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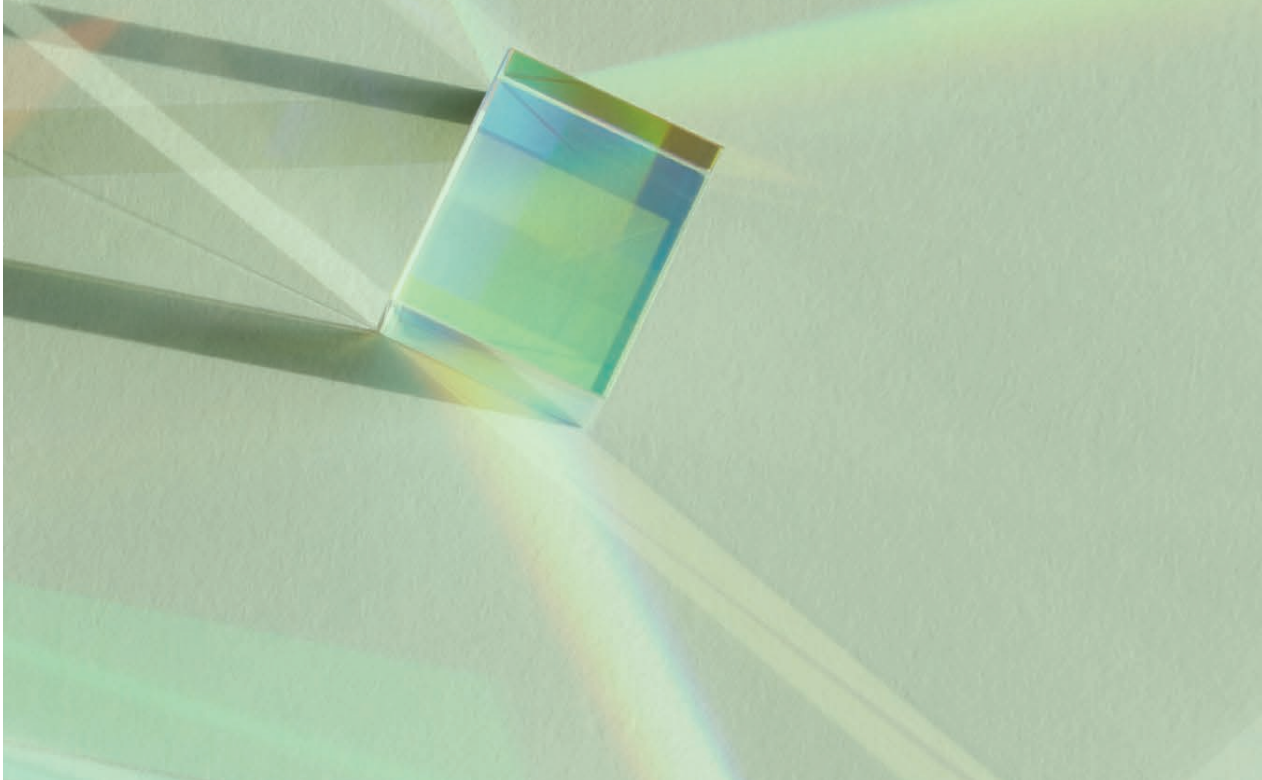

1

CHAPTER 1

Electromagnetic waves

STUDY DESIGN DOT POINTS

- identify all electromagnetic waves as transverse waves travelling at the same speed, *c*, in a vacuum as distinct from mechanical waves that require a medium to propagate
- identify the amplitude, wavelength, period and frequency of waves
- calculate the wavelength, frequency, period and speed of travel of waves using: $\lambda = \frac{v}{f} = vT$
- explain the wavelength of a wave as a result of the velocity (determined by the medium through which it travels) and the frequency (determined by the source)
- describe electromagnetic radiation emitted from the Sun as mainly ultraviolet, visible and infrared
- compare the wavelength and frequencies of different regions of the electromagnetic spectrum, including radio, microwave, infrared, visible, ultraviolet, x-ray and gamma, and compare the different 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
- explain the formation of optical phenomena: rainbows; mirages
- investigate light transmission through optical fibres for communication

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LESSONS

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1A Introduction to waves

STUDY DESIGN DOT POINT

- identify all electromagnetic waves as transverse waves travelling at the same speed, *c*, in a vacuum as distinct from mechanical waves that require a medium to propagate

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

What type of waves are all around us?

When most people think of waves, they picture water waves moving across the ocean, however, this is just one example of a wave. In reality, waves are all around us. Sound, light, earthquakes, and plucking a guitar string are examples of waves that can be found in everyday life. This lesson defines what a wave is and identifies the difference between mechanical waves and electromagnetic waves.

KEY TERMS AND DEFINITIONS

electromagnetic wave a wave that consists of perpendicular electric and magnetic field oscillations

longitudinal wave a wave in which the oscillations are parallel to the direction of wave travel and energy transmission

mechanical wave a wave which requires a material medium

medium (waves) a physical substance through which a wave propagates

oscillate to move back and forth in a regular motion

propagate the way in which a wave travels

transverse wave a wave in which the oscillations are perpendicular to the direction of wave travel and energy transmission

vacuum a region that does not contain matter

wave the transmission of energy via oscillations from one location to another without the net transfer of matter

Wave definition 1.1.1.1

As waves are a method of energy transfer they are fundamental to many physics phenomena.

Theory and applications

From sound to light, or ocean waves to earthquakes, the transmission of energy by wave propagation is fundamental to almost every branch of physics. It is only through the understanding of what a wave is, that these phenomena can be described.

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What is a wave?

A wave is the transmission of energy via oscillations from one location to another without the net (overall) transfer of matter. The direction a wave travels is defined by the direction of the energy transmission. The oscillations that form a wave can either be perpendicular (transverse) or parallel (longitudinal) to the motion of the wave.

It is energy, not matter, that is transferred by a wave. Figure 1 shows the transfer of energy without the net transfer of matter within a transverse ocean wave. Even though the wave is moving to the left, the matter, including the ball, that makes up the wave is oscillating perpendicular to the wave direction (up and down) without being pushed horizontally.

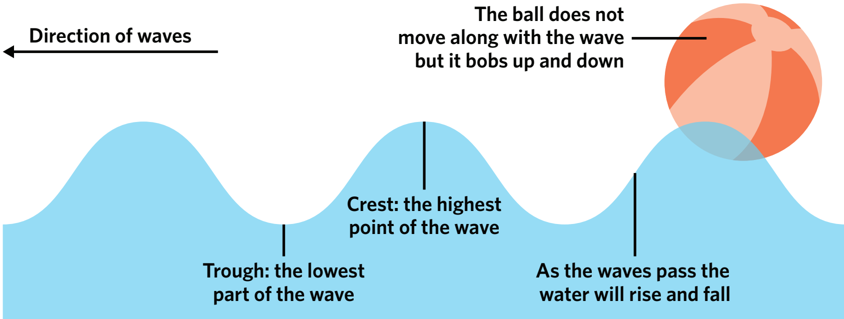


Figure 1 Water and a beach ball oscillate vertically as the wave moves

Figure 2 shows there is also no net transfer of matter within a longitudinal sound wave. Each air molecule vibrates about the same point, parallel to the direction of the wave (in this instance from left to right).

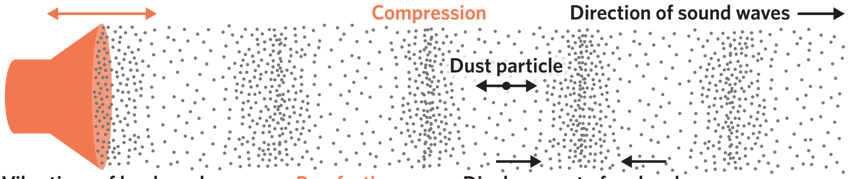


Figure 2 A dust particle within a sound wave oscillates back and forth

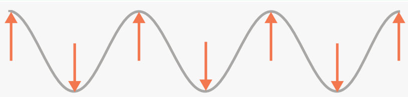
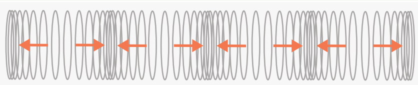
How do transverse and longitudinal waves differ?[1]

Waves can be distinguished by the direction of the oscillation in relation to the direction of their movement. Table 1 compares the properties of the two types of longitudinal and transverse waves.

KEEN TO INVESTIGATE?

1 **What is a wave?**
Search YouTube: Physics - waves - introduction

Table 1 Transverse vs. longitudinal waves

	Transverse wave	Longitudinal wave
Diagram		
Movement of oscillations	Perpendicular to the direction of wave propagation. For a transverse wave travelling to the right, oscillations could occur in any perpendicular direction, such as up and down or into and out of the page, but not left and right.	Parallel to the direction of wave propagation. For a longitudinal wave travelling to the right, the particles in the medium must oscillate left and right. Longitudinal waves are also commonly referred to as compression waves.
Common examples	Waves in strings, electromagnetic waves, and water waves.	Sound waves, waves in springs, or the primary (P) waves in an earthquake.
Key features	Crests: points on a wave with maximum positive displacement. Troughs: points on the wave with maximum negative displacement.	Compressions: the points on a wave where particles are most closely grouped together (under the most pressure). Rarefactions: points where particles are most spread out (under the least pressure).

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Progress questions

Question 1

A point on a transverse wave will oscillate in which direction compared to the direction of the wave?

A. parallel

B. perpendicular

C. both A and B

Question 2

Which of the following is an example of a longitudinal wave?

A. a horizontal spring undergoing vertical oscillations

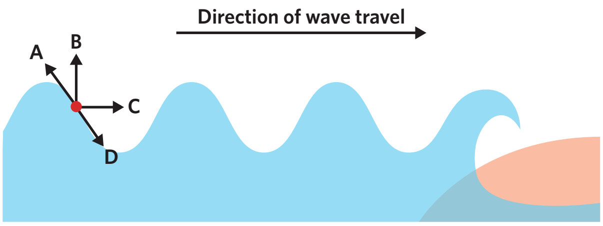
B. a violin string being plucked

C. a note from a speaker playing a song

D. a water ripple

Question 3

In which direction does the particle move at the instant shown: A, B, C or D?



Question 4

Sound is best described as a

A. longitudinal pressure wave transmitting air particles from a source to a receiver.

B. transverse pressure wave transmitting wave maxima from a source to a receiver.

C. longitudinal pressure wave transmitting energy from a source to a receiver.

D. transverse pressure wave transmitting energy from a source to a receiver.

VCAA 2016 exam Section B Detailed study 6 Q1

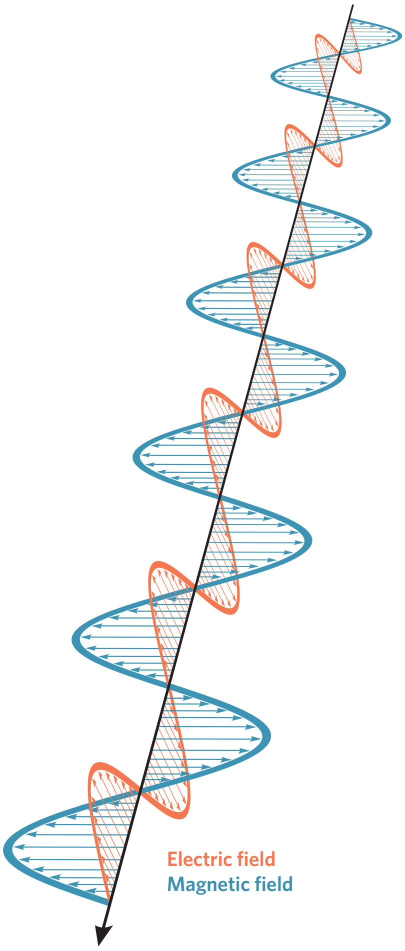


Figure 3 Oscillations of the electric and magnetic fields propagating through space

KEEN TO INVESTIGATE?

[2] **How do electric and magnetic fields create waves?**
Search YouTube: Electromagnetic waves and the electromagnetic spectrum | physics

Mechanical and electromagnetic waves 1.1.1.2

There are two main categories of waves that this course will focus on: electromagnetic waves and mechanical waves. Electromagnetic waves are defined by the oscillations of the electromagnetic and magnetic fields while mechanical waves are the oscillations of particles with a medium.

Theory and applications

An electromagnetic wave is the transmission of light energy through oscillations within the electric and magnetic fields (see Figure 3)[2]. It is common to refer to electromagnetic waves as light, since the visible light that the human eye can see is an example of an electromagnetic wave.

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How are electromagnetic waves distinct from mechanical waves?

An electromagnetic wave is a propagating oscillation of the electric and magnetic fields, whereas a mechanical wave is a propagating oscillation of the physical matter within a medium. Figure 4 shows a venn diagram of the main similarities and differences between these two types of waves

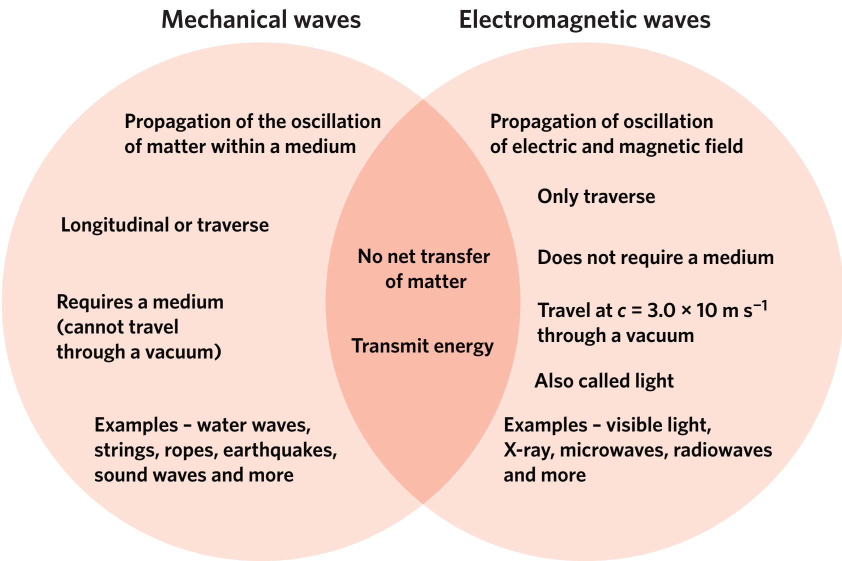
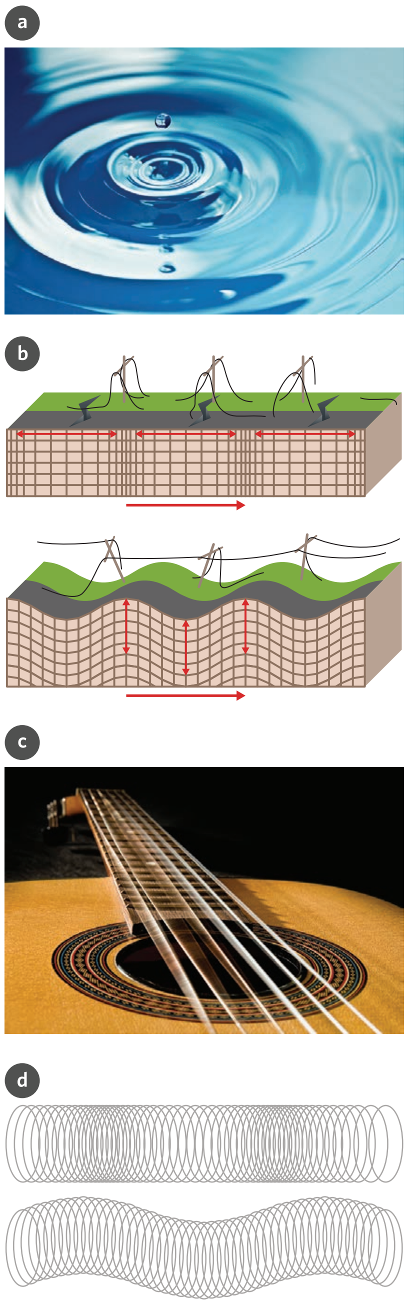


Figure 4 Venn diagram of similarities and differences

Examples of mechanical waves include sound waves (Figure 2), which transfers energy through the air (or another medium), a ripple in a pond (Figure 5(a)), which transfers energy through water, and an earthquake (Figure 5(b)) which transfers energy through the ground. In these examples, the particles oscillate about their mean (neutral) position; they do not travel with the wave as it propagates.

USEFUL TIP

It doesn't matter whether we are moving towards or away from an electromagnetic wave, it will always move at the same speed of 3.0×10^8 m s^{-1} through a vacuum.



Images (top to bottom): Dmitry Naumov, IreneuszB/ Shutterstock.com

Figure 5 Examples of mechanical waves in **(a)** a pond, **(b)** an earthquake, **(c)** guitar string, and **(d)** a slinky.

Progress questions

Question 5

A mechanical wave can be best described as

A. the transmission of matter through a medium without the net transfer of energy.

B. the transmission of alternating electric and magnetic fields without the net transfer of matter.

C. the transmission of energy through a medium without the net transfer of matter.

D. the transmission of energy through a vacuum without the net transfer of matter.

Question 6

Which of the following is false about an electromagnetic wave?

A. They exist as the transfer of energy through the oscillation of matter.

B. They all travel at 3.0×10^8 m s^{-1} through a vacuum.

C. They are all transverse waves.

D. They do not require a material medium to propagate through.

Continues →

Question 7

Identify which of the following properties only apply to: (E) electromagnetic waves, (M) mechanical waves, or (B) both.

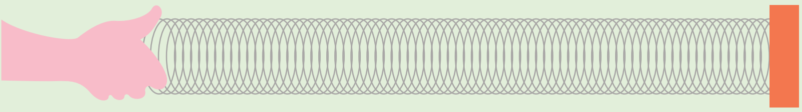
Propagation of an oscillation moving energy from one location to another	
Travel at a speed of $c = 3.0 \times 10^8$ m s^{-1} through a vacuum.	
Can be either transverse or longitudinal waves	
Require a medium to propagate	
Include: sound waves and ocean waves	
Also known as light	

Theory summary

- A wave is the transmission of energy via oscillations from one location to another without the net transfer of matter.
- All electromagnetic waves:
  - travel at the same speed in a vacuum known as the speed of light. The speed of light is denoted by the symbol '*c*' which is commonly written as $c = 3.0 \times 10^8$ m s^{-1}.
  - are transverse waves. The oscillation of the electric and magnetic field is perpendicular to the direction that an electromagnetic wave moves.
  - do not require a medium to propagate through. Therefore they can travel through a vacuum such as deep space.
- All mechanical waves:
  - exist as the transfer of energy through matter which means they requirea medium to propagate (travel) through such as air or water.
  - can be longitudinal or transverse.

The content in this lesson is considered fundamental prior knowledge to light as a wave (Unit 4 AOS 1).

CONCEPT DISCUSSION



Think of a slinky (a stretchy spring). The slinky can support longitudinal waves and transverse waves. How must the slinky be shaken to produce transverse waves? How must the slinky be shaken to produce longitudinal waves?

Prompts:

- The oscillating movement of a longitudinal wave is in the direction of the wave motion.
- The oscillating movement of a transverse wave is perpendicular to the wave motion.
- A wave on a slinky moves in the direction that the slinky is aligned with.

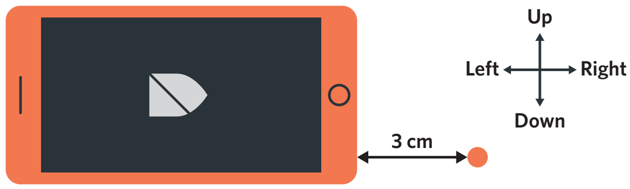
1A Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 8-10.

Finn begins playing music out loud from his phone. The air particle shown (not drawn to scale) starts initially at rest 3 cm away from the phone speaker.



Question 8 (1 MARK)

The particle will oscillate

A. left and right.

B. up and down.

C. The particle will not oscillate as sound is not a mechanical wave.

Question 9 (1 MARK)

The particle will

A. oscillate back and forth while being pushed to the right in the wave direction.

B. be pushed to the right in the wave direction without oscillating.

C. oscillate back and forth about its initial position.

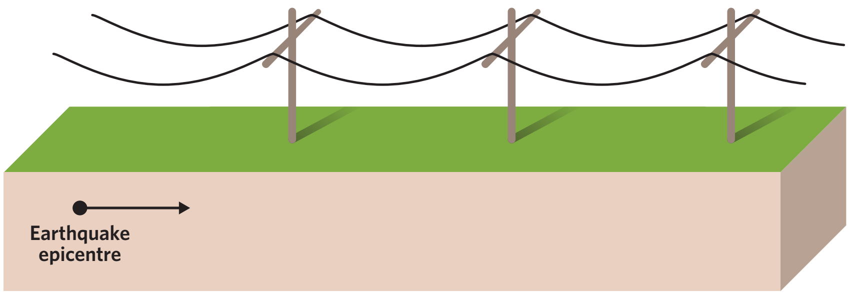
Question 10 (2 MARKS)

Describe the resulting motion of this air particle in relation to its initial position.

Exam-style

Question 11 (1 MARK)

An earthquake is propagating primary waves through the ground in the direction as shown. Consider a series of power line poles in front of the epicentre.



Which of the following diagrams best describes the movement of the power line poles? Assume they will not fall over.

A. 

B.

C.

D.

Adapted from VCAA 2018 exam Multiple choice Q10

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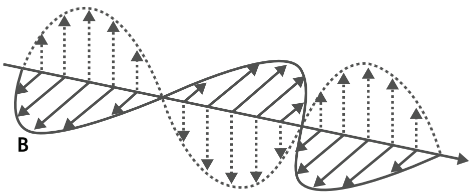
Question 12 (3 MARKS)

The image shows a representation of an electromagnetic wave.

a. Correctly label the electric field and direction of energy transfer on the electromagnetic wave shown. (2 MARKS)



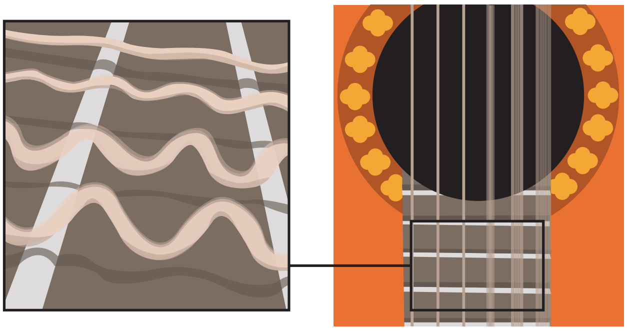
b. Assume the electromagnetic wave is travelling through a vacuum. At what speed would the wave pictured above be travelling at? Answer in metres per second (m s^{-1}). (1 MARK)

Adapted from VCAA 2020 exam Short answer Q14

Question 13 (2 MARKS)

A 0.60 m long guitar string (as pictured) is plucked, causing it to vibrate.

Is this wave longitudinal or transverse? Explain your answer.



Question 14 (1 MARK)

A star moving directly away from Earth and emits an electromagnetic wave. The speed of this electromagnetic wave is measured on Earth. Assume it is travelling through a vacuum.

Which one of the following is true?

A. The speed of the light is greater than 3.0×10^8 m s^{-1}.

B. The speed of the light is less than 3.0×10^8 m s^{-1}.

C. The speed of the light observed on earth is $c = 3.0 \times 10^8$ m s^{-1}.

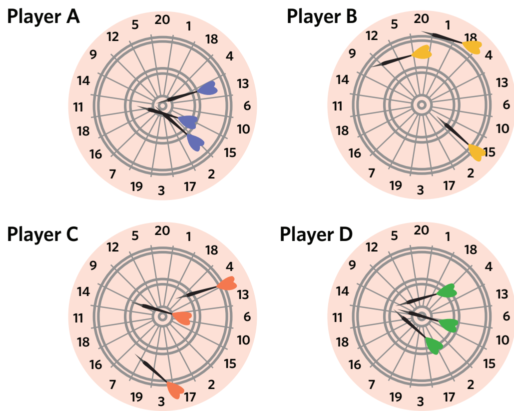
D. Not enough information is provided to answer the question.

Adapted from VCAA 2015 exam Section B Detailed Study 1 Q3

Key science skills

Question 15 (1 MARK)

The aim of darts is to hit the bullseye at the centre of the dartboard. Four darts players (A, B, C and D) each threw three darts. The results of their throws are shown.



Which one of the players produced a set of attempts that could be described as being precise but inaccurate?

A. player A

B. player B

C. player C

D. player D

VCAA 2020 exam Multiple choice Q1

FROM LESSON 11C

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1B Wave fundamentals

Image: Andrew Berezovsky/Shutterstock.com

Why do sound waves make the water bounce?

Knowledge of the properties of waves is important to be able to understand many aspects of the physical world including sound and light. All waves, including electromagnetic waves, can be defined by their properties. This lesson covers: identifying these properties, calculating them, and explaining why they are important.

KEY TERMS AND DEFINITIONS

amplitude (waves) the magnitude of an oscillation's maximum value from the neutral point within a wave

crest a point on the wave where the amplitude is a maximum positive value

displacement the change in position of an object (vector quantity)

frequency the number of cycles completed per unit of time

period the time taken to complete one cycle

trough a point on the wave where the amplitude is a maximum negative value

wave cycle the process of a wave completing one full oscillation, ending up in a final configuration identical to the initial configuration

wavelength the distance covered by one complete wave cycle

wave speed the speed at which a wave transfers its energy through a medium

FORMULAS

- **frequency-period inverse relationship**
  $f = \frac{1}{T}$
- **wave equation (frequency)**
  $v = f\lambda$
- **wave equation (period)**
  $v = \frac{\lambda}{T}$

STUDY DESIGN DOT POINTS

- identify the amplitude, wavelength, period and frequency of waves
- calculate the wavelength, frequency, period and speed of travel of waves using: $\lambda = \frac{v}{f} = vT$
- explain the wavelength of a wave as a result of the velocity (determined by the medium through which it travels) and the frequency (determined by the source)

1A 1B 1C 1D 1E

1.1.2.1 Wave properties

1.1.3.1 & 1.1.4.1 The wave equation

ESSENTIAL PRIOR KNOWLEDGE

1A Definition of a wave

1A Light and sound waves

11B Understanding units

See questions 1–3.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

Wave properties 1.1.2.1

Four important properties of waves include: amplitude, wavelength, period, and frequency. They are essential to describing the behaviour of all waves.

Theory and applications

Even though light is an electromagnetic transverse wave and sound is a mechanical longitudinal wave, both types of waves are defined by the same properties. In order to describe the behaviour of light, sound, or any other wave, their properties (see Table 1) must first be identified.[1]

KEEN TO INVESTIGATE?

1 **What are the properties of a wave?**
Search YouTube: Wave motion | waves | physics

Table 1 Wave properties

Property	Representation	Units
Wavelength	λ	Length often in metres (m)
Frequency	f	Cycles per second often in Hz or s^{-1}
Period	T	Time often in seconds (s)
Amplitude	A	Displacement often in metres (m) **OR** pressure often in pascal (Pa)

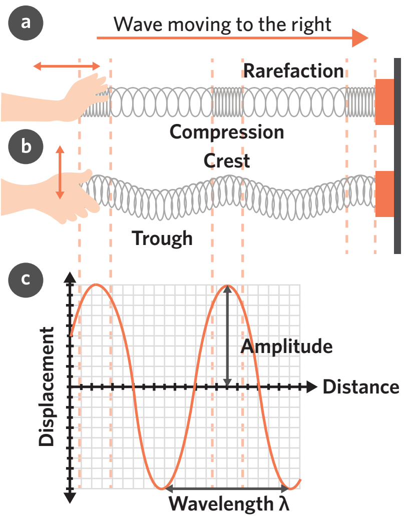

Figure 1 **(a)** A longitudinal wave and **(b)** a transverse wave. **(c)** Graph of either longitudinal or transverse wave with displacement on horizontal axis.

How are the properties of waves identified?

Wave properties are often given numerically and always with an accompanying unit. Quantities in physics only have meaning when in reference to units. In a question, always pay careful attention to the unit that puts the value into perspective. E.g. Students measured the properties of a sound wave that has a wavelength $\lambda = 38$ cm, a frequency $f = 0.020$ MHz, and an amplitude of $A = 100$ Pa.

USEFUL TIP

The unit of the wavelength when referring to light is often given in nanometers (nm). A nanometer represents one billionth (10^{-9}) of a metre.

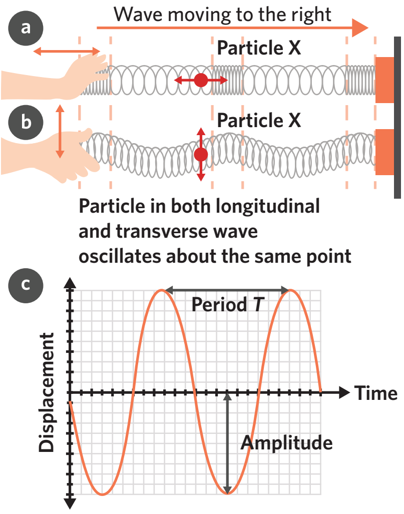

Figure 2 A particle moves **(a)** left/right in a longitudinal wave and **(b)** up/down in a transverse wave. **(c)** Graph of particle movement of either longitudinal or transverse wave with time on the horizontal axis.

Period and frequency are mathematically related through the formula:

FORMULA

$$f = \frac{1}{T}$$

f = frequency (Hz or s^{-1})
T = period (s)

This shows that frequency and period are inversely proportional. With an inverse relationship if frequency doubles then period will halve and vice versa. Frequency has two standard units which are both equivalent to each other ($1 \text{ Hz} = 1 \text{ s}^{-1}$), but Hertz (Hz) is more commonly used than per second (s^{-1}).

Transverse waves (e.g. light) and longitudinal waves (e.g. sound) can be graphed to show their properties.[2] Graphs can provide additional information depending on what is being represented on the horizontal or vertical axis.

To graph a wave with the horizontal axis (see Figure 1) as distance we must freeze a longitudinal or transverse wave at one point in time.

To graph a wave with time on the horizontal axis (see Figure 2) we must consider the movement of a single particle within that wave over a period of time. The particle will oscillate about the same location along the length of the wave. The particle moves perpendicular in a transverse wave and parallel in a longitudinal wave when compared to the direction of wave travel.

KEEN TO INVESTIGATE?

2 **How are transverse waves created?**
Search: Wave on a string simulation

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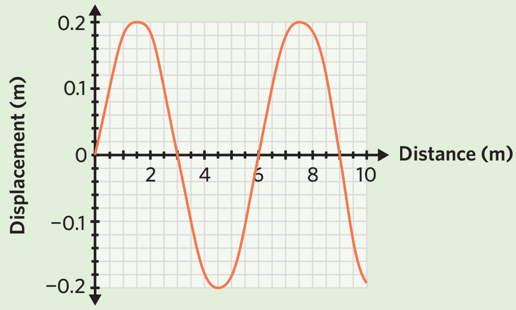
WORKED EXAMPLE 1

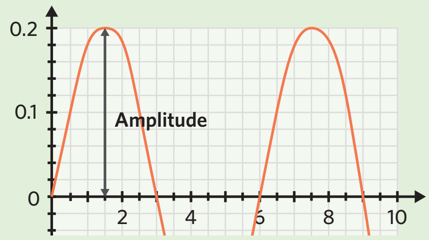
A wave is graphed at a single point in time.



a. Identify the amplitude. Make sure to use correct units in your answer.

The unit of the final answer must be the unit represented on the vertical axis which is metres (m).

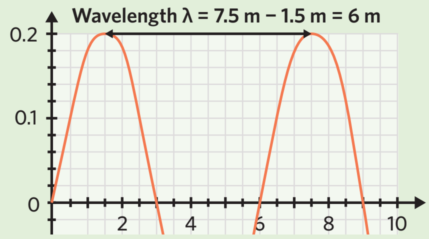
$A = 0.2$ m



b. Identify the wavelength. Make sure to use correct units in your answer.

The unit of the final answer must be the unit represented on the horizontal axis which is metres (m).

$\lambda = 6$ m



c. Find the period and calculate the wave's frequency.

The graph given has distance on its horizontal axis, therefore the period is unable to be found. Frequency is calculated from the period of the wave. As the period can't be found, neither can the frequency.

Why are wave properties so important?

The properties of a wave determines how they behave. They determine the speed, energy and many other characteristics a wave possesses. Note that a wave will have a greater energy if amplitude or frequency increases.

For electromagnetic waves the amplitude (also known as intensity) tells us how bright the light is. By knowing the wavelength and frequency of an electromagnetic wave, its characteristics and uses can be determined. For example low frequency wavelengths such as microwaves are used by smartphones for communication.

For sound, frequency tells us the pitch while amplitude represents the volume. Turning up the volume in the car is actually just increasing the amplitude of the sound waves being produced.

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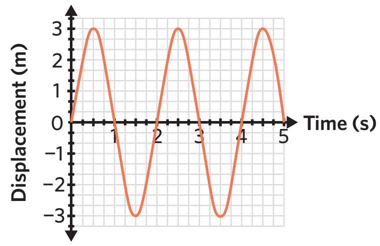
USEFUL TIP

There are many other types of waves besides electromagnetic and sound but the focus of a majority of questions throughout the course will be in terms of light and sound.

Progress questions

Use the following graph to answer questions 1–3.

The graph shows a transverse wave over time.



Question 1

What does the horizontal axis represent?

A. time in seconds

B. period in seconds

C. displacement in metres

D. pressure in pascal

Question 2

Identify the period and calculate the frequency of the wave.

A. $T = 1$ s and $f = 1$ Hz

B. $T = 2$ s and $f = \frac{1}{2}$ Hz

C. $T = 3$ s and $f = \frac{1}{3}$ Hz

D. $T = 6$ s and $f = \frac{1}{6}$ Hz

Question 3

Identify the wavelength.

A. $\lambda = 2$ m

B. $\lambda = 3$ m

C. $\lambda = 4$ m

D. Unable to be identified from graph

Question 4

What is the physical effect of increasing the amplitude of an electromagnetic wave?

A. increase in volume

B. increase in brightness

C. decrease in pitch

D. change of colour

The wave equation 1.1.3.1 & 1.1.4.1

The physical properties of the medium through which a wave travels determines its speed and the source of the wave determines its frequency. Wavelength is determined by its relationship to frequency and wave speed through the wave equation.

Theory and applications

The speed and frequency of a wave are both determined by external factors. In order to change their values these external factors must also change.

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How does the medium determine the wave-speed?

Wave speed is the speed at which the wave transfers its energy through a medium from one place to another. It is determined by the physical properties of the medium in which it travels (e.g. material, density, and temperature) (see Table 2 and 3). Even the speed of light is changed by the medium through which it travels as seen in Table 2.

Table 2 Electromagnetic wave speed through different materials.

Material	Electromagnetic wave speed
Nothing	3.0×10^8 m s^{-1}
Glass	1.97×10^8 m s^{-1}
Diamond	1.24×10^8 m s^{-1}
Water	2.26×10^8 m s^{-1}

Table 3 Sound wave speed through different materials.

Material	Sound wave speed
Air at sea level	340 m s^{-1}
Air at high altitude	303 m s^{-1}
Water	1482 m s^{-1}
Steel	5960 m s^{-1}

MISCONCEPTION

'The speed of a wave is the speed of an individual particle.'

Wave speed is the speed at which the crests and troughs, or compressions and rarefactions, move. An individual particle within the wave can be moving, faster, slower or not at all without actually affecting the speed of the wave.

How does the source determine the frequency?

Wave frequency will be determined by how fast the source of the wave is vibrating/oscillating. The faster the source is vibrating the higher the frequency of a wave. Take sound for example, a speaker vibrating slower will produce a sound at a lower frequency. Light is another example, the faster an atom vibrates, such as when it gets hotter, the higher the frequency electromagnetic wave it will produce.

USEFUL TIP

Don't forget that frequency and period are linked through an inverse relationship. This means that the source will also determine the period of a wave. The faster the source vibrates the higher the frequency and the lower the period will be.

Progress questions

Question 5

What could a student do to change the wave speed along a rope?

A. Change the frequency of wave generation.
B. Use a rope with different physical properties.
C. Change the period of wave generation.
D. Increase the amplitude of the waves.

Question 6

A particle begins to vibrate at a faster rate than before. The electromagnetic wave the atom produces will be

A. a higher frequency than before.
B. a lower frequency than before.
C. the same frequency as before.
D. a higher amplitude than before.

How do the speed and frequency determine wavelength?

Wavelength can be found using speed and frequency through the wave equation. This equation relates the three quantities and holds for all types of waves including light.

FORMULA

$$v = f\lambda$$

v = wave speed (m s^{-1})
f = frequency (Hz or s^{-1})
λ = wavelength (m)

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USEFUL TIP

Velocity is defined by how fast something moves (speed) and in what direction it moves. When referring to v in this chapter concerning waves, only the speed is considered.

The wave equation using period instead of frequency, given $f = \frac{1}{T}$, takes the following form:

FORMULA

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

v = wave speed (m s^{-1})
λ = wavelength (m)
T = wave period (s)

WORKED EXAMPLE 2

A wave of frequency 48 Hz is travelling along a string at a speed of 24 m s^{-1}. Calculate the wavelength, λ.

Step 1

Identify the frequency and velocity of the wave, and the equation that relates these variables.

$f = 48$ Hz, $v = 24$ m s^{-1}, $\lambda = ?$

$v = f\lambda$

Step 2

Substitute values into the equation and solve for wavelength λ. Pay attention to the correct units and significant figures.

$24 = 48 \times \lambda$

$\lambda = \frac{24}{48} = 0.50$ m

Progress questions

Question 7

Identify the speed that light travels through a vacuum in kilometres per second (km s^{-1}).

A. 300 km s^{-1}

B. 300 000 km s^{-1}

Question 8

A loudspeaker emits a sound of frequency 30 Hz. The speed of sound in air in these conditions is 330 m s^{-1}. Which one of the following best gives the wavelength of the sound?

A. 30 m

B. 11 m

C. 3.3 m

D. 0.091 m

VCAA 2015 exam Detailed Study 6 Q1

Question 9

Which of the following will occur when the frequency of a wave is doubled?

A. The amplitude will double.

B. The speed will double.

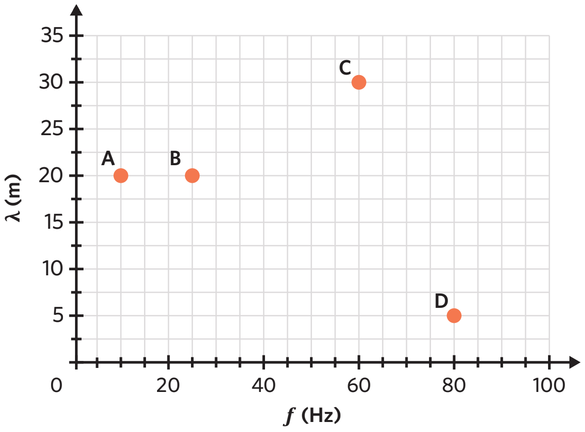
C. The wavelength will double.

D. The period will halve.

Continues →

Question 10

Which of the four waves has the greatest speed?



Theory summary

- The properties that waves have that determine their behaviour are:
  - frequency, period, wavelength, and amplitude.
  - the properties are found by graphing the wave.
- All waves can be represented by a graph.
  - Graphs showing the wave at a single point in time will have distance as its horizontal axis.
    - Such graphs are used to find wavelength and amplitude.
  - Graphs showing a particle in the wave over a period in time will have time as its horizontal axis.
    - Such graphs are used to find period, frequency, and amplitude.
- Wave speed is determined by the medium through which the wave travels.
- Wave frequency is determined by the source of the wave.
- $v = f\lambda$ relates frequency and wavelength to wave speed.
- $v = \frac{\lambda}{T}$ relates wavelength and period to wave speed.

Table 4 Which property can be found from a graphed wave?

Graph type	Amplitude	Wavelength	Period	Frequency
Displacement distance	✓	✓	✗	✗
Displacement time	✓	✗	✓	✓ using $f = \frac{1}{T}$

The content in this lesson is considered fundamental prior knowledge to light as a wave (Unit 4 AOS 1).

CONCEPT DISCUSSION

Discuss the difference between wave speed and the frequency of a wave. Does both or just one affect wavelength? If so, how?

Prompts:

- What is wave speed and what determines its value?
- What is frequency and what determines its value?
- Is there a mathematical relationship that relates frequency and wave speed to wavelength?

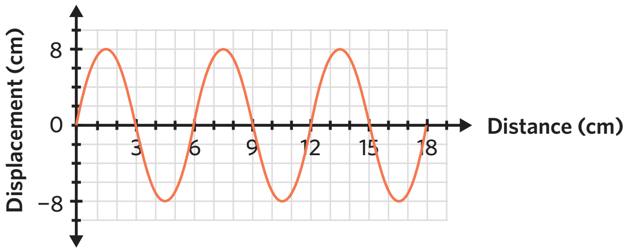
1B Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 11–14.

The diagram shows part of a travelling wave. The wave propagates with a speed of 18 m s^{-1}.



Question 11 (1 MARK)

What unit is represented on the horizontal and vertical axis?

A. mm

B. cm

C. m

Question 12 (1 MARK)

What is the wavelength?

A. 3 cm which is 0.03 m

B. 6 cm which is 0.06 m

C. 9 cm which is 0.09 m

D. 12 cm which is 0.12 m

Question 13 (1 MARK)

Which equation allows us to find frequency from wave speed and wavelength?

A. $v = f\lambda$

B. $v = \frac{\lambda}{T}$

C. $f = \frac{1}{T}$

Question 14 (3 MARKS)

Identify the amplitude and calculate the frequency of the wave.

Adapted from 2021 VCAA exam Multiple choice Q13

Exam-style

Question 15 (2 MARKS)

A set of speakers at a school assembly are driving sound waves at a frequency of 135 Hz. Calculate the resulting wavelength in metres (m), assuming the speed of sound in air is 340 m s^{-1}.

Adapted from 2018 VCAA exam Short answer Q11a

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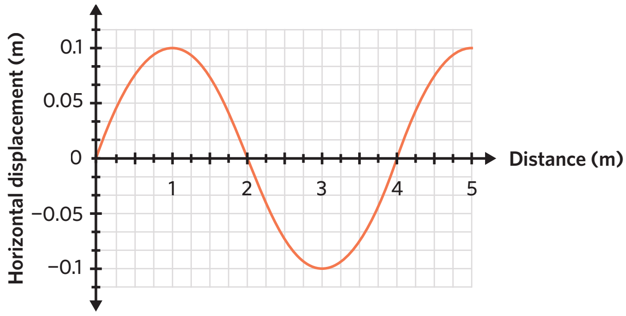
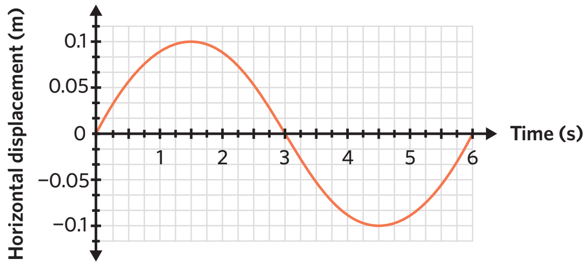
Question 16 (5 MARKS)

The two graphs were generated from a longitudinal wave in a spring that is travelling horizontally to the right. Take displacement to the right as positive.





a. Which graph relates to the whole spring, and which specifically relates to one point of the spring? (1 MARK)

b. What is the amplitude of the wave? (1 MARK)

c. What is the wavelength of the wave? (1 MARK)

d. What is the period of the wave? (1 MARK)

e. What is the frequency of the wave? (1 MARK)

Question 17 (2 MARKS)

A cruise ship's instruments determine the time between the crests of a series of massive waves is $T = 30.0$ s and the distance between them, or wavelength, is $\lambda = 500$ m.

a. Calculate the speed the wave is travelling in m s^{-1}. (1 MARK)

b. Calculate the frequency of the wave in Hz. (1 MARK)

Question 18 (2 MARKS)

Students are using a microwave oven to reheat their food.

Take the speed of microwaves to be 3.0×10^8 m s^{-1}. The label on the microwave oven claims it produces microwaves of wavelength 0.040 m to 0.060 m.

a. Calculate the period of the 0.040 m microwaves. Give an answer in seconds. (1 MARK)

b. Identify whether electromagnetic waves with $\lambda = 0.040$ m or $\lambda = 0.060$ m have greater energy. (1 MARK)

Adapted from VCAA (NHT) 2018 exam Short answer Q11a

Question 19 (1 MARK)

Identify why increasing wave frequency does not increase wave speed.

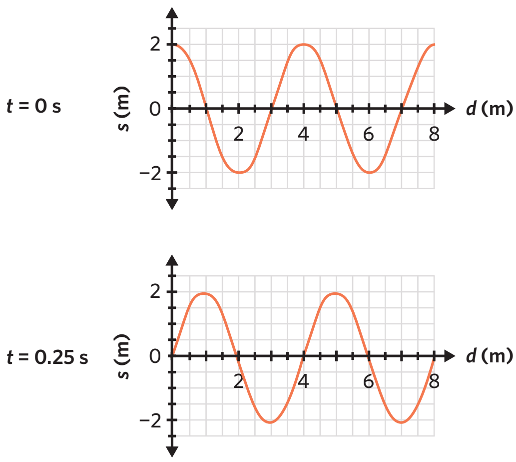
Question 20 (4 MARKS)

The two displacement-distance graphs represent a mechanical wave at two points in time.

a. Determine the wavelength of this wave. (1 MARK)

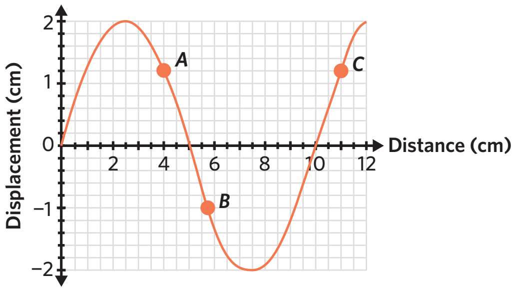
b. What is the lowest possible frequency of the wave? (2 MARKS)

c. What is the speed of the wave based on this frequency? (1 MARK)



Question 21 (4 MARKS)

The following graph relates to a transverse wave in a string that is moving to the right.



a. In what direction (up, down, left, right) are the particles located at positions *A*, *B* and *C* moving at the instant shown? If a particle is not moving, write 'not moving'. (3 MARKS)

b. What will be the location of particle *A* after another period has passed? (1 MARK)

Question 22 (3 MARKS)

Mobile phones emit electromagnetic waves of around $f = 450 \times 10^6$ Hz.

Take the speed of light to be 3.0×10^8 m s^{-1}.

What is the wavelength of light produced by a mobile phone? Provide an answer in centimetres.

Question 23 (2 MARKS)

A student is using waves to determine the identity of an unknown gas.

They measure that the frequency of sound waves through the gas is 534 Hz and the wavelength is 0.500 m. Calculate the speed of the wave, and hence determine which gas the sound is passing through.

Gas	Speed of sound (m s^{-1})
Helium	1007
Krypton	221
Hydrogen	1270
Nitrogen	349
Oxygen	326
Carbon dioxide	267

Question 24 (2 MARKS)

Dominique is singing a note with a period of 0.005 s. She finds that the note is flat (the frequency is too low).

Explain whether she should make the period of the note longer or shorter to correct her pitch.

Key science skills

Question 25 (3 MARKS)

Izzy and Emma are using a technique called interferometry to each take 5 repeated measurements of the wavelength of a laser that has an actual wavelength of 695 nm.

Izzy takes the following measurements: 690 nm, 697 nm, 693 nm, 694 nm, 707 nm.

Emma takes the following measurements: 697 nm, 698 nm, 694 nm, 699 nm, 696 nm.

Identify and explain which set of results is more accurate and which set is more precise.

FROM LESSON 11C

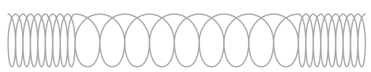
Previous lessons

Question 26 (2 MARKS)

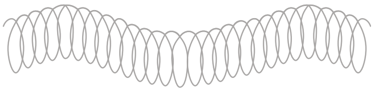
Which image shows an example of a transverse wave. Explain your answer.

FROM LESSON 1A

N



M



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1C Everyday electromagnetism

Image: Artstrov/Shutterstock.com

What type of everyday electromagnetic wave does this symbol represent?

Sunlight is just one type of electromagnetic wave (also called electromagnetic radiation) that is a part of a whole family of electromagnetic waves. This lesson introduces the concept of light emitted from the Sun as electromagnetic waves and discusses the properties and uses of other electromagnetic waves which are collectively called the electromagnetic spectrum.

STUDY DESIGN DOT POINTS

- describe electromagnetic radiation emitted from the Sun as mainly ultraviolet, visible and infrared
- compare the wavelength and frequencies of different regions of the electromagnetic spectrum, including radio, microwave, infrared, visible, ultraviolet, x-ray and gamma, and compare the different uses each has in society

1A 1B 1C 1D 1E

1.1.5.1 & 1.1.6.1 The electromagnetic spectrum

ESSENTIAL PRIOR KNOWLEDGE

1A Describe electromagnetism

1B Understand frequency and wavelength

See questions 4–5.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

KEY TERMS AND DEFINITIONS

electromagnetic spectrum the range of all electromagnetic waves ordered by frequency and wavelength

radiation the transmission of energy in the form of electromagnetic waves or high-speed particles

The electromagnetic spectrum 1.1.5.1 & 1.1.6.1

All possible frequencies of electromagnetic waves comprise the electromagnetic spectrum. The different regions of the electromagnetic spectrum all have valuable uses within society.

Theory and applications

Many modern technologies, from mobile phones to medical equipment, as well the ability to see light, rely upon the electromagnetic spectrum. The electromagnetic spectrum is divided into regions defined by their frequency range as shown in Figure 1.

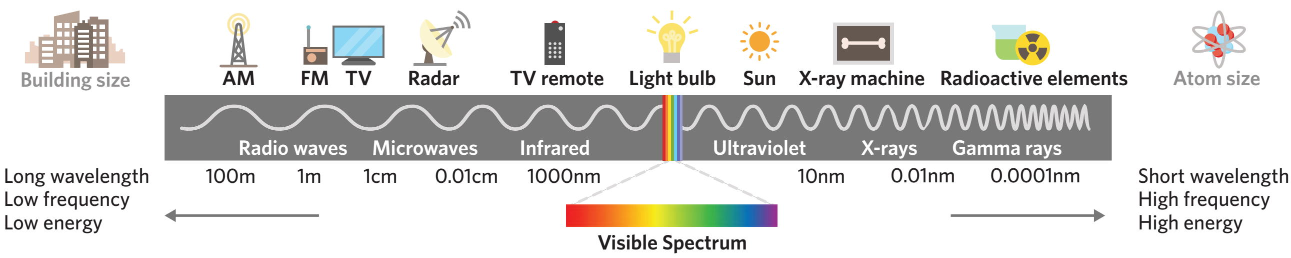

Image: VectorMine/Shutterstock.com

Figure 1 The electromagnetic spectrum

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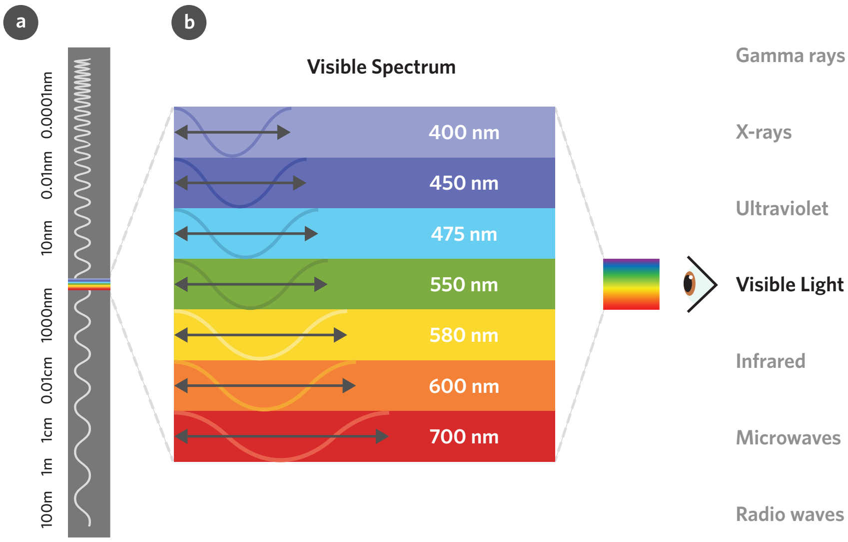
USEFUL TIP

It is common to refer to all types of electromagnetic radiation as 'light'. Light that we can see is called 'visible' light. This is a very small region of the entire spectrum.

The visible spectrum makes up a very small proportion of the electromagnetic spectrum. Although the human eye can distinguish about over a million different colours within this visible region, the other regions are invisible to the human eye. Figure 2(a) shows that only one small region of the electromagnetic spectrum (shown in Figure 2(b) with wavelengths between ≈ 390 nm and ≈ 780 nm) is visible light.



Images (left to right), udaix: VectorMinet/Shutterstock.com

Figure 2 The visible spectrum of electromagnetic radiation **(a)** and their wavelengths **(b)**

How do frequency and wavelength influence the properties of electromagnetic waves?

The Sun emits radiation mostly as infrared (≈ 50%), visible light (≈ 40%), and ultraviolet (≈ 10%). See Figure 3.

Electromagnetic radiation from the visible part of the spectrum is generally better than infrared at penetrating (transmitting) through the Earth's atmosphere.

The shorter wavelength, higher energy (blue) spectral region of the visible spectrum scatters as it passes through the atmosphere more than the longer wavelength, lower energy (red) spectral region. This causes the sky to appear blue and the Sun to appear yellow on Earth.

The more dangerous non-visible higher energy ultraviolet radiation (which has a higher frequency and shorter wavelength than visible light) is mostly absorbed by the ozone layer around the Earth, but some reaches the surface.

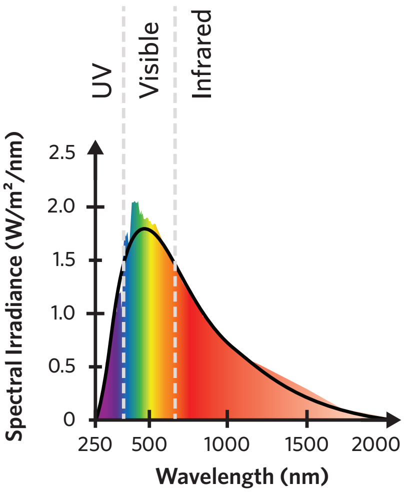


Figure 3 Graph showing the proportions of radiation emitted from the Sun

MISCONCEPTION

'All radiation is dangerous.'

Electromagnetic radiation makes up all of the waves of the electromagnetic spectrum, some of which are harmless to humans (e.g. visible light) and others that are very dangerous (e.g. gamma radiation).

Progress questions

Question 1

What determines the wave properties of electromagnetic waves?

A. wavelength and frequency

B. radiation and distance

Question 2

Which of the following statements about radio waves, microwaves, infrared, visible, ultraviolet, x-ray, and gamma rays is false?

A. They are all examples of electromagnetic waves.

B. They are all different with no shared properties.

C. They all exist on a spectrum and have some common properties.

Continues →

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Question 3

Why is the sky blue?

A. Because all the other colours except blue are absorbed by the atmosphere.

B. Blue light is scattered more than other colours because it travels as shorter, smaller waves.

Question 4

Rollo points an electromagnetic wave detector at the Sun. The detector picks up large amounts of infrared, visible light, and a moderate amount of ultraviolet radiation. Which is the best reason that he detects only very small amounts of light from the other parts of the spectrum?

A. Even though the Sun produces a large amount of all types of electromagnetic radiation, the atmosphere absorbs most of the light that is not infrared, visible or ultraviolet.

B. The Sun does not release other types of light.

C. The other types of radiation are mostly absorbed by other celestial bodies like Mercury, Mars, Venus, and the Moon.

D. The Sun mainly emits infrared, visible, and ultraviolet radiation.

How are the properties of electromagnetic waves utilised by society?

The following summarises the properties and uses of the seven regions of the electromagnetic spectrum in order of increasing frequency and increasing energy.

Radio waves

- Travel long distances uninterrupted due to their long wavelength.
- Diffract around obstacles like buildings and mountains and can reflect off the ionosphere to help travel long distances.
- Mostly used in radio and television communications (see Figure 4) where they are emitted by radio towers and picked up by antennae on devices such as car radios

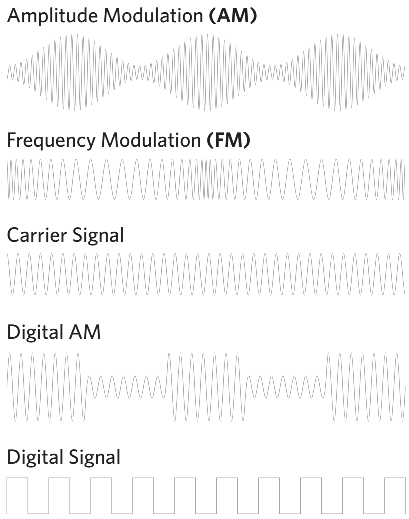

Image: Fouad A. Saad/Shutterstock.com

Figure 4 The different shapes of radio waves

Microwaves

- Used to heat food in microwave ovens.
- Also used for mobile phone signals, Wi-Fi and radar systems.
- Cosmic microwave background (CMB) radiation is electromagnetic radiation which was created in the early stages of the universe and continues to reach Earth, and provides strong evidence for the Big Bang Theory.

Infrared[1]

- All objects emit electromagnetic radiation due to the thermal vibration of charged particles. At temperatures for which life exists most of this radiation is infrared. For this reason thermal vision goggles use infrared and convert it to visible light to 'see' temperature – see Figure 5.
- When infrared radiation hits an object, it causes the particles in that object to vibrate so the object heats up. Radiator heaters and heating lamps use this principle.
- It is also used in some forms of signal transmission such as TV remote controls.

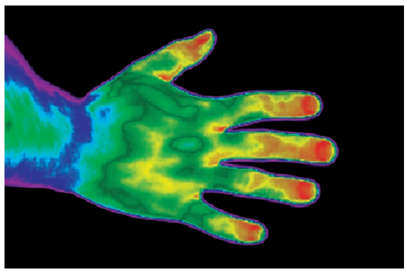

Image: pongpinun traisrisilp/Shutterstock.com

Figure 5 A thermal image

KEEN TO INVESTIGATE?

[1] **How does infrared help us at the scene of a crime?**
Search YouTube: Solving crime with infrared

Visible

- It allows humans (and many species) to see.
- When we see an object as coloured, the object is reflecting the wavelengths of the colour it appears to be and absorbing the complementary (all other) wavelengths (see Figure 6). White light contains all frequencies of visible light.
- Red is at the low frequency/long wavelength end of the visible spectrum and violet is at the high frequency/short wavelength end as shown in Figure 2.

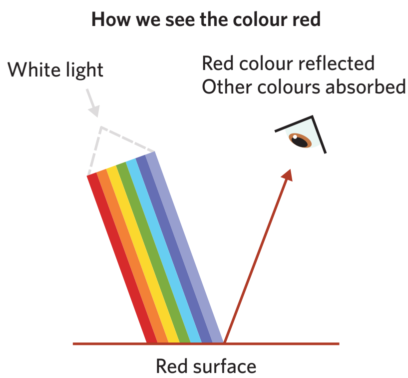

Image: udaix/Shutterstock.com

Figure 6 How we see colours

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KEEN TO INVESTIGATE?

[2] **Why does tonic water glow in the dark under UV light?**
Search YouTube: The world in UV

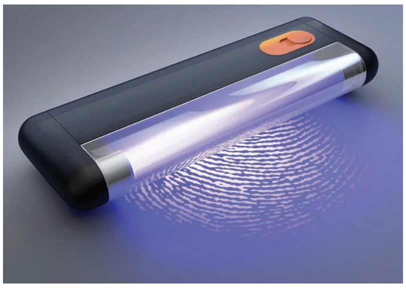

Image: imagineerinx/Shutterstock.com

Figure 7 Body oils fluoresce under UV

Image: Teo Tarras/Shutterstock.com

Figure 8 A medical x-ray image

MISCONCEPTION

'Radio waves are the sound from the radio.'

Radio waves are the electromagnetic wave that carries information between the radio antennas and the radio, the radio itself then transforms a radio wave into a sound wave.

Ultraviolet[2]

- Used in sterilisation processes and to cure (harden) different materials due to its high energy.
- Used in black lights (UV light bulbs) for forensic analysis (see Figure 7) as it causes other substances, including bodily fluids, to fluoresce (emit visible light).
- Produced along with visible light and infrared by the Sun.

X-ray

- High energy and highly penetrating.
- Useful for imaging bone structures as they pass easily through soft tissue (see Figure 8).
- Can damage the DNA in cells or even kill cells in significant doses.
- Produced by cosmic objects and used by astronomers to study those objects.

Gamma rays

- Higher energy, more penetrating, and more damaging than x-rays.
- Produced by nuclear reactions.
- Used in medicine to target and kill tumour cells but care must be taken to minimise damage to other cells.
- Produced by cosmic objects and used by astronomers to study those objects.

Progress questions

Question 5

Which of the following best gives the different regions of the electromagnetic spectrum in order from longest wavelength to shortest wavelength?

A. ultraviolet, visible light, infra-red, microwaves

B. microwaves, ultraviolet, visible light, infra-red

C. visible light, ultraviolet, infra-red, microwaves

D. microwaves, infra-red, visible light, ultraviolet

2018 VCAA (NHT) exam Section A Q15

Question 6

Moving along the entire electromagnetic spectrum from radio to gamma waves, which option correctly describes the way wavelength, frequency, and energy change?

	Wavelength	**Frequency**	**Energy**
A.	Decreases	Increases	Increases
B.	Increases	Decreases	Increases
C.	Increases	Increases	Decreases
D.	Decreases	Increases	Decreases

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Theory summary

- Electromagnetic radiation emitted from the Sun is mainly composed of ultraviolet, visible and infrared light.
- Figure 9 shows how the electromagnetic spectrum can be divided into spectral regions according to frequency and/or wavelength which determine their properties.

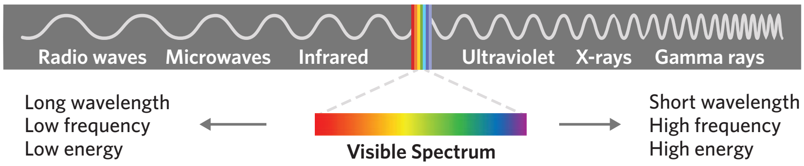

Image: MaciejForyszewski/Shutterstock.com

Figure 9 The electromagnetic spectrum

KEEN TO INVESTIGATE?

What electromagnetic waves are outside of our visible spectrum?
Search YouTube:
The Electromagnetic Spectrum

How do solar flares occur?
Search YouTube: A guide to solar flares

The content in this lesson is considered fundamental prior knowledge to light as a wave (Unit 4 AOS 1).

CONCEPT DISCUSSION

Radio waves and microwaves are used to communicate information, such as the information of a voice between mobile phones. Other regions of the electromagnetic spectrum could carry information in the same way. Discuss why visible light and gamma waves, for example, are not used in communication technology in the same way as radio waves and microwaves.

Prompts:

- What property must an information-carrying signal have in order to reach its destination?
- What are the properties of visible light or gamma waves, for example?

1C Questions

Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

Deconstructed exam-style

Use the following information to answer questions 7–9.

A student was asked to design an experiment to investigate the light that is emitted from the Sun using a spectroscope. Some examples of spectroscopes are shown.

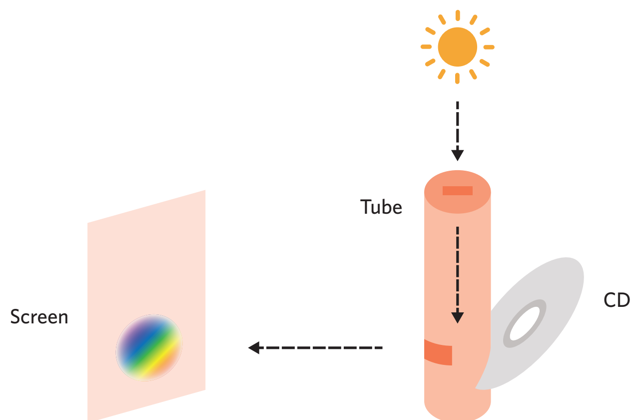

Image: Imfoto/Shutterstock.com

Question 7 (1 MARK) 🌶

Which of the following is not an important safety precaution that the student must follow?

A. Be careful not to touch hot surfaces that have been in the Sun.

B. Do not stand in the Sun for a prolonged period of time.

C. Only do this investigation on a very bright sunny day.

D. Point the spectroscope at reflected light from a white piece of paper.

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Question 8 (1 MARK)

Some spectroscopes might show black lines on the spectrum as shown.
What do these black lines represent?

A. frequency of the light

B. wavelength of the light

C. all electromagnetic waves

D. absorbed light by the atmosphere

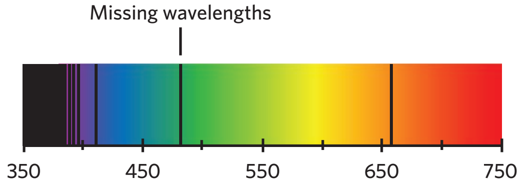


Image: pOrbital.com/Shutterstock.com

Question 9 (2 MARKS)

Describe the difference between ultraviolet and infrared light and give a possible reason why they are difficult to see through a spectroscope.

Exam-style

Question 10 (3 MARKS)

We can show how a radio transforms radio waves into sound as the translation of verbal language into sign language. As the presenter speaks, the interpreter translates the information into Auslan (sign language) so that deaf people can access the information.

Using the table, match the stages of translating verbal language into sign language with the stages of transforming a radio signal into sound (shown in an incorrect order).

Transforming a radio signal into sound	Translating verbal language into sign language
Radio emits sound	Presenter speaks
Radio station sends a radio wave signal	Translator hears the spoken words
Radio receives radio waves	Translator communicates in sign language

Image: Dave Hewison Photography /Shutterstock.com

Question 11 (1 MARK)

Order the following regions of the electromagnetic spectrum from longest wavelength to shortest wavelength.

orange light x-rays microwaves radio ultraviolet infrared

Question 12 (1 MARK)

Order the following regions of the electromagnetic spectrum from highest energy to lowest energy.

red light radio ultraviolet blue light infrared gamma

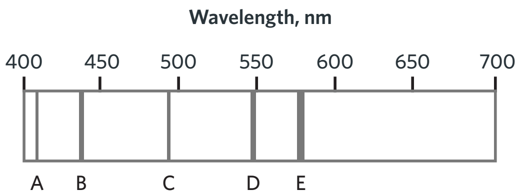
Question 13 (1 MARK)

The vertical lines in the diagram show the wavelengths of light which a mercury atom can emit (known as an emission spectrum). The following list gives the five visible colours that are emitted by the mercury atom.

yellow green blue-green blue violet

Identify which band (A, B, C, D or E) represents the green emission.

Adapted from VCAA 2018 exam Short answer Q19a



Key science skills

Question 14 (2 MARKS)

Students measure the wavelength of a red laser to be 658 nm. Express this wavelength in the appropriate SI unit to two significant figures.

FROM LESSON 11B

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Previous lessons

Question 15 (1 MARK)

When radiation from the Sun reaches the Earth's surface, it has to travel to the Earth's atmosphere and then through the atmosphere. Identify the property of electromagnetic waves that allows them to reach Earth's atmosphere from the Sun.

FROM LESSON 1A

Question 16 (1 MARK)

All waves of the electromagnetic spectrum in a vacuum have the same

A. energy.

B. speed.

C. wavelength.

D. frequency.

FROM LESSON 1A

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1D Refraction and reflection

STUDY DESIGN DOT POINT

- 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: $n_1\sin(\theta_c) = n_2\sin(90°)$

1A 1B 1C **1D** 1E

- **1.1.7.1** Refractive indices and light at boundaries
- **1.1.7.2** Snell's Law
- **1.1.7.3** Total internal reflection and critical angle

ESSENTIAL PRIOR KNOWLEDGE

- 1A Speed of light in a vacuum
- 1A Light as electromagnetic waves
- 1B Velocity and frequency of waves
- Using $\sin(\theta)$ and $\sin^{-1}(a)$

See questions 6–9.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

Image: LifeisticAC/Shutterstock.com

Why does light only shine out of the edges and the letters?

The understanding of light as electromagnetic waves can help explain how light behaves as it moves between different materials. This lesson discusses the behaviour of electromagnetic waves at boundaries between different materials, and how this behaviour is predicted and utilised for applications in everyday life.

KEY TERMS AND DEFINITIONS

angle of incidence the angle to the normal of a ray approaching a medium boundary

angle of reflection the angle to the normal of a ray reflected at a medium boundary

angle of refraction the angle to the normal of a ray refracted at a medium boundary

critical angle the angle above which total internal reflection occurs

normal an imaginary line perpendicular to the medium boundary at the point of incidence

refraction the change in direction of a wave moving between two mediums with different refractive indices

refractive index for a given medium, the ratio of the speed of light in a vacuum to the speed of light in that medium

total internal reflection the reflection of all incident light at a boundary between two mediums

transmission the transfer of wave energy through or between wave mediums

FORMULAS

- **refractive index**
  $n = \frac{c}{v}$
- **refractive index and wave speed**
  $n_1v_1 = n_2v_2$
- **Snell's Law**
  $n_1\sin(\theta_1) = n_2\sin(\theta_2)$
- **critical angle**
  $n_1\sin(\theta_c) = n_2$
- **wave equation (frequency)**
  $v = f\lambda$

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Refractive indices and light at boundaries 1.1.7.1

When light crosses a boundary between different mediums it can change speed. This change in speed causes it to refract (change direction - see Figure 1). The refractive index is a measure of the speed of light travelling through a specific medium. The greater the refractive index the slower light moves in that medium.

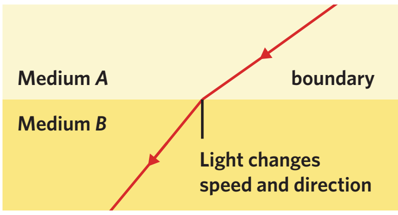

Figure 1 Refraction can occur when light changes speed.

Theory and applications

Light travels fastest through a vacuum because there is no matter for it to interact with. When light reaches a boundary between two mediums it can change both speed and direction of travel causing phenomena such as mirages and rainbows which are covered in Lesson 1E.

How is the refractive index of a medium determined?

The speed of light in a medium will depend on the physical characteristics of the medium (including temperature, density, and type of material) and the frequency of the light. The refractive index, n, is found from the ratio between the speed of light in a vacuum, c, and the speed of light in that medium, v.

FORMULA

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

n = refractive index of medium (no units)
c = speed of light in a vacuum (3.0×10^8 m s^{-1})
v = speed of light in medium (m s^{-1})

Because the speed of light never exceeds c, the minimum value for a refractive index is one ($n \geq 1$). The speed of light in air is very close to c so n_{air} is approximately equal to 1.00, whereas light travels slower in water which has refractive index $n_{water} = 1.33$.

From the definition of refractive index, the refractive indices and speeds of light in two different mediums can be related mathematically.

FORMULA

$$n_1 v_1 = n_2 v_2$$

n_1 = refractive index of first medium (no units)
v_1 = speed of light in first medium (m s^{-1})
n_2 = refractive index of second medium (no units)
v_2 = speed of light in second medium (m s^{-1})

WORKED EXAMPLE 1

Light in a glass block has a speed of 2.0×10^8 m s^{-1} and the speed of light in water is 1.15 times faster than light in the glass block.

a. Calculate the refractive index of the glass block.

Step 1

Identify wave speed and refractive index, and the formula that relates these variables.

$v_{glass} = 2.0 \times 10^8$ m s^{-1}, $c = 3.0 \times 10^8$ m s^{-1},
$n_{glass} = ?$

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

Step 2

Substitute values into the formula and solve for the refractive index of the glass block n_{glass}. Note the correct answer for the refractive index will not have any units.

$$n_{glass} = \frac{3.0 \times 10^8}{2.0 \times 10^8} = 1.50 = 1.5$$

Continues →

b. Calculate the refractive index of the water.

Step 1

Identify the wave speeds and refractive indices, and the formula that relates these variables.

$n_1 = n_{glass} = 1.5, v_1 = v_{glass} = 2.0 \times 10^8 \text{ m s}^{-1}$,
$n_2 = n_{water} = ?, v_2 = v_{water} = ?$

$n_1 v_1 = n_2 v_2$

Step 2

Calculate the speed of light in the water v_2. It is stated in the question that v_2 is 1.15 times faster than v_1.

$v_2 = v_1 \times 1.15 = 2.0 \times 10^8 \times 1.15$

$v_2 = 2.30 \times 10^8 = 2.3 \times 10^8 \text{ m s}^{-1}$

Step 3

Substitute values into the formula and solve for the refractive index of water n_2.

$1.5 \times 2.0 \times 10^8 = n_2 \times 2.3 \times 10^8$

$$n_2 = \frac{1.5 \times 2.0 \times 10^8}{2.3 \times 10^8} = 1.30 = 1.3$$

USEFUL TIP

Dividing $\frac{\textit{speed of light in the water}}{\textit{speed of light in the glass block}}$ can give an indication as to how many times faster light travels through the water than the glass.

Progress questions

Question 1

Higher refractive indices correspond to

A. lower speeds of light in a medium.

B. higher speeds of light in a medium.

Question 2

Which of the following statements is true?

A. $n = 1$ is the lowest possible value for a refractive index.

B. A vacuum has refractive index $n = 1$.

C. When light moves through a medium with refractive index $n = 1$, it is travelling at $3.0 \times 10^8 \text{ m s}^{-1}$.

D. All of the above

Image: noprati somchit/Shutterstock.com

Figure 2 Reflection and refraction often occur at the same time

How does light behave at boundaries between mediums?

How light moves as it changes between mediums depends on the refractive indices of those mediums as well as the angle that it arrives at the boundary between them. We use the refractive indices and the angle it arrives at the boundary to predict:

- which direction the light will move in,
- at what angle the light will deviate.

Whenever light hits a boundary between two mediums, some of the light will reflect back into the medium it is travelling in as shown in Figure 2. Light that is transmitted from one medium into another may refract (change direction). This is caused by light slowing down or speeding up as it travels between the mediums.

The angles of incidence (θ_i), reflection ($\theta_{reflect}$), and refraction (θ_r), are always measured between the relevant ray of light and the normal. Light will always be reflected at the same angle to the normal as it was incident ($\theta_i = \theta_{reflect}$). The amount and direction light will refract depends on the ratio between the refractive indices of the two mediums.

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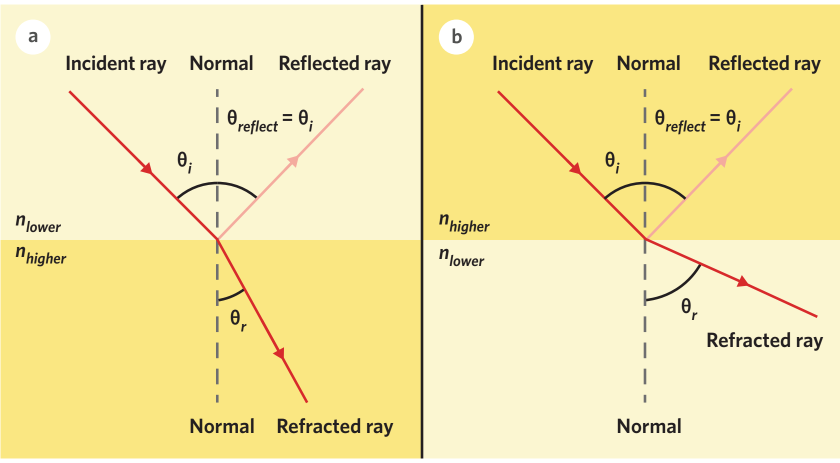


Figure 3 Rays of light at a boundary where the light is moving into **(a)** a slower medium and **(b)** a faster medium.

When light travels from its current medium into one with a higher refractive index, as in Figure 3(a), it:

- bends towards the normal,
- therefore the angle of refraction θ_r will be less than the angle of incidence θ_i.

When light travels from its current medium into one with a lower refractive index, as in Figure 3(b), it:

- bends away from the normal,
- therefore the angle of refraction θ_r will be greater than the angle of incidence θ_i.[1]

An easy way to see refraction in action is to put a pencil partially into a glass of water. Due to the refraction of the light coming off the pencil at the air-water boundary, the pencil will appear bent or disjointed, as shown in Figure 4.

Progress questions

Question 3

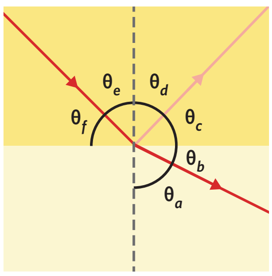
Light will reflect

A. only when light hits a shiny surface, such as a mirror.

B. whenever light reaches the boundary between two different mediums.

Question 4

Which option correctly identifies the angles of incidence, reflection and refraction in the diagram?



	Angle of incidence	Angle of reflection	Angle of refraction
A.	θ_a	θ_b	θ_c
B.	θ_e	θ_d	θ_a
C.	θ_f	θ_c	θ_b
D.	θ_e	θ_d	θ_c

Continues →

MISCONCEPTION

'If the incident light travels in the direction normal to the boundary, crossing the boundary will have no effect on it.'

Light crossing the boundary at an angle of incidence of 0° means that it will not change direction, however its speed (and therefore its wavelength) will still be affected by changing medium. When passing between mediums, the frequency of light will be unchanged.

KEEN TO INVESTIGATE?

1 **Why does light bend when it enters glass?**
Search YouTube: Why does light bend when it enters glass?

Image: Kuki Ladron de Guevara/Shutterstock.com

Figure 4 Refraction makes a pencil in water appear disjointed.

Question 5

Which of the following statements is correct?

A. Light bends towards the normal whenever it enters a medium with a high refractive index.

B. Light bends away from the normal whenever it enters a medium with a high refractive index.

C. Light bends towards the normal whenever it passes from a lower refractive index medium to a higher refractive index medium.

D. Light bends towards the normal whenever it passes from a higher refractive index medium to a lower refractive index medium.

Snell's Law 1.1.7.2

Snell's Law gives a formula for light passing between mediums, relating the refractive indices of each medium with the angle of incidence and angle of refraction.

Theory and applications

We use Snell's Law to calculate the direction light, compared to the normal, will move after travelling through the boundary between mediums. Snell's Law has a wide range of applications in optics, the branch of physics that studies the behaviour of light, helping construct cameras, eyeglasses and contact lenses.

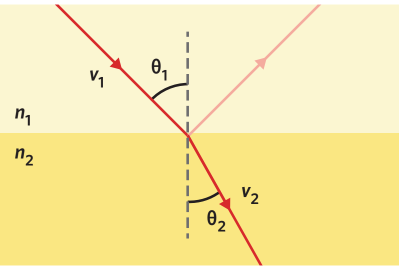


Figure 5 Snell's Law at a boundary between two mediums.

How is Snell's Law used to calculate refraction?

The angle of refraction is related to the incident angle and the refractive indices of the boundary medium by Snell's Law. The relationship between these four values is shown in Figure 5.

FORMULA

$$n_1\sin(\theta_1) = n_2\sin(\theta_2)$$

n_1 = refractive index of first medium (no units)
θ_1 = angle to the normal in first medium (°)
n_2 = refractive index of second medium (no units)
θ_2 = angle to the normal in second medium (°)

One of the primary applications of Snell's Law is in the making of eyeglasses. By manipulating the shape and thickness of the glass lenses, the direction that the light travels towards the eye can be altered. This means that glasses can be made to correct inaccuracies in the way the eyes focus light.[2]

Images appear blurry when the rays of light coming off them are focused at a point that is not on the retina, as shown in Figure 6(a). Optometrists use Snell's Law to calculate the exact shape and thickness of lenses to change the direction of incoming light, such that the eye refracts the rays to focus exactly onto the retina, shown in Figure 6(b).

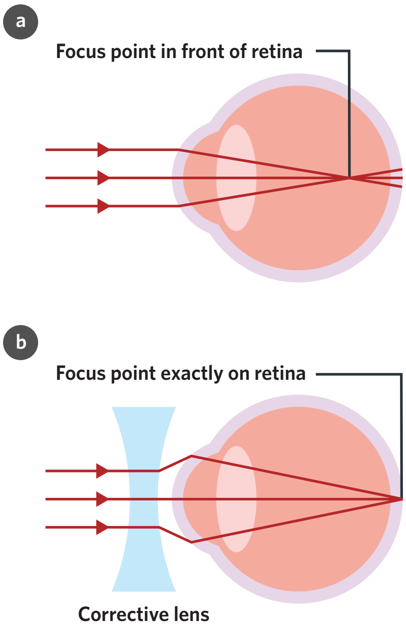


Figure 6 **(a)** Light incorrectly focused by the eye, and **(b)** correctly focused with a corrective lens.

KEEN TO INVESTIGATE?

[2] **Why does a convex lens magnify an image?**
Search YouTube: Lenses and virtual images explained

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WORKED EXAMPLE 2

A ray of light passes from air ($n = 1.00$) to water ($n = 1.33$). If the incident angle of the ray is 43.0°, calculate the angle of refraction.

Step 1

Identify the refractive indices and angles of incidence and refraction, and Snell's Law which relates these variables. Note that the incident ray in this case refers to the light while it is travelling through the air.

$n_1 = n_{air} = 1.00$, $n_2 = n_{water} = 1.33$, $\theta_1 = \theta_{air} = 43.0°$, $\theta_2 = \theta_{water} = ?$

$n_1\sin(\theta_1) = n_2\sin(\theta_2)$

Step 2

Substitute values into Snell's Law and solve for the light ray's angle of refraction in water θ_2. Ensure that the calculator and the unit of the final answer is in degrees (°).

$1.00 \times \sin(43.0°) = 1.33 \times \sin(\theta_2)$

$\theta_2 = \sin^{-1}\left(\frac{1.00 \times \sin(43.0°)}{1.33}\right) = 30.84 = 30.8°$

Progress questions

Question 6

A ray of light passes from glass ($n = 1.50$) into an unknown medium ($n = ?$). The angle of incidence is $\theta_i = 45.0°$ and an angle of refraction is $\theta_r = 50.0°$. What is the refractive index of the unknown medium?

A. 1.38

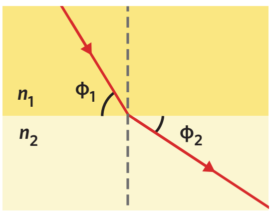
B. 1.63

C. 1.35

D. 1.67

Question 7

Which of the following relationships between the four labelled variables is correct?



A. $n_1\sin(\phi_1) = n_2\sin(\phi_2)$

B. $n_2\sin(\phi_1) = n_1\sin(\phi_2)$

C. $n_1\sin(90 - \phi_1) = n_2\sin(90 - \phi_2)$

D. $n_2\sin(90 - \phi_1) = n_1\sin(90 - \phi_2)$

USEFUL TIP

All the angles used in refraction formulas must be angles between a ray of light and the normal. If given an angle ϕ between a ray of light and the boundary, we can find the angle between the ray and the normal by using $\theta = 90 - \phi$ in calculations instead.

Total internal reflection and critical angle 1.1.7.3

The critical angle is the incident angle at which the refracted angle is 90°. Light with an incident angle greater than the critical angle will be totally internally reflected.

Theory and applications

It is possible for light to be refracted at a 90 degree angle away from the normal, or even for it to become impossible for light to be transmitted through a boundary. These phenomena, critical angle and total internal reflection, allow for gemstones to sparkle and for the construction of edge-lit LED panels.

Why does the critical angle only exist sometimes and how is it determined?

When light hits a boundary between the medium it is travelling through and one with a lower refractive index, it bends away from the normal (provided $\theta_i \neq 0°$). As a result, the angle of incidence can be increased to a point where the angle of refraction reaches 90°. The incident angle at which this occurs is called the critical angle, and is depicted in Figure 7.

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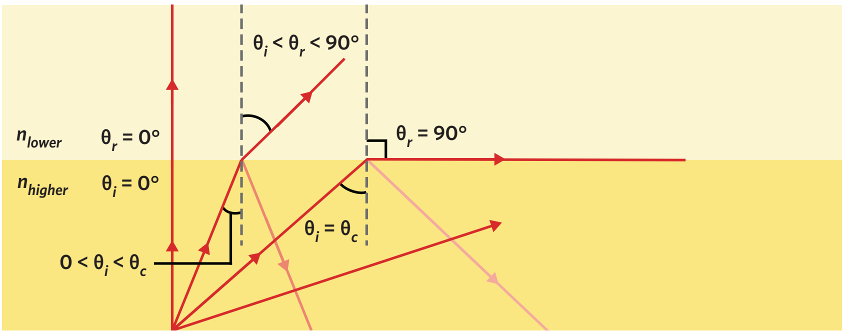

Figure 7 Formation of a critical angle

The critical angle exists when light hits a boundary to a medium with a lower refractive index. If it reaches a boundary between its current medium and one with a higher refractive index then the refracted ray would bend towards the normal, and so the angle of refraction cannot reach 90° since $\theta_i > \theta_r$.

To find the critical angle θ_c using Snell's Law, we assume that $\theta_1 = \theta_c$ and $\theta_2 = 90°$. Since $\sin(90°) = 1.00$, Snell's Law can be rewritten to find the critical angle as:

STRATEGY

The formula $n_1\sin(\theta_c) = n_2$ is an official VCAA formula, however it assumes that the light is moving from medium 1 towards medium 2. In critical angle calculations, always ensure that n_1 corresponds to the medium light is initially moving through.

FORMULA

$$n_1\sin(\theta_c) = n_2$$

n_1 = refractive index of first medium (no units)
θ_c = critical angle between the medium (°)
n_2 = refractive index of second medium (no units)

Rearranging for θ_c:

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

See Table 1 for the critical angles for yellow light travelling in various materials reaching a boundary with air. Note that materials with lower refractive indices have higher critical angles in air.

Table 1 The critical angle and refractive index of yellow light at the boundary with air at 20°C.

Material	Critical angle at boundary with air	Refractive index
Distilled water	48.6°	1.33
Table salt	41.8°	1.50
Glass	37.0° to 41.1°	1.52 to 1.66
Diamond	24.4°	2.42

WORKED EXAMPLE 3

What is the critical angle for light passing from oil into air, given that $n_{oil} = 1.46$ and $n_{air} = 1.00$?

Step 1

Identify the refractive indices and the formula that relates refractive indices to critical angle. Ensure that the medium assigned to n_1 is the source (incident) medium for this calculation.

$n_1 = n_{oil} = 1.46$, $n_2 = n_{air} = 1.00$, $\theta_c = ?$

$n_1\sin(\theta_c) = n_2$

Step 2

Substitute values into the formula and solve for the critical angle θ_c.

$1.46 \times \sin(\theta_c) = 1.00$

$\theta_c = \sin^{-1}\left(\frac{1.00}{1.46}\right) = 43.23 = 43.2°$

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Why does total internal reflection occur and how is it useful?

If the angle of incidence is greater than the critical angle (i.e. $\theta_i > \theta_c$), then the angle of refraction will be greater than 90°, so the light cannot be transmitted and will remain in its initial medium. This is known as total internal reflection, and is shown in Figure 8.

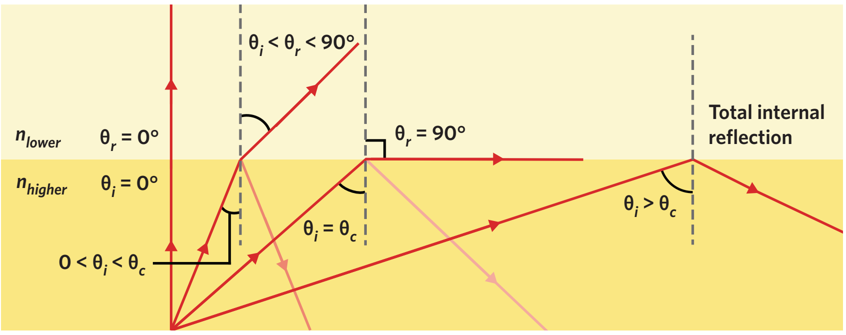

Figure 8 Increasing angle of incidence beyond the critical angle

A common instance of total internal reflection is the sparkling of gemstones (see Figure 9). Gems are cut in specific ways such that incoming light will be totally internally reflected many times before leaving the gem (usually through the top section), giving it a sparkly appearance. Diamonds have a particularly high refractive index of over 2.4 (and therefore low critical angle) so they are especially good at this.[3]

Total internal reflection is also used to make edge-lit LED signs, like the exit sign shown at the start of this lesson. Light is shone into a thin glass panel at an angle such that it will totally internally reflect off the inside surfaces, and only leave the panel through the edges or through a design etched on the surface. This way the panel glows only in certain parts, and appears transparent in others.

MISCONCEPTION

'Total internal reflection happens because light is refracted into its initial medium.'

Total internal reflection occurs because at angles greater than the critical angle, it is impossible for light to transmit and refract into the other medium, and so all light is reflected..

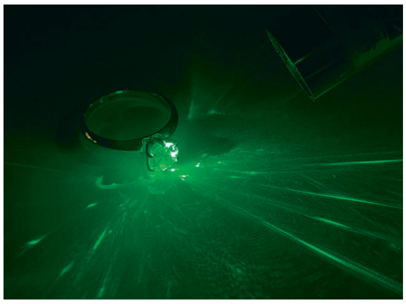

Figure 9 Total internal reflection inside a gemstone

KEEN TO INVESTIGATE?

3 **What does it look like to shine a laser into a diamond?**
Search YouTube: 5 Total internal reflection in diamond

Progress questions

Question 8

A ray of light is travelling through water ($n = 1.33$) and hits a boundary between the water and air ($n = 1.00$). Which statement, if any, reflects what will occur at the boundary.

A. The critical angle exists and total internal reflection will occur.

B. The critical angle exists and total internal reflection might occur.

C. The critical angle does not exist and total internal reflection will not occur.

D. None of the above

Question 9

Which of the following correctly describes why total internal reflection occurs?

A. Because the light hits a highly reflective surface, such as a mirror.

B. Because the angle of refraction would be over 90 degrees, the light refracts back into its initial medium.

C. Because the angle of refraction would be over 90 degrees, the light cannot be transmitted into the second medium and thus all light is reflected into its initial medium.

D. Because light always reflects at a boundary between mediums.

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Theory summary

- Refractive index is the ratio of speed of light in a vacuum to speed of light in a medium.
- At a boundary between mediums, light always reflects and can also be transmitted.
- The angle of reflection always equals the angle of incidence.
- Snell's Law mathematically describes the refraction of waves at a boundary.

The decision flowchart in Figure 10 shows outcomes for different instances of light hitting a boundary, including direction of refraction, critical angle, and total internal reflection.

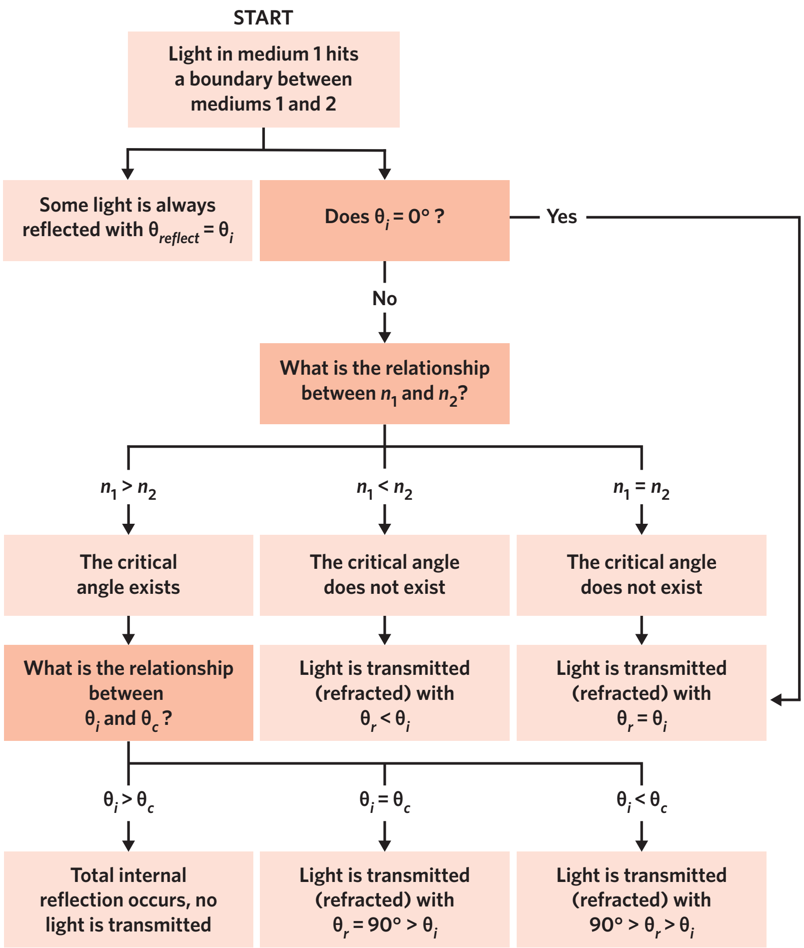


Figure 10 Decision flow chart for light at boundaries

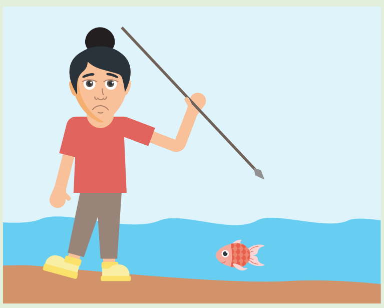
KEEN TO INVESTIGATE?

How can we make things appear invisible?
Search YouTube: A real invisibility shield how does it work?

STRATEGY

Use Figure 10 to determine how light will move at a boundary given certain parameters, or alternatively if the light's movement is already known use Figure 10 to determine the relationships between parameters that result in that outcome.

CONCEPT DISCUSSION



Sunny is standing in a lake to go spear fishing. There is a fish nearby her that is effectively motionless, and she is able to throw her spear in a perfectly straight line. However, whenever she throws her spear at the fish it always misses and travels above the fish instead.

Discuss with reference to refraction, why despite throwing her spear directly towards where she sees the fish, Sunny does not spear it.

Prompts:

- How does the light travel from the fish to Sunny's eyes?
- How does this differ from the paths light takes from objects in air to people's eyes?

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1D Questions

Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

Deconstructed exam-style

Use the following information to answer questions 10-13.

A light wave is travelling in a body of saltwater, which is enclosed in a plastic container. The wavelength and frequency of a light wave in saltwater are 510 nm and 4.085×10^{14} Hz. Take $c = 3.00 \times 10^8$ m s^{-1}.

Question 10 (1 MARK) 🌶

What is the speed of the light wave in saltwater?

A. 3.00×10^8 m s^{-1}

B. 2.08×10^8 m s^{-1}

C. 2.25×10^8 m s^{-1}

Question 11 (1 MARK) 🌶

What is the refractive index of the saltwater?

A. 1.33

B. 1.00

C. 1.44

Question 12 (1 MARK) 🌶

If light travelling in medium 1 hits a boundary between mediums 1 and 2, what condition must be met for the critical angle to exist?

A. $n_1 > n_2$

B. $n_1 < n_2$

C. No condition must be met.

Question 13 (4 MARKS) 🌶🌶🌶

What range of values can the refractive index of the plastic take such that it is possible for total internal reflection to occur?

Exam-style

Question 14 (1 MARK) 🌶

The refractive index of polycarbonate is 1.60. Calculate the speed of light in polycarbonate.

Question 15 (1 MARK) 🌶

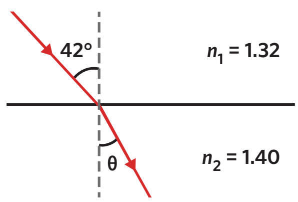
The desired critical angle for an optical fibre with $n_{core} = 1.7$ is 48°. What refractive index would the cladding of the fibre need in order to achieve this critical angle?

Question 16 (2 MARKS) 🌶

A ray of light passes through the boundary between air ($n = 1.00$) and glass. The incident angle is 45.0° and the refracted angle is 30.0°. Calculate the refractive index of the glass.

Question 17 (2 MARKS) 🌶

A ray of light is observed to bend when passing between two transparent liquids. Calculate the angle of refraction of the ray if it has an incident angle of 42.0°.



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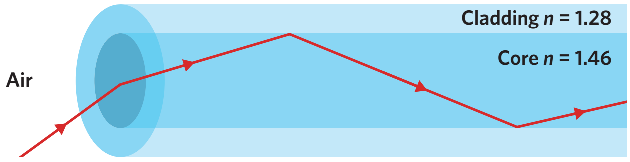
Question 18 (2 MARKS)

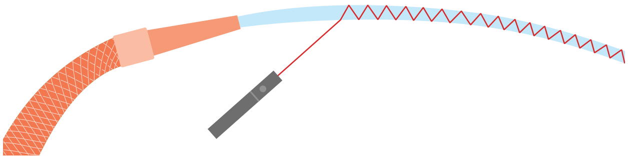
An optical fibre has a core with a refractive index of 1.46 and a cladding with a refractive index of 1.28. Calculate the critical angle inside the optical fibre.

Adapted from VCAA 2018 exam Short answer Q12b



Question 19 (2 MARKS)

A laser light passes into and is then guided by the stream of a hose. Explain how it is possible for the stream to guide the light.



Question 20 (2 MARKS)

A glass fibre has a critical angle of 50° in air. Will total internal reflection still be possible inside the fibre if it is placed in a tub of water with $n = 1.33$? Assume the refractive index of air is 1.00.

Question 21 (1 MARK)

A monochrome light ray passes through three different mediums, as shown in the diagram. Assume that v_1 is the speed of light in Medium 1, v_2 is the speed of light in Medium 2, and v_3 is the speed of light in Medium 3. Which one of the following would best represent the relative speeds in the mediums?

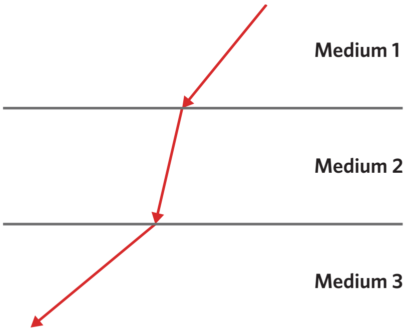
A. $v_1 > v_2 > v_3$

B. $v_1 > v_3 > v_2$

C. $v_3 > v_2 > v_1$

D. $v_3 > v_1 > v_2$

VCAA 2019 exam Multiple choice Q9

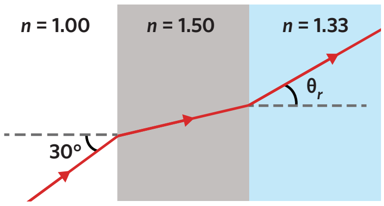


Question 22 (3 MARKS)

The speed of a ray of light passing between two mediums with unknown refractive indices increases by a factor of 1.2. If the ray of light has a refracted angle of 60°, what is the incident angle?

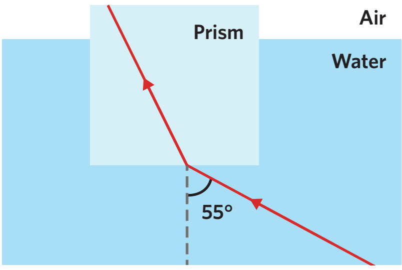
Question 23 (3 MARKS)

A light ray passes from air ($n = 1.00$) into a glass cube ($n = 1.50$) and then into a liquid ($n = 1.33$). The boundaries between the mediums are parallel. Calculate the magnitude (in degrees) of the difference between the initial incident angle of 30° and the final refracted angle.



Question 24 (4 MARKS)

A cubic prism is floating in water and has a refractive index such that $v_{prism} = 0.80 \times v_{water}$ and $v_{prism} = 0.60 \times v_{air}$. A monochromatic light ray from the water hits the prism at 55° to the normal. Determine whether the ray will be totally internally reflected the next time it reaches a boundary, assuming the next boundary is on the opposite face of the prism. Do not assume values for the refractive indices of air or water.



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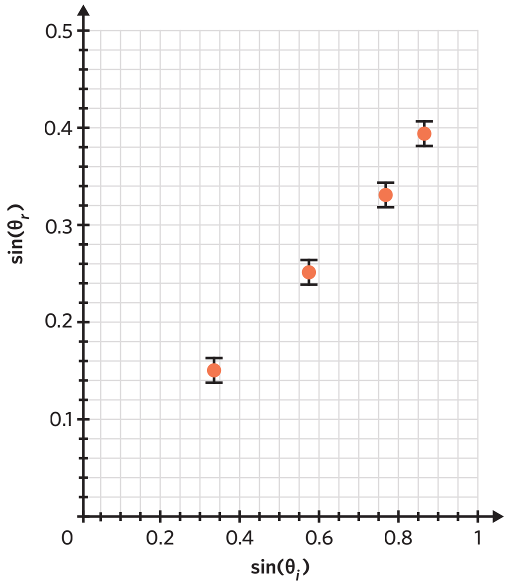
Key science skills

Question 25 (7 MARKS)

A scientist is analysing the diamond engagement ring given to them by their fiancé. They vary the incident angle of a 540 nm green laser light and record the refracted angle after it moves from air ($n = 1.00$) into the diamond. Real diamonds have refractive indices above 2.80.

a. What are the dependent and independent variables in this experiment? Also name one controlled variable in this experiment. (3 MARKS)

b. The scientist plots the results. Calculate the gradient of the line of best fit. (2 MARKS)



c. Use the value of the gradient to determine whether the diamond analysed is real. (2 MARKS)

FROM LESSONS 11A & 11E

Previous lessons

Question 26 (3 MARKS)

Frequency and wavelength are both properties of waves. Briefly describe each of these and identify which of these is only determined by the wave source.

FROM LESSON 1B

Question 27 (1 MARK)

Which of the following statements about electromagnetic waves is true?

A. X-rays have longer wavelengths than wavelengths in the ultraviolet region.

B. The Sun releases mostly waves in the ultraviolet part of the spectrum.

C. X-rays are higher energy electromagnetic waves than all other electromagnetic waves, apart from gamma rays.

D. Radio waves and infrared waves have the same frequency.

FROM LESSON 1C

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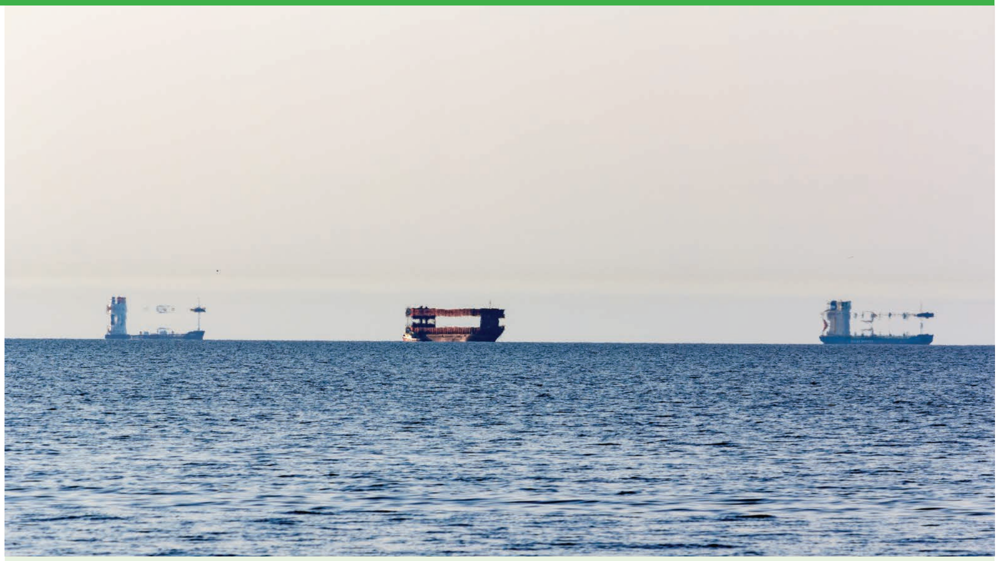
1E White light and optical phenomena



STUDY DESIGN DOT POINTS

- 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
- explain the formation of optical phenomena: rainbows; mirages
- investigate light transmission through optical fibres for communication

1A 1B 1C 1D 1E

1.1.8.1 White light and colour dispersion
1.1.9.1 Rainbows
1.1.9.2 Mirages
1.1.10.1 Optical fibres

ESSENTIAL PRIOR KNOWLEDGE

1C The electromagnetic spectrum
1D Behaviour of light at boundaries
1D Total internal reflection and critical angle

See questions 10–12.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

Why do we see the top of the ships twice?

Reflection and refraction of light can lead to a range of phenomena especially when they interact with the human eye. For example, the dispersion of white light through prisms and other phenomena; rainbows and mirages.

Light phenomena are not only beautiful or occasionally confusing but also help Australians access films and games from overseas through fibre optic cables laid on the ocean floor.

KEY TERMS AND DEFINITIONS

cladding layer of a lower refractive index material forming a protective coating around the inner core of a fibre optic cable

dispersion the separation of white light into its constituent colours due to the different refractive indices for different frequencies (colours) of light in a given medium

fibre optic cable a single cable containing one or more optical fibres encased in cladding to protect it from the environment

illusion a deceptive or misinterpreted sensory experience

mirage an optical illusion caused by the refraction of light rays due to changes in air temperature and pressure

optical fibre a glass fibre that utilises total internal reflection to transmit light over long distances

rainbow an arch of colours caused by the dispersion of the Sun's light through water in the atmosphere

White light and colour dispersion 1.1.8.1

White light is not a particular colour or frequency of light, but a combination of the continuous visible spectrum of electromagnetic radiation. We perceive this combination of colours as white light and can observe a spectrum when we separate the light through a prism or lens.

Theory and applications

The way that white light splits into its constituent frequencies as it travels through a prism is called dispersion (see Figure 1).

Image: Mila Drumeva/Shutterstock.com

Figure 1 When white light is dispersed through a prism, a rainbow is observable

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How does dispersion occur?

Instead of thinking about all the colours of light as it travels through a prism, let's consider red ($\lambda \approx 700$ nm) and violet ($\lambda \approx 380$ nm) waves as the frequencies of these colours are the extremes of the visible spectrum (see Figure 2(a)).

When white light is shone onto the prism, this effect is seen across the whole spectrum as each of the colours have different frequencies (see Figure 2(b)).

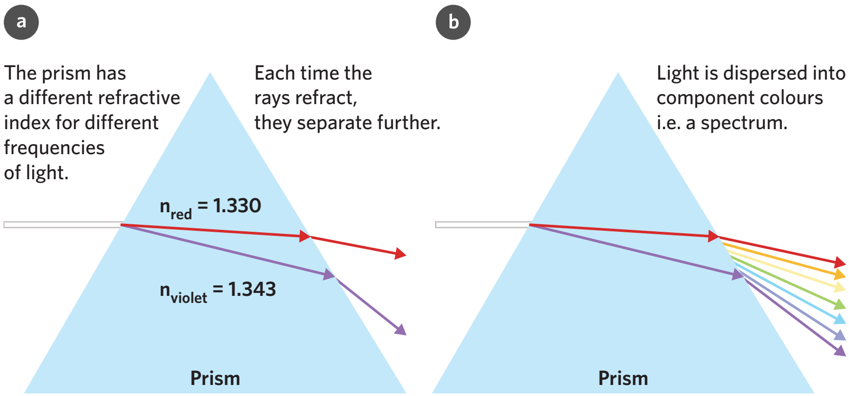

Figure 2 (a) Red and violet waves being refracted through a prism. (b) White light being dispersed into its component colours.

From Lesson 1D, we know that it is the speed of the light that changes as we enter a new medium. The refractive index of the prism is dependent upon the frequency of the light. This results in different angles of refraction for the components of white light that transmit through the prism.[1]

KEEN TO INVESTIGATE?

1 **How do the different indexes of refraction impact the dispersed light?**
Search: Dispersion of light simulation

Progress questions

Question 1

White light is

A. a single frequency of light.

B. visible light waves with extremely high intensity.

C. the full, continuous electromagnetic spectrum.

D. the full, continuous spectrum of visible light.

Question 2

Which colour of light will refract to a greater extent when entering the prism?

A. orange light

B. green light

C. blue light

Question 3

For which colour of light will the medium have the highest refractive index?

A. orange light

B. green light

C. blue light

Lenses also disperse white light into a spectrum in the same way that it is dispersed for a prism, with some examples shown in Figure 3. This is an important factor to consider when designing the lenses used in scientific instruments and cameras.

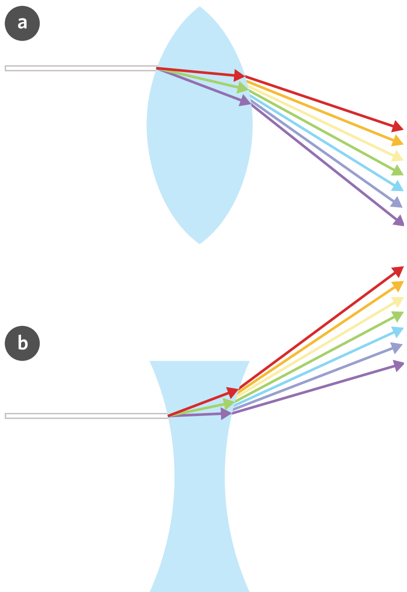

Figure 3 White light dispersion through (a) a convex lens and (b) a concave lens.

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Rainbows 1.1.9.1

Rainbows are an optical phenomenon caused by the dispersion of white light by water droplets in the atmosphere.

Theory and applications

Rainbows are an application of dispersion and reflection where sunlight disperses through numerous raindrops, acting as prisms and reflecting this dispersed sunlight towards an observer's eyes.

How are rainbows formed?

Rainbows are only visible when the following conditions are met:

- the Sun is behind the observer,
- there are water droplets in the air,
- the observer is far enough away from the water droplets,
- sufficiently bright sunlight reaches the water droplets to disperse and reflect light into the observer's eyes.

Much like Figure 2, we can analyse the dispersion of white light through a raindrop by looking at the extreme ends of the visible spectrum of light, red light and violet light (see Figure 4). The other colours fall between.

MISCONCEPTION

'Total internal reflection always occurs within the raindrop.'

Most light that travels into a raindrop is lost back to the environment and only a small proportion of it reaches our eyes as a rainbow. This is because the internal reflection that is required for a rainbow to form is not total.

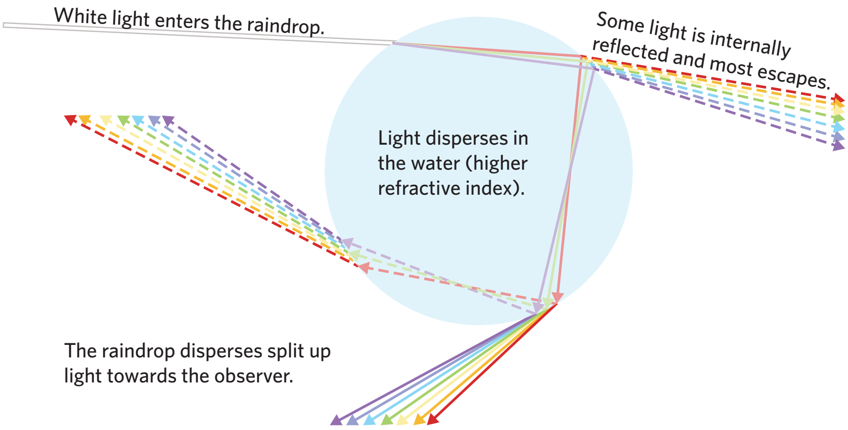

Figure 4 Dispersion and refraction of sunlight through a raindrop

Each droplet in a rainbow disperses the whole spectrum of white light into a cone; however, the observer is so far away from the rainbow itself we do not see the whole rainbow from each raindrop. Every drop instead reflects one colour, dependent on its location, into our eye. The combination of potentially millions of raindrops each sending a single colour to our eyes is the rainbow (see Figure 5).

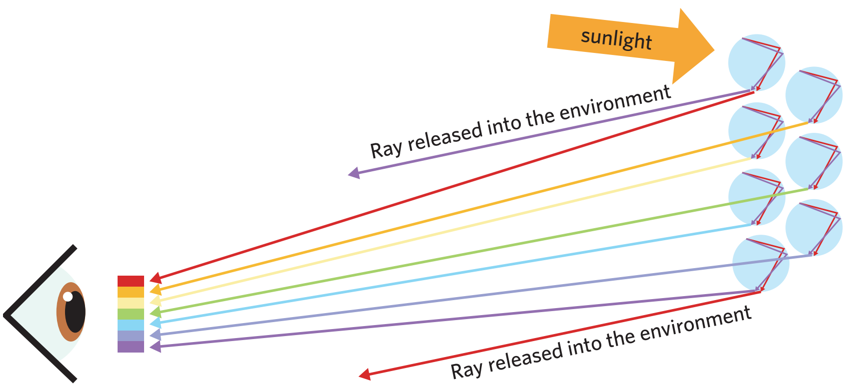

Figure 5 Model of each raindrop's contribution to the rainbow

The combination of thousands of raindrops lead to a continuous spectrum of light being seen instead of seven blocks of colour.

In Figure 5, note that the raindrop reflecting red light is on top and violet on the bottom due to the different angles they refract from the raindrop. The different angles they disperse from the raindrops lead to the order we see the rainbow.

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As we move towards or away from the rainbow, our angle to the rainbow changes meaning that different colours of light will reach our eyes from raindrops in similar locations.[2]

KEEN TO INVESTIGATE?

[2] **What occurs in a raindrop during the formation of a rainbow?**
Search: Rainbow formation simulation

Progress questions

Question 4

Are the orange and green colours in a rainbow likely to have reached an observer's eyes from the same raindrop?

A. Yes, they could be from the same raindrop.

B. No, they can not be from the same raindrop.

C. There is no way of knowing if they are from the same raindrop or not.

Question 5

According to the rainbow's observer, is a raindrop reflecting green likely to be above or below a raindrop reflecting red light?

A. There is no way of knowing which raindrop would be above or below the other.

B. Green is more likely to be above red.

C. Red is more likely to be above green.

Mirages 1.1.9.2

Mirages are an optical phenomena that occur as light travels through air that has a range of temperatures and densities. They allow us to see the sky and the clouds on the road as if it was a mirror.

Theory and applications

Mirages occur only when the air has a range of temperatures between our eyes and the object we are looking at. Surfaces that easily heat up, such as roads or deserts, transfer that heat energy to the air above. This creates a gradient of both air density and temperature above the road (see Figure 6).

Image: simoncritchell/Shutterstock.com

Figure 6 The road is reflecting the sky due to the mirage.

How are mirages formed?

Air's refractive index will be higher the more cold and dense it is. As light moves through air with this gradient of refractive indices its speed will change according to Snell's Law. This causes the light to refract and change direction. When the light refracts enough towards an observer's eyes, as shown in Figure 7, a mirage occurs.

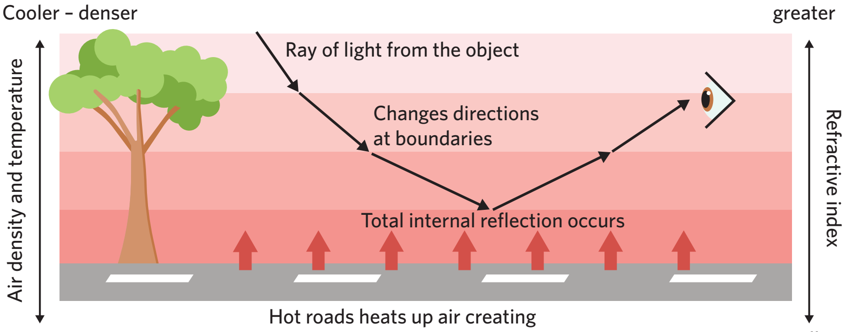


Figure 7 A model representing how mirages occur

The appearance of a reflection of cars or the sky or on the road is an optical illusion created because our brains assume all light travels in straight lines. In Figure 8, the red ray represents the light reflected from the top of the tree.

By extending a ray on the same angle as when it entered the eye, in the opposite direction, we see the tree reflected below where the actual object resides.[3]

KEEN TO INVESTIGATE?

[3] **What is a mirage?**
Search YouTube: What is a mirage?

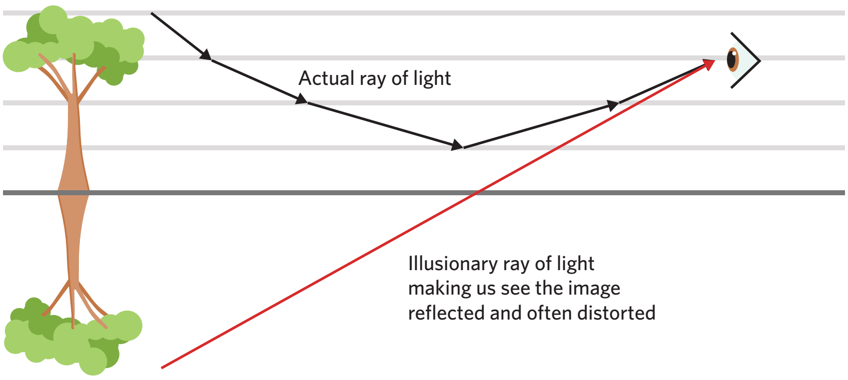


Figure 8 The ray of light that creates the illusion

Note that Figure 7 and 8 are models, which are limited, and cannot represent all the physics that goes into a mirage. Importantly, rays that travel through the temperature gradient change speed, and therefore bend, continuously with the change in temperature until either total internal reflection occurs or the light bends enough to turn into the observer's eye. The limitations of models are covered in Chapter 11.

Progress questions

Question 6

As the temperature of the air increases, its refractive index

A. decreases.

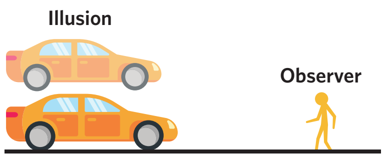
B. increases.

Question 7

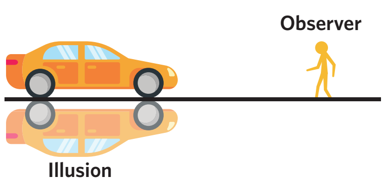
A person is observing a car drive down a road on a hot day.

Considering that the road is hot and the conditions for a mirage are met, which of the following illusions are most likely?

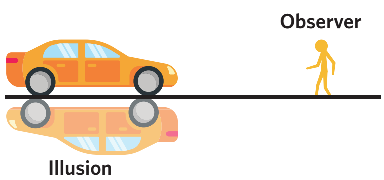
A.



B.



C.



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Optical fibres 1.1.10.1

Optical fibres utilise total internal reflection to efficiently transport light through a cable from one location to another.

Theory and applications

Large fibre-optic cables, made up of bundles of optical fibres, running along the ocean floor and between continents form the backbone of the internet and all other telecommunications.

Why do we use fibre-optic cables to communicate?

When light in the optic fibre hits the lower refractive index cladding it undergoes total internal reflection (see Figure 9). The light repeatedly reflects from one side to the other along the length of the tube. As total internal reflection occurs, little light is absorbed or lost at each reflection point. This allows information to travel efficiently over long distances within optical fibres.

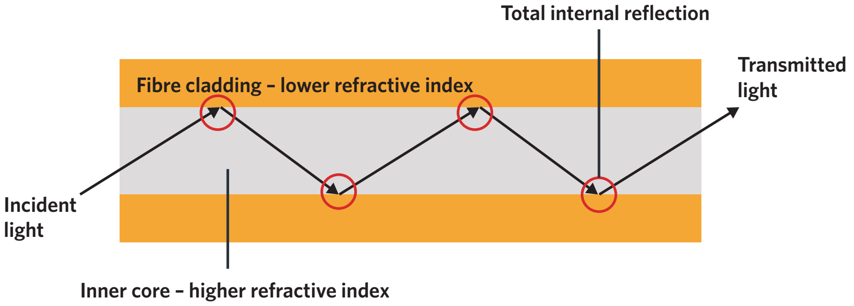

Figure 9 The anatomy of an optical fibre and where total internal reflection occurs

As fibre-optic cables can transfer data using a large range of frequencies, they can transfer more data than other technologies with smaller frequency bands. This allows fibre optics to be a powerful tool for transferring large amounts of data quickly and efficiently. A 10-Gbps (gigabit per second) connection can transmit any of the following per second:

- Video and audio from 16 TV channels
- Over 1000 e-books
- 130 000 audio channels

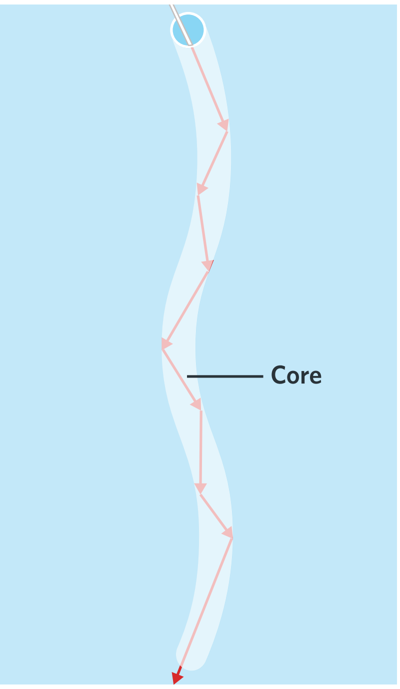

Figure 10 Light moving through an optical fibre as it bends

Progress questions

Question 8

If the fibre cladding had a higher refractive index than the inner core, could the fibre optic cable work as designed?

A. No, it would be impossible for total internal reflection to occur.

B. Yes, as total internal reflection would still occur.

Question 9

Which property of optical fibres makes them ideal for transmitting data? **(Select all that apply)**

I. can process lots of data

II. minimal loss of data over long distances

III. small size

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Theory summary

- White light is the human brain's way of interpreting the continuous spectrum of light entering the eye simultaneously.
- Dispersion is the phenomenon of white light being spread into a spectrum of its constituent frequencies.
- The combination of dispersion, refraction, and reflection cause other optical phenomena (see Table 1).

Table 1 Dispersion, refraction, reflection and their inclusion in other phenomena

Phenomena	Dispersion	Refraction	Total internal reflection
Rainbows	✓	✓	×
Mirages	×	✓	✓
Fibre optic cables	×	×	✓

CONCEPT DISCUSSION

Image: Shimon Bar/Shutterstock.com

The patch of sky between a primary (bottom) and secondary rainbow (top) is called Alexander's band. Notice how, compared to the light below the primary rainbow, Alexander's band is less bright. Discuss possible reasons as to why the light below the primary rainbow is more bright than the light between the primary and secondary rainbows.

Prompts:

- When light refracts through water, what direction does it bend?
- In what direction is the sunlight coming from?
- When light refracts through a raindrop, some of it is reflected elsewhere. Could this affect how bright light is above or below the rainbow?

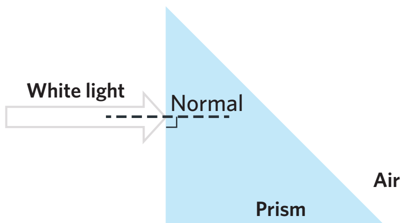
1E Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 10–12.

White light is incident on a prism with a refractive index higher than the air. It first hits the prism parallel to the normal.



Question 10 (1 MARK)

As the light enters the prism will it disperse or refract?

A. Yes, as white light enters a prism it will disperse and refract.

B. Yes, the prism has a higher refractive index than the air so it will refract but not disperse.

C. No, the white light will neither disperse nor refract as the incident light is parallel to the normal.

D. There is not enough information to be able to determine what will happen.

Question 11 (1 MARK)

After the light travels through the prism, what happens to the light as it passes through the boundary between the prism and the air?

A. The already dispersed light will disperse further.

B. The light will disperse.

C. The light will return to being white light.

D. There is not enough information to be able to determine what will happen.

Question 12 (4 MARKS)

Explain what happens to the white light as it passes into and out of this prism.

Exam-style

Use the following information to answer questions 13 and 14.

Fibre-optic cables allow the transfer of information over incredibly long distances with little to no loss of information or energy.

Question 13 (1 MARK)

Identify which light phenomenon allows this to occur.

Question 14 (1 MARK)

Which property of the structure of optical fibres allow this to occur?

A. The outer cladding is made of a reflective material causing it to reflect along the entire length of the fibre.

B. The inner cladding is exposed to the air. As air has a lower refractive index than the cladding it allows total internal reflection to occur.

C. The outer cladding has a higher refractive index than the inner cladding.

D. The inner cladding has a higher refractive index than the outer cladding.

Question 15 (3 MARKS)

Describe why rainbows are not as bright as the Sun despite consisting of light reflected from the Sun.

Question 16 (3 MARKS)

Light inside diamonds is totally internally reflected off multiple surfaces, giving diamonds their famous shine. The shine of diamonds also exhibits multiple colours when a white light is incident on the diamond.

Explain why diamonds exhibit a colourful shine, justifying your response with relevant theory.

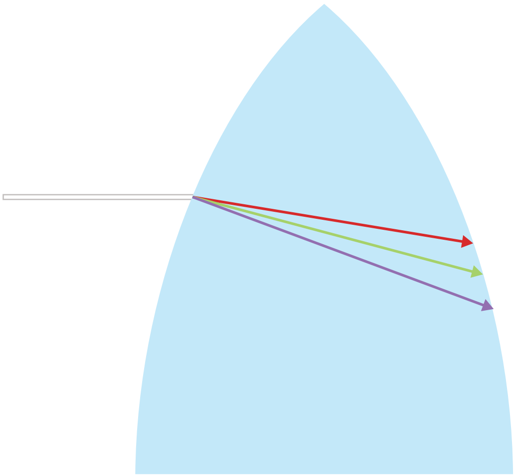
Image: DiamondGalaxy/Shutterstock.com

Question 17 (4 MARKS)

Katya sees a rainbow form in front of her. Her friend Mo remarks that it must be possible to reach the end of the rainbow but Katya disagrees. Explain whether Katya or Mo is correct using the theory of the creation of a rainbow.

Question 18 (4 MARKS)

The diagram shows red, green, and violet light passing through a convex lens.



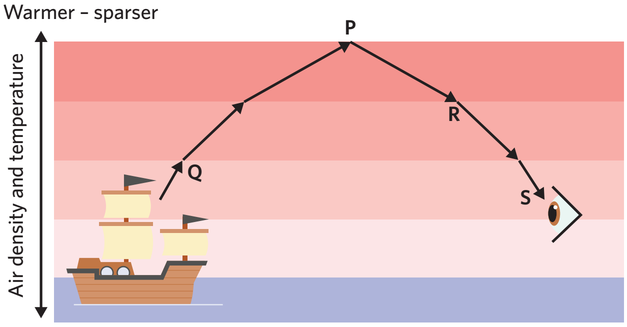
a. What can be concluded about how the refractive index of the lens changes based on the frequency of light? (2 MARKS)

b. Draw arrows to show the path of the red, green and violet light after exiting the lens. (2 MARKS)

Use the following information to answer questions 19–21.

There are two types of mirages, inferior and superior. Superior mirages (displayed in the diagram) occur only when the air's temperature increases with height whereas inferior mirages occur when the air's temperature decreases with height. Superior mirages often occur when the surface is cooler than the air, for example a cold ocean.

A superior mirage occurs due to similar processes to inferior mirages.



Question 19 (1 MARK)

At which point on the graph does total internal reflection occur?

A. P

B. Q

C. R

D. None of the above.

Question 20 (1 MARK)

Is the refractive index higher at point P or point S?

Question 21 (3 MARKS)

Explain where the 'mirage' or illusory image will form and why it will form there in the case of a superior mirage.

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Key science skills

Question 22 (4 MARKS)

Toni Stark is investigating the effect of lens shape on colour dispersion. She shines white light through a glass lens and records the distance between the dispersed red and violet light. She then replaces the glass lens with a plastic lens that has greater curvature, and repeats the measurements.

a. Is this a valid scientific experiment? Explain why or why not. (2 MARKS)

b. Suggest a change to the experimental design in order to make the results more valid. Justify your answer. (2 MARKS)

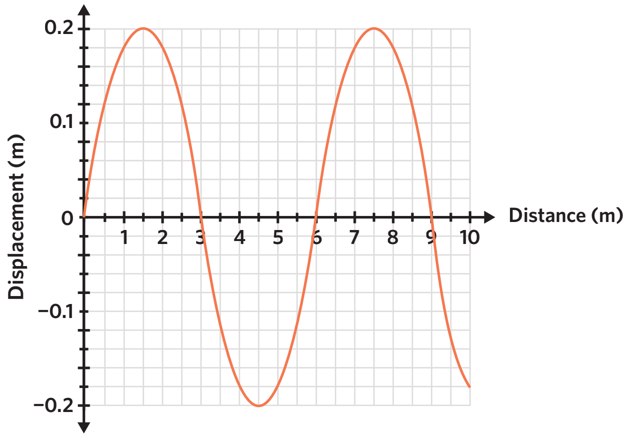
FROM LESSON 11C

Previous lessons

Question 23 (2 MARKS)

Determine the amplitude and wavelength of this mechanical wave.

FROM LESSON 1B



Question 24 (1 MARK)

A string is being plucked at 10 Hz, producing waves of wavelength 0.15 m. What is the period of these waves?

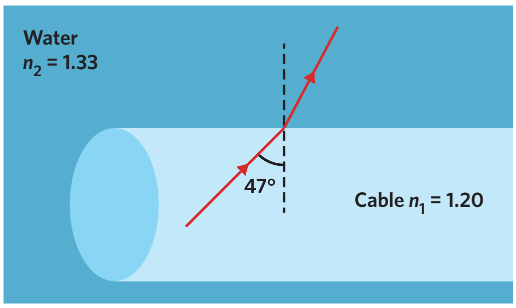
FROM LESSON 1B

Question 25 (2 MARKS)

The diagram shows light in a cable that is submerged in water.

With respect to the normal, at what angle would the light refract when leaving the cable?

FROM LESSON 1D



Chapter 1 review

Mild Medium Spicy

These questions are typical of 40 minutes worth of questions on the VCE Physics Exam.

Total marks: 30

Section A

All questions in this section are worth one mark.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 1

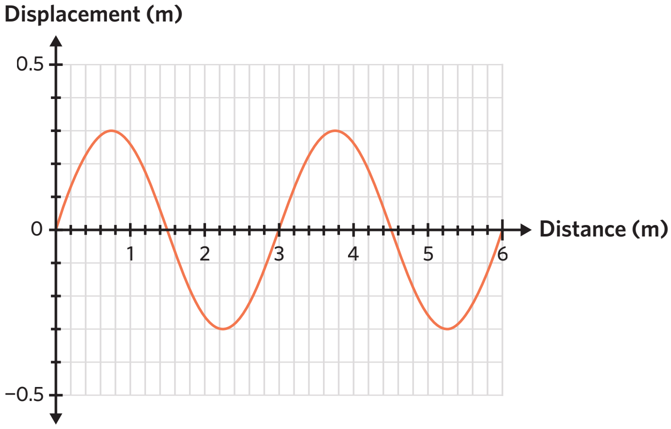
Which option best identifies the properties of the wave?

A. wavelength = 6 m, amplitude = 0.3 m, frequency = 3 Hz

B. wavelength = 3 m, amplitude = 0.3 m, frequency = 0.33 Hz

C. wavelength = 3 m, amplitude = 0.25 m, frequency = 3 Hz

D. wavelength = 3 m, amplitude = 0.3 m, frequency unknown



Question 2

Which of the following gives the order of light from shortest to longest wavelength?

A. radio, infrared, blue, green, red

B. blue, green, red, infrared, radio

C. radio, infrared, red, green, blue

D. infrared, radio, red, green, blue

Question 3

Which of the following options lists the regions of electromagnetic spectrum from the fastest to slowest waves in a vacuum?

A. gamma rays, x-rays, ultraviolet, visible, infrared, microwaves, radio waves

B. radio waves, microwaves, infrared, visible, ultraviolet, x-rays, gamma rays

C. They all travel at random speeds and therefore it is impossible to rank them.

D. They all travel at the same speed.

Question 4

Determine which of these wavelengths is not a component of white light.

A. infrared

B. red

C. green

D. blue

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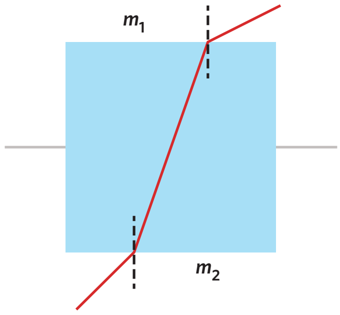
Question 5

A glass block ($n = 1.50$) and a bowl of water ($n = 1.33$) are being used in a refraction experiment. The medium surrounding the experiment is air ($n = 1.00$). The student conducting the experiment records a diagram of the experiment, in which light travels from medium 1 (m_1), to the glass block, to medium 2 (m_2). What can be concluded about the experimental setup?



A. The glass block is fully submerged in water.

B. The glass block is only surrounded by air.

C. The glass block is partially submerged in water.

D. Unable to conclude any of the above statements.

Section B

In questions where more than one mark is available, appropriate working must be shown.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 6 (1 MARK)

Identify two properties common to all electromagnetic waves.

Question 7 (1 MARK)

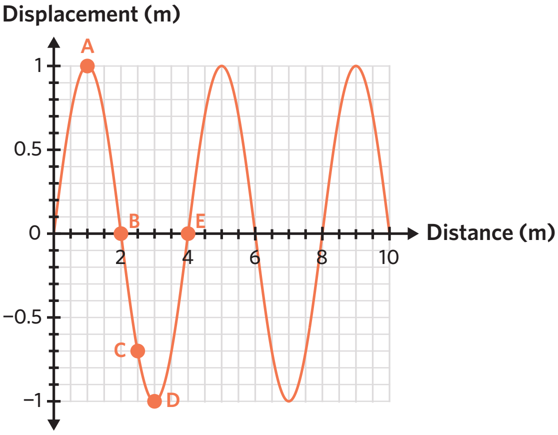
A light-year is the distance light travels in a year and is a common unit of measurement to use when describing astronomical scales. Assuming that an average year has 365 days, convert 0.75 light-years to metres.

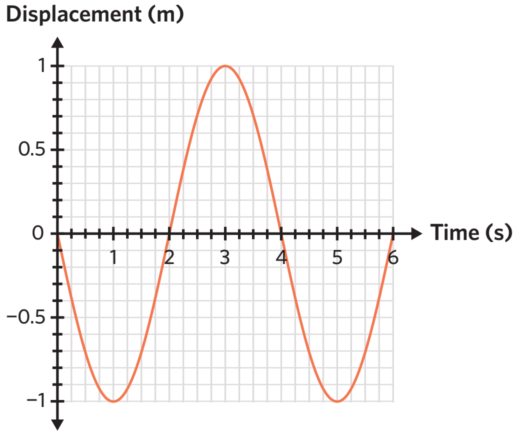
Question 8 (2 MARKS)

Two media have refractive indices of 1.30 and 1.40. Determine the ratio of the speed in the higher refractive index medium to the speed in the lower refractive index medium. Express your answer in decimal form.

Question 9 (7 MARKS)

The two graphs represent the characteristics of the same transverse wave travelling along a rope. The displacement-distance graph depicts the rope at $t = 0$ s. The displacement-time graph represents a single particle on the rope.





a. Calculate the speed of the wave. (2 MARKS)

b. In which direction (up, down, left, or right) is particle C moving at the instant shown? (1 MARK)

c. Which particle (A, B, C, D or E) could the displacement-time graph represent? (1 MARK)

d. Draw the displacement-distance graph at $t = 1.0$ s. (3 MARKS)

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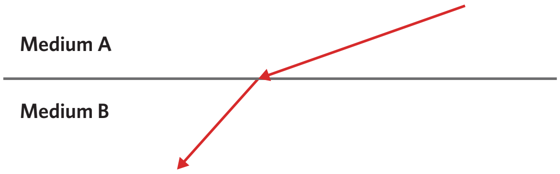
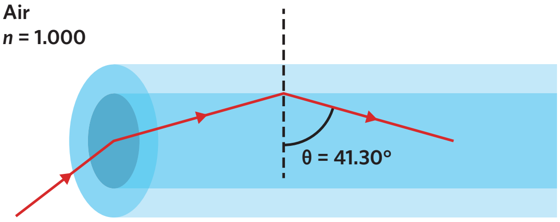
Question 10 (3 MARKS)

Students observe a light ray moving between medium A and medium B. What can be concluded about the refractive indices of the two media? Would this conclusion be impacted if the ray passed through this boundary in the opposite direction?



Question 11 (3 MARKS)

Students are experimenting with an optical fibre and a selection of monochromatic lasers of different colours.



Colour	Red	Yellow	Green	Blue	Violet
Refractive index in fibre optic cable	1.509	1.511	1.513	1.517	1.521

a. Describe the conditions, with reference to refractive indices and the angle of incidence, required for total internal reflection to occur in an optic fibre. (2 MARKS)

b. If the light was directed so that it travelled directly along the centre of the cable and did not touch the edge, which of the five colours would reach the end of the cable first? (1 MARK)

Question 12 (5 MARKS)

When sunlight travels through a raindrop, it splits into its constituent parts.

a. Identify and describe the phenomenon that splits white light into its constituent colours when it travels through a medium. (2 MARKS)

b. Explain why more than one raindrop is required to create a rainbow. (3 MARKS)

Question 13 (3 MARKS)

An observer is standing some distance away from a tree. Suppose that the air is cold at the middle height of the tree, and the air gets gradually warmer at heights lower and higher than this. Explain whether it would be possible for the observer to see a mirage above and/or below the tree.

1A Introduction to waves

Progress questions

1. B
2. C
3. B
4. C
5. C
6. A
7. B, E, M, M, M, E

Deconstructed exam-style

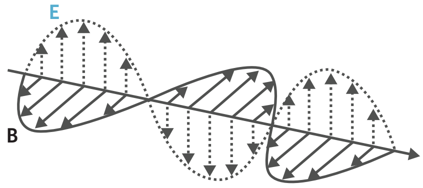
8. A
9. C
10. [The particle oscillates left and right.[1]][Its initial position (3 cm from the speaker) is the point about which the oscillations occur.[2]]

- I have explicitly addressed the oscillation of the air particle.[1]
- I have explicitly addressed the initial position of the particle.[2]

Exam-style

11. D. The power line poles will oscillate left and right about the same point.

12. a.



b. 3.0×10^8 m s^{-1}

13. [The wave is transverse[1]][as the displacement is perpendicular to the direction the wave is travelling.[2]]

- I have explicitly addressed whether the wave is longitudinal or transverse.[1]
- I have used the relevant theory: direction of oscillation compared to the direction of wave travel.[2]

14. C. Light always travels at 3.0×10^8 m s^{-1} through a vacuum.

Key science skills

15. D. 'Precise but inaccurate' suggests the results will be clustered tightly but not close to the true value (bullseye).

FROM LESSON 11C

1B Wave fundamentals

Progress questions

1. A
2. B
3. D
4. B
5. B
6. A
7. B
8. B
9. D
10. C

Deconstructed exam-style

11. B
12. B
13. A
14. $A = 8$ cm (1 MARK)

Need correct units to gain full mark

$\lambda = 0.06$ m (1 MARK)

$v = f\lambda$

$18 = f \times 0.06$

$f = \frac{18}{0.06} = 3 \times 10^2$ Hz (1 MARK)

Exam-style

15. $v = f\lambda \Rightarrow 340 = 135 \times \lambda$ (1 MARK)

$\lambda = 2.52$ m (1 MARK)

16. a. Whole spring: displacement-distance graph.

One point: displacement-time graph.

b. $A = 0.10$ m

c. $\lambda = 4.0$ m

d. $T = 6.0$ s

e. $f = \frac{1}{T} = \frac{1}{6.0} = 0.17$ Hz or s^{-1}

17. a. $v = \frac{\lambda}{T} = \frac{500}{30.0} = 16.7$ m s^{-1}

b. $f = \frac{1}{T} = \frac{1}{30.0} = 3.33 \times 10^{-2}$ Hz

18. a. $v = \frac{\lambda}{T} \Rightarrow 3.0 \times 10^8 = \frac{0.040}{T}$

$T = 1.3 \times 10^{-10}$ s

b. The waves with $\lambda = 0.040$ m have a greater energy, as they have a greater frequency.

19. [Wave speed is dependent only on the medium in which the wave is propagating, so will not change when frequency changes.[1]]

- I have used the relevant theory: the dependence of wave speed on the medium.[1]

20. a. $\lambda = 4$ m from either graph

b. For lowest possible frequency, the wave has moved through $\frac{1}{4}$ of a cycle in 0.25 s (1 MARK)

$\frac{1}{4}T = 0.25$ s

$T = 1$ s

$f = \frac{1}{T} = 1$ Hz (1 MARK)

c. $v = f\lambda = 1 \times 4 = 4$ m s^{-1}

21. a. A: up (1 MARK)

B: up (1 MARK)

C: down (1 MARK)

b. Same location on the wave

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22. $f = 450 \times 10^6$ Hz (1 MARK)

$v = f\lambda$

$3.0 \times 10^8 = 450 \times 10^6 \times \lambda$ (1 MARK)

$\lambda = 0.67$ m, the question requires the answer to be in centimetres.

$\lambda = 67$ cm (1 MARK)

23. $v = f\lambda = 534 \times 0.500 = 267$ m s^{-1} (1 MARK)

The unknown gas is carbon dioxide. (1 MARK)

24. [Dominique should make the period shorter[1]][as by decreasing period she would increase frequency of her note.[2]]

- I have explicitly addressed the question.[1]
- I have used the relevant theory: the relationship between period and frequency.[2]

Key science skills

25. [Izzy has more accurate data and Emma has more precise data.[1]][Izzy's average (696.2 nm) is closer than Emma's average (696.8 nm) to the actual wavelength (695 nm).[2]][The range of Emma's measurements (5 nm) is smaller than Izzy's range (17 nm).[3]]

- I have explicitly addressed the question.[1]
- I have used the relevant theory: the definition of accuracy.[2]
- I have used the relevant theory: the definition of precision.[3]
- I have used the provided data in my answer.

FROM LESSON 11C

Previous lessons

26. [Image *M* is an example of a transverse wave.[1]][In image *M*, the oscillations are perpendicular to the direction of wave travel.[2]]

- I have explicitly addressed which image shows a transverse wave.[1]
- I have used the relevant theory: oscillations perpendicular to direction of travel in transverse waves.[2]

FROM LESSON 1A

1C Everyday electromagnetism

Progress questions

1. A
2. B
3. B
4. D
5. D
6. A

Deconstructed exam-style

7. C

8. D

9. [Ultraviolet light has a much shorter wavelength/higher frequency/higher energy than infrared or vice-versa.[1]] [Generally humans are unable to see infrared or ultraviolet light as their wavelengths are outside the visible spectrum.[2]]

- I have used the relevant theory: the relationship between wavelength/frequency/energy.[1]
- I have used the relevant theory: humans have a narrow range of waves that are visible.[2]

Exam-style

10. Radio station sends a radio wave signal → Presenter speaks (1 MARK)

Radio receives radio waves → Translator hears the spoken words (1 MARK)

Radio emits sound → Translator communicates in sign language (1 MARK)

11. Radio, microwaves, infrared, orange light, ultraviolet, x-rays

12. Gamma, ultraviolet, blue light, red light, infrared, radio

13. D. Green has the second longest wavelength of the visible colours that mercy emits.

Key science skills

14. 658 nm $= 658 \times 10^{-9}$ m (1 MARK)

$658 \times 10^{-9} = 6.6 \times 10^{-7}$ m (1 MARK)

FROM LESSON 11B

Previous lessons

15. Electromagnetic waves do not need a medium to propagate.

OR

Electromagnetic waves can travel through a vacuum.

FROM LESSON 1A

16. B. All the components of the electromagnetic spectrum in vacuum will have the same speed.

$c = 3.0 \times 10^8$ m s^{-1}

FROM LESSON 1A

1D Refraction and reflection

Progress questions

1. A
2. D
3. B
4. B
5. C
6. A
7. C
8. B
9. C

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Deconstructed exam-style

10. B

11. C

12. A

13. Find the speed of light in saltwater.

$v = f\lambda = 510 \times 10^{-9} \times 4.085 \times 10^{14}$

$v = 2.08 \times 10^{8}$ (1 MARK)

Find the refractive index of the saltwater.

$n_1 = \frac{c}{v} = \frac{3.00 \times 10^8}{2.08 \times 10^8} = 1.44$ (1 MARK)

$\Rightarrow$ Refractive index of plastic, n_2, must be less than the refractive index for saltwater but for the critical angle to exist, and must be greater than or equal to 1 since 1 is the lowest possible refractive index. (1 MARK)

$1 \leq n_2 < 1.44$ (1 MARK)

Exam-style

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

$v = \frac{c}{n} = \frac{3.00 \times 10^8}{1.60} = 1.88 \times 10^8 \text{ m s}^{-1}$

15. $n_2 = n_1 \sin(\theta_c)$

$n_{cladding} = 1.7 \times \sin(48°) = 1.3$

16. $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$

$1.00 \times \sin(45.0°) = n_{glass} \times \sin(30.0°)$ (1 MARK)

$n_{glass} = \frac{\sin(45.0°)}{\sin(30.0°)} = 1.41$ (1 MARK)

17. $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$

$1.32 \times \sin(42.0°) = 1.40 \times \sin(\theta_r)$ (1 MARK)

$\theta_r = \sin^{-1}\left(\frac{1.32 \times \sin(42.0°)}{1.40}\right) = 39.1°$ (1 MARK)

18. $n_1 \sin(\theta_c) = n_2$

$1.46 \times \sin(\theta_c) = 1.28$ (1 MARK)

$\theta_c = \sin^{-1}\left(\frac{1.28}{1.46}\right) = 61.2°$ (1 MARK)

19. [When the laser light passes into the stream of water, it can be guided by total internal reflection since water has a higher refractive index than air.[1]][Each subsequent reflection inside the stream will experience total internal reflection if it is incident at greater than the critical angle.[2]]

- I have explicitly addressed how the light is guided by the stream.[1]
- I have used the relevant theory: total internal reflection and critical angle.[2]

20. $n_1 \sin(\theta_c) = n_2$

$n_{glass} \sin(50°) = 1.00$

$n_{glass} = \frac{1.00}{\sin(50°)} = 1.3$ (1 MARK)

$n_{glass} < n_{water}$

$\Rightarrow$ Total internal reflection would not be possible anymore since it would require that $n_{glass} > n_{water}$ (1 MARK)

21. D. Crossing the boundary from medium 1 into medium 2, light refracts towards the normal

$\Rightarrow n_1 < n_2$

Crossing the boundary from medium 2 into medium 3, light refracts away from the normal

$\Rightarrow n_3 < n_2$

Since the boundaries are parallel and $\theta_3 > \theta_1$, Snell's Law indicates $n_3 < n_1$

$\Rightarrow n_3 < n_1 < n_2$

Since $n \propto \frac{1}{v}$, $v_3 > v_1 > v_2$

22. $v_2 = 1.2 \times v_1$

$n_1 v_1 = n_2 v_2$

$\frac{n_1}{n_2} = \frac{v_2}{v_1} = 1.2$ (1 MARK)

$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$

$1.2 \sin(\theta_i) = \sin(60°)$ (1 MARK)

$\theta_i = \sin^{-1}\left(\frac{\sin(60°)}{1.2}\right) = 46°$ (1 MARK)

23. Since both boundaries the light passes through are parallel, the angle of refraction from the first boundary will be the angle of incidence on the second boundary.

By Snell's Law at the first boundary:
$n_{air} \sin(\theta_{air}) = n_{glass} \sin(\theta_{glass})$

By Snell's Law at the second boundary:
$n_{glass} \sin(\theta_{glass}) = n_{water} \sin(\theta_{water})$

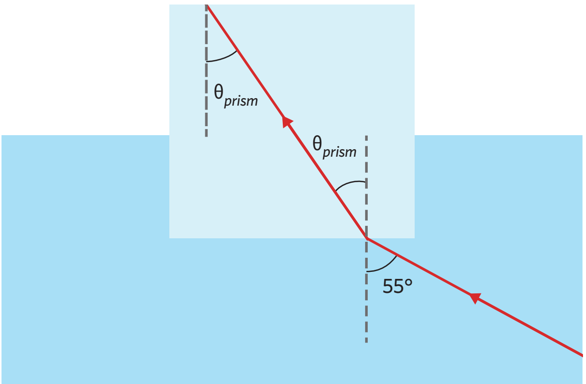
$n_{air} \sin(\theta_{air}) = n_{water} \sin(\theta_{water})$ (1 MARK)

$1.00 \times \sin(30°) = 1.33 \times \sin(\theta_{water})$

$\theta_{water} = \sin^{-1}\left(\frac{1.00}{1.33} \times \sin(30°)\right) = 22°$ (1 MARK)

$\theta_{air} - \theta_{water} = 30 - 22 = 8°$ (1 MARK)

24. Since both boundaries the light passes through are parallel, the angle of refraction from the first boundary will be the angle of incidence on the second boundary.



$n_1 v_1 = n_2 v_2$ implies that $\frac{n_1}{n_2} = \frac{v_2}{v_1}$

$\Rightarrow \frac{n_{water}}{n_{prism}} = \frac{v_{prism}}{v_{water}} = 0.8$ and $\frac{n_{air}}{n_{prism}} = \frac{v_{prism}}{v_{air}} = 0.6$ (1 MARK)

$\Rightarrow n_{water} = 0.8 \times n_{prism}$ and $n_{air} = 0.6 \times n_{prism}$

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By Snell's Law at the water-prism boundary:

$n_{water}\sin(55°) = n_{prism}\sin(\theta_{prism})$

$\theta_{prism} = \sin^{-1}\left(\frac{n_{water}}{n_{prism}}\sin(55°)\right) = \sin^{-1}(0.8 \times \sin(55°)) = 41°$

(1 MARK)

The critical angle for the prism-air boundary will have:

$n_{prism}\sin(\theta_c) = n_{air}$

$\theta_c = \sin^{-1}\left(\frac{n_{air}}{n_{prism}}\right) = \sin^{-1}(0.6) = 36°$ (1 MARK)

$\Rightarrow$ The light will totally internally reflect since $\theta_{prism} > \theta_c$

(1 MARK)

Key science skills

25. a. Dependent: angle of refraction (1 MARK)

Independent: angle of incidence (1 MARK)

Controlled: laser wavelength **OR** incident medium refractive index **OR** diamond refractive index (1 MARK)

b. Use two points on a line of best fit to determine the gradient.

$gradient = \frac{rise}{run} = \frac{0.39 - 0.15}{0.90 - 0.35}$ (1 MARK)

$gradient = 0.44$ (1 MARK)

Depending on the line of best fit drawn, answers between 0.38 and 0.50 are acceptable.

c. $n_1\sin(\theta_1) = n_2\sin(\theta_2)$

$\frac{n_2}{n_1} = \frac{\sin(\theta_1)}{\sin(\theta_2)}$

In this case, $\sin(\theta_1) = \sin(\theta_i)$, $\sin(\theta_2) = \sin(\theta_r)$, $n_1 = 1.00$, and $n_2 = n_{diamond}$

$\Rightarrow n_{diamond} = \frac{\sin(\theta_i)}{\sin(\theta_r)} = \frac{run}{rise} = \frac{1}{gradient}$

$n_{diamond} = \frac{1}{0.44} = 2.3$ (1 MARK)

The diamond is not real since $2.3 < 2.80$. (1 MARK)

FROM LESSONS 11A & 11E

Previous lessons

26. [Frequency is the number of wave cycles completed in a unit of time.[1]][Wavelength is the distance covered by one complete wave cycle, or the distance between two crests/two troughs.[2]][Frequency is determined entirely by the wave source.[3]]

- I have used the relevant theory: wave frequency.[1]
- I have used the relevant theory: wavelength.[2]
- I have explicitly addressed which property is completely determined by wave source.[3]

FROM LESSON 1B

27. C. The x-ray region of the electromagnetic spectrum is the second most energetic after gamma radiation.

FROM LESSON 1C

1E White light and optical phenomena

Progress questions

1. D **2.** C **3.** C **4.** B

5. C **6.** A **7.** B **8.** A

9. I, II and III

Deconstructed exam-style

10. C

11. B

12. [As the light passes into the prism it does not disperse.[1]] [This is because the light hits the prism parallel to the normal so no refraction occurs.[2]][When the light leaves the prism, each frequency of light refracts differently and therefore the white light disperses.[3]][Despite being white light within the prism, the difference in the refractive indexes of the medium for each frequency of light allows dispersion to occur.[4]]

- I have explicitly addressed what happens to the white light as it passes into the prism.[1]
- I have used the relevant theory: refraction and dispersion.[2]
- I have explicitly addressed what happens to the white light as it passes out of the prism.[3]
- I have used the relevant theory: refraction and dispersion.[4]

Exam-style

13. Total internal reflection

14. D. Total internal reflection can only occur when travelling from a medium of higher refractive index to a medium of lower refractive index.

15. [Rainbows are a result of refraction and reflection occurring[1]] [however, these processes are not ideal and light escapes at each boundary which does not reach the observer.[2]][This means the light that we see as a rainbow is only a small percentage of the Sun's light.[3]]

- I have used the relevant theory: refraction and reflection.[1]
- I have explicitly addressed the inefficiency in these processes.[2]
- I have related my answer to the context of the question.[3]

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16. [Diamonds exhibit a colourful shine because white light shone onto the diamond is dispersed into its constituent colours.[1]] [White light consists of a continuous spectrum of the colours within the visible spectrum of light,[2]] [and these colours are dispersed by the diamond because the diamond's refractive index is dependent on the frequency (colour) of light.[3]]

- I have explicitly addressed why diamonds have a colourful shine.[1]
- I have used the relevant theory: white light.[2]
- I have used the relevant theory: colour dispersion.[3]

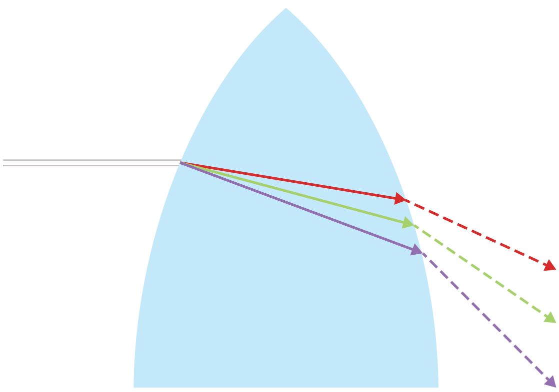
17. [Katya is correct and Mo is incorrect.[1]] [Rainbows are created through the dispersion of white light through numerous raindrops.[2]] [As a person gets closer to a rainbow, you see a rainbow formed by different raindrops.[3]] [This means that you can never reach the end of a rainbow as it is not a static object but an illusion that moves with you.[4]]

- I have explicitly addressed whether Katya or Mo is correct.[1]
- I have used the relevant theory: rainbows.[2]
- I have explicitly addressed rainbows as an illusion.[3]
- I have related my answer to the context of the question.[4]

18. a. [Because the higher frequency colour (violet) is refracted more towards the normal than the lower frequency colour (red),[1]] [it can be concluded that the refractive index of the lens decreases as frequency decreases.[2]]

- I have used the relevant theory: refraction.[1]
- I have explicitly addressed the relationship between refractive index and frequency.[2]

b.



- I have drawn three arrows.
- I have drawn the arrows such that they separate further and do not cross.

19. A. At point P the light changes direction, suggesting total internal reflection occurred.

20. Point S

21. [The mirage will form above the actual object.[1]] [It forms here as the angle of the ray reaching the eye is coming from above the eye.[2]] [As the human brain believes this to be a straight line, we see the image at the end of this straight line, above the actual position of the object.[3]]

- I have explicitly addressed where the mirage will form.[1]
- I have referenced the angle of the ray with respect to the eye.[2]
- I have used the relevant theory: mirages.[3]

Key science skills

22. a. [No, the experiment is not valid[1]] [because there is more than one independent variable in this experiment.[2]]

- I have explicitly addressed the validity of the experiment.[1]
- I have used the relevant theory: experimental validity and independent variables.[2]

b. [After choosing a single independent variable, Toni should take multiple measurements of the distance between the red and purple light for each lens.[1]] [Increasing the amount of measurements increases the validity of results by helping to account for the variability of the data and personal error.[2]]

- I have explicitly addressed a change to the experimental design.[1]
- I have used the relevant theory: validity.[2]

FROM LESSON 11C

Previous lessons

23. From the graph:

Amplitude = 0.2 m (1 MARK)

Wavelength = 6 m (1 MARK)

FROM LESSON 1B

24. $T = \frac{1}{f} = \frac{1}{10} = 0.10\text{ s}$

FROM LESSON 1B

25. $n_1\sin(\theta_1) = n_2\sin(\theta_2) \Rightarrow 1.20 \times \sin(47°) = 1.33 \times \sin(\theta_2)$ (1 MARK)

$\theta_2 = 41°$ (1 MARK)

FROM LESSON 1D

Chapter 1 review

Section A

1. D. The amplitude of the graph is the maximum displacement in one direction and the wavelength can be found from the distance between two peaks or troughs. The frequency cannot be determined from a displacement-distance graph.

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2. B. Using the electromagnetic spectrum, blue light has a shorter wavelength than radio waves.

3. D. All electromagnetic waves travel at $c = 3.0 \times 10^8$.

4. A. White light consists of all components of the visible light spectrum. Infrared light is not part of the visible spectrum.

5. C. As the angle of incidence of light travelling from medium 1 to water is different from the angle of refraction when light travels from water to medium 2, the two mediums must be made of different materials.

Section B

6. Any two of the following: all travel at the $c = 3.0 \times 10^8$ m s^{-1} in a vacuum; can travel through a vacuum (no medium required); have an associated wavelength, frequency and energy; transfer energy; behave as a transverse waves; or other properties not covered in Chapter 1.

7. One year $= 60 \times 60 \times 24 \times 365 = 3.15 \times 10^7$ s

   $v = \frac{s}{t} \Rightarrow s = vt = 3.0 \times 10^8 \times 3.15 \times 10^7 \times 0.75 = 7.1 \times 10^{15}$ m

8. $n_1 v_1 = n_2 v_2$

   $1.30 \times v_1 = 1.40 \times v_2$ (1 MARK)

   $\frac{v_2}{v_1} = \frac{1.30}{1.40} = 0.9285 = 0.929$ (1 MARK)

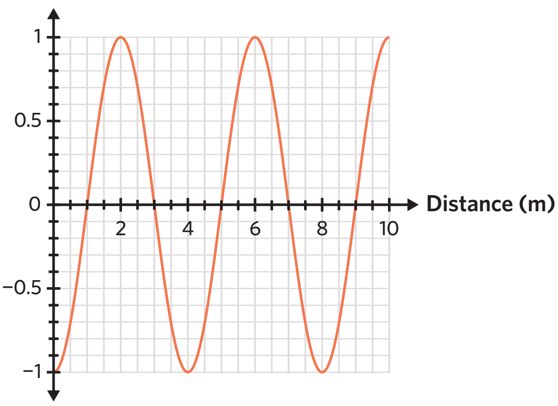
9. **a.** From the displacement-distance graph $\lambda = 4$ m and from the displacement-time graph $T = 4$ s (1 MARK)

   $v = \frac{\lambda}{T} = \frac{4}{4} = 1$ m s^{-1} (1 MARK)

   b. Particle C is moving upwards.

   c. The displacement-time graph must show the movement of a particle which has displacement 0 m at $t = 0$ s and has its displacement decrease just after $t = 0$ s. Particle E is the only particle which fits this description.

   d. **Displacement (m)**



✓ ✗ I have labelled both axes including units.

✓ ✗ I have used an appropriate and consistent scale on both axes.

✓ ✗ I have drawn a sinusoidal wave with an amplitude of 1 m and a wavelength of 4 m.

✓ ✗ I have drawn a graph which starts with a minimum at $d = 0$ m and ends with a maximum at $d = 10$ m.

10. [$n_A < n_B$[1]][as, from B to A, the ray bends away from the normal.[2]] [Note that the direction of the ray's travel is not important, since if it travelled instead from A to B then it would be bending towards from the normal, again implying that $n_A < n_B$.[3]]

✓ ✗ I have explicitly addressed the relationship between the refractive indices.[1]

✓ ✗ I have used the relevant theory: refraction.[2]

✓ ✗ I have explicitly addressed the significance of the ray's direction of travel.[3]

11. **a.** $n_{internal} > n_{external}$ **OR** $n_{core} > n_{cladding}$ (1 MARK)

    Angle of incidence must be greater than the critical angle. (1 MARK)

    b. Red (since it has the lowest refractive index so it travels fastest).

12. **a.** [Dispersion is occuring.[1]][Dispersion is the process of white light being separated into its constituent colours when each colour refracts by a different amount as it enters and leaves a medium.[2]]

✓ ✗ I have explicitly addressed the relevant phenomenon.[1]

✓ ✗ I have used the relevant theory: dispersion of white light.[2]

    b. [A rainbow is a result of the combination of numerous rays of light from thousands of raindrops.[1]][Although each raindrop disperses the light, due to the differing angles that the wavelengths of light leave the raindrop, only one wavelength will reach the observer from each raindrop.[2]][This means that many raindrops are required to see the overall effect of each colour of a rainbow as it appears.[3]]

✓ ✗ I have explicitly addressed the need for multiple raindrops.[1]

✓ ✗ I have used the relevant theory: rainbows and dispersion.[2]

✓ ✗ I have related my answer to the context of the question.[3]

13. [Mirages occur below the object (inferior) when the air gets gradually warmer below a certain height.[1]][Mirages form above the object (superior) when the air gets gradually warmer above a certain height.[2]][In this scenario, the air gets gradually warmer both above and below the midpoint of the tree's height, therefore it should be possible for the observer to see both a superior and an inferior mirage.[3]]

✓ ✗ I have explicitly addressed how inferior mirages form.[1]

✓ ✗ I have explicitly addressed how superior mirages form.[2]

✓ ✗ I have addressed whether a superior and/or inferior mirage will form.[3]

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2A Temperature fundamentals

Progress questions

1. liquid, gas, changes to fit the container it's in, more spread out, increases, move and collide randomly

2. A

3. B

4. average, translational kinetic

5. B **6.** A **7.** C **8.** A

Deconstructed exam-style

9. D

10. B

11. [Initially, the particles in the cup of coffee have greater average translational kinetic energy than in her hand because the coffee is at a greater temperature.[1]] [As the cup warms the hand, the average translational kinetic energy of the particles in the cup of coffee decreases and the average translational kinetic energy of the particles in her hand increases.[2]] [When thermal equilibrium is reached, the average translational kinetic energy of the particles in each system will be equal.[3]]

- I have explicitly addressed the average translational kinetic energies at the beginning.[1]
- I have explicitly addressed the average translational kinetic energies as the coffee warms her hand.[2]
- I have explicitly addressed the average translational kinetic energies at thermal equilibrium.[3]

Exam-style

12. 735 K = (735 − 273.15)°C = 462°C

13. a. −170°C = (−170 + 273.15) K = 103 K

b. ΔT = 450°C − (−170°C) = 620°C = 620 K

14. [Temperature is a measure of the average translational kinetic energy of the random disordered motion of the particles in a system.[1]] [Hence, the average translational kinetic energy of the atoms and molecules will be greater during the day than during the night.[2]]

- I have used the relevant theory: temperature as a measure of average translational kinetic energy of particles.[1]
- I have explicitly addressed the kinetic energy of atoms and molecules during the day compared with during the night.[2]

15. [Archie is incorrect.[1]] [Temperature is a measure of the average translational kinetic energy of the random disordered motion of the atoms and molecules in a system.[2]] [The collective change in speed of the basketball, and its particles as a result, is not related to the particles' random disordered motion.[3]]

- I have explicitly addressed whether Archie is correct.[1]
- I have used the relevant theory: temperature as a measure of average translational kinetic energy of particles.[2]
- I have related my answer the the context of the question.[3]

16. a. The internal energy of the water in the Olympic pool would be greater than the internal energy of water in the backyard pool. This is because the Olympic pool has a greater volume, and more water particles than a backyard pool.

b. The average translational kinetic energy of the water molecules in the backyard pool would be the same as the average translational kinetic energy of the water molecules in the Olympic pool. This is because the pools are at the same temperature.

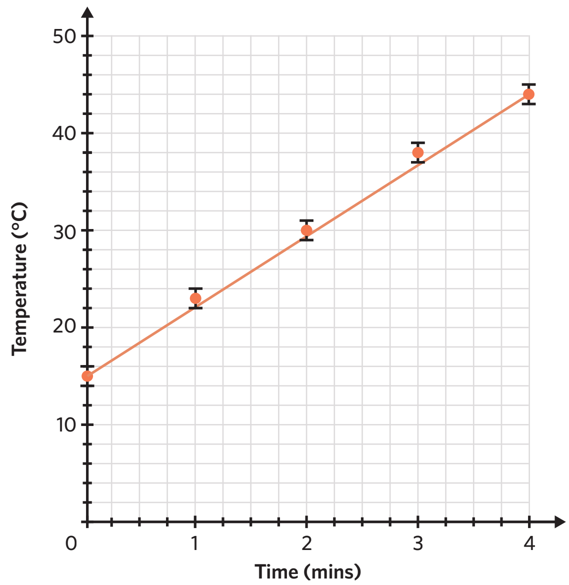
17. [Particles in water (a liquid) are free to move around each other, whereas particles in ice (a solid) are stuck together,[1]] [which explains the macroscopic properties of liquids being able to change shape and solids having a fixed shape.[2]] [Hence, liquid water can flow as a thin stream into a bottle and then take the bottle's shape, whereas ice cannot.[3]]

- I have used the relevant theory: the kinetic theory of matter for solids and liquids.[1]
- I have used the relevant theory: the macroscopic properties of solids and liquids.[2]
- I have explicitly addressed the properties of water that allow it to fill the bottle easily.[3]

Key science skills

18. a. $\textit{Uncertainty} = \frac{1}{2} \times \textit{smallest division on scale} = \frac{1}{2} \times 2°C = \pm 1°C$

b.



- I have drawn time on the horizontal axis and temperature on the vertical axis.
- I have used an appropriate and consistent scale so the data takes up at least half of each axis.