

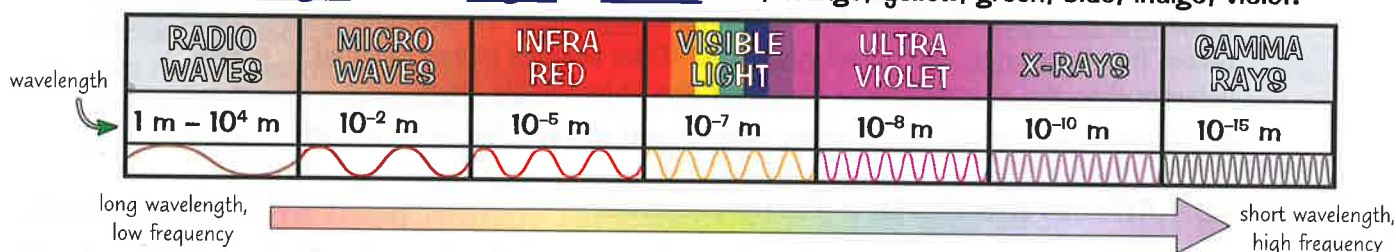
# Electromagnetic Waves

You've learned a lot about light so far, but light's just one small part of the EM spectrum...

## There's a Continuous Spectrum of EM Waves

- 1) Electromagnetic (EM) waves are transverse waves (p.32).
- 2) They all travel at the same speed through a vacuum (space). But they travel at different speeds in different materials (which can lead to refraction and dispersion, p.34).
- 3) EM waves vary in wavelength from around  $10^{-15}$  m to more than  $10^4$  m.
- 4) We group them based on their wavelength and frequency — there are seven basic types, but the different groups merge to form a continuous spectrum.
- 5) EM waves are generated by a variety of changes in atoms and their nuclei, giving a large range of frequencies. E.g. changes in the nucleus of an atom create gamma rays (p.51) and visible light is often produced by changes in an electron's energy level (p.50). This also explains why atoms can absorb a range of frequencies — each one causes a different change.
- 6) Our eyes can only detect a small part of this spectrum — visible light. Different colours of light have different wavelengths — from longest to shortest: red, orange, yellow, green, blue, indigo, violet.

Electromagnetic waves aren't vibrations of particles, they're vibrations of electric (p.84) and magnetic (p.85) fields. This means they can travel through a vacuum.



- 7) All EM waves transfer energy from a source to an absorber. For example, when you warm yourself by an electric heater, infrared waves transfer energy from the thermal energy store of the heater (the source) to your thermal energy store (the absorber).
- 8) The higher the frequency of the EM wave, the more energy it transfers (and so the more dangerous it is for humans — see below).

## Different EM Waves Have Different Properties

As you saw on p.34, when EM waves meet a boundary they can be absorbed, transmitted, refracted or reflected. What happens depends on the materials at the boundary and the wavelength of the EM wave — e.g. some materials absorb some wavelengths of light but reflect others. This is what causes things to be a certain colour (p.40).

Differences in how EM waves are transmitted, reflected and absorbed have implications for human health:

- 1) Radio waves are transmitted through the body without being absorbed.
- 2) Some wavelengths of microwaves can be absorbed, causing heating of cells, which may be dangerous.
- 3) Infrared (IR) and visible light are mostly reflected or absorbed by the skin, causing some heating too. IR can cause burns if the skin gets too hot.
- 4) Ultraviolet (UV) is also absorbed by the skin. But it has a higher frequency, so it is potentially more dangerous. It's a type of ionising radiation (p.50) and when absorbed it can cause damage to cells on the surface of your skin, which could lead to skin cancer. It can also damage your eyes and cause a variety of eye conditions or even blindness.
- 5) X-rays and gamma rays are also ionising, so they can cause mutations and damage cells too (which can lead to cancer). But they have even higher frequencies, so transfer even more energy, causing even more damage. They can also pass through the skin and be absorbed by deeper tissues.

EM waves are sometimes called EM radiation.

Most of the UV radiation produced by the Sun that hits the Earth's atmosphere gets absorbed.

## Learn about the EM spectrum and wave goodbye to exam woe...

Here's a handy mnemonic for the order of EM waves: 'Rock Music Is Very Useful for eXperiments with Goats'.

Q1 Explain why gamma rays are more dangerous to humans than visible light.

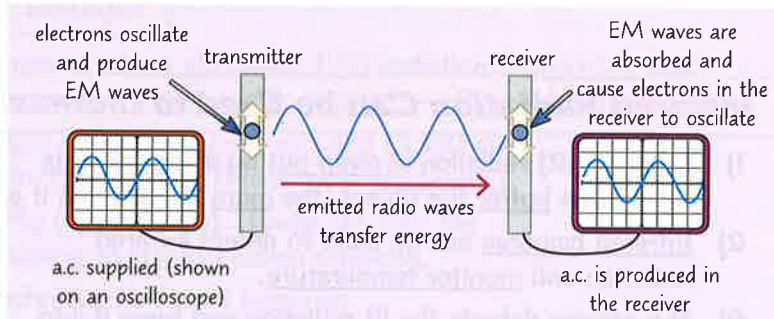
[2 marks]

# EM Waves for Communication

Different EM waves have different properties, which make them useful to us in different ways.

## Radio Waves are Made by Oscillating Charges

- 1) EM waves are made up of oscillating electric and magnetic fields.
- 2) Alternating currents (a.c.) (p.79) are made up of oscillating charges. As the charges oscillate, they produce oscillating electric and magnetic fields, i.e. electromagnetic waves.
- 3) The frequency of the waves produced will be equal to the frequency of the alternating current.
- 4) You can produce radio waves using an alternating current in an electrical circuit. The object in which charges (electrons) oscillate to create the radio waves is called a transmitter.
- 5) When transmitted radio waves reach a receiver, the radio waves are absorbed.
- 6) The energy carried by the waves is transferred to the electrons in the material of the receiver.
- 7) This energy causes the electrons to oscillate and, if the receiver is part of a complete electrical circuit, it generates an alternating current.
- 8) This current has the same frequency as the radio wave that generated it.

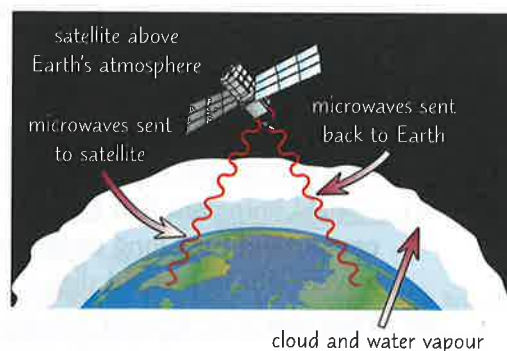


## Radio Waves are Used Mainly for Communication and Broadcasting

- 1) Long-wave radio (wavelengths of 1 – 10 km) can be received halfway round the world from where they started, because long wavelengths bend around the curved surface of the Earth. This makes it possible for radio signals to be received even if the receiver isn't in the line of sight of the transmitter.
- 2) Short-wave radio signals (wavelengths of about 10 m – 100 m) can, like long-wave, be received at long distances from the transmitter. That's because they are reflected by the Earth's atmosphere.
- 3) Bluetooth® uses short-wave radio waves to send data over short distances between devices without wires (e.g. wireless headsets so you can use your phone while driving a car).
- 4) The radio waves used for TV and FM radio transmissions have very short wavelengths. To get reception, you must be in direct sight of the transmitter — the signal doesn't bend or travel far through buildings.

## Microwaves and Radio Waves are Used by Satellites

- 1) Communication to and from satellites (including satellite TV signals and satellite phones) uses EM waves which can pass easily through the Earth's watery atmosphere.
- 2) These waves are usually microwaves, but can sometimes be relatively high frequency radio waves.
- 3) For satellite TV, the signal from a transmitter is transmitted into space and picked up by the satellite receiver dish orbiting thousands of kilometres above the Earth.
- 4) The satellite transmits the signal back to Earth in a different direction, where it's received by a satellite dish on the ground.



## Size matters — and my wave's longer than yours...

Producing radio waves — who knew it was so tricky? It's worth it though — they're just so darn useful.

Q1 Explain why signals between satellites are usually transmitted as microwaves.

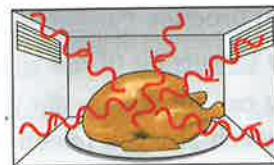
[1 mark]

# Microwaves and Infrared

Haven't had enough uses of EM waves? Good, because here are just a few more uses of those incredibly handy waves — complete with the all-important reasons for why they have been used. Get learning.

## Microwave Ovens Also Use Microwaves

- 1) In microwave ovens, the microwaves are absorbed by water molecules in food.
- 2) The microwaves penetrate up to a few centimetres into the food before being absorbed and transferring the energy they are carrying to the water molecules in the food, causing the water to heat up.
- 3) The water molecules then transfer this energy to the rest of the molecules in the food by heating — which quickly cooks the food.



## Infrared Radiation Can be Used to Increase or Monitor Temperature

- 1) Infrared (IR) radiation is given out by all hot objects — and the hotter the object, the more IR radiation it gives out.
- 2) Infrared cameras can be used to detect infrared radiation and monitor temperature.
- 3) The camera detects the IR radiation and turns it into an electrical signal, which is displayed on a screen as a picture. This is called thermal imaging.
- 4) Thermal imaging is used by police to see suspects that are trying to escape or hide in the dark.
- 5) Infrared sensors can be used in security systems. If a change in infrared radiation is detected, an alarm sounds or a security light turns on.
- 6) Absorbing IR radiation causes objects to get hotter. Food can be cooked using IR radiation — the temperature of the food increases when it absorbs IR radiation, e.g. from a toaster's heating element.
- 7) Electric heaters heat a room in the same way. Electric heaters contain a long piece of wire that heats up when a current flows through it. This wire then emits lots of infrared radiation (and a little visible light — the wire glows). The emitted IR radiation is absorbed by objects and the air in the room — energy is transferred by the IR waves to the thermal energy stores of the objects, causing their temperature to increase.



Different colours represent different amounts of IR radiation being detected. Here, the redder the colour, the more infrared radiation is being detected.

## Infrared Can Also Transfer Information

- 1) Infrared radiation can also be used to transfer information.
- 2) For example, it can be used to send files between mobile phones or laptops. The distances must be fairly small and the receiver must be in the line of sight of the emitter.
- 3) This is also how TV remote controls work. In fact, some mobile phones now have built in software which means that you can use your phone as a TV remote.
- 4) Optical fibres are thin glass or plastic fibres that can carry data (e.g. from telephones or computers) over long distances as pulses of infrared radiation. They usually use a single wavelength to prevent dispersion (p.34), which can otherwise cause some information to be lost.
- 5) They use total internal reflection (p.38) to send lots of data over long distances.

## Revision time — adjust depending on brain wattage...

The next time you're feeling hungry and zap some food in the microwave, think of it as doing revision.

Q1 Give three uses of infrared radiation.

[3 marks]

## More Uses of EM Waves

And we're still not finished with uses of waves — is there no end to their talents...

### Photography Uses Visible Light

- 1) Visible light is the light that we can see. So it's only natural that we use it for illuminating things so that we can see them.
- 2) Photographic film reacts to light to form an image. This is how traditional cameras create photographs.
- 3) Digital cameras contain image sensors, which detect visible light and generate an electrical signal. This signal is then converted into an image that can be stored digitally or printed.

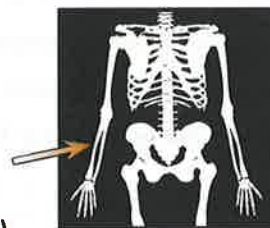


### Ultraviolet is Used in Fluorescent Lamps

- 1) Fluorescence is a property of certain chemicals, where ultraviolet (UV) radiation is absorbed and then visible light is emitted. That's why fluorescent colours look so bright — they actually emit light.
- 2) Fluorescent lights use UV to emit visible light. They're energy-efficient (p.26) so they're good to use when light is needed for long periods (like in your classroom).
- 3) Security pens can be used to mark property (e.g. laptops). Under UV light the ink will glow, but it's invisible otherwise, helping to identify stolen property.
- 4) Bank notes and passports use a similar technique to detect forges — genuine notes and passports have special markings that only show up under UV light.
- 5) Ultraviolet radiation is sometimes used to sterilise water. It kills bacteria in the water, making it safe to drink. (Gamma rays are used in a similar way, see below.)

### X-rays Let Us See Inside Things

- 1) X-rays can be used to view the internal structure of objects and materials, including our bodies.
- 2) They affect photographic film in the same way as light, meaning you can take X-ray photographs. But X-ray images are usually formed electronically these days.
- 3) Radiographers in hospitals take X-ray images to help doctors diagnose broken bones — X-rays are transmitted by flesh but are absorbed by denser material like bones or metal.
- 4) To produce an X-ray image, X-ray radiation is directed through the object or body onto a detector plate. The brighter bits of the image are where fewer X-rays get through, producing a negative image (the plate starts off all white).
- 5) X-rays are also used in airport security scanners to detect hidden objects that can't be detected with metal detectors.



### Gamma Rays are Used for Sterilising Things

- 1) Gamma rays are used to sterilise medical instruments — they kill microbes (e.g. bacteria).
- 2) Food can be sterilised in the same way — again killing microbes. This keeps the food fresh for longer, without having to freeze it, cook it or preserve it some other way, and it's perfectly safe to eat.
- 3) Some medical imaging techniques such as tracers (p.55) use gamma rays to detect cancer.
- 4) Gamma radiation is also used in cancer treatments (p.56) — radiation is targeted at cancer cells to kill them. Doctors have to be careful to minimise the damage to healthy cells when treating cancer like this.

### Don't lie to an X-ray — they can see right through you...

I hate to say it, but go back to page 45 and re-read all of the uses for electromagnetic waves to really learn them.

- Q1 State two uses of ultraviolet radiation. [2 marks]
- Q2 Suggest one advantage of sterilising food with gamma rays. [1 mark]