Physics Knowledge Organiser
P13 - Electromagnetic waves

Electromagnetic Waves (EM Waves): Producing Them

EM waves can be generated by changes in atoms or the nuclei of atoms. For instance, gamma rays are produced due to changes in the nucleus of an atom (see nuclear decay topic).

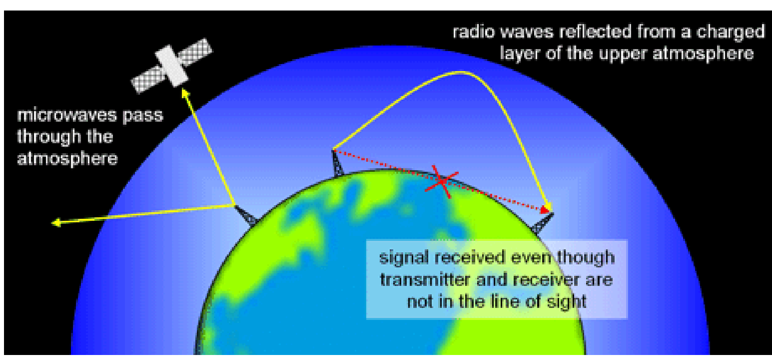
HT: radio waves can be produced by oscillations in electrical circuits. This is how a TV/radio broadcast is produced. It is received (e.g. by your TV aerial) by another electrical circuit; the radio waves create an alternating current with the same frequency as the radio wave itself. More on alternating current in the electricity topic – but it is enough to say for now that it involves oscillations.

Dangers Of EM Waves

Ultraviolet waves, X-rays and gamma rays are potentially dangerous types of EM waves, since they can have hazardous effects on human tissues. How severe the effects are depends on the type of radiation and the size of the **dose** received.

Doses of radiation are measured according to how great the risk of harm to the body is. The radiation dose, or danger due to **exposure** to radiation, is measured in **sieverts** (Sv).

A specific risk due to exposure to ultraviolet waves: they cause skin to prematurely age and increase the risk of skin cancer.
X-rays and gamma rays are **ionising** types of radiation. This means they can damage DNA, causing mutations and therefore increasing the risk of cancer.



Key Terms	Definitions
Radiation dose	Measure of the risk of harm due to exposure to radiation. (Sieverts)
Exposure	Receiving and absorbing radiation (by the body).
Sievert	The measure of radiation dose. As with the usual prefix: 1000 millisieverts (mSv) = 1 sievert (Sv)
Ionising	Describes radiation that forms ions by 'knocking' electrons off atoms to make ions.
Cancer	Type of disease caused by specific mutations to DNA, resulting in cells dividing out of control (making a tumour).

Applications Using EM Waves

It is not exaggerating to say that EM waves dominate our technology and our lives. Here are some examples of the practical applications of EM waves:

- **Radio waves**: used for *television*, *radio* and Bluetooth. A signal carried by radio waves can get from a transmitting mast to a receiver by being reflected off a layer in the atmosphere.
- **Microwaves**: obviously, cooking food, but also communication with *satellites* and *mobile phones*; Wi-Fi internet. Unlike radio waves, microwaves can pass through the atmosphere (see diagram bottom left). In microwave ovens, the microwaves cause the water particles in the food to vibrate, heating it up.
- **Infrared**: electrical heaters, cooking food, infrared cameras. All objects emit infrared, but hotter objects emit more. An infrared camera detects infrared instead of visible light, so it can see hotter objects in the dark – night vision.
- **Visible light**: *fibre optic communication* (like the best broadband). Optical fibres reflect pulses of light all the way along their length. The pulses of light transmit the information.
- **Ultraviolet**: *sun tanning* beds… however, look at the dangers of UV in the other box.
- **X-rays**: both medical imaging for *diagnosis* (like broken bones) and medical *treatments*. X-rays can pass through soft tissue (like muscle), but not bone. That's why an X-ray image works to show up bones, and any breaks.
- **Gamma rays**: used in medical treatments such as radiotherapy and also for imaging (see radiation topic)

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Electromagnetic Waves (EM Waves)

EM waves are always **transverse waves**. They transfer energy from the source of the waves to an **absorber** – object that absorbs the wave. EM waves occur all over the universe naturally, and we can produce them ourselves for all sorts of uses.

EM waves all travel at the **same velocity** through empty space (a vacuum) – at what we call the speed of light. However, the wavelength of EM waves varies from a few kilometres to wavelengths even smaller than an atom. The EM waves form a **continuous spectrum**, but for convenience we've grouped the infinite types of waves into seven groups of wavelengths, based on their properties. Learn the order of EM waves in the EM spectrum. Notice that a *longer* wavelength equates to a *lower* frequency and vice versa – this is clear from the wave equation.

Long wavelength → Short wavelength

Radio waves	Microwaves	Infrared	Visible light	Ultraviolet	X-rays	Gamma rays

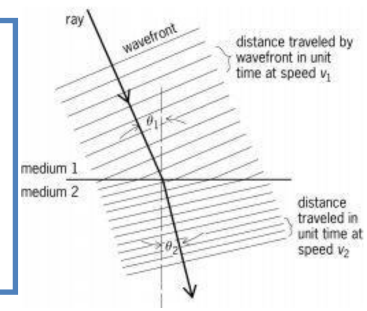
Low frequency → High frequency

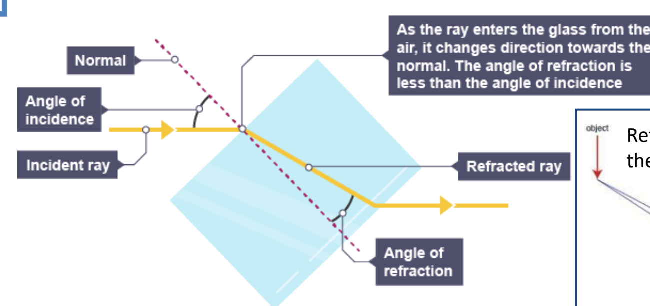
Visible light is the only kind of EM wave we can detect with our eyes (hence the name). Thus, we can only detect a limited range of EM waves without special equipment. However, it is easy to understand examples of how EM waves transfer energy. If you are standing in front of a fire, you feel the warmth thanks to infrared. Getting sunburn is due to the transfer of energy by

Key Terms	Definitions
Reflection	Rebounding of a wave from a surface. The angle between the **incident** (in-going) wave and the **normal** is the same as the angle between the reflected wave and the normal.
Refraction	Changing direction of a wave due to a change in the **medium** it is travelling through.
Absorption	'Taking in' energy from a wave and transferring it to another form, usually heat. For instance, you warming up if you lie in the sunshine (revising science, of course).
Transmission	A wave travelling through a material. Right now, visible light waves are being transmitted through the air to your eyes.
Media	*Singular 'medium'*. The medium is the material through which a wave travels.
Normal	A 'construction line' (made up line to help with diagram drawing) at right angles to a surface at the point where the wave hits the surface.

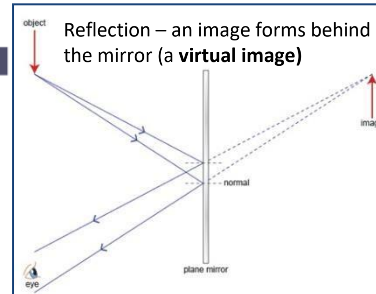
HT: More On Refraction

Refraction is due differences in the velocity of the waves in difference media. The diagram shown here represents the **wave fronts**. The wave slows down as it enters medium 2, but the near edge slows first. The other end is faster, as it is still in medium 1. This is what causes the 'bending' of the wave towards the normal.





Reflection – an image forms behind the mirror (a **virtual image)**



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Properties Of EM Waves

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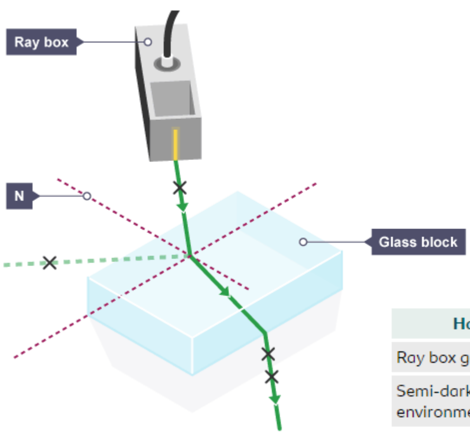
All EM waves can be **reflected**, **refracted**, **absorbed** or **transmitted** *depending* on the wavelength of the EM wave and the **medium** they are travelling through, or surface they are reaching. Reflection is shown in the

Investigating the reflection of light by different types of surface and the refraction of light by different substances (Physics Only)

Method:

1. Set up a ray box, slit and lens so that a narrow ray of light is produced.
2. Place a 30 cm ruler near the middle of a piece of paper and draw a line parallel to the longer side of the block, Use a protractor to draw a light at a right angle. Label this line with 'N' for normal.
3. Place the longest side of the rectangular acrylic block against the first line with the normal near the middle of the block. Carefully draw around the block.
4. Use the ray box to shine a ray of light at the point where the normal meets that block. This is the incident ray.
5. The angle between the normal and the incident ray is called the angle of incidence. Move the ray box to change the angle of incidence. The aim is to see a reflected ray from the block and a ray that leaves the opposite face of the block.
6. Use a pencil to mark the path of the incident ray, reflected ray and refracted ray by drawing two crosses and joining them up.
7. Repeat the process for a rectangular glass block.
8. Measure the angles of incidence, reflection and refraction for each block.

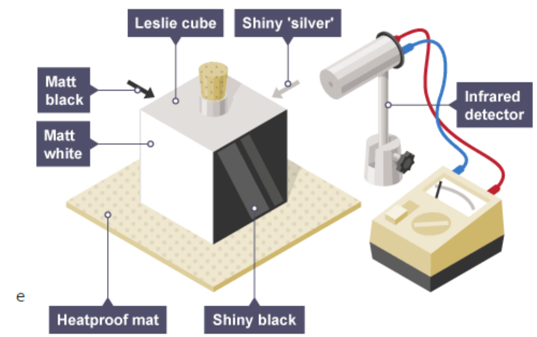


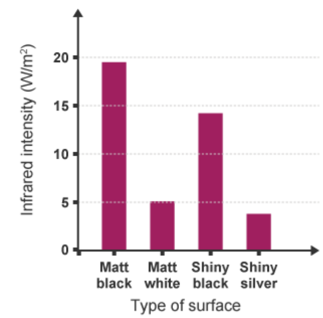
Hazard	Consequence	Control measures
Ray box gets hot	Minor burns	Do not touch bulb and allow time to cool
Semi-dark environment	Increased trip hazard	Ensure environment is clear of potential trip hazards before lowering lights

Investigate how the amount of IR radiation absorbed or radiated by a surface depends on the nature of that surface

Method:

1. Place a Leslie cube on a heat resistant mat. Fill it, almost to the top, with boiling water and replace the lid.
2. Leave for a minute so the surface of the cube can reach the temperature of the water.
3. Use the IR detector to measure the intensity of IR radiation emitted from each surface. Make sure the detector is the same distance from each surface for each reading.





Hazard	Consequence	Control measures
Boiling water	Scalds	Pour water slowly, using a funnel if necessary. Do not move the Leslie cube until it has cooled.

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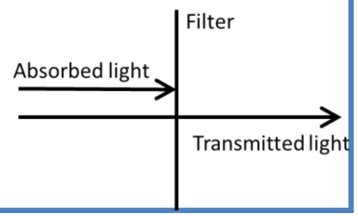
Visible light

We can only see a tiny proportion of the EM spectrum. The visible light part of the spectrum is divided into narrow bands of frequencies that we see as different colours. We can separate mixtures of colours of light using filters. These work by absorbing certain wavelengths of light and **transmitting** other wavelengths. This is shown on the diagram

The colour of an **opaque** object depends on which wavelengths of visible light it absorbs, and which it reflects. Whichever it reflects, that's the colour it looks. If it reflects all colours, the object looks white. If it absorbs all the colours then it will look black.

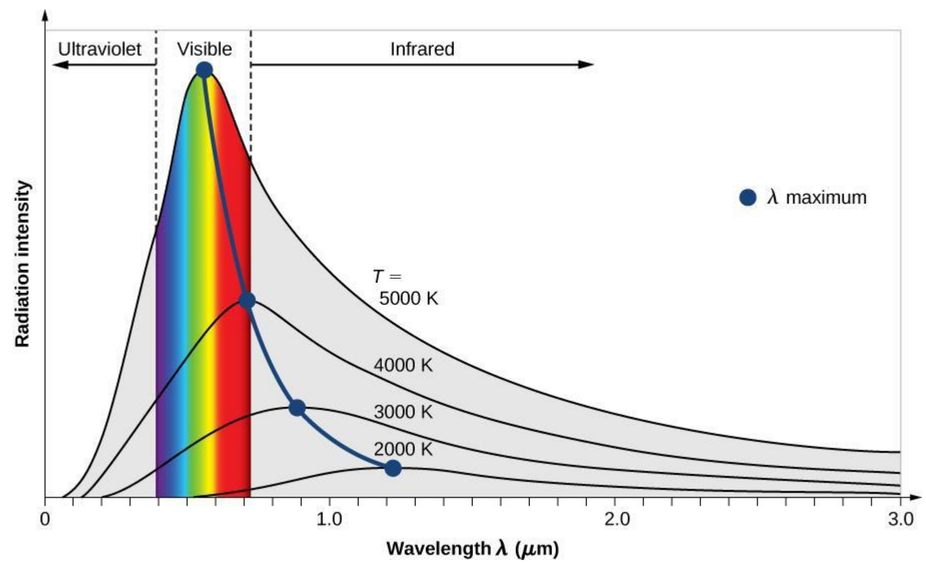


Key Terms	Definitions
Specular reflection	Reflection of light from a smooth surface in a single direction
Diffuse reflection	Reflection of light from a rough surface in many directions. The light is 'scattered'.
Opaque	Object that is not transparent, so it does not transmit light. It reflects (some) light instead.
Transparent	Object that transmits all light wavelengths. See-through.
Translucent	Object that transmits some light, so not totally see-through, but partially.
Body	When talking about infrared radiation, we refer to objects as bodies.
Black body	A hypothetical perfect absorber and emitter of radiation.

Infrared radiation

All objects (called 'bodies' in this topic!), at any temperature, will emit and absorb infrared radiation. The hotter the object, the more infrared radiation it radiates per second (or per minute, or whatever). The amount of infrared also depends on the colour of the object/body. Black surfaces are better absorbers and emitters than pale coloured surfaces. In theory (but not real life), there exist **perfect black bodies**, which absorbs ALL the radiation that hits it. These perfect black bodies would also be the best possible emitters of radiation. Although they don't really exist, black bodies are helpful models for understanding infrared radiation.

- Any body/object at a constant temperature is absorbing and emitting radiation at the same rate (because otherwise its temperature would change). If it absorbs radiation at a faster rate than it is emitted, then the body warms up.
- Increasing the temperature of a body increases the intensity of the radiation it emits increases (as already stated), but the intensity of the *shorter* wavelengths increases faster than the others (as shown on the graph). This is why, if you get something hot enough, it will glow with visible light.
- We can model the Earth as a black body, absorbing infrared radiation from the Sun and emitting it back into space. If this is in perfect balance, the temperature of the Earth stays exactly the same. Awkwardly, however, the emission of infrared radiation back into space is being disturbed somewhat by greenhouse gases.



Black body radiation

The graph shows the distribution of wavelengths of radiation emitted by a body at four different temperatures (shown on the Kelvin scale). The peak emission shifts into the visible part of the spectrum if the body is hot enough. At everyday temperatures, bodies don't glow because they simply aren't hot enough to emit in that part of the spectrum.