EM Spectrum

PHYSICS • WAVES • EM SPECTRUM

Section 1: Below Infrared

• What are electromagnetic waves?

Charged particles, like electrons, are surrounded by electric fields. If a charged particle is accelerated, the electric field changes. This changing electric field produces a changing magnetic field. A changing magnetic field produces a changing electric field. This process repeats and results in a wave, which travels at high speed. These are known as electromagnetic waves.

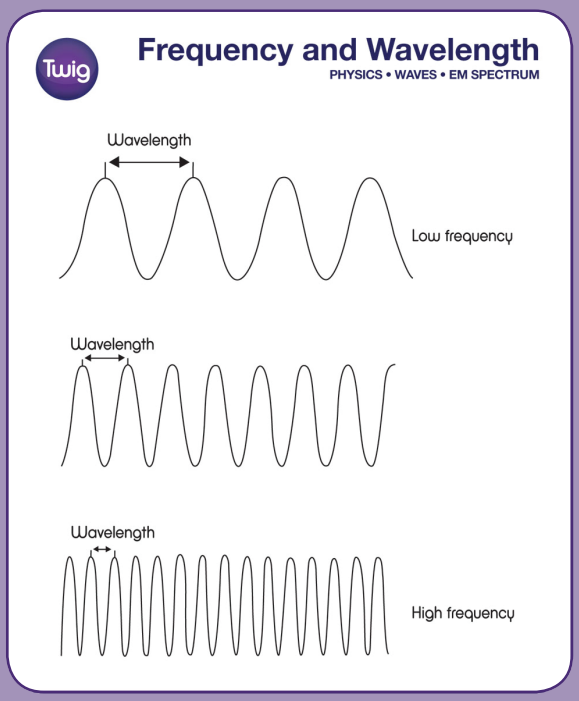
Electromagnetic waves can be created when electrons are made to vibrate. The number of times the electron vibrates every second determines the number of waves, which are produced each second: this is known as the frequency of the wave. The distance between the peaks on the produced wave is known as the wavelength: this is related to the frequency. High-frequency waves have short wavelengths.

Some of these waves can be detected by our eyes. We call these visible light. There are other electromagnetic waves which we cannot detect. These include radio waves, microwaves, infrared, ultraviolet, X-rays and gamma rays.

• Suggested Films

- **The Electromagnetic Spectrum**
- **What Makes Up the Electromagnetic Spectrum?**

DIAGRAM 01:



Extension Question

Q1. How fast do electromagnetic waves travel?

In a vacuum all electromagnetic waves travel at approximately 300,000,000 m/s. This is known as the speed of light. Information and matter cannot travel faster than the speed of light. The speed of electromagnetic waves in other materials can vary. For example, in glass, visible light travels at around 200,000,000 m/s. In addition, the frequency of a wave may mean that instead of passing through a material, it is absorbed.

• What are radio waves?

These antenna dishes can detect radio waves from outer space

The lower the energy of the wave, the lower the frequency. The lowest energy waves are radio waves. These have long wavelengths, approximately longer than 30cm. If an electric current is passed back and forth in a conductor, this will cause the electrons to oscillate and radio waves will be produced. If these waves reach another conductor, they can cause the electrons in that conductor to oscillate, producing a small electrical current. This can be used for communication.

• Suggested Film

- **Submarine Communication**

• What are microwaves?

If electrons are made to oscillate at a frequency higher than that used to generate radio waves, about 2 billion times per second, the waves which are produced are known as microwaves. Although, as with all parts of the electromagnetic spectrum, it is not possible to define an exact boundary between the two types of waves. Microwaves can be considered to have a wavelength of less than 30cm and greater than a few millimetres. As with radio waves, microwaves can be used for communication. Because microwaves have a higher frequency than radio waves, they can carry more information, although it is generally more difficult to use them to communicate over large distances.

• Suggested Films

- How Do Mobile Phones Work?

Extension Questions

Q2. How do microwave ovens work?

As well as being useful for communication, microwaves can also be used to heat food. Water molecules are polar, which means that one side of the molecule has a slight positive charge, and the other has a slight negative charge. When in an electric field, the water molecules will try to rotate to align themselves with the field. The microwaves used in a microwave oven have a frequency of 2.45 Gigahertz (this means they oscillate 2,450,000,000 times per second), which means that the water molecules rapidly rotate back and forward, trying to align with the constantly changing field. This vibration is equivalent to a rise in temperature; as they do this they will transfer energy to other molecules in the food, causing them to vibrate and increase their temperature.

Q3. What are terahertz waves?

Terahertz waves have a wavelength ranging from about 0.3 to 1mm, shorter than microwaves but longer than infrared. Until technology improved recently, it was difficult to produce terahertz waves which can pass through materials like paper or clothing. Recently, body scanners have been introduced at many airports. There are two different types of scanners which use two different technologies: one uses reflected X-rays, the other uses terahertz waves.

Section 2: IR, Visible and UV

• What is infrared?

Waves with wavelengths shorter than about 0.3mm and longer than around 0.007mm (7 micrometres) are known as infrared. Objects which are hot generally emit large amounts of infrared. Around half of all the energy that reaches the Earth from the Sun is in the form of infrared radiation.

The frequencies at which the atoms in many molecules vibrate, are within the range of frequencies for infrared light. As molecules will absorb light at these frequencies, we can use infrared light to identify which molecules are present in a sample. This is known as infrared spectroscopy and involves using a range of frequencies of infrared, and noting which are absorbed by the sample.

• Suggested Film

- Infrared: Snake Hunt

Infrared light is given off by warm objects such as human beings

Extension Questions

Q4. How is infrared used to detect alcohol?

Breathalysers use infrared to determine the amount of alcohol in a breath sample. Infrared light is passed through a chamber containing the sample, and the amount of infrared light absorbed at each wavelength is noted. This can be used to indicate the amount of alcohol (ethanol) present in the sample, as the oxygen-hydrogen bond in ethanol absorbs strongly in the infrared.

Q5. How does night vision work?

There are several ways to produce night vision devices. Thermal imaging looks for the infrared that is emitted by warm objects, which of course limits detection to objects like humans, animals and vehicles, but is often used by law enforcement to find and track individuals.

Alternatively, infrared light can be used to illuminate the surroundings. This is invisible to humans, but an infrared detector can be used to pick up the reflected infrared and display an image. As early as the Second World War, military systems which worked on this principle were used. But as the infrared light used to illuminate the surroundings was visible to the enemy, who were using the same technology, it was of limited use. For similar reasons, these systems are not often used by the military today, but are used in security systems.

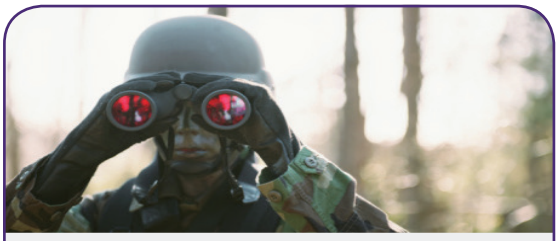
Image intensifiers not only work by detecting infrared, they detect the small amounts of light which are present at various wavelengths, and increase their intensity to make them visible to the human eye.

Q6. What is blackbody radiation?

A blackbody is an object that absorbs all incident electromagnetic radiation - from anywhere in the spectrum. The radiation emitted by such an object is known as blackbody radiation. A range of wavelengths is emitted, but the wavelength at which the emission is strongest depends on the temperature of the object. The higher the temperature of the object, the shorter the wavelength of light emitted. Objects at room temperature mostly emit infrared light which is invisible to us, but at a temperature of around 600°C objects begin to emit enough visible light that a red glow is visible. At higher temperatures, objects glow orange then yellow. The Sun, with its surface temperature of around 5500°C, acts as an imperfect blackbody and emits most of its radiation in the visible light region. Its peak emission is in the green part of the visible spectrum. The Sun does not look green, as it also emits other wavelengths which mix to make the Sun appear white (although it appears slightly yellow from Earth, as blue light is scattered by the atmosphere).

• What range of electromagnetic waves can humans see?

- **Suggested Films**
  - **The Electromagnetic Spectrum**
  - **What Makes Up the Electromagnetic Spectrum?**
  - **FactPack: Animal Vision**



Night vision goggles detect infrared light

Humans can see light with wavelengths that are between 0.4 and 0.75 micrometres (a micrometre is a millionth of a metre), although this varies slightly between individuals. Waves like this are produced when electrons within atoms change position, dropping from higher to lower energy levels. Visible light is only a very small part of the electromagnetic spectrum, but this is the region where the Sun emits most strongly. Some birds and insects can detect shorter wavelengths, and are able to detect ultraviolet light. The ability to see longer, infrared wavelengths is less common, but some snakes have an organ which allows them to detect infrared to help them find prey. It is not clear whether they “see” an image in infrared.

• What is ultraviolet light?

Electromagnetic waves with wavelengths shorter than 0.4 micrometres and longer than 0.01 micrometres are referred to as ultraviolet. These can be produced when free electrons recombine with atoms. Wavelengths from 0.4 micrometers to 0.01 micrometres are referred to as UVA, UVB and UVC light, depending on their wavelength; all three can damage our skin.

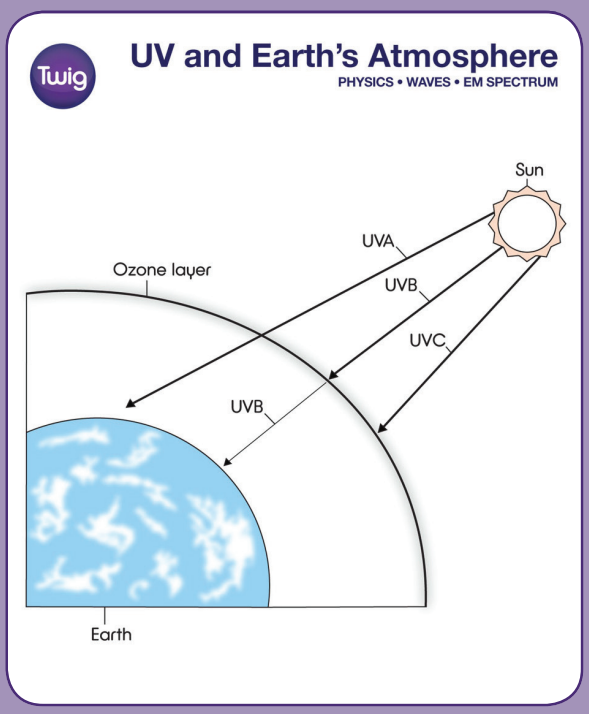
Of these, UVA has the longest wavelength, and unlike UVB, is able to pass through glass. UVB and UVC are thought to be more dangerous than UVA, and are known to cause DNA damage and eventually skin cancer. The skin's response to this is the production of the pigment melanin: this is what causes tanning. If large amounts of these rays reach the skin, cells are damaged resulting in sunburn.

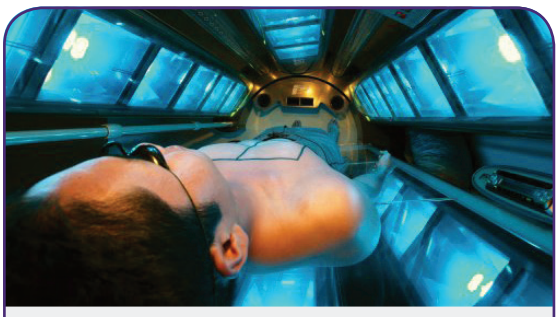
Although UVC is considered the most dangerous of these, it is almost entirely blocked by the Earth's atmosphere, in particular by the ozone layer.

• Suggested Films

- **The Electromagnetic Spectrum**
- **What Makes Up the Electromagnetic Spectrum?**

DIAGRAM 02:





It is the UV light in sunlight that causes our skin to tan and burn

Extension Questions

Q7. How is UV used in lighting?

Although UV light is invisible to humans, it can be used in lighting. In fluorescent lamps an electric current is used to excite a gas. As electrons in these atoms drop back to lower energy levels, UV light is released. The coating on the wall of the lamp is made of material that absorbs UV light and emits visible light. This is the process used in energy saving light bulbs and is very efficient, and unlike tungsten filaments light bulbs, very little heat is produced.

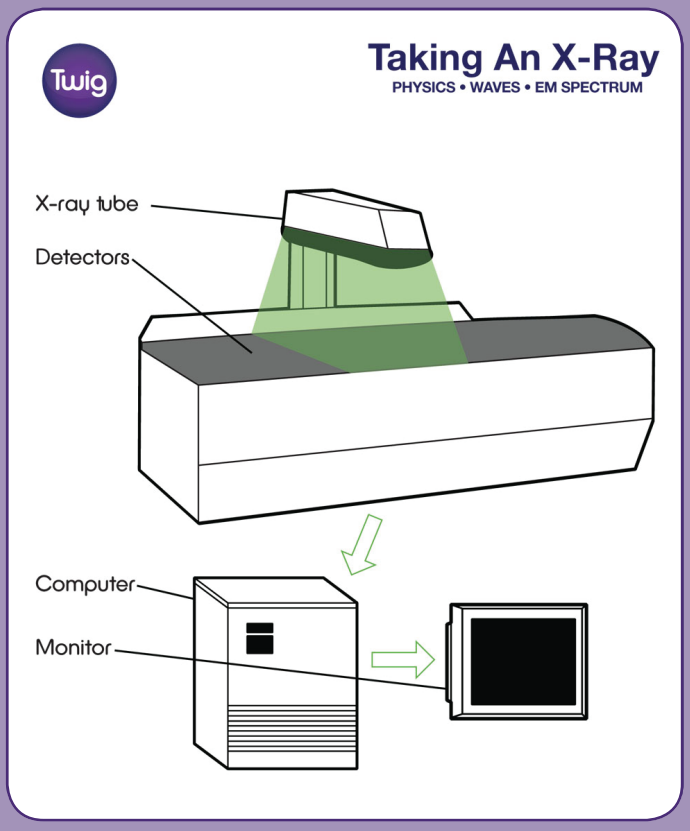
Q8. What is vacuum UV?

At wavelengths between 0.1 and 0.2 micrometres, UV is absorbed by air and light, and is known as vacuum UV for this reason. Using vacuum conditions whenever these wavelengths are required would be difficult. However, the absorption is due to oxygen molecules, and the need for a vacuum can be avoided by using nitrogen instead of air. This is important for the semiconductor industry that uses vacuum UV in a process known as photolithography. A semiconductor is coated in a chemical and exposed to UV light, which is passed through a mask. The UV activates the chemical, and the pattern contained on the mask is left on the semiconductor. The surface can then be etched, and eventually an integrated circuit can be constructed.

Section 3: X-rays and Gamma Rays

• What are X-rays?

DIAGRAM 03:



Waves with a wavelength between 0.01 and 10 nanometres (nm) are known as X-rays. These waves can be created when an electron in an atom is ejected (usually by a free electron travelling at high speed) from a very low energy level. This gap is then filled by an electron from a higher energy level, and a high energy wave is emitted. These waves have very high frequencies, as high as exahertz (1000 billion, billion hertz). Electromagnetic waves which have frequencies as high as this, have high enough energy that it is possible for them to eject electrons from atoms, turning them into positively charged ions. For this reason we say that X-rays are a form of ionising radiation.

• Suggested Film

- Waves in Medicine

This picture of the human torso was put together using a series of X-ray images

Extension Question

Q9. How are X-rays used in medicine?

Short wavelength X-rays can pass through flesh but are absorbed by bone. If photographic film is placed on the other side of the patient, the X-rays which pass through will affect the film, leaving the areas where the rays were blocked by bone unaffected. An image of the bones inside the body can be produced this way, although modern X-ray equipment usually uses digital detectors rather than film. Tissue does absorb x-rays to an extent, and so features other than bone can usually be seen and used for diagnosis.

• What are gamma rays?

Electromagnetic rays with a wavelength less than 0.01nm are usually called gamma rays. In fact, the boundary between gamma rays and X-rays is difficult to define, and sometimes the same wave could be considered a short wavelength X-ray or a long wavelength gamma ray. For this reason, waves are often classified by their origin. Although X-rays are emitted by electrons within atoms, gamma rays are emitted from the nucleus of an atom, or when matter and antimatter annihilate.

It is very difficult to block gamma rays, and shielding often uses thick lead or concrete to reduce exposure. Gamma rays are a form of ionising radiation and can cause damage to living tissue. They can be less damaging than other forms of radiation, because their ability to penetrate almost anything can mean that they pass through the human body without being absorbed significantly.

• How are gamma rays used in medicine?

Gamma rays can be used to sterilise some medical equipment

Although gamma rays can be dangerous to humans, and exposure increases the risk of cancer, they are often used in radiotherapy to kill cancer cells. The ability of gamma rays to pass through human tissue also means that gamma ray emitters can be used as tracers. Substances which emit gamma rays are taken internally. Because the gamma rays they emit can be detected from outside the body, their distribution can be mapped, and used to produce images for investigation and diagnosis.

• Suggested Film

- Waves in Medicine

• Quizzes

EM Spectrum

Basic

• What is the speed of light in a vacuum?

A – 300,000,000 m/s

B – 340 m/s

C – 186,000 m/s

D – 200,000 m/s

• What is the name for the range of possible electromagnetic waves?

A – the spectral distribution

B – the electric field

C – the electromagnetic spectrum

D – the magnetic field

• What wavelengths does electromagnetic radiation have?

A – a few millimetres

B – hundreds of kilometres

C – from a fraction of the size of an atom to thousands of kilometres

D – less than a few centimetres

• What is the name for the process in which electrons are freed from atoms or molecules?

A – radiation

B – ionisation

C – oscillation

D – nuclear fission

Advanced

• How is the frequency of a wave related to its wavelength?

A – high-frequency waves have long wavelengths

B – they are not related

C – high-frequency waves have short wavelengths

D – most low-frequency waves have short wavelengths, but not all

• How is the energy of a wave related to its frequency?

A – the energy of a wave only depends on its speed

B – high-frequency waves have low energies

C – the energy of a wave only depends on what it is travelling through

D – high-frequency waves have large energies

• What types of waves are able to free electrons from atoms or molecules?

A – radio waves, infrared and visible light

B – radio waves, X-rays and gamma rays

C – infrared, visible light and ultraviolet

D – ultraviolet, X-rays and gamma rays

EM Spectrum

Basic

• When is electromagnetic radiation created?

A – when light changes direction

B – when charged particles oscillate

C – when particles change direction

D – when particles collide

Advanced

• Can electromagnetic waves move through a vacuum?

A – no, they need a medium to travel through

B – no, they only travel in space because it is not a perfect vacuum

C – yes, they don't need a medium to travel through

D – yes, but they travel very slowly

• What is a transverse wave?

A – a wave that travels faster than sound

B – a wave that oscillates in the direction of travel

C – a wave which travels at the speed of light

D – a wave that oscillates at right angles to the direction of travel

• Answers

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