Mastering Physics

MODULE 3
NSW

Waves and Thermodynamics

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Contents

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Words to Watch

account, account for State reasons for, report on, give an account of, narrate a series of events or transactions.

analyse Interpret data to reach conclusions.

annotate Add brief notes to a diagram or graph.

apply Put to use in a particular situation.

assess Make a judgement about the value of something.

calculate Find a numerical answer.

clarify Make clear or plain.

classify Arrange into classes, groups or categories.

comment Give a judgement based on a given statement or result of a calculation.

compare Estimate, measure or note how things are similar or different.

construct Represent or develop in graphical form.

contrast Show how things are different or opposite.

create Originate or bring into existence.

deduce Reach a conclusion from given information.

define Give the precise meaning of a word, phrase or physical quantity.

demonstrate Show by example.

derive Manipulate a mathematical relationship(s) to give a new equation or relationship.

describe Give a detailed account.

design Produce a plan, simulation or model.

determine Find the only possible answer.

discuss Talk or write about a topic, taking into account different issues or ideas.

distinguish Give differences between two or more different items.

draw Represent by means of pencil lines.

estimate Find an approximate value for an unknown quantity.

evaluate Assess the implications and limitations.

examine Inquire into.

explain Make something clear or easy to understand.

extract Choose relevant and/or appropriate details.

extrapolate Infer from what is known.

hypothesise Suggest an explanation for a group of facts or phenomena.

identify Recognise and name.

interpret Draw meaning from.

investigate Plan, inquire into and draw conclusions about.

justify Support an argument or conclusion.

label Add labels to a diagram.

list Give a sequence of names or other brief answers.

measure Find a value for a quantity.

outline Give a brief account or summary.

plan Use strategies to develop a series of steps or processes.

predict Give an expected result.

propose Put forward a plan or suggestion for consideration or action.

recall Present remembered ideas, facts or experiences.

relate Tell or report about happenings, events or circumstances.

represent Use words, images or symbols to convey meaning.

select Choose in preference to another or others.

sequence Arrange in order.

show Give the steps in a calculation or derivation.

sketch Make a quick, rough drawing of something.

solve Work out the answer to a problem.

state Give a specific name, value or other brief answer.

suggest Put forward an idea for consideration.

summarise Give a brief statement of the main points.

synthesise Combine various elements to make a whole.

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Wave Characteristics

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3.1 Role Of the Medium Carrying Wave Energy

Conduct an investigation to create mechanical waves in a variety of situations to explain the role of the medium in the propagation of mechanical waves.
Conduct an investigation to create mechanical waves in a variety of situations to explain the transfer of energy involved in the propagation of mechanical waves.

Role of the medium carrying wave energy

- Mechanical waves (water, wind, waves in ropes and strings and springs, soundwaves and those in all musical instruments) all occur because the particles in the medium oscillate and transfer energy from one particle to the next.
- Waves transfer energy without transferring the matter of the medium with the energy.
- The amount of energy carried is represented by the amplitude of the wave.


All waves need an input source of energy to form in any medium.

Sample Questions

1. (a) Give five other examples of mechanical waves travelling through different mediums.

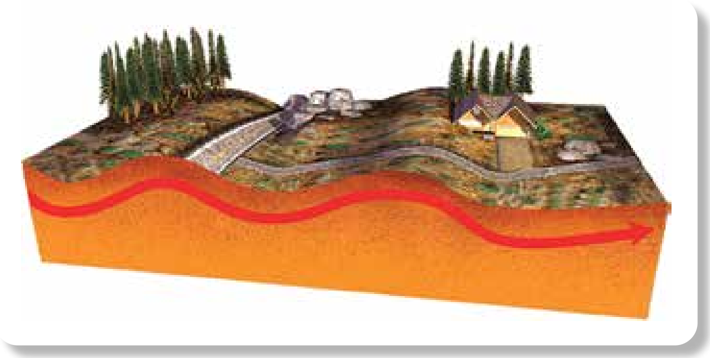
(b) For each example, indicate how we can demonstrate that this wave carries energy.

(c) For each example state the source of energy forming the wave.

2. Soundwaves travel more efficiently through wood than they do through air. Suggest a reason for this.

3. Mechanical waves will not travel through space. Why not?


Making waves in heavy ropes can use a lot of energy in a training session.


During an earthquake, the ground can transmit energy as the waves go through it.


Sand sprinkled on a drum skin shows the waves formed when it vibrates.

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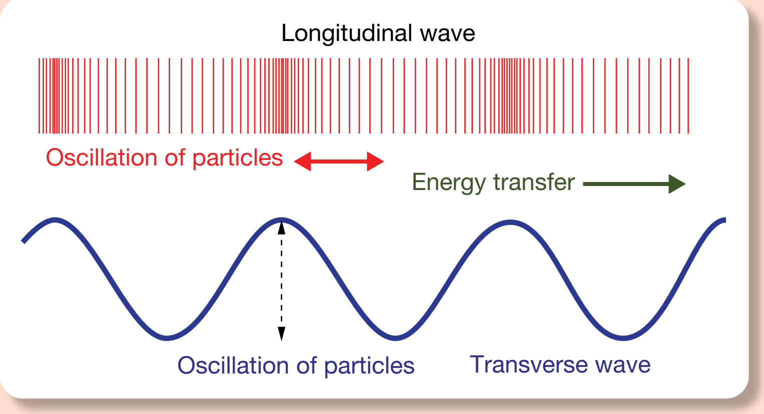
3.3 Transverse and Longitudinal Matter Waves

Conduct investigations to explain and analyse differences between transverse and longitudinal waves.

Transverse and longitudinal matter waves

Transverse matter waves

Particle motion in a medium carrying a transverse wave is oscillation at 90° to the direction of propagation of the energy.



Longitudinal matter waves

Particle motion in a medium carrying a longitudinal wave is oscillation back and forth in the same plane as the direction of propagation of the energy.

General properties of waves

- The **wavelength** of a wave is the distance from one point on the wave to the next identical point on the wave. This is measured in centimetres or metres.
- The **period** of a wave is the time it takes one wavelength of the wave to pass a point, usually measured in seconds.
- The **frequency** of a wave is the number of wavelengths that pass a point each second. Frequency is measured in hertz (Hz) where 1 Hz = 1 oscillation per second.
- The **energy** carried by a wave depends on its frequency and amplitude. The higher the frequency and the larger the amplitude, the more energy the wave carries.
- The **amplitude** of a wave is the distance from the **zero displacement position** of the matter particles to a maximum displacement position (a **crest** or **trough**). Measured in m or cm.

Transverse waves only

- The **zero displacement position** indicates where the particles would be if no energy was being transferred through the medium.
- A **crest** is a position of maximum upward displacement of a particle – the 'top of the wave'.
- A **trough** – position of maximum downward displacement of a particle of the medium carrying the wave – the 'bottom of the wave'.
- In a transverse wave, the direction of the oscillation of particles in matter is at 90° to the direction of the transfer of energy.

Longitudinal waves only

- Rarefactions – position in a longitudinal wave where particles are closer together than when undisturbed – higher pressure region.
- Compressions – position in a longitudinal wave where particles are further apart than when undisturbed – lower pressure region.
- The centre positions of both **rarefactions** and **compressions** are positions of zero displacement in a longitudinal wave.
- In a longitudinal wave, the direction of oscillation of particles in matter is back and forth along the direction of the transfer of energy.

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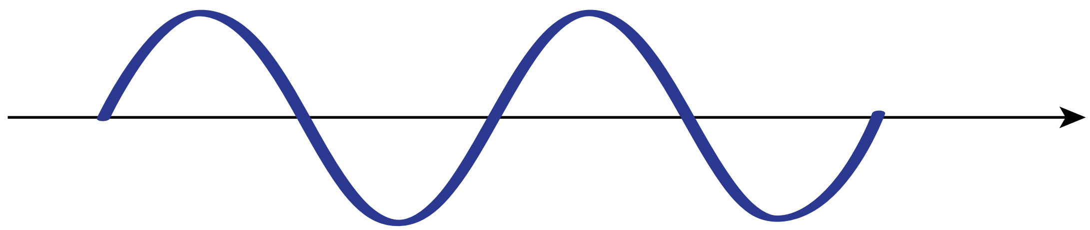
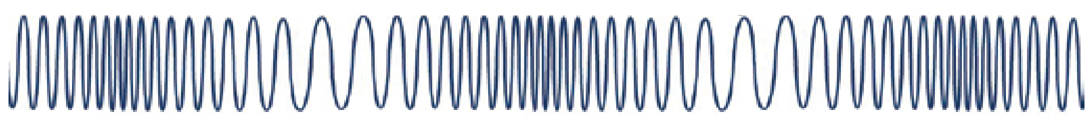
Sample Questions

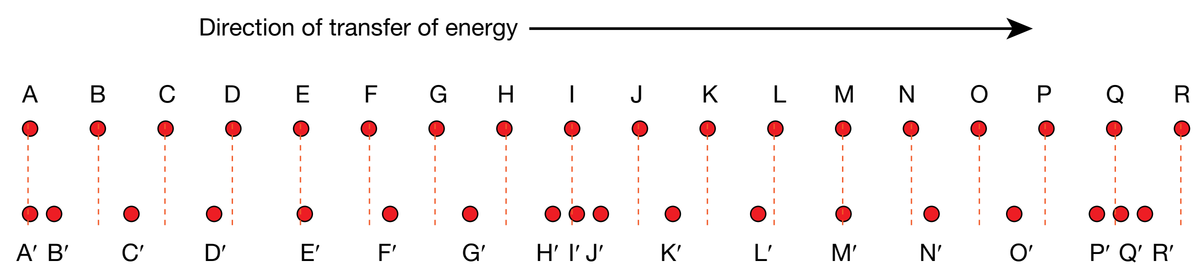
1. Label the features of the transverse wave below. Label two different wavelengths.



2. Label the features of the longitudinal wave below. Label two different wavelengths.



3. The diagram shows the undisturbed positions of the particles in a medium (first row of dots A to R), and their positions when a longitudinal wave passes through the medium (second row of dots, A′ to R′). Vertical lines mark the zero displacement positions of each particle in the medium.



On the diagram label:
(a) Two wavelengths.
(b) A compression.
(c) A rarefaction.
(d) Two particles at maximum displacement from their zero position.
(e) Two particles with zero displacement.

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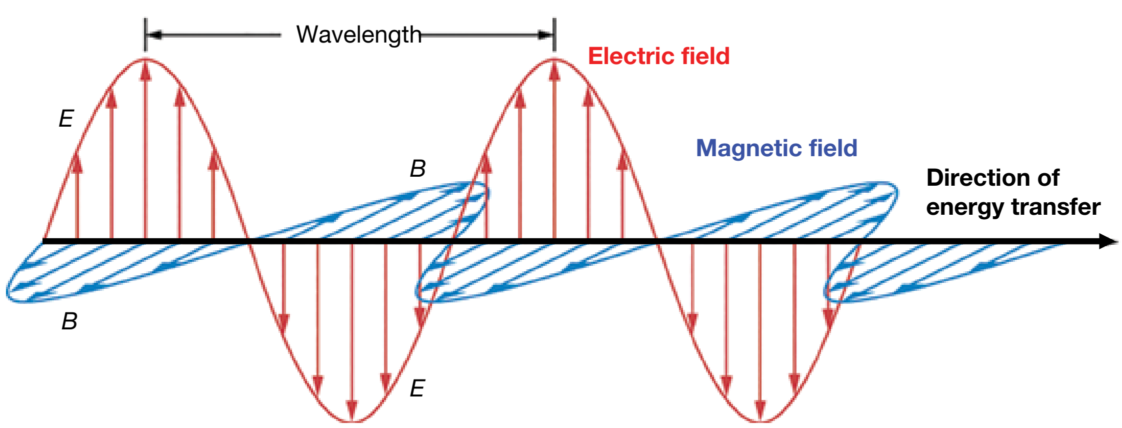
3.4 Electromagnetic Waves

Conduct investigations to explain and analyse differences between mechanical and electromagnetic waves.

Electromagnetic waves

Electromagnetic transverse waves are different from transverse matter waves in that they:

- Can travel through a vacuum.
- All travel at the speed of light (3×10^8 m s^{-1}) in a vacuum — they slow down a little in other media.
- Electromagnetic waves are **self-propagating alternating electric and magnetic fields**.
- Because the motion of the changing magnetic and electric fields are at right angles to the direction in which they carry energy, electromagnetic waves are classified as transverse waves.
- In electromagnetic waves, the energy is directly proportional to the frequency of the **photons** (the particles which make up EMR) which constitute the radiation as given by Planck's quantum theory equation, $\boldsymbol{E = hf}$, which you shall learn about later.
- The **wavelength** of an electromagnetic wave is the distance between the peaks of successive magnetic or electric field pulses.
- We usually refer to the **intensity** of an electromagnetic wave rather than to its amplitude. The intensity of an electromagnetic wave depends on the number of photons in the beam. Each photon will have energy dependent on its frequency.
- The **period** of an electromagnetic wave is the time for one wavelength to pass a given point.
- The **frequency** of an electromagnetic wave is is the number of wavelengths that pass a point each second. Frequency is measured in hertz (Hz).
- Because electromagnetic waves are really hard to draw, we usually draw them as transverse matter waves. The flaw in doing this is that the energy carried by a transverse wave is indicated by the amplitude of the wave.
- The best known electromagnetic waves are gamma rays, X-rays, ultraviolet rays, visible light rays, infra-red, microwaves, radio waves (which include TV waves).
- The shortest wavelength, highest frequency, most energetic rays are the gamma rays.



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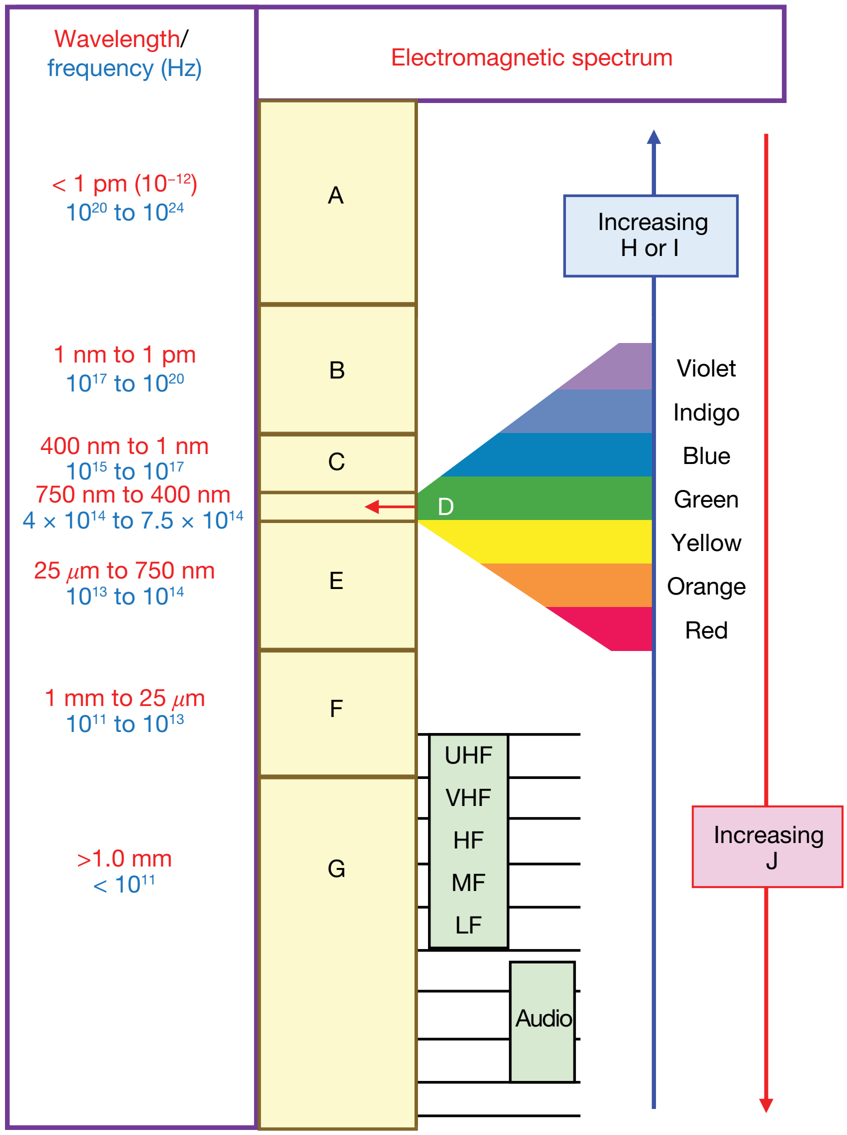
Sample Questions

Note: The wavelength and frequency data in this diagram is approximate only. It will vary slightly to that in other resources.

1. Research information to identify the labels in the diagram.



2. From this diagram of the electromagnetic spectrum:

(a) Which visible light photons would carry more energy, orange photons or blue photons? Justify your choice of answer.

(b) Is the energy carried by electromagnetic photons proportional to their wavelength, frequency or amplitude?

(c) An electromagnetic photon has a wavelength of 5.0 m. What type of ray is it?

(d) An electromagnetic photon has a wavelength of 5.0 cm. What type of ray is it?

(e) An electromagnetic photon has a wavelength of 5.0 mm. What type of ray is it?

(f) An electromagnetic photon has a wavelength of 5.0 μm. What type of ray is it?

(g) An electromagnetic photon has a wavelength of 5.0 nm. What type of ray is it?

3. (a) Which electromagnetic waves have the highest frequencies?

(b) Which electromagnetic radiation has the shortest wavelength?

(c) What is the same for all EMR in a vacuum?

(d) What is the relationship between the wavelength (λ), and frequency (f), of an EMR?

(e) Which electromagnetic radiation has the longest wavelength?

(f) What rays do police use in speed detection devices?

(g) Name three electromagnetic radiations which have a higher frequency than visible light

(h) How does visible EMR from the Sun differ from the non-visible EMR from the Sun?

(i) State a property that is shared by infra-red waves and ultraviolet waves?

(j) Which electromagnetic radiation has the lowest frequency?

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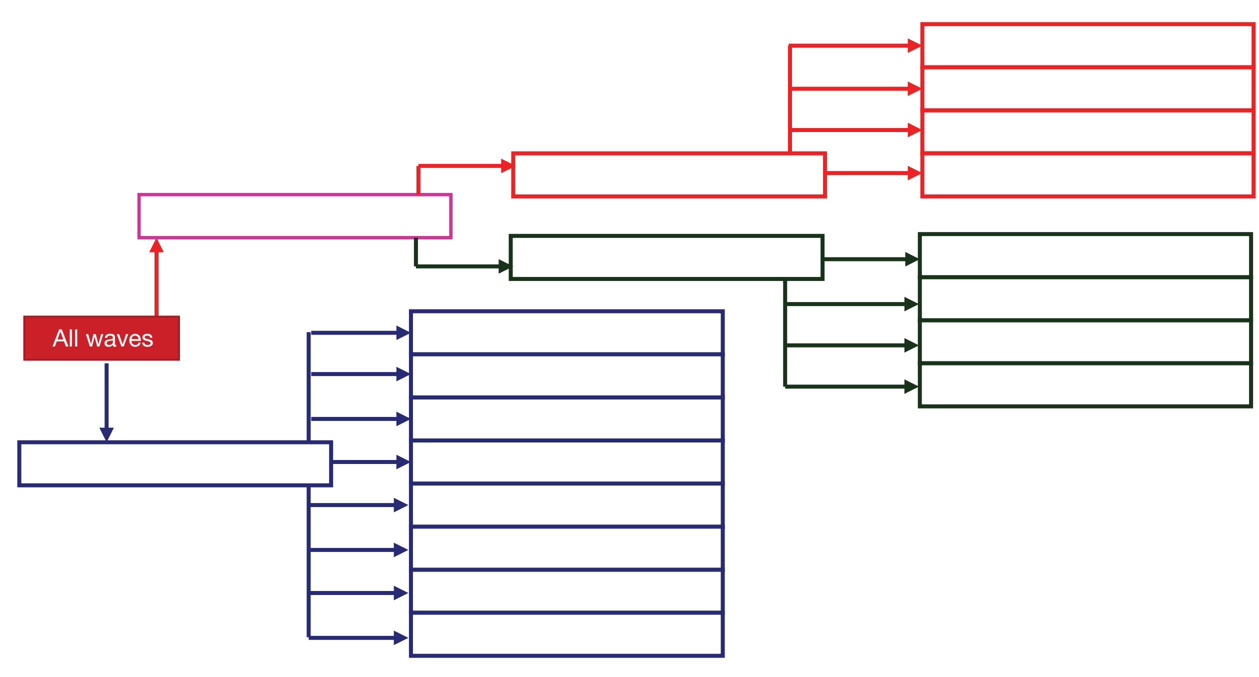
Some general wave questions

Sample Questions

1. Complete the diagram below to summarise the classification of waves.



2. Consider the diagram which has been drawn life size, and represents 2.1 seconds of time. Find:

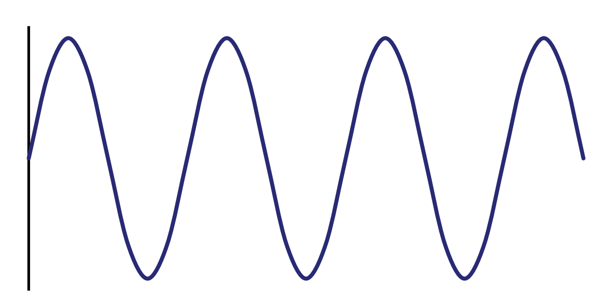
(a) The wavelength of the wave (λ).

(b) The amplitude of the wave (A).

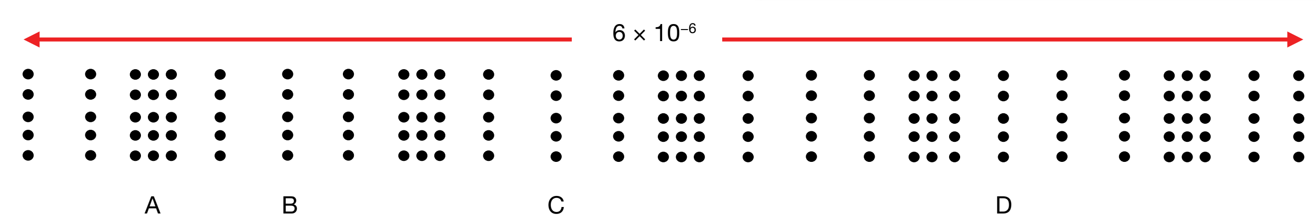
(c) The period of the wave (T).

(d) The frequency of the wave (f).

(e) The velocity of the wave (note $v = f\lambda$).



3. Consider the longitudinal wave shown.



(a) What is the wavelength of the wave?

(b) How many wavelengths are shown in the diagram?

(c) What is the distance AB on this diagram?

(d) What distance is represented by CD?

(e) If the energy took 0.8 s to travel from position C to position D, what is the period of the wave?

(f) Which way are the particles in the medium for this wave oscillating?

(g) If this wave was to carry more energy, which property would be different?

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3.5 The Wave Equation

Solve problems and/or make predictions by modelling, deriving and applying the following relationships to a variety of situations: $v = f\lambda$ and $f = \frac{1}{T}$.

The wave equation

- **Period and frequency:** The period of a wave motion is inversely proportional to its frequency. This applies to all forms of waves. This is represented mathematically by the equations shown.

$$T = \frac{1}{f} \quad \text{or} \quad f = \frac{1}{T}$$

Where T = period of the wave in s
f = frequency of the wave in s^{-1} (hertz, Hz)

- **Velocity, frequency, period and wavelength:** The relationships between velocity, frequency, period and wavelength is represented by the equations shown.

$$v = f\lambda \quad \text{or} \quad v = \frac{\lambda}{T}$$

Where v = velocity of the wave in m s^{-1}
λ = wavelength of the wave in m
T = period of the wave in s
f = frequency of the wave in s^{-1} (hertz, Hz)

Sample Questions

1. Sound travels through air at about 330 m s^{-1}. Find the wavelength of the sound of frequency 200 Hz.

2. The 'G' above middle C on the piano has a frequency of 492 Hz. Calculate its wavelength.

3. The speed of light is 3×10^8 m s^{-1}. A laser light has a wavelength of about 650 nm (nm = $\times 10^{-9}$ m).

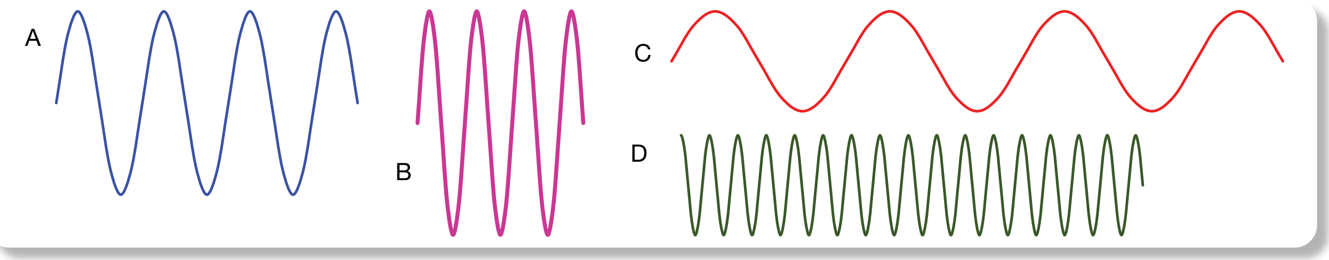
(a) Calculate the frequency of this light.

(b) What colour is it?

4. The table shows information about various colours of visible light. Calculate the missing data, rounding your answer to the nearest 5 units. (Note that these figures will differ slightly in various resources.)

Colour	Frequency range ($\times 10^{12}$ Hz)	Wavelength range (nm)
Red	430 to 480	
Orange	480 to 510	
Yellow	510 to 540	
Green		490 to 560
Blue		450 to 490
Violet		390 to 450

5. Each wave below has been drawn life size. Each represents 1.0 s of time. For each find its frequency, wavelength, amplitude, period and velocity.



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6. What is the frequency of a wave with a period of 0.005 s?
(A) 20 Hz
(B) 100 Hz
(C) 200 Hz
(D) 2000 Hz

7. What is the wavelength of a 30 Hz wave moving at 60 m s^{-1}?
(A) 0.5 m
(B) 2.0 m
(C) 20 m
(D) 1800 m

8. A 500 Hz wave has a wavelength of 0.4 m. How long does it take to travel 600 m?
(A) 0.8 s
(B) 1.2 s
(C) 1.5 s
(D) 3.0 s

9. A wave has a frequency of 400 Hz and a wavelength 2.5 m. What is its velocity?
(A) 100 m s^{-1}
(B) 160 m s^{-1}
(C) 1000 m s^{-1}
(D) 10 000 m s^{-1}

10. A 20 m s^{-1} wave completes one vibration as it moves 2 m. What is its frequency?
(A) 2 Hz
(B) 10 Hz
(C) 20 Hz
(D) 40 Hz

11. Find the speed of a 4 cm wave which has a frequency of 8 Hz.
(A) 0.32 m s^{-1}
(B) 0.50 m s^{-1}
(C) 12 m s^{-1}
(D) 32 m s^{-1}

12. What is the period of a 400 Hz wave?
(A) 1.3×10^{-6} s
(B) 2.5×10^{-3} s
(C) 750 000 s
(D) 1.2×10^{10} s

13. What is the frequency of a 400 nm light wave?
(A) 4×10^{9} Hz
(B) 4×10^{12} Hz
(C) 7.5×10^{12} Hz
(D) 7.5×10^{14} Hz

14. The frequency of a wave is 2.00 Hz and its speed is 5.00 m s^{-1}. Find its wavelength
(A) 0.2 m
(B) 0.4m
(C) 1.25 m
(D) 2.5 m

15. What is the frequency of a 0.02 m wave that has a speed of 0.4 m s^{-1}?
(A) 0.05 Hz
(B) 0.5 Hz
(C) 2.0 Hz
(D) 20 Hz

16. A 3.0 m wave has a frequency of 14 Hz. At what speed does this wave travel?
(A) 0.21 m s^{-1}
(B) 4.67 m s^{-1}
(C) 42 m s^{-1}
(D) 588 m s^{-1}

17. The speed of a 0.8 m wave is 65 m s^{-1}. What is the frequency of the wave?
(A) 52 Hz
(B) 81.25 Hz
(C) 136.4 Hz
(D) 250 Hz

18. A wave has a frequency of 500 Hz and a speed of 200 m s^{-1}. Find its wavelength.
(A) 0.4 m
(B) 2.5 m
(C) 700 m
(D) 100 000 m

19. An electromagnetic wave has a frequency of 101 700 000 hertz. What is its wavelength?
(A) 2.95×10^{6} m
(B) 0.33 m
(C) 2.95 m
(D) 3.3 m

20. 330 m s^{-1} soundwaves have a frequency of 250 Hz. What is their wavelength?
(A) 4×10^{-3} m
(B) 0.76 m
(C) 1.32 m
(D) 83 000 m

21. What is the frequency of a 650 nm light ray?
(A) 2.2×10^{-6} Hz
(B) 4.6×10^{12} Hz
(C) 7.5×10^{12} Hz
(D) 4.6×10^{14} Hz

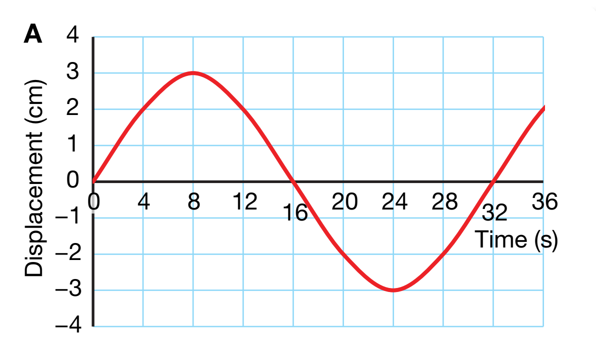
3.6 Analysing Wave Graphs

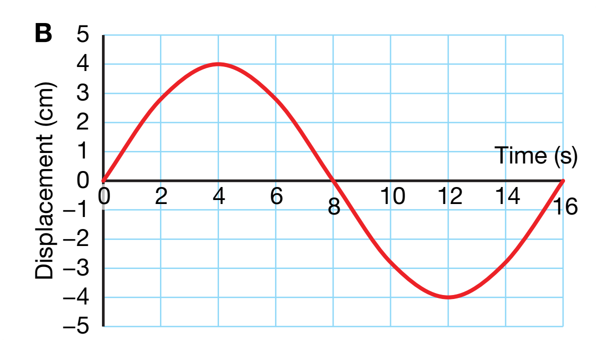
Construct and/or interpret graphs of displacement versus time and displacement versus position of transverse and longitudinal waves and relate the features of these graphs to the wave characteristics of velocity, frequency, period, wavelength, displacement and amplitude.

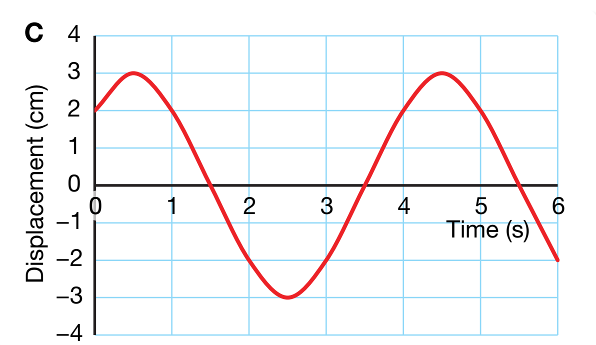
Analysing wave graphs 1

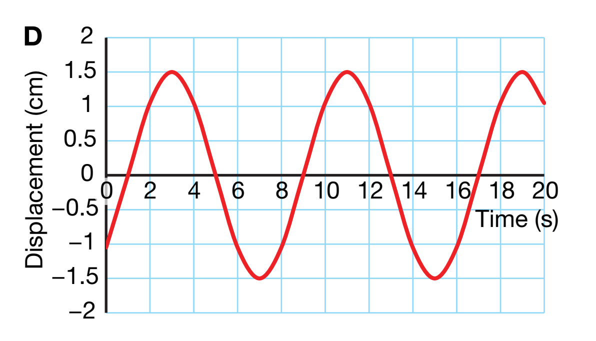
Sample Questions

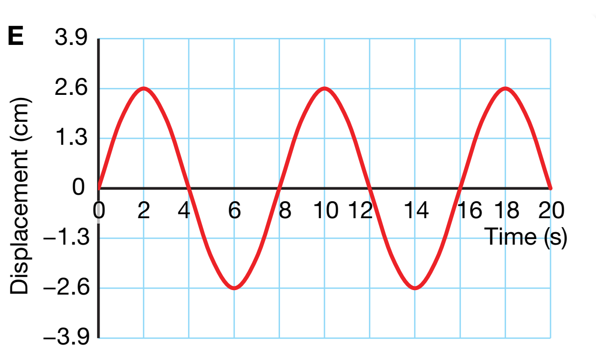
1. The graphs show the displacement of a particle in several waves, each of wavelength 1.6 m. Determine, for each wave, the: (a) Period. (b) Frequency. (c) Amplitude. (d) Speed of the wave.

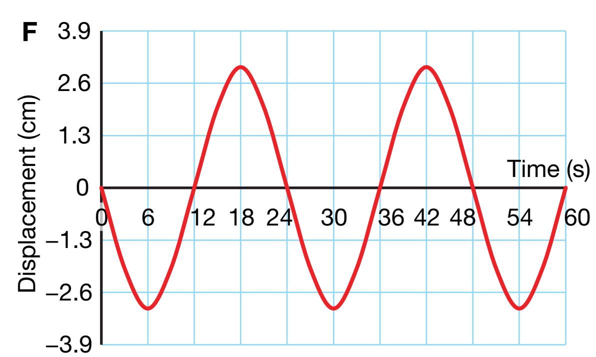












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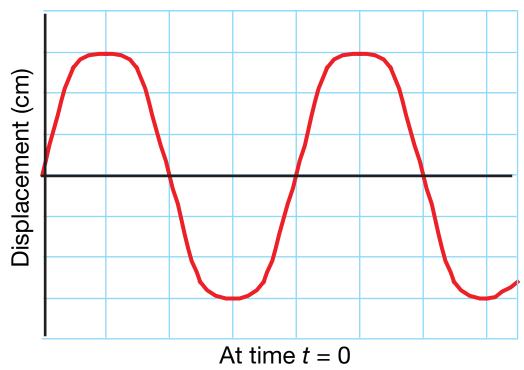
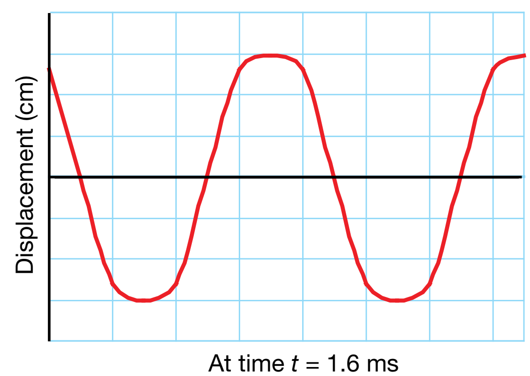
Analysing wave graphs 2

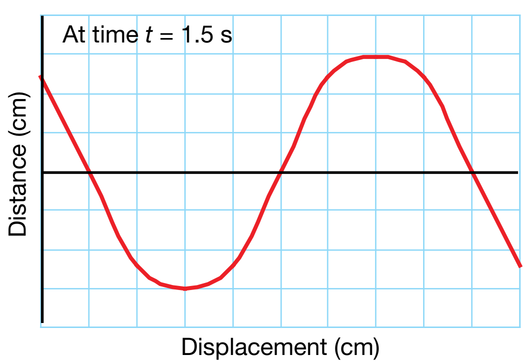
Sample Questions

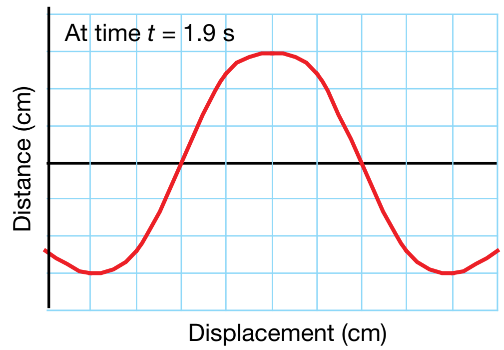
1. The graphs show two positions of a wave 1.6 s apart. Calculate the period and frequency of the wave.



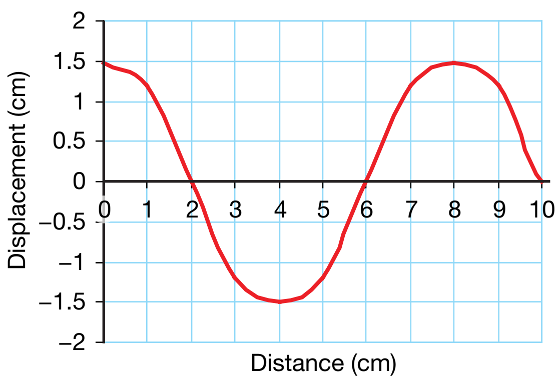


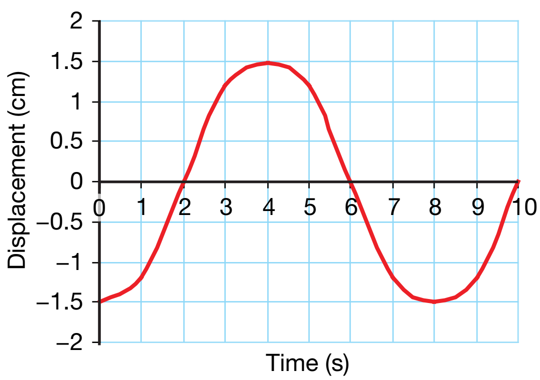
2. The graphs show two positions of a wave 0.4 s apart. Calculate the period and frequency of the wave.





3. The graphs show the displacement of a water particle plotted against the distance the wave travels and time. Analyse these graphs to determine the wavelength, period, frequency, amplitude and speed of the water wave.





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Answers

3.1/2 Role Of the Medium Carrying Wave Energy

1. (a), (b) Answers for (a) and (b) combined.

(i) Water waves at the beach can knock you over because they carry large amounts of energy.

(ii) Soundwaves from loud music can cause the windows to rattle and the curtains to move in our homes.

(iii) Earthquake waves can cause cracks in roads and cause buildings to fall down.

(iv) If you thump one end of a long desk, someone else feels the energy transmitted through the desk to the other end.

(v) Ultrasound waves transmit energy which can be used to form an image of a baby in its mother's womb.

(c) (i) Water waves are formed as the movement of air (wind) transfers energy into the surface water.

(ii) Soundwaves are produced by the input of energy through plucking strings, blowing into instruments, or hitting them with a drum stick.

(iii) Earthquake waves are cause by the interaction of tectonic plates in the crust, and by convection currents in molten magma under the crust.

(iv) The energy source is provided by the person who thumps the desk.

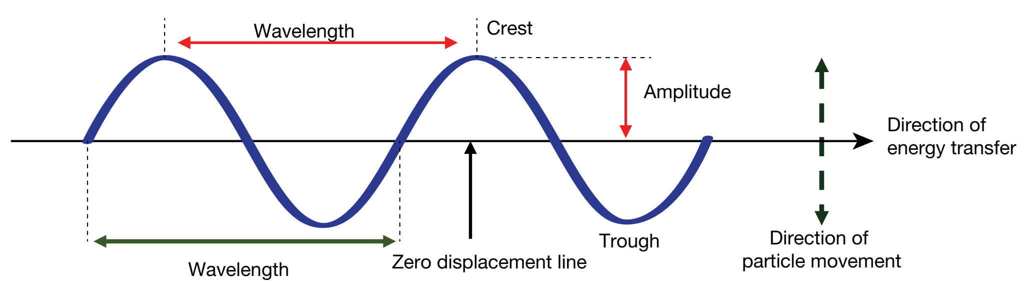
(v) Ultrasound waves are produced from the very high frequency vibration of 'transducers' in the electronic equipment which produces them.

2. The wood is denser than air – its particles are closer together, and the transfer of energy is therefore more efficient because its particles will interact more than air particles.

3. In space there is no medium to transmit energy from one particle to the next.

3.3 Transverse and Longitudinal Matter Waves

1.



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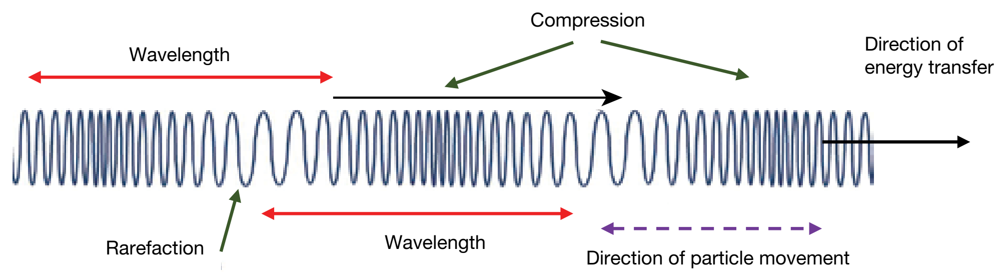
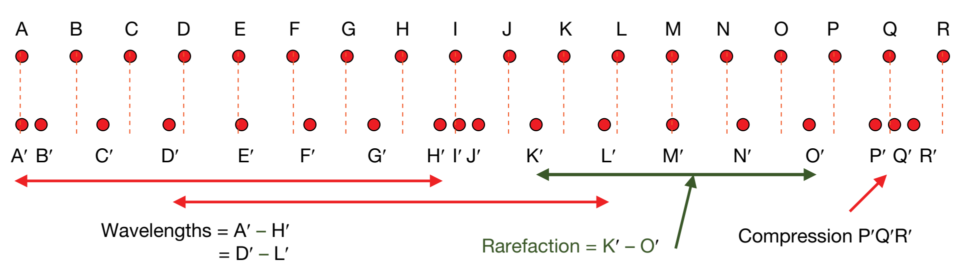


3.



Zero displacement particles = A′ and E′ and I′ and M′ and Q′
Maximum displacement particles = B′ and H′ and J′ and P′

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