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2018 HIGHER SCHOOL CERTIFICATE COURSE MATERIALS

Year 10 Headstart Science

Physical World

Term 1 – Week 2

Name ……………………………………………………….

Class day and time ……………………………………………

Teacher name ………………………………………………...

Term 1 – Week 2 – Theory

THE WAVE MODEL: PART II

MATHEMATICS OF WAVES

FREQUENCY

In the previous booklet, you were introduced to the features of transverse and longitudinal waves. Some terms you will need to remember are **amplitude** and **wavelength**.

Another term that needs to be understood about waves is **frequency**:

Frequency measures oscillations per unit of time

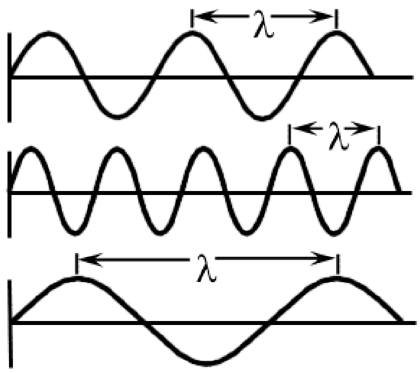
The frequency of a wave refers to the **number of oscillations produced per second**. For example, if a slinky is pushed forwards and backwards two times every second, the frequency will be two oscillations per second.

Frequency is usually measured in the units hertz, abbreviated by the symbol Hz. The unit hertz means 'per second'. In the slinky example above, the frequency of the slinky movement can be said to be 2 Hz. A sound wave that hits your ear at a rate of 250 compressions per second has a frequency of 250 Hz.

The frequency of a wave is inversely related to the wave's wavelength.

If the wavelength of a wave is doubled, the frequency is halved. If the frequency of a wave is doubled, the wavelength is halved.

The diagram on the right shows this relationship between frequency and wavelength. Assuming the three waves travel at the same speed, the wave with the greatest wavelength has the lowest frequency, while the wave with the highest frequency has the shortest wavelength.



The relationship between frequency and wavelength can be demonstrated using a slinky simulating transverse waves. If a person moves the slinky up and down faster, the frequency increases. However, the distance between the peaks of the slinky wave (wavelength) becomes shorter.

SPEED

The speed of any wave can be calculated by multiplying together the frequency of the wave and the wavelength. Mathematically, this relationship can be expressed as:

$$\boldsymbol{v = f\lambda}$$

Where:

- v represents velocity and is expressed in metres per second (m/s)
- f represents frequency and is expressed in hertz (Hz)
- λ represents wavelength and is expressed in metres (m)

The relationship between the velocity of a wave, its frequency and the wavelength is a logical one. For example, consider a wave that has a frequency of 50 Hz and a wavelength of 0.5m. This means that 50 oscillations of the wave would be produced each second, and each wave cycle would be of length 0.5m. Multiplying these two quantities together results in a total distance of 25m. Since this is over a time period of one second, the velocity of the wave is 25 m/s.

Example 1

Calculate the velocity of a wave which has a frequency of 2500 Hz and a wavelength of 40 cm.

Solution

$v = f\lambda$

$Since\ \lambda\ is\ expressed\ in\ metres, \lambda = 0.4$

$Therefore: v = 2500 \times 0.4$

$v = 1000\ m/s$

Example 2

Calculate the frequency of a wave which has a velocity of 1250 m/s and a wavelength of 0.25 m.

Solution

$v = f\lambda$

$f = \frac{v}{\lambda}$

$f = \frac{1250}{0.25}$

$f = 5000\ \text{Hz}$

THE SPEED OF LIGHT AND SOUND WAVES

In the previous section, it was explained that the speed of a wave depended on two factors:

- Frequency, f
- Wavelength, λ

Because of this, it should come as no surprise that different waves have a different speed, as each type of wave has its own frequency and wavelength.

Visible light has a speed of $3 \times 10^8 \mathrm{m/s}$. Visible light is actually made up of rays of different wavelengths and frequencies. Together, the different colours we see form the visible spectrum of light, but all rays of visible light have a speed of $3 \times 10^8 \mathrm{m/s}$. The wavelengths of visible light range from about 380 to 750 nanometres ($10^{-9} m$). The frequencies of waves in the visible spectrum range from about 790 to 400 terahertz (10^{12} Hz). Using the equation for calculating the speed of waves covered previously, the speed of light can be confirmed. E.g. blue light has a wavelength of 450nm and a frequency of $6.67 \times 10^{14}\ Hz$, so the speed of red light must be: $v = f\lambda = 6.67 \times 10^{14} \times 450 \times 10^{-9} = 3 \times 10^8 m/s$.

In air, sound waves have a speed of approximately 340 ms^{-1}. In different mediums, sound waves travel at different speeds.

Like visible light, the speed of sound waves is determined by $v = f\lambda$. Likewise, if a question gives you f and v, you can solve to find λ.

THE ELECTROMAGNETIC SPECTRUM

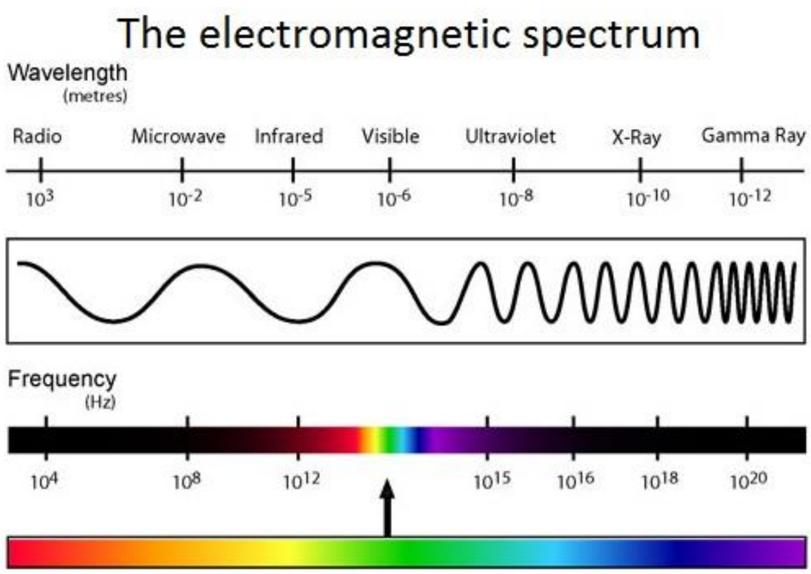
Sound waves require a medium to travel through, such as air. For example, sound can be heard on Earth but not in places with a vacuum, such as in space.

On the other hand, **light does not require a medium** in order to travel and propagate. This confused early scientists and led to great debates about whether light was particle or a wave. This debate is studied in HSC Physics (Space module).

Today, our understanding of light defines it as a wave. Visible light is a type of **electromagnetic wave**, which propagates through a series of alternating magnetic and electric fields. A change in an electric field causes a changing magnetic field, which generates another magnetic field and so on. This is the way light propagates, and it is known as the self-propagating property of electromagnetic waves.

The range of colours we are able to see are electromagnetic waves of certain frequencies and wavelengths, together forming the visible spectrum.

However, many other electromagnetic waves of different wavelengths and frequencies exist. Together, these waves form the **electromagnetic spectrum**.



The electromagnetic spectrum is the range of various electromagnetic waves of different frequencies and wavelengths. These waves have many different properties. However, as electromagnetic waves are self-propagating, they do not require a medium to travel.

All electromagnetic waves travel at a speed of $3 \times 10^8 m/s$.

We will now investigate the various different types of waves that make up the electromagnetic spectrum and explore how these waves are used.

GAMMA RAYS

Gamma rays are the waves with the shortest wavelength in the electromagnetic spectrum, typically featuring wavelengths in the region of 10^{-12} m. Since the speed of all electromagnetic radiation is a constant, gamma rays have very high frequencies, about 10^{20} Hz.

Gamma rays are extremely high energy waves and are very harmful if not controlled. Gamma rays are produced in nuclear reactions (such as radioactive decay, nuclear fission, nuclear fusion), or from violent events in space (such as star death). The sun produces gamma rays, but these are blocked by our atmosphere. Some radioactive elements that produce gamma rays when they undergo decay include plutonium and uranium.

Because gamma rays are high energy, they are harmful to life. Gamma rays can damage DNA (important molecules inside our cells), causing mutations or death due to deadly illnesses like cancer. However, under controlled use, gamma rays have many useful purposes:

- Gamma rays can be used to **kill cancerous cells in radiotherapy**. Healthy cells may also be killed, causing the side effects of radiotherapy.
- Along with X-Rays, gamma rays can be used to produce **medical scans.**
- The ability of gamma rays to kill living cells also makes it useful for killing living organisms such as bacteria through irradiation. This allows gamma rays to **sterilise medical equipment** as well as prolonging food life.

X-RAYS

X-rays are waves in the electromagnetic spectrum with the second shortest wavelength, after gamma rays. X-rays typically have a wavelength of ranging around 10^{-10} m, and frequency around the vicinity of 10^{18}Hz.

X-rays are most commonly produced when **fast moving electrons hit atomic nuclei at high speeds**. For example, X-rays can be commonly produced by firing an electron beam at a metal target.

X-rays of different wavelengths have different penetrating powers, so they are very useful for **imaging purposes**. The most commonly known use of X-rays is in **medical imaging** where X-rays allow doctors to see bone structure.

X-rays are able to produce such images because they can penetrate flesh, but not bone, allowing an accurate picture of bone material to be generated. This is useful in medicine, allowing easy diagnosis of broken bones and other injuries without the need for invasive methods of examination like exploratory surgery.

X-rays are also useful for a variety of other purposes:

- **Airport luggage scanners** use X-rays to inspect luggage before it is allowed on aircraft.
- **X-ray crystallography** uses patterns produced by X-rays diffracting in atomic crystal lattices to visualise the structure of atomic crystal lattices (e.g. glass, diamond, metals etc).
- **Industrial radiography** uses X-rays to generate images of parts to allow for their inspection. This is useful for detecting problems such as metal fatigue or improper welding.

ULTRAVIOLET RADIATION

Ultraviolet light is a type of electromagnetic radiation in the electromagnetic spectrum between visible light as X-rays. Ultraviolet light is high energy and is named because the UV spectrum begins beyond the visible light spectrum, higher than violet (the highest frequency of visible light).

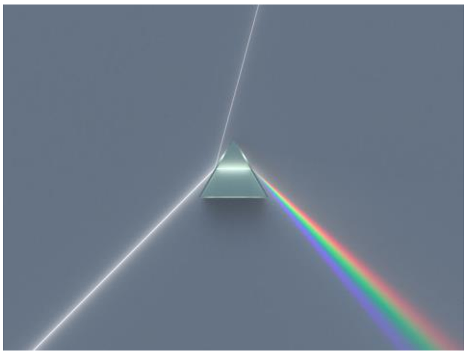
The most common source of ultraviolet light is sunlight. However, UV light can also be produced, such as through electric arcs and special types of lamps such as black lights.

UV light can be highly damaging if exposed in high quantities to humans and other living organisms. UV radiation can cause **sunburn**, **DNA damage**, **damage to the immune system** and **skin cancer**. This is why people wear sunscreen at the beach – to block out the UV portion in sunlight.

Despite its potential harmful impacts, UV light also has a range of useful applications:

- UV light on certain substances produces strong oxidants. This can be used in **air purification** to break down undesirable pathogens present in the air.
- Ultraviolet lamps can be used in medical facilities and workplaces to **sterilise** tools and equipment.
- UV radiation can be used to **disinfect drinking water**, as UV radiation is effective at eliminating viruses and bacteria.
- In controlled amounts, UV light can be used in **phototherapy** to treat skin conditions such as eczema and vitiligo.
- **Security features** can be integrated onto items such as credit cards and passports through a UV watermark that is visible under UV radiation.

VISIBLE LIGHT



The visible spectrum is defined as the portion of the EM spectrum that is **visible to the human eye**. The visible light spectrum is a small component of the entire EM spectrum, situated between ultraviolet radiation and infrared rays.

As mentioned previously, the wavelengths of visible light range from about 380 to 750 nanometres (10^{-9} m). The frequencies of waves in the visible spectrum range from about 790 to 400 terahertz (10^{12} Hz). The colour of visible light with the highest frequency is violet, while the colour of light with the lowest frequency is red.

All the colours we see are combinations of different rays of visible light. A common way to demonstrate this is to pass white light through a glass prism, as shown above. Different colours refract through the prism at slightly different rates, producing a rainbow at the other side.

Visible light is what allows humans and most animals to see. It is also the portion of light that plants use for energy (via photosynthesis), and is the portion of the EM spectrum that our Sun emits most intensely.

INFRARED RAYS

Infrared rays are a type of electromagnetic radiation with a frequency below that of visible light. Typically, infrared rays have a frequency in the vicinity of 10^{12} Hz and a wavelength of about 10^{-5} m. Infrared rays are named so because the type of visible light wave with the lowest frequency is red, and infrared rays have a frequency lower than that of red light.

Infrared rays are produced from the heat of relatively low temperature objects like body heat, warm water, the ground on a hot day, etc.

Infrared rays have a range of different purposes and applications:

- **Thermal images** can be produced using thermographic cameras. This can be used to see better at night (nightvision), or for medical purposes (e.g. airport scanning for flu-infected travelers). The picture on the right shows a dog viewed through an IR camera. Lighter spots correspond to hotter regions on the dog's body.
- Infrared rays are used in **remote control devices** such as for TVs. These rays emitted from controllers are detected by a device, which converts the ray into an electrical signal to control the device
- Infrared radiation can also be used for **heating purposes**. Some examples include infrared saunas as well as de-icers for aircraft wings.
- Weather satellites can use infrared rays to analyse temperatures in the atmosphere, oceans and clouds for **meteorology** purposes. This allows better weather forecasting.

MICROWAVES

Microwaves are the type of electromagnetic radiation that lies between radio waves and infrared rays. They have a frequency of about 10^8 Hz and have a wavelength usually a few centimetres in length. Microwaves are very similar to radio waves and are actually sometimes called short-wave radio waves (referring to their shorter wavelengths compared to radio waves).

Microwaves are generated by electrons which are vibrating in electrical devices. The production of microwaves is produced in some electrical devices through an aerial. For example, many radios have aerials. Although radios transmit and receive radio waves, microwaves are very similar to radio waves, only shorter in wavelength.

Microwaves are used for many different purposes, including:

- A **microwave oven** allows the heating of food by causing water, fats and sugars in foods to absorb energy from microwaves generated.
- Microwaves are used for **communication purposes** (e.g. mobile phones, mobile internet, WIFI signals).
- The technology of **radar** uses microwaves. Radar technology involves emitting microwaves that are reflected back to a receiver to detect objects. It is commonly used in aircraft, ships and weather forecasting equipment today.

RADIO WAVES

Radio waves are the final type of electromagnetic radiation. Radio waves have the longest wavelength and lowest frequency of all electromagnetic waves. Typically, the wavelengths of radio waves range from tens of centimetres to hundreds of metres. When a frequency is selected for a radio station, the frequency refers to the radio wave emitted by that radio station. For example, when we listen to popular channels like 'Today FM' 104.1, these numbers actually mean the FM station's broadcast frequency – 104.1 MHz, or $104.1 \times 10^6\ Hz$. The wavelength of these radiowaves must therefore be:

$$c = f\lambda$$

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{104.1 \times 10^6} = 2.88\ m$$

Like microwaves, radio waves are produced by vibrating or oscillating electrons in an electronic device (e.g. radio).

Radio waves are typically most used for communication purposes. Their long wavelengths allow them to reflect off the ionosphere or diffract around the Earth, giving radio waves **very long maximum ranges**.

Term 1 – Week 2 – Homework

1. Define the term ‘frequency’. **[1 mark]**

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2. With reference to waves, describe the relationship between speed, frequency and wavelength. **[2 marks]**

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3. Calculate the velocity of a wave which has a frequency of 3,000 Hz and a wavelength of 200 cm. **[1 mark]**

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4. Calculate the wavelength of a wave which has a frequency of 50,000 Hz and a velocity of 3×10^8 m/s. **[1 mark]**

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5. Calculate the frequency of a wave which has a velocity of 2.4×10^7 m/s and a wavelength of 25 cm. **[1 mark]**

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6. Explain what is meant by the 'electromagnetic spectrum' and identify THREE wavebands which are part of the 'electromagnetic spectrum'. **[3 marks]**

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7. Do all waves require a medium to travel? Support your answer to this question with an example. **[2 marks]**

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8. Discuss the use of Gamma rays and its impact on society. **[4 marks]**

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9. Relate the use of X-rays to its properties. **[3 marks]**

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10. Ultraviolet radiation can be extremely harmful. Identify the primary source of UV radiation, and describe the detrimental effects exposure to this radiation can cause. **[3 marks]**

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11. A science teacher was explaining to her class that different colours of the visible light spectrum corresponded to different frequencies. Red had the lowest frequency and violet had the highest. One of her students then asked the question "what is the frequency of white light?"

    Suggest a valid response the teacher may give to the student. **[3 marks]**

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12. Explain why infrared technology is commonly used by search and rescue teams. **[2 marks]**

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13. Describe the uses of microwaves in society. **[3 marks]**

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14. Describe the uses of radio waves. **[3 marks]**

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15. During a radio program, the radio host announces "you are listening to 'the EDGE' 96.1". From this information, determine the wavelength of the radiowaves that your radio must be receiving. (Hint: the speed of light is one of those constants you should memorise for life!) **[2 marks]**

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End of homework

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