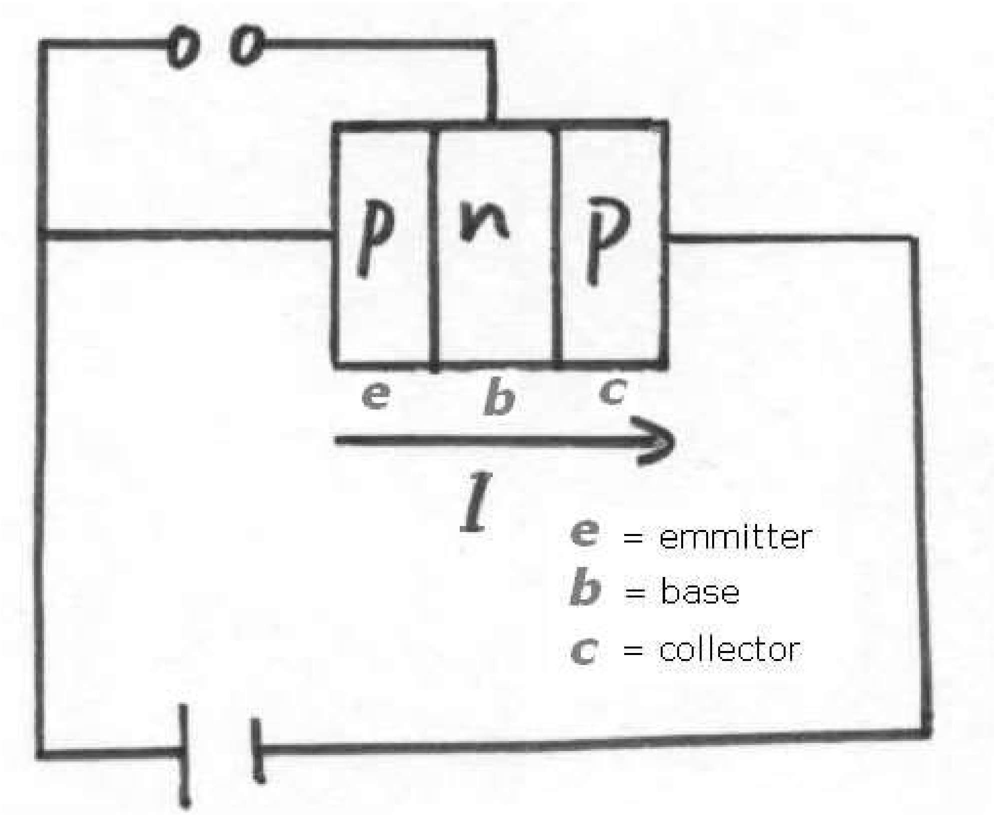
- **Present** the information to other students. You may use visual aids, such as overhead transparency graphics or power point presentation. Keep the information simple and produce just the summary asked for in the syllabus point.

Sample information

Radio and electronics required the ability to increase the voltages of signals to drive loudspeakers and other electrical devices. This could be achieved by vacuum tubes.

The tubes however were fragile, lost vacuum slowly and the electrodes corroded.

In 1948 Bardeen, Brattain and Shockley discovered the transistor. It consists of an n-type semiconductor, called the base, between two p-type semiconductors, called the emitter and the collector.



A small AC current in the emmitter-base circuit produces a large current flow in the emmitter-collection circuit that is proportional to the AC current in the emmitter-base circuit. This is a transistor amplifier.

The transistor is small, long lasting and reliable, not depending on any moving parts. It quickly replaced the vacuum tube in many electronic devices.

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

- At first, germanium was widely used as a semi-conductor because it was easier to purify than other known semi-conductors, such as silicon.

- Silicon eventually replaced the germanium as semi conducting material of choice in transistors because :
    - it is the second most abundant element on earth by weight, which means it is relatively cheap
    - it retains its semi conducting properties at relatively high temperatures (when compared to germanium)
    - it can handle higher electric currents before overheating (which destroys its semi conductor properties)
    - it forms an oxide that can be doped and made into thin, flat layers
    - processing techniques were developed to produce very pure, single crystal forms
    - in single-crystal form (very pure silicon), the molecular structure of the material is uniform, thus ensuring consistency of properties.

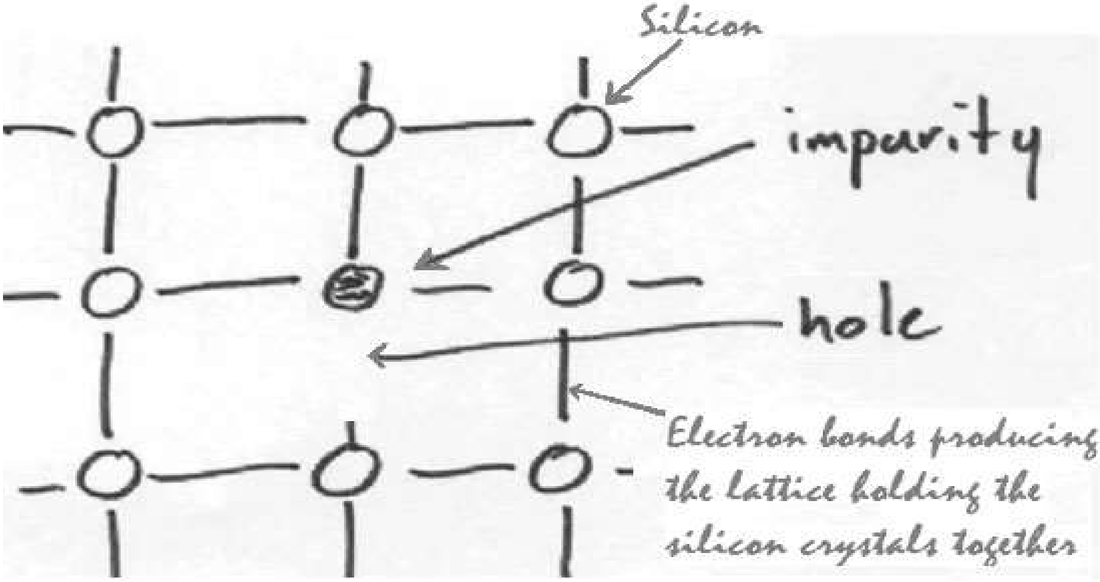
describe how 'doping' a semiconductor can change its electrical properties

- Doping is the addition of an impurity (such as gallium or arsenic) to a semiconductor in the ratio of about one part per million.

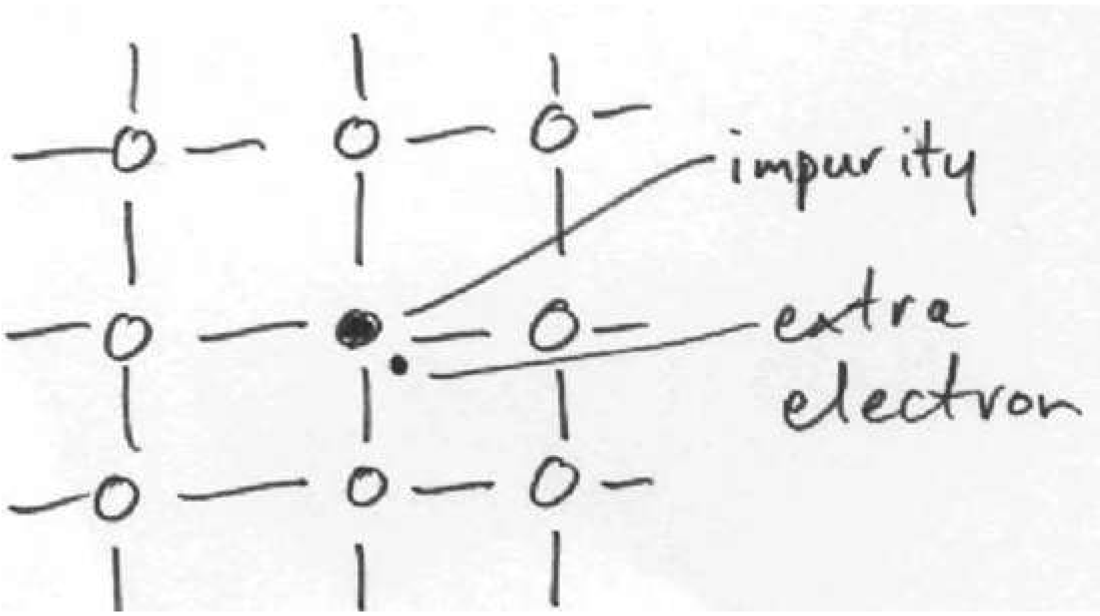
- The atoms of the doping element need to fit reasonably well into the semi-conductor lattice structure so as not to distort it and impede electron flow.
- The doping element needs to have either one more valence electron than the semi-conductor itself or one less valence electron than the semi-conductor material.
- Doping increases the potential conductivity of the semiconductor (extra electrons or holes to act as charge carriers).

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

- In p-type semiconductors there are more positive holes than negative charge carriers. Elements such as aluminium and gallium (3 valence electrons) are used as doping agents with silicon to produce p-type semiconductors.



- In n-type semiconductors there are more negative charge carriers than positive holes. Elements, such as arsenic and phosphorus (5 valence electrons), are used as doping agents with silicon to produce n-type semiconductors.



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

- A thermionic device contains a cathode that emits electrons only when heated to a high temperature. It requires a separate heating circuit to heat the cathode, which takes time to heat up. A solid state device uses semiconductors to generate a flow of electrons and does not require a heating circuit.
- Solid state devices work immediately, require less power and then produce less heat than equivalent thermionic devices.
- A thermionic device requires a near vacuum to allow electrons to flow between the electrodes, thus they are commonly packaged in an evacuated glass tube. Solid state devices operate at normal air pressures and are commonly packaged in thermosetting plastic.
- Modern solid-state devices are very much smaller than thermionic devices, allowing electronic equipment to be reduced in size.
- The combined advantages of smaller size, simpler and cheaper construction, lower power requirements and speed of operation make solid state devices more attractive to electronics manufacturers than equivalent 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

- In deciding the **type of data** necessary for this investigation, you need to:
    1. select appropriate sources
    2. consider the type of information about the invention of the transistor that must be gathered.

- Scientific journals and the Internet should be good data sources to **gather** information about the impact of the discovery of the transistor. Use a search engine and type in some words or phrases like *History of the Transistor*, *How Microchips Work*, *The Basics of Microprocessors*.
- You should **process** this information by only selecting material that is relevant to the discovery of the transistor and to its impact on
- **Analyse** the information to make a generalisation regarding the impact of the devices using transistors on society.
- You can justify the generalisation by seeking **evidence** for how aspects of society have changed due to the use of transistors in the devices you have chosen

Sample information

The discovery of the transistor led to the development of integrated circuits. Many thousands of transistors and other electronic components could be constructed on a tiny microchip.

Complex circuits could be miniaturised allowing for faster transfer, storage and processing of information. Tiny processors capable of controlling very complex processes could be incorporated into a wide range of appliances. Many tasks that were formerly done manually could now be done by a small electronic device.

Increased capacity to handle such information has resulted in numerous developments in areas such as medical diagnosis and treatment, entertainment, commerce, industrial design and communications.

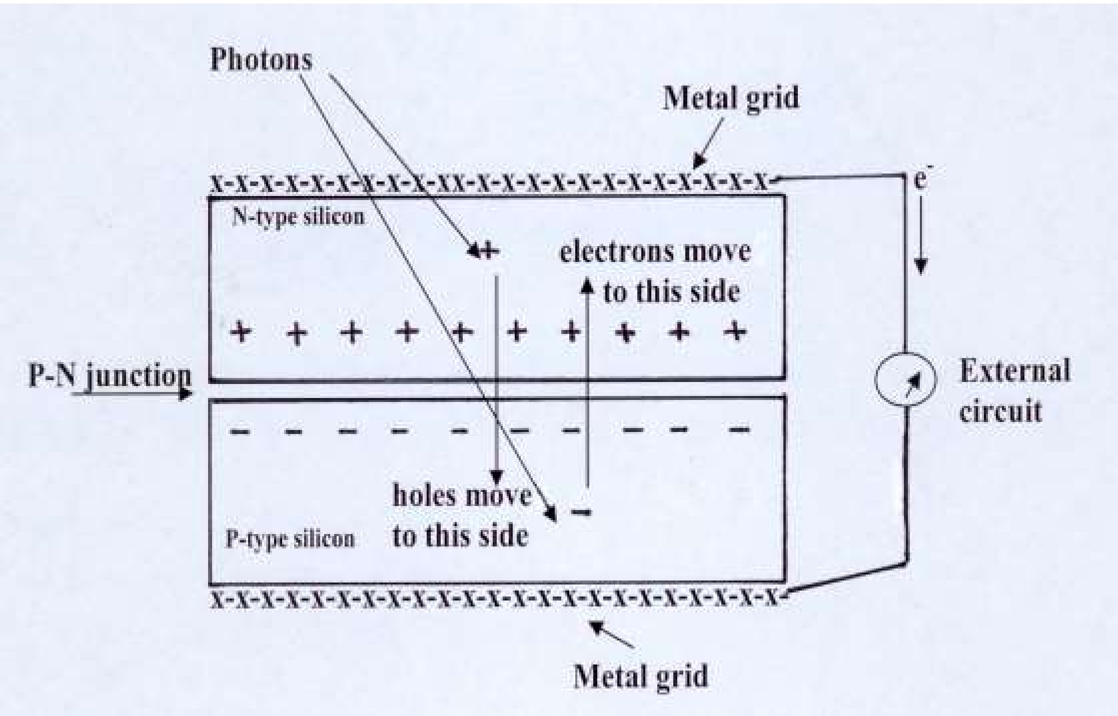
identify data sources, gather, process and present information to summarise the effect of light on semiconductors in solar cells

- To find up to date information go to the Internet. Use a search engine and type in words such as 'light', 'semiconductor', 'solar cells' and 'effect'. Skim the information and choose that which is relevant to your task.You might choose two or three different sources. Energy Production animations and java applets. ▸ Educypedia-science

- **Process** the information by assessing the reliability of it from all the sources. You may choose to incorporate information from several sources.

- **Present** your data using an appropriate medium. What you choose will depend partly on the audience. You may choose a power point presentation, an overhead transparency or just give an oral or written presentation with a diagram.

- Some information that could get you started is: When light strikes a semiconductor material a certain portion of the light (depends upon the covering of the semiconductor) is absorbed into the semiconductor material. The energy of the absorbed light, in the form of photons, is transferred to the semiconductor resulting in electrons and positively charged holes moving across the PN-junction in opposite directions. An electric field within the photovoltaic cell acts to force the electrons in a certain direction. A metal grid on either side of the solar cell allows the electrons to collect and, if connected to an external circuit, a current will flow.



9.4 From ideas to implementation: 4. Superconductivity

outline the methods used by the Braggs to determine crystal structure

- Sir William and Lawrence Bragg studied crystals using X-rays. They examined the patterns produced by the X-rays after the rays passed through the crystal and hit a photographic screen. The patterns were used to determine the internal structure of the crystals.

- X-rays were produced by allowing high energy cathode rays to strike a metal anode. These rays were directed at a crystal of a metal salt. (The first tried were sodium chloride, NaCl, and zinc sulfide, ZnS).

- A photographic plate was placed in the path of the X-rays exiting the crystal. The X-rays hitting the photographic plate produced a pattern of bright spots.

- 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.
- The Braggs' work was direct evidence for the periodic atomic structure of crystals postulated for several centuries.
- Their research provided a method, used for the next 50 years, to determine a number of simple crystal structures.
- A mathematical expression, Braggs Law, developed for explaining these patterns of X-rays, allowed the future study of material structure using other types of electromagnetic (e-m) beams.
- The application of this technique has been crucial in determining the structure of important biological substances, such as DNA, and in the development of the transistor and microchip.

identify that metals possess a crystal lattice structure

- The atoms in a crystal are in a regular repeating pattern called the crystal lattice.
- A crystal lattice is defined by a repeated three-dimensional unit.
- The basic building block of these crystalline structures is known as the "unit cell" and this "unit cell" repeats itself over and over to form a lattice.
- When a pure metal starts to form from a cooling molten state, the atoms arrange themselves in an ordered geometrical pattern that is repeated over and over again producing a crystalline structure.

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

- In a metal, the valence electrons are thought of as being shared by all the positive ions. Therefore, the electrons are free to move throughout the crystal lattice.
- Metals have many electrons that are free to move.
- Metals are good conductors of electricity.

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

- Chemical impurities disrupt the lattice integrity which, in turn, impedes the free movement of electrons. Similarily, free electron movement is impeded by rapid minor position changes (vibrations) in the lattice. The vibrating lattice collides with free moving electrons, thus deflecting or scattering them from their linear progress through the crystal.

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

Your teacher may give you Internet sites to research. One such site is:

Superconductor Information for the Beginner Joe Eck, superconductors.org, USA.

- To **process** the sources you research, assess their reliability by comparing the information provided on that site with similar information from other sources. Look for consistency of information.

- A table like the one below is an effective tool to assist you to process the information.

MATERIAL	TYPE	CRITICAL TEMPERATURE (T *c*) (K)
mercury	metal	4.15
tin	metal	3.69
lead	metal	9.20
TlBaCaCuO	ceramic	125

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

- Electrons are the charge carriers in a metal. At room temperatures, the metallic bonds (the lattice) holding the conductor together vibrates and interferes with electron movement through the conductor. Along with impurities and imperfections in the lattice itself, these three factors are responsible for resistance effects (energy loss and restricted current flow) in a conductor.

- Superconductivity describes the state reached in a conductor when the resistance to electron movement in a conductor drops to zero. Research has shown that there are two types of superconductors. For a number of pure metals, superconductivity occurs at temperatures from close to absolute zero and up to 23K (Type I). For another group of conductors, ones that have been manufactured using alloys of metals and metal oxides, superconductivity (Type II) has been demonstrated to occur at higher temperatures (in the range of 120 K).

- At temperatures below the critical temperature, lattice effects impeding electron movement changes dramatically from impeding to assisting electron flow. That assistance comes about by an effect that pairs electrons and assists them to move freely through the conductor. The theory is called the BCS theory and is more fully explained in the next section.

discuss the BCS theory

- The **BCS** theory (after is proponents US physicists John **B**ardeen, Leon **C**ooper and John **S**chrieffer) explains superconductivity in terms of electron pairs and packets of sound waves related to lattice vibrations (called phonons).

- At temperatures below the critical temperature for particular metals (or metal alloys), the movement of electrons is enhanced by lattice vibrations (phonons) which cause electric field effects resulting in electron pairing (by overcoming what would normally be strong repulsive forces between like charges) and an assisted passage through the lattice with negligible energy loss.

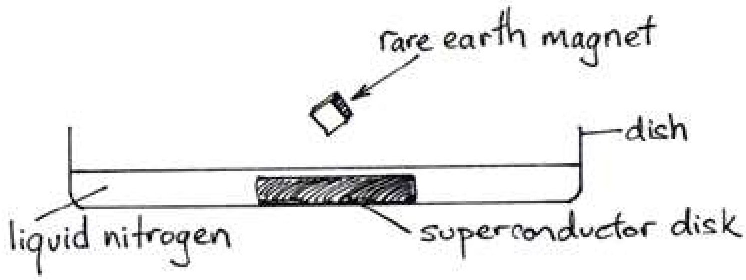
- At temperatures below the critical temperature for the particular conductor, the cooper pairs (as the electron pairs are called) stay together. Because resistance is effectively zero, very narrow wires can carry very large currents. The lower the temperature, below the critical temperature, the higher that current can be. That current produces a magnetic field around the conductor. The strength of the magnetic field will reach a point where it will cause the loss of the superconducting state thus putting an effective limit on the current that can flow in any particular superconductor.

- The practical application of superconductors is based on the combination of critical temperature (T_c the point below which superconductivity occurs), the critical field (H_c the strength above which superconductivity is stopped) and the current density (J_c above which superconductivity ceases).

perform an investigation to demonstrate magnetic levitation

- Your teacher will explain how this investigation can be **performed** safely in your course. The effect is called the Meissner Effect.

The Meissner Effect



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 superconductor will not allow a magnetic field to penetrate its interior.
- An external magnetic field causes currents to flow inside the super conductor. These currents generate a magnetic field inside the superconductor that just balances the field that would have otherwise penetrated the material.
- This effect was discovered in1933 by Meissner and Ochsenfeld and is known as the Meissner Effect.
- A magnet placed above a superconductor that is cooled below its critical temperature will induce a field inside the superconductor by the Meissner Effect. That field balances the external field and causes the magnet to "levitate" above the superconductor.

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

- Engineering journals and the Internet should be good data sources to **gather** information about the "maglev" train. Use a search engine and type in some of the words like *Maglev* or *applications of superconductivity.*
- **Process** your information making sure you assess its reliability by comparing information from various sources.

The following links may be useful:

Maglev Transport Wikipedia

Maglev Quicklinks Innovative Transport Technologies, University of Washington, USA.

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

- **Process** your information and check its reliability by comparing with information from other sources. The information provided with the following syllabus dot point demonstrates the scope and depth required. The best place to gather up-to-date information is on the Internet.

One place to start is **Uses for superconductors** ▸ Joe Eck, Superconductors.org, US

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

- Superconductors and their applications provide significant advantages as indicated in the following examples:
  - Superconductors carry large currents with no heat loss and can generate very strong magnetic fields.
  - Particle accelerators that use superconducting electro-magnets are cheaper to run because they use less electricity to produce the needed magnetic fields.
  - Superconductorshave beneficial applications in medical imaging techniques. **SQUIDs (S**uperconducting **QU**antum **I**nterference **D**evices) are sensitive enough to detect the very weak magnetic fields caused by electrical currents in the human brain. The devices have allowed doctors to develop better images of brain disorders.
  - Superconductors have been used in Japan to make experimental, magnetically levitated trains.
  - Electric generators made with superconducting wire are far more efficient, and about half the size, than conventional generators wound with copper wire.
  - New superconductive films may result in the miniaturisation and increased speed of computer chips.

- The limitations of superconductors include the technical difficulties of achieving and reliably sustaining the extremely low temperatures required to achieve superconductivity. The materials, of which they are made, are often brittle, are hard to manufacture and they are difficult to make into wire.