Light Basics

Study Design

Light as a wave

- **describe light as an electromagnetic wave which is produced by the acceleration of charges, which in turn produces changing electric fields and associated changing magnetic fields**
- **identify that all electromagnetic waves travel at the same speed, *c*, in a vacuum**
- **compare the wavelength and frequencies of different regions of the electromagnetic spectrum, including radio, microwave, infrared, visible, ultraviolet, x-ray and gamma, and identify the distinct uses each has in society**
- **investigate and analyse theoretically and practically the behaviour of waves including:**

  – refraction using Snell's Law: $n_1\sin(\theta_1) = n_2\sin(\theta_2)$ and $n_1v_1 = n_2v_2$

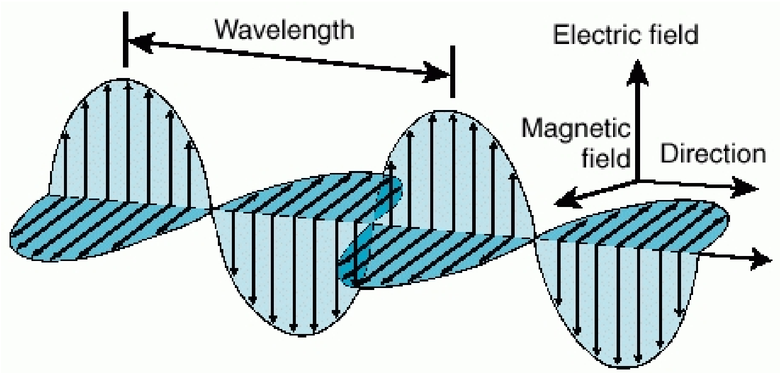
  – total internal reflection and critical angle including applications: $n_1\sin(\theta_c) = n_2\sin(90°)$
- **investigate and explain theoretically and practically colour dispersion in prisms and lenses with reference to refraction of the components of white light as they pass from one medium to another**

Production of light from matter

- **compare the production of light in lasers, synchrotrons, LEDs and incandescent lights.**

Light is the only thing that we can see. But what is light? Maxwell developed an answer to question of what the nature of light is, when he discovered that light was an electromagnetic radiation within the frequency range of 4.3×10^{14} to 7×10^{14} Hz. These waves activate the "electrical antennae" in the retina of the eye. He understood that light of any kind is energy carrying waves of electric and magnetic fields that continually regenerate each other and travel at a single fixed speed, the speed of light.

An accelerating charge creates a changing current. Every current is surrounded by a magnetic field, so every changing current is surrounding by a changing magnetic field. We also know that every changing magnetic field will induce an EMF, in other words, generates an electric field. This is electromagnetic induction.



If the magnetic field is oscillating, the electric field that it generates will be oscillating, too. This oscillating electric field induces an oscillating magnetic field. The vibrating electric and magnetic fields regenerate each other to make up an **electromagnetic wave**, which emanates from the vibrating charge.

In summary, light is an energy- carrying electromagnetic wave that emanates from vibrating electrons in atoms.

Speed of Light (in a vacuum)

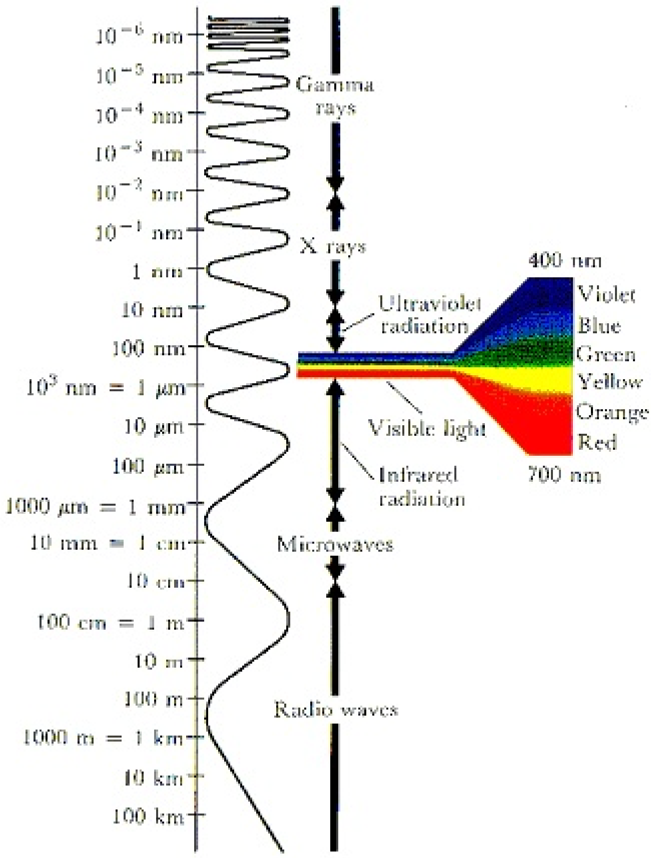
There is only one speed for which the electric and magnetic fields remain in perfect balance, reinforcing each other as they carry energy through space. If light were to slow down, its changing electric field would generate a weaker magnetic field, which in turn, would generate a weaker electric field, and so on, until the wave dies out. This would result in a loss of energy, which is incompatible with the law of conservation of energy. So light can't slow down.

If light were to speed, up a similar argument prevails.

At only one speed does mutual induction continue indefinitely, with neither loss nor gain in energy, and this is accepted as 3.0×10^8 m s^{-1}, c (from the Latin word for speed celeritas) – the speed of light.

Electromagnetic spectrum

In a vacuum, all electromagnetic waves move at the same speed, c, the speed of light. They differ from one another in their wavelength (and thus frequency). The electromagnetic spectrum includes waves with an enormous range of wavelengths, from hundreds of kilometres to smaller than the size of the nucleus of an atom.



Visible light, ($\sim 4.3 \times 10^{-7}$m to $\sim 6.9 \times 10^{-7}$m) is detected by the retina of the eye. The longer wavelengths (lower frequency waves) appear red, and the shorter wavelengths (higher frequency waves) appear violet. The limits of the visible spectrum are not well defined, because eye sensitivity drops off gradually at both long and short wavelengths.

Visible light makes up less than 10^{-6} % of the measured electromagnetic (EM) spectrum.

By 1864 the Scottish physicist, James Maxwell, had worked out a mathematical theory of electromagnetism. He developed a series of equations to show that the energies of heat, light and electricity are propagated in free space (vacuum) as electromagnetic waves, their different properties being due to differences in wavelength and frequency. Such waves travel at the same speed - the speed of light. They are *transverse waves* in which the disturbance is a time variation in both an electric and a magnetic field set at right angles to each other.

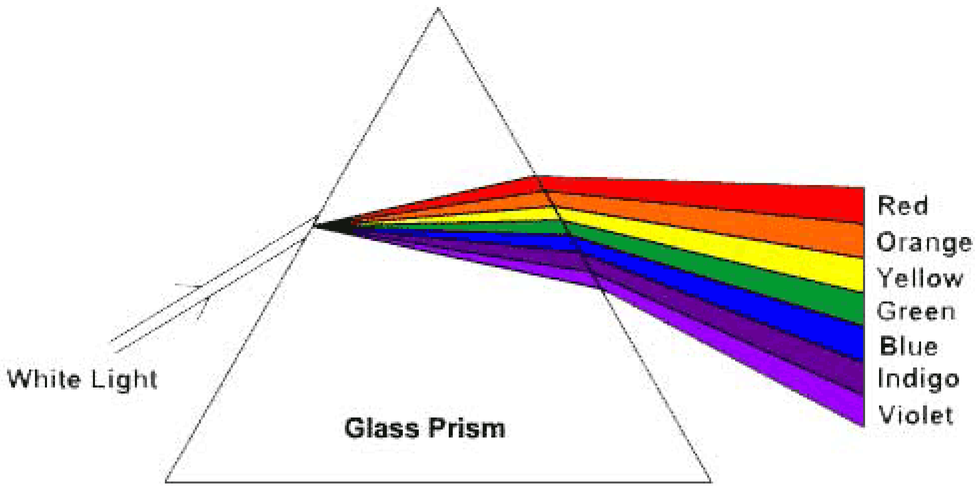
Maxwell suggested that the vibrating electric charges that produced light were the electric charges in the atom. Maxwell's theory also did not require, as a necessity, the idea that light had to have a medium through which to travel. For years scientists had been searching for the medium or 'aether' through which light travelled. Maxwell's work only assumed light to be travelling in an electromagnetic field and not necessarily a 'particle medium'.

Creation of Electromagnetic Waves

Name	**Generated by**	**Detected by**	**Properties**
Gamma-rays	Changes of energy levels in the nucleus	a) Photography b) Ionisation chamber	a) Penetrates matter b) Ionise gases c) Causes photo-electric emission
X-rays	Rapid deceleration of fast moving electrons (e.g. by tungsten target)		
UV	Orbital electrons of atoms. E.g. the Sun	a) Photography b) Photoelectric cell	a) Absorbed by glass b) Can cause many chemical reactions (e.g. the tanning of human skin) c) Ionise atoms in the atmosphere resulting in the ionosphere
Visible light	Re-arrangement of outer orbital electrons in atoms and molecules. (e.g. incandescent solids)	a) Eye b) Photography c) Photocell	Can cause chemical action
Infra-red	Outer electrons in atoms and molecules	a) Photography by special plate b) Heating effect	a) Useful for 'seeing' molecular structures b) Less scattered than visible light by atmosphere
Micro-waves	Micro-wave generators	Micro-wave receivers	a) Microwave ovens b) Radar communication
Radio Waves	Oscillating electrons in radio aerials	Tuned electric circuit	Different wavelengths find specialised uses in radio communications

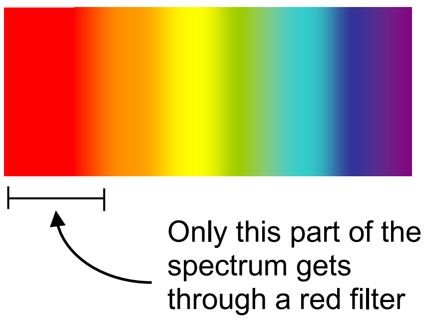
White Light

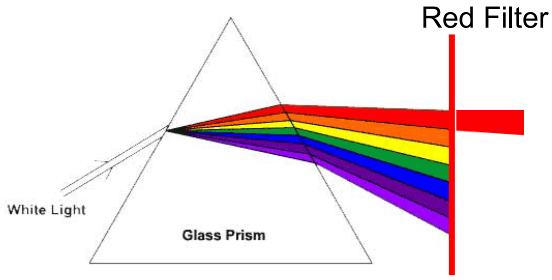
White light is made up of all of the colours of the visible spectrum. The light can be split into its constituent colours by shining it through a prism, as shown in the diagram below. These same colours are observed when you look at a rainbow.



Colour by Filtering

When you look through a piece of coloured cellophane, everything you see is tinged with the colour of the cellophane. The cellophane is acting as a *filter*. A filter is an object that only lets through a small part of the visible spectrum through. For instance, a red filter would only let through the red part of the visible spectrum. The filter would absorb all of the other colours.

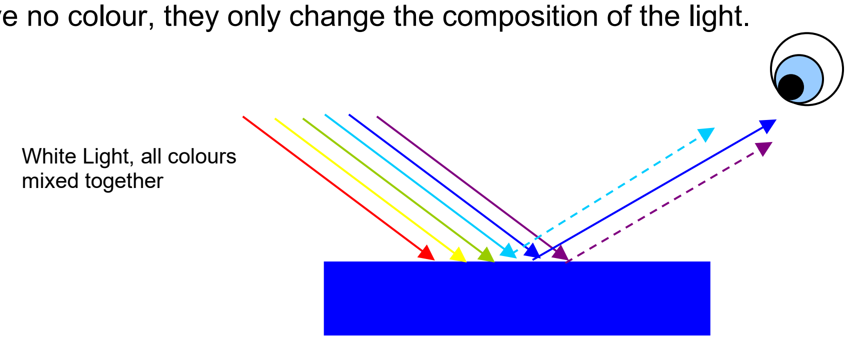




When you look at an object through a red filter, only red light from an object will pass through the filter, so you observe the object to be red. If you have two filters in a row, light will only pass through both of them if there is a region of overlap between the two filters. For example, a red filter followed by a yellow filter would let through a little orange light, as the orange light can pass through both filters.

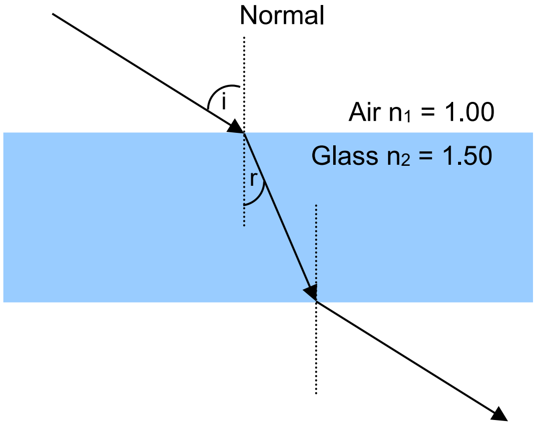
Colour by Reflection

Coloured objects do not reflect the entire visible spectrum equally. An object that appears blue will reflect blue light, and a little cyan and violet. Hence these are the only colours that reach your eye, so you perceive the object to be blue. Note that it is the *light* that is blue, not the *object*. Objects have no colour, they only change the composition of the light.



Refraction of Light

A ray of light travels along a straight path within the same medium, e.g. air, water or glass. However, experiments show that when a ray of light enters one medium from another, the ray often changes direction at the point of incidence.



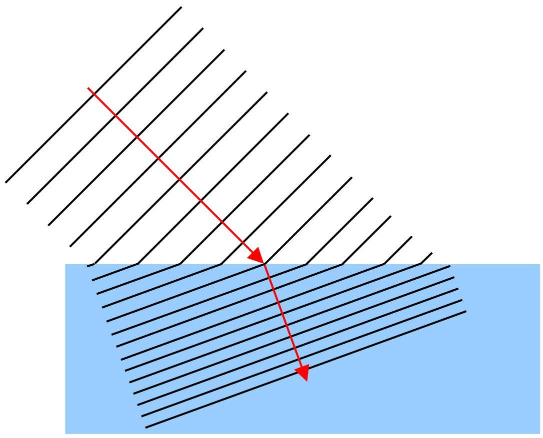
This change of direction is due to **refraction**. Refraction is the bending of the light path as it passes from one transparent material to another.

The angle between the incident ray and the normal to the boundary between the two media is called the angle of incidence. The angle between the refracted ray and the normal is called the angle of refraction. The change of direction depends on the angle of incidence and the media.

Why Light Refracts

Light travels at different speeds in different materials. In a vacuum, it travels at 3×10^8 m s^{-1}. In other transparent materials, such as glass and water, the speed is reduced. This reduction in speed causes the wavefront in the material to lag behind the wavefront outside the material. This causes the direction of the wavefront to change as shown in the diagram below.

The amount of refraction depends on the change of speed between the two materials. If there is not a change in speed, the wavefront will not change direction at all. If the change in speed is large, then a large amount of bending will occur.



Notice that the wavefronts have become closer together in the medium. This means that the wavelength of the light has been reduced. Because the speed of the wave has also been reduced the frequency of the wave will stay the same $f = \frac{v}{\lambda} = \text{constant}$

Refractive Index

Although it is the speed of light in a material that determines how much refraction occurs, speeds can be cumbersome numbers to deal with. Instead, we define another quantity called the refractive index (*n*), which is equal to the speed of light in a vacuum (*c*), divided by the speed of light in the material (*v*)

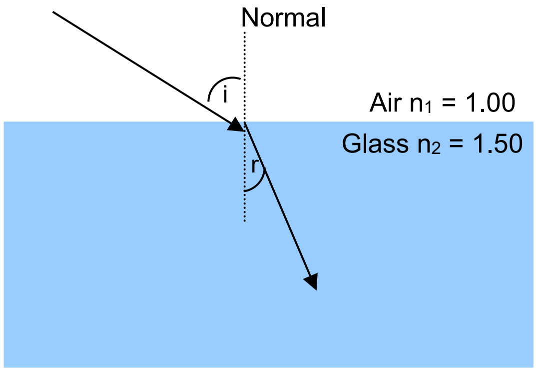
$$n = \frac{c}{v}$$

The table below shows the speed of light in different mediums and the refractive index in these materials, using a wavelength of 589 nm and a temperature of 20^0.

Medium	Speed of light (ms^{-1})	Absolute refractive index
Vacuum	3.0×10^8	1.00000
Air	3.0×10^8	1.000293
Water	2.25×10^8	1.333
Silica	2.0×10^8	1.458
Glycerine	2.0×10^8	1.473
Diamond	1.24×10^8	2.419

When light goes from a medium of low refractive index to one of high refractive index, the light ray will bend towards the normal. Conversely, when light goes from a medium of high refractive index to one of low refractive index, the light ray will bend away from the normal.

Snell's Law



The amount of refraction can be determined using Snell's Law.

$$n_1 \sin i = n_2 \sin r$$

or

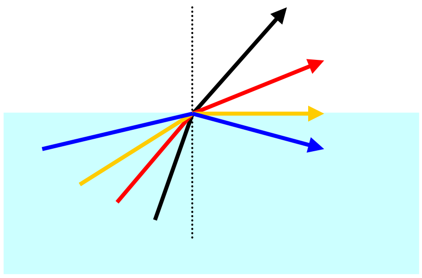
$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1} = \frac{v_1}{v_2}$$

or

$$n_1 v_1 = n_2 v_2$$

Where v_1 = speed of light in medium 1,
v_2 = speed of light in medium 2,
n_1 = absolute refractive index of medium 1
n_2 = absolute refractive index of medium 2

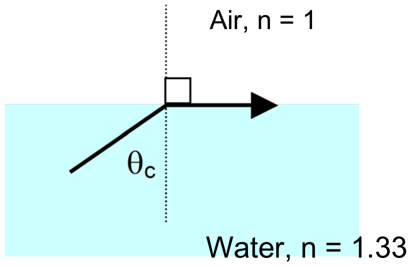
Total Internal Reflection



When light travels from a medium of high refractive index to a medium of low refractive index, it bends away from the normal, as shown in the diagram below. Eventually, and angle of incidence is reached such that the refracted ray skims along the surface of the medium (the orange line in the diagram). If the angles of incidence are greater that this angle, then the refracted ray will not leave the material. It will be *totally internally reflected*. In the diagram, the blue ray has been totally internally reflected.

The Critical Angle

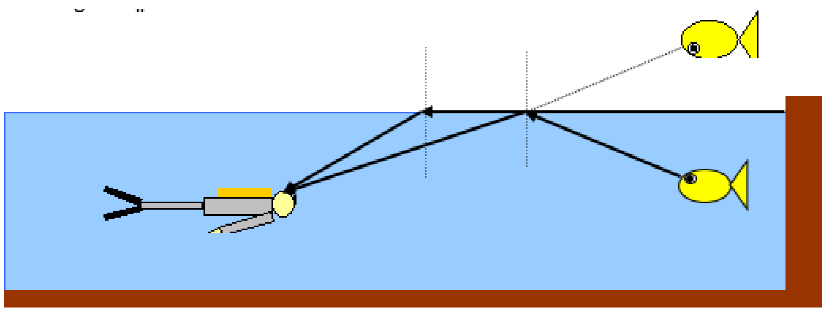
The critical angle is the angle at which the refracted way will skim across the surface of the material (the orange ray above). For angles of incidence greater than this critical angle, the ray will be totally internally reflected. The critical angle can be calculated using *Snell's Law*.



$$n_1\sin\theta_1 = n_2\sin\theta_2$$
$$1.33\sin\theta_c = 1\sin 90$$
$$\sin\theta_c = \frac{1}{1.33}$$
$$\theta_c = 48.8$$

Total Internal Reflection in Water

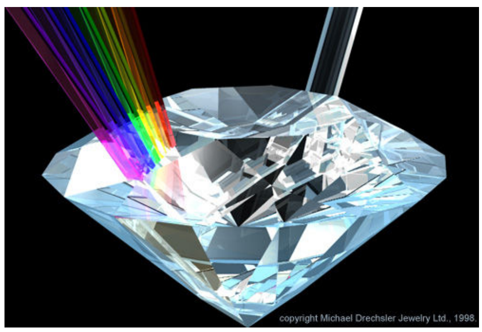
A person who is underwater and looking towards the sky will see a distorted view of the world. When the diver looks at an angle of 48.8° to the vertical (the critical angle), he sees the light from the bank. If he looks at an angle bigger than that, he will see the bottom of the pool reflected in the water's surface.



Because of total internal reflection the diver sees an image of a fish in the sky as shown in the diagram.

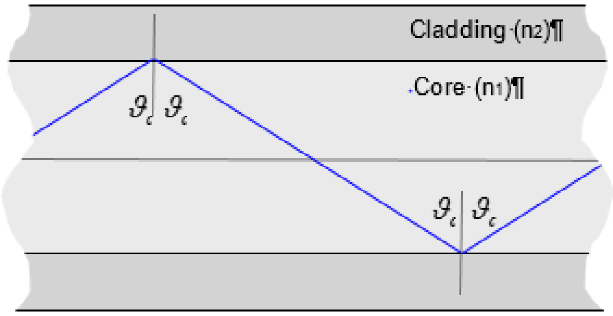
Refraction in Diamonds

Jewellers cut gems, such as diamonds, to make them appear luminescent. They achieve this by making angles within the crystal that will totally internally reflect light. Hence any light that enters the diamond is totally internally reflected and comes back out again. This is how a diamond appears to sparkle even though no light can pass through the metal mount that holds the diamond in place. Diamonds are used because they have the highest refractive index of any material and thus they have the smallest critical angle.



Fibre Optic Cable

An optical fibre can be modelled as a pipe with like being shone down it. Total internal reflection can be used to transmit light signals down optical fibres.



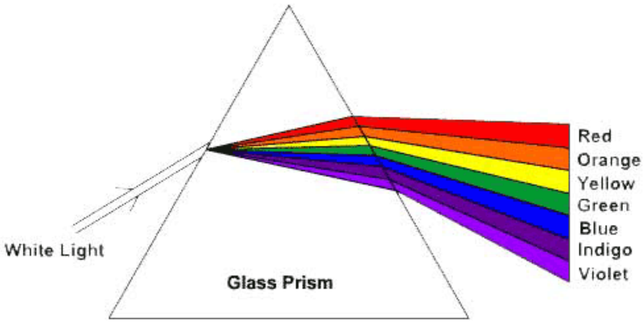
If light travels along the fibre at an angle greater than the critical angle, it will totally internally reflect in the fibre and will bounce along the fibre. If the light comes in at too steep and angle, it will escape the fibre.

Optical Fibre Network

In an optical fibre network, and electronic signal, from a phone or a computer, is converted to a light signal. The light signal is transmitted along an optical fibre at the speed of light towards its destination. Once the signal has reached its destination, it is converted back to an electrical signal for use by an appliance.

Optical fibre networks have many advantages over the copper wire networks. The main advantage is the amount of data that can be sent down one fibre. Another advantage is that the fibre transmits an optical signal and therefore it will be unaffected by electrostatic interference, from things like thunderstorms and power lines.

Changing refractive index



The refractive index of a material is actually an average refractive index for that material. This is because the refractive index of a material depends on the wavelength of light travelling through the material. For example; the refractive index of silica ranges from 1.55 for light at a wavelength of 200nm, to 1.46 for light at 700nm. This is a large difference in speed and therefore a large difference in the angle of refraction. The effect that this has is to separate the colours of white light. This process is known as **dispersion**.

The Photon Model

In 1901, Max Planck was attempting to solve a puzzling discrepancy between the observed spectrum of light from a black body and the theoretical predictions of Maxwell's electromagnetic theory. He postulated that electromagnetic energy was emitted and absorbed in packets or quanta, each one carrying a definite amount of energy. The energy was proportional to the frequency, f, and given by the equation: E = *hf* where *h* is Planck's constant

The constant "h" is called Planck's constant and has the value of

6.626×10^{-34} Js or 4.136×10^{-15} eVs.

Planck's radical suggestion produced a better fit between theory and experiment but was not widely accepted since it disagreed with the essentially continuous nature of radiation as described by Maxwell's theory.

In 1905, Albert Einstein extended Planck's idea and suggested that light was not merely emitted in discrete amounts or quanta, but that it retained its identity, travelled through space as a particle of light energy or photon and was ultimately absorbed by matter as a complete quantum of energy.

Quantum Physics

In a radical departure from classical ideas, theoretical physicist Max Planck proposed that energy travels in discrete packets called quanta. Prior to Planck's work with black body radiation, energy was thought to be continuous, but this theory left many phenomena unexplained. While working out the mathematics for the radiation phenomena he had observed, Planck realised that quantised energy could explain the behaviour of light. His revolutionary work laid the foundation for much of modern physics.

In 1900 Max Planck began to study the range of electromagnetic radiation that emanates from a very hot body (black body radiation). When a body is heated, it first glows red; with further heating it turns to white and eventually blue (ie. the wavelength of light emitted becomes shorter and it frequency becomes higher with increasing temperature).
Experiments showed that the amount of energy that is emitted falls off to zero at high and low wavelengths. As the temperature of the body changes, the hump in the energy distribution curve shift.

Planck attempted to use classical theory to explain the strange behaviour of this distribution curve. Classical theory predicted that the amount of energy emitted by a hot body should increase continuously as the frequency increases. Planck could not explain the observed energy distribution using classical theory, so he developed a new concept. This was that energy is radiated in discrete packets or bundles called **quanta** (singular: a quantum), rather than in continuous amounts as Wave Theory implies. The energy-radiated (*E*) is proportional to the frequency (*f*) of the radiation. The two quantities were connected by a proportionality constant (*h*).

$$E = \frac{hc}{\lambda} \qquad \text{c = speed of light.}$$

This is also written as **E = hf** where **f** is the frequency of the light.

Photons

The modern theory of light is a merging of the wave and the particle models. Light is imagined to travel in a stream of packets or *quanta* of energy. The energy carried by each quantum is proportional to the frequency of light and can be found from Planck's equation: $E = hf$. Greater intensity of light has more photons - each photon still has the same energy.
Photons are neither particles nor waves. They have a set of properties that have some similarities to particles when travelling through a vacuum and when in a gravity field, and some similarities to waves when refracting and interfering.

Wave-Particle duality of light

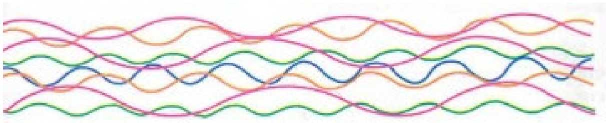
The paradoxical view of the nature of light was built into Einstein's original formulation of the photon model. The energy of the light was supposed to be carried in the form of a particle or photon, the energy of the photon was defined in terms of the frequency of the radiation, and frequency is an essentially wavelike property! One possible way of dealing with this paradox is to treat light as a wave some of the time and as a particle at other times.

The behaviour of waves varies across the electromagnetic spectrum. Low frequency photons such as radio-waves and microwaves exhibit distinctly wave-like behaviours such as diffraction and interference, but have no particle-like properties. Around the middle of the spectrum in the visible light region, photons have both wave and particle properties. They interfere and diffract like waves, and also interact with electrons in the photoelectric effect as particles do. At the high frequency end of the spectrum, X-ray and gamma ray photons behave much more like particles than waves.

Lasers

The first laser was invented in 1958, however Einstein (in 1917) predicted stimulated emission.

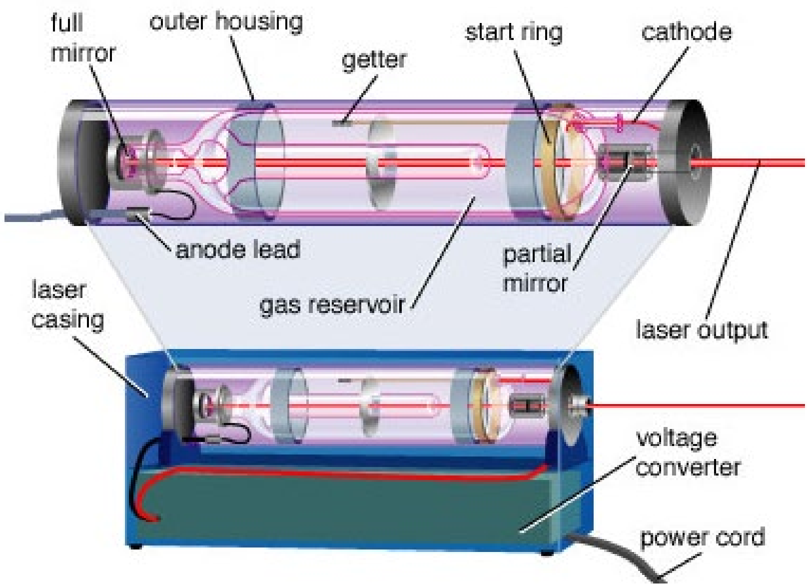
Light emitted by a common lamp is incoherent, that is, photons of many frequencies and in many phases of vibration are emitted. A beam of incoherent light spreads out after a short distance, becoming wider and less intense with increased distance.



Even if the beam is filtered so that it is formed with a single frequency waves (monochromatic), it is still incoherent, for the waves are out of phase with each other. The wave spreads and becomes weaker with distance.

A beam of photons having the same frequency, phase, and direction – that is, a beam of identical photons – is said to be **coherent**. A beam of coherent light spreads and weakens very little.

A laser is a device that produces a beam of coherent light. The laser has a source of atoms called an *active medium*, which can be either a gas, liquid or solid. The atoms are excited to metastable states (particular excited state of an atom that has a longer lifetime than the ordinary excited states) by an external source of energy.

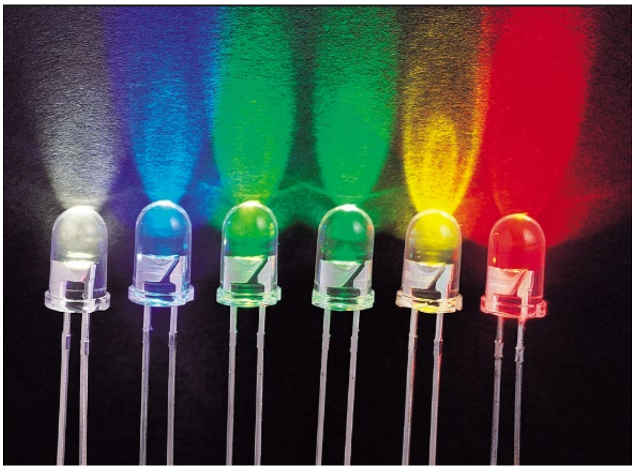


When most of the atoms in the medium are excited, a single photon from an atom that undergoes de-excitation can start a chain reaction. This photon strikes another atom, stimulating it into emission, and so on, producing coherent light. Most of this light is initially at random directions. Light travelling along the laser axis, however, is reflected from mirrors coated to selectively reflect light of the desired wavelength. One mirror is totalling reflecting, while the other is partially reflecting. The reflected waves reinforce each other after each round-trip reflection between the mirrors, thereby setting up a to - and - fro resonance condition wherein the light builds up to an appreciable intensity. The light that escapes through the more transparent – mirrored end makes up the laser beam.

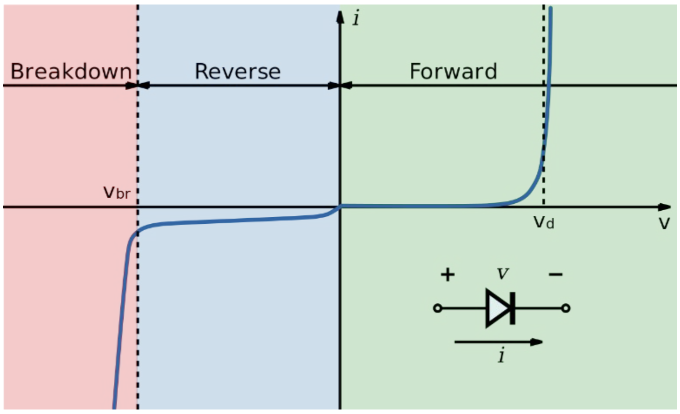
Present models produce beams ranging from infrared through ultraviolet.

The laser is not a source of energy. It is simply a converter of energy that takes advantage of the process of stimulated emission to concentrate a certain fraction of its energy (commonly 1%) into radiant energy of a single frequency moving in a single direction, due to spatial coherence.

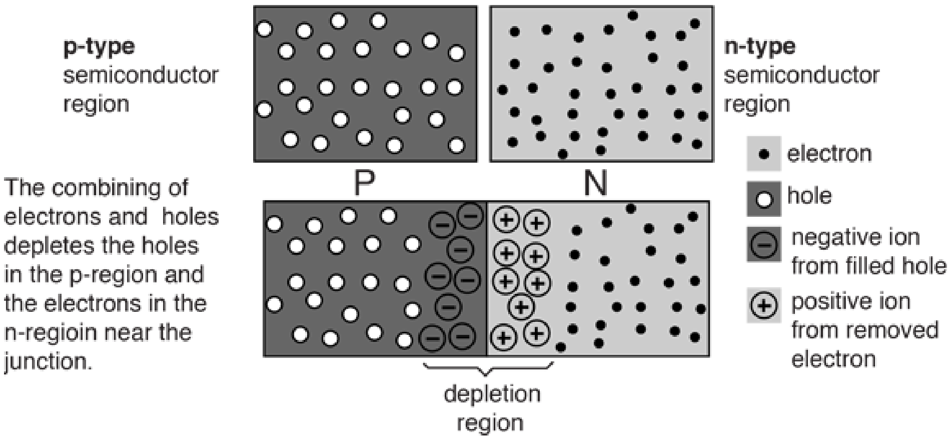
Light emitting Diodes



Light Emitting Diodes **(LED’s)** are diodes that emit light when a current passes through them at a suitable voltage. Their V-I graphs are similar to that of an ordinary diode.



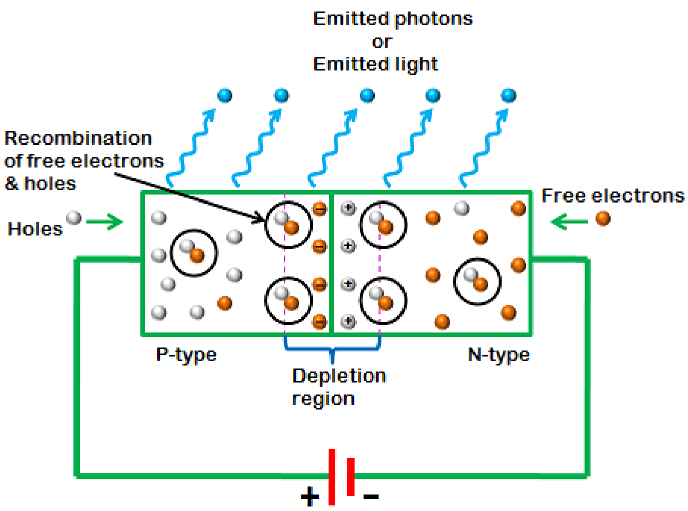
LEDs use a p-n junction to create these specific conditions. This is where a p-type semiconductor (which contains free positively charged carriers, known as holes) and an n-type semiconductor (which contains free negatively charged carriers, electrons) join. These junctions are the building blocks of every semiconductor electronic device.



The depletion region is a region between the p-type and n-type semiconductor where no mobile charge carriers (free electrons and holes) are present. This region acts as a barrier to the current: it opposes the flow of electrons from the n-type semiconductor and the flow of holes from the p-type semiconductor. To overcome the barrier of the depletion layer, we need to apply a voltage which is greater than the barrier potential of the depletion layer. Once this voltage is applied the current starts flowing.

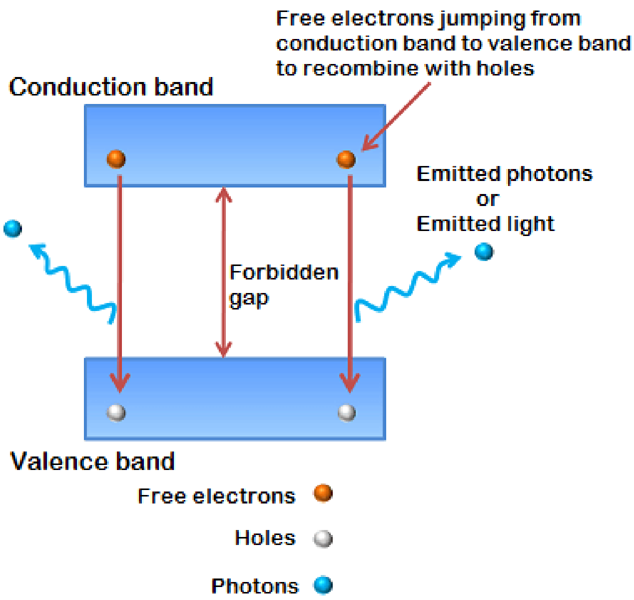
How LED's produce light

When the p-type semiconductor is connected to the positive terminal and the n-type is connected to the negative terminal the LED is said to be forward biased. The positive terminal attracts electrons, creating more holes in the p-type semiconductor. Likewise, the holes are attracted to negative terminal, creating more free electrons in the n-types semiconductor.



The charge carriers recombine as the electrons cross from the n-region and recombine with the holes existing in the p-region. As the free electrons in the conduction band recombine with the holes in the valence band they release energy in the form of photons. This phenomenon is called electroluminescence, the emission of light from a semiconductor under an electric field. Luminescence is different to other kinds of light emission, such as incandescence, because it provides no heat. Other kinds of luminescence include chemiluminescence (as in glow sticks) and phosphorescence (glow in the dark paint).

When the valence electron leaves the parent atom, they leave an empty space in the valence shell, called a hole (a positively charged carrier). The energy level of the free electrons in the conduction band is high compared to the energy level of the holes in the valence band. Therefore, the free electrons in the conduction band need to lose energy (in the form of light) in order to recombine with the holes in the valence band.



In normal silicon diodes, the energy gap between conduction band and valence band is small. As a result, low energy photons are released. These low energy photons have low frequency which is invisible to human eye.

In LEDs, the energy gap between conduction band and valence band is larger so the free electrons in LEDs have greater energy than the free electrons in silicon diodes. As a result, higher energy photons are released. These high energy photons have high frequency which is visible to human eye.

All diodes emit photons but not all diodes emit in the visible spectrum. The material in an LED is selected based on the desired emission wavelength
The energy of the photon is given by E = hf, where h is Planck's constant and f is the frequency.

Since c = fλ, on substitution this becomes $E = \frac{hc}{\lambda}$

The efficiency of the generation of light in the LED increases with an increase in injected current and with a decrease in temperature.

Output characteristics of an LED

The amount of output light emitted by the LED is directly proportional to the amount of forward current flowing through the LED.

What determines the colour of an LED?

The material used for constructing LED determines its colour. The wavelength of the emitted light depends on the energy gap of the material.

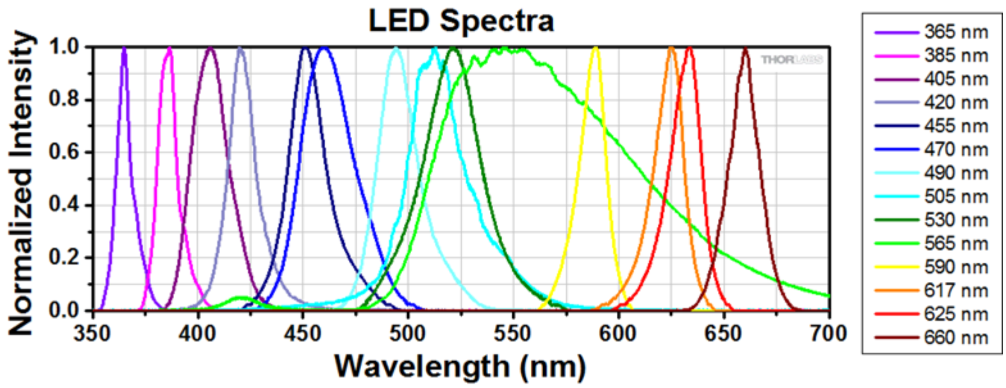
Different materials emit different colours of light.

- Gallium Arsenide (GaAs) – infra-red
- Gallium Arsenide Phosphide (GaAsP) – red to infra-red, orange
- Aluminium Gallium Arsenide Phosphide (AlGaAsP) – high-brightness red, orange-red, orange, and yellow
- Gallium Phosphide (GaP) – red, yellow and green
- Aluminium Gallium Phosphide (AlGaP) – green
- Gallium Nitride (GaN) – green, emerald green
- Gallium Indium Nitride (GaInN) – near ultraviolet, bluish-green and blue
- Silicon Carbide (SiC) – blue as a substrate
- Zinc Selenide (ZnSe) – blue
- Aluminium Gallium Nitride (AlGaN) – ultraviolet

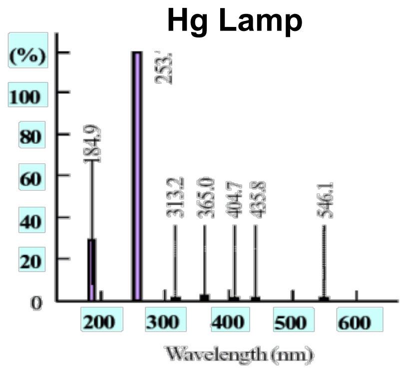
Advantages of LED

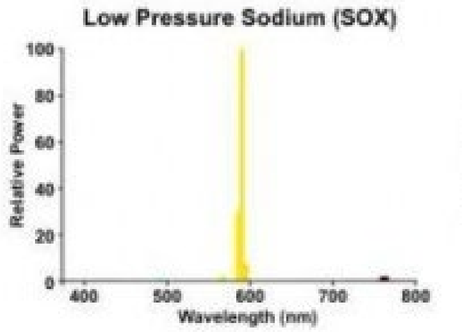
1. The brightness of light emitted depends on the current flowing. Hence, the brightness can be easily controlled.
2. Consume little energy.
3. Cheap and readily available.
4. Long lifetime. Improved physical robustness,
5. Can be switched ON and OFF very quickly (~1 ns).
6. Can emit different colours of light.

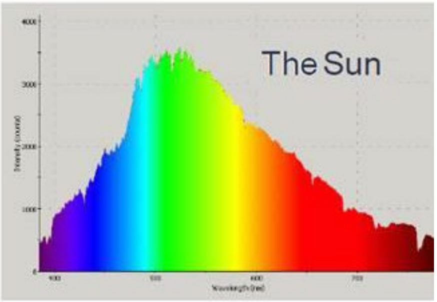
Some Common Visible Spectra

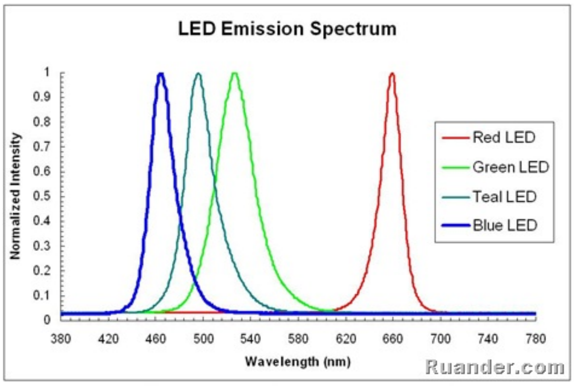


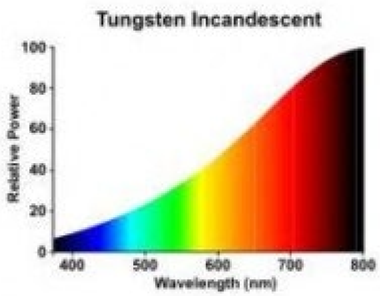
ThorLabs USA

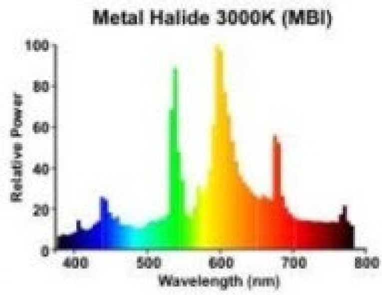

Hg Lamp
(%)
100
80
60
40
20
0
184.9
253.7
313.2
365.0
404.7
435.8
546.1
200
300
400
500
600
Wavelength (nm)

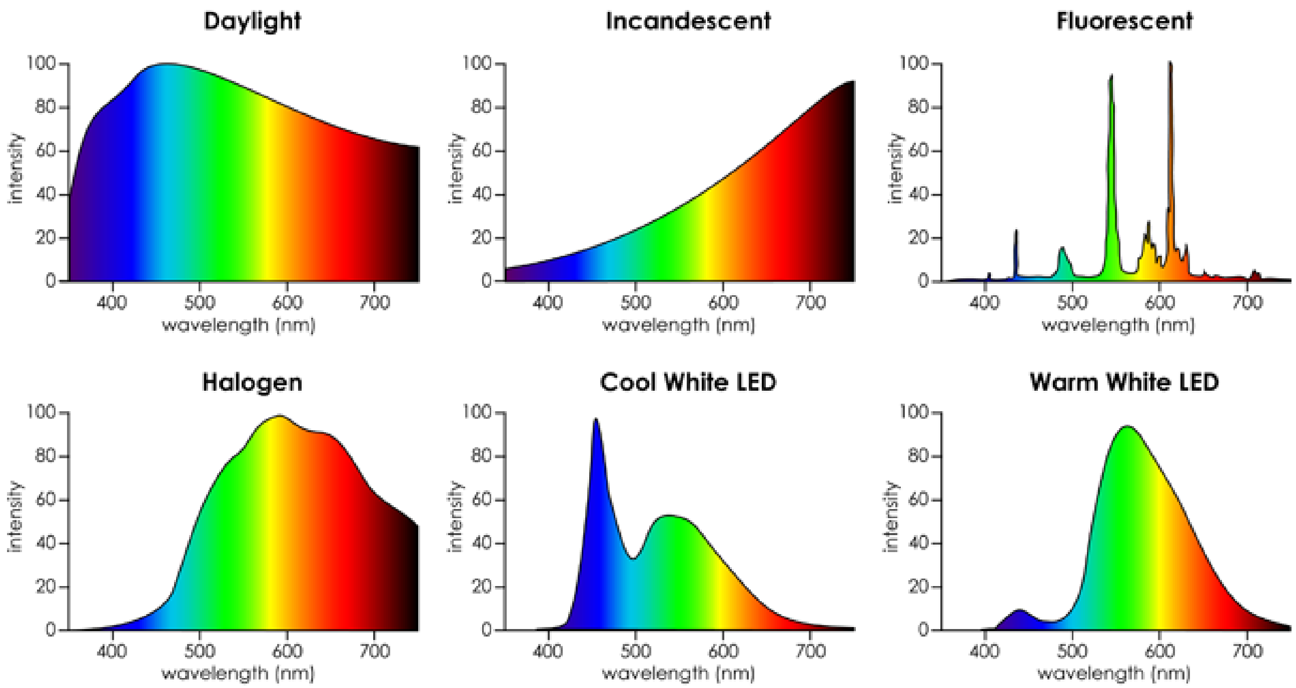

Low Pressure Sodium (SOX)
Relative Power
100
80
60
40
20
0
400
500
600
700
800
Wavelength (nm)


The Sun


LED Emission Spectrum
Normalized Intensity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
380
420
460
500
540
580
620
660
700
740
780
Wavelength (nm)
Red LED
Green LED
Teal LED
Blue LED
Ruander.com


Tungsten Incandescent
Relative Power
100
80
60
40
20
0
400
500
600
700
800
Wavelength (nm)

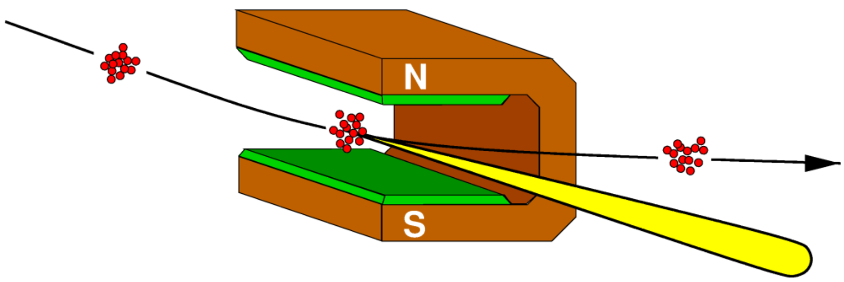

Metal Halide 3000K (MBI)
Relative Power
100
80
60
40
20
0
400
500
600
700
800
Wavelength (nm)



Synchrotron Radiation

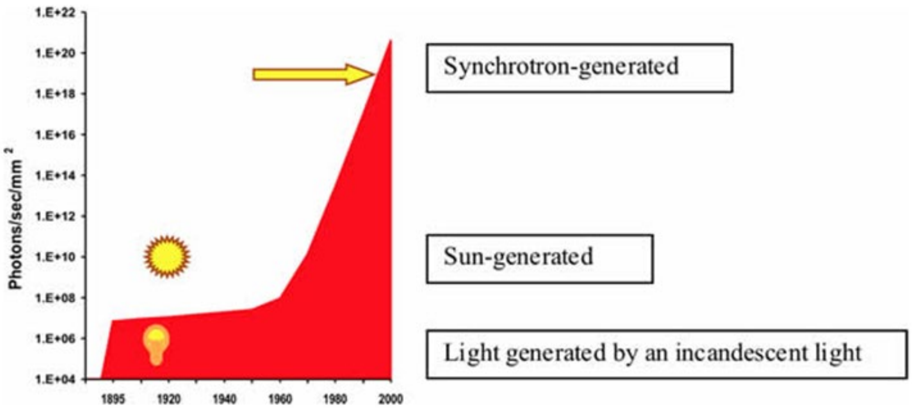
As a particle accelerates it releases energy in the form of electromagnetic radiation. This reduces the particle's energy, and thus slows the particle down: more energy is then required to accelerate it. In order to get particles up to near the speed of light this acceleration process needs to occur over a long distance. It is more convenient to bend the path around in a circle so that the particles can be accelerated round and round a loop. Because of this most particle accelerators are often circular (synchrotrons). Unfortunately, more radiation is released in this bending process.

In order to bend the electron beam it is placed in a magnetic field, the black line shows the path of the electron beam, the yellow shows that the electromagnetic radiation is emitted tangentially to the path of the electrons. The right hand slap rule can be used to determine the direction the beam will bend.

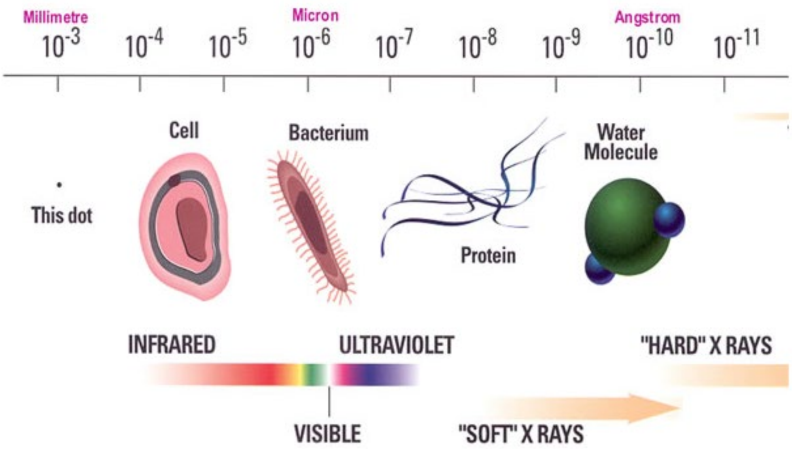


The radiation that comes off a synchrotron can be manipulated by how tight the bend is, and this radiation can be very useful for different purposes. The radiation comes off a synchrotron at a tangent to the circle.

Synchrotrons can emit a broad range of electromagnetic radiation, from microwaves to X-rays, with the potential to be tuned to a required frequency. On top of this they have a high intensity or brightness, and the beam is coherent (the light waves are synchronised).



Synchrotron Light



- Is produced in the range of wavelengths (λ) from 10^{-11} (hard X-rays) to10^{-1} m (microwaves). These photons have energies respectively from 10^5 eV (hard X-rays) down to 10^{-5} eV (microwaves).
- It is of high intensity (brilliance)
- Emitted in short pulses.
- Arrives in parallel rays (collimated)
- Is coherent (all photons are in phase – wave property)
- Highly polarised (limited to a single plane for direction of wave vibration)
- Specific wavelengths can be isolated using **diffraction gratings** or **monochromators** and used for examining objects whose structural dimensions is similar to the single wavelength.
- Light is released as a very narrow cone from the bending magnets and this is then focussed to provide a very narrow beam at the work station.
- **Brightness** is a measure of how many photons per mm^2 per second there are. If the originating electron beam is widened the brightness will be less. The narrower the cone of light the greater the brightness.

X-rays & Synchrotron X-rays

- A conventional X-ray is a useful diagnostic tool as it will allow us to detect fractures is bones due to the X-ray being able to penetrate the fracture site.
- There is no coherence or collimation with conventional X-rays and they are low intensity.
- Synchrotron X-rays are high intensity, collimated and coherent. This allows them to extract more detail than a conventional X-ray.
- The tuneability of synchrotron radiation allows us to interact with lighter atoms than conventional X-rays, this means we can see clearly flesh as well as bones, resulting in a much more detailed image of the fracture site and the surrounding tissues.