

Exercise walk-through

7.1

Progressive waves

A-Level Physics

7.1 Progressive waves and the wave equation

Name: _____ Class: _____ Date: _____ **Total: 28 marks**

KEY WORDS progressive wave • wavelength • frequency • amplitude
• oscillate

Objective

Answer exam questions on **progressive waves** : what a wave transfers, the terms that describe it, reading its two graphs, and the **wave equation** $v = f\lambda$. Syllabus 7.1, learning outcomes 1, 2, 4, 5 and 6.

You must be able to:

- describe wave motion in a rope, a spring and a ripple tank, and state what a progressive wave transfers
- use the terms displacement, amplitude, wavelength, period, frequency and speed
- read the wavelength, period and amplitude from graphs of displacement against distance and against time

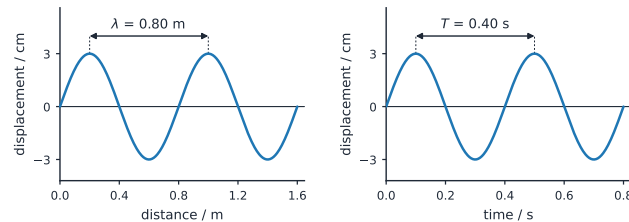
- derive $v = f\lambda$, and use it with kHz, MHz and ms

1 Key knowledge and worked examples

■ Key knowledge: waves and their terms

- a **progressive wave** transfers **energy** from one place to another without transferring matter: each particle **oscillates** about its own rest position (a rope's hump runs along while each piece moves up and down; a floating cork in a ripple tank bobs but does not travel)

Term	Meaning	Unit
displacement	the distance of a particle from its rest position, in a given direction	m
amplitude	the maximum displacement from the rest position	m
wavelength λ	the distance between two neighbouring points in phase, such as two crests	m
period T	the time for one complete oscillation	s
frequency f	the number of oscillations per unit time, $f = \frac{1}{T}$	Hz
speed v	the distance the wave travels per unit time	$\frac{\text{m}}{\text{s}}$



The same wave: a snapshot along the wave, and one particle over time

- a **displacement–distance** graph gives λ and the amplitude; a **displacement–time** graph gives T and the amplitude: read the axis label first
- the amplitude is measured from the rest position, never crest to trough

■ Key knowledge: the wave equation

Deriving it (2 marks): in one period T the wave moves forward one wavelength λ , so

$$v = \frac{\lambda}{T}; \text{ and } f = \frac{1}{T}, \text{ so } v = f\lambda.$$

- prefixes: 1 kHz = 10^3 Hz, 1 MHz = 10^6 Hz, 1 GHz = 10^9 Hz, 1 ms = 10^{-3} s

■ **Key knowledge: particle travel and wave travel**

A particle travels $4A$ in one complete oscillation, so $D = 4nA$ over n complete cycles. The wave travels $s = n\lambda$ in time $t = n/f$. These are different distances. A progressive-wave profile at $t + T/4$ is shifted by $\lambda/4$ in the propagation direction; points oscillate and do not travel with the profile.

■ **Worked example: reading the two graphs**

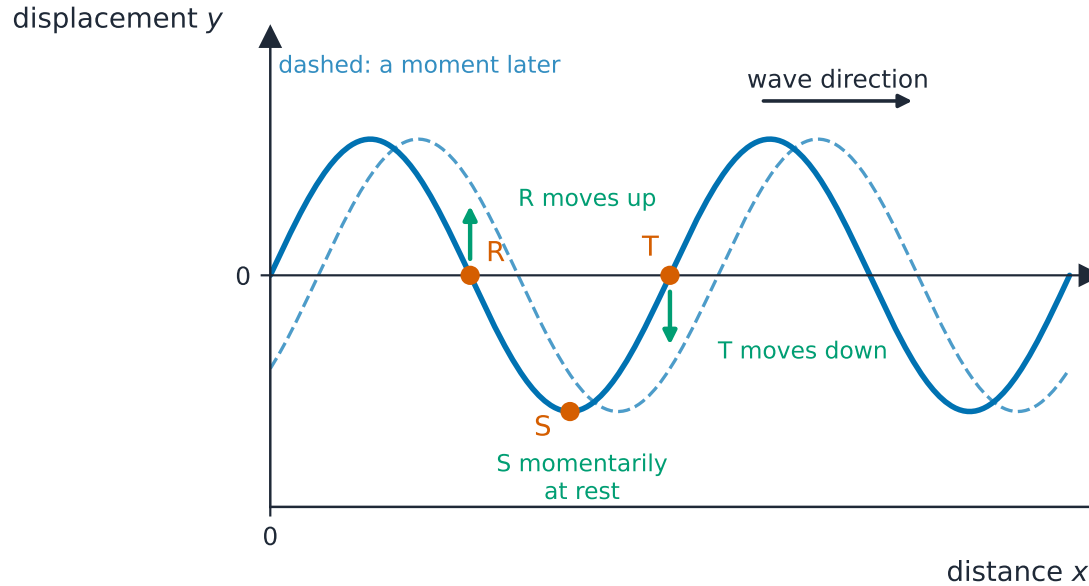
For the wave in the graphs above:

1. **Wavelength** – from the distance graph, crest to crest: $\lambda = 0.80$ m.
2. **Period and frequency** – from the time graph: $T = 0.40$ s, so $f = \frac{1}{T} = 2.5$ Hz.
3. **Amplitude** – 3.0 cm on either graph, not the 6.0 cm from crest to trough.
4. **Speed** – wave equation, $v = f\lambda = 2.5 \times 0.80 = 2.0 \frac{\text{m}}{\text{s}}$.

■ **Worked example: the wave equation with prefixes**

1. **Radio** – a station broadcasts at 97.5 MHz and radio waves travel at $3.00 \times 10^8 \frac{\text{m}}{\text{s}}$:
from $v = f\lambda$, $\lambda = \frac{v}{f} = \frac{3.00 \times 10^8}{97.5 \times 10^6} = 3.08$ m.
2. **Ultrasound** – 2.0 MHz in soft tissue at $1540 \frac{\text{m}}{\text{s}}$: $\lambda = \frac{v}{f} = \frac{1540}{2.0 \times 10^6} = 7.7 \times 10^{-4}$ m.
3. **Sound** – period 5.0 ms, wavelength 1.7 m: $v = \frac{\lambda}{T} = \frac{1.7}{5.0 \times 10^{-3}} = 340 \frac{\text{m}}{\text{s}}$.

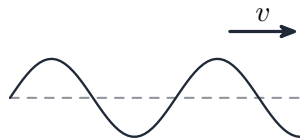
■ **Worked example: which way does a particle move?**



1. **Redraw** – draw the wave a moment later, moved a little in the direction of travel (dashed).
2. **Read off** – each particle moves straight up or down to reach the dashed wave: R moves up and T moves down.
3. **Crests and troughs** – a particle at a crest or a trough, such as S, is momentarily at rest.

Exercises 2.1·2.2

2.1 State what is transferred by a progressive wave, and what is not. [2]

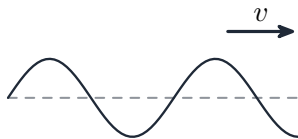


2.2 Define the **wavelength** of a progressive wave. [1]

wavelength

Exercises 2.1·2.2

2.1 State what is transferred by a progressive wave, and what is not. [2]



2.1

- a progressive wave transfers **energy**
- it does not transfer matter: the particles oscillate about fixed positions

2.2 Define the **wavelength** of a progressive wave. [1]

wavelength

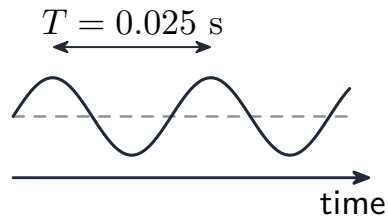
2.2

- the distance between two neighbouring points on the wave that are in phase (for example two crests)

Exercise 2.3

2.3 A wave has a period of 0.025 s. Calculate its frequency.

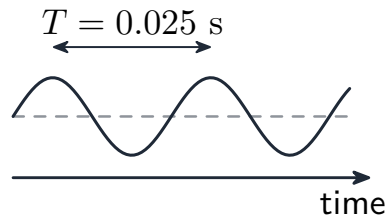
[1]



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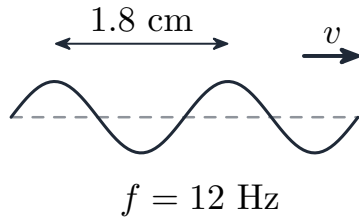


2.3

- $$f = \frac{1}{T} = \frac{1}{0.025 \text{ s}} = 40 \text{ Hz}$$

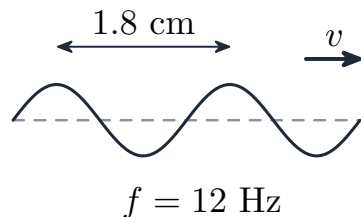
Exercise 2.4

2.4 Water waves in a ripple tank have a wavelength of 1.8 cm and a frequency of 12 Hz. Calculate their speed. [2]



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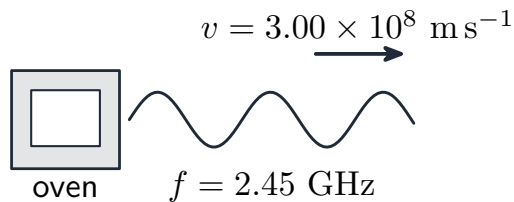
2.4

- wave equation, $v = f\lambda$, with $\lambda = 0.018 \text{ m}$

$$v = f\lambda = 12 \text{ Hz} \times 0.018 \text{ m} = 0.22 \frac{\text{m}}{\text{s}}$$

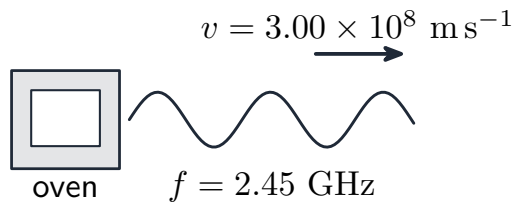
Exercise 2.5

2.5 A microwave oven uses waves of frequency 2.45 GHz , travelling at $3.00 \times 10^8 \frac{\text{m}}{\text{s}}$. Calculate their wavelength. [2]



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$$\lambda = \frac{v}{f} = \frac{3.00 \times 10^8 \text{ m s}^{-1}}{2.45 \times 10^9 \text{ s}^{-1}} = 0.122 \text{ m}$$

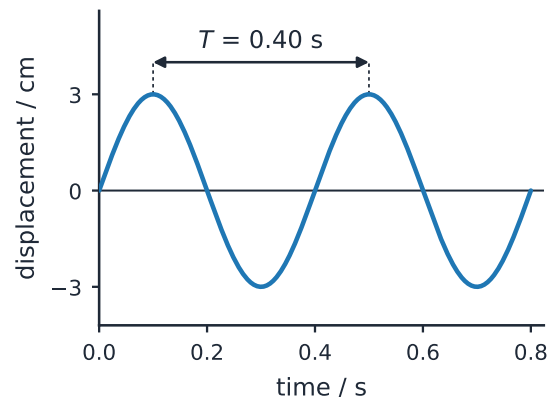
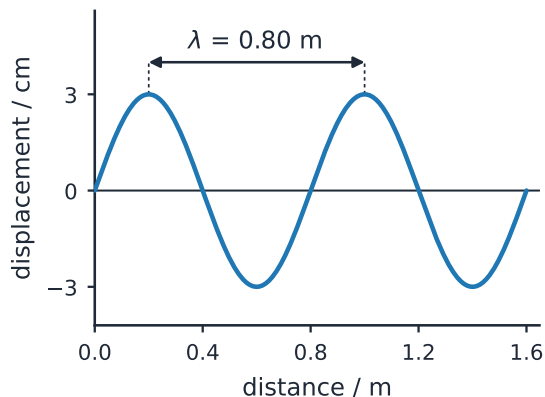
2.5

- from $v = f\lambda$: $\lambda = \frac{v}{f}$

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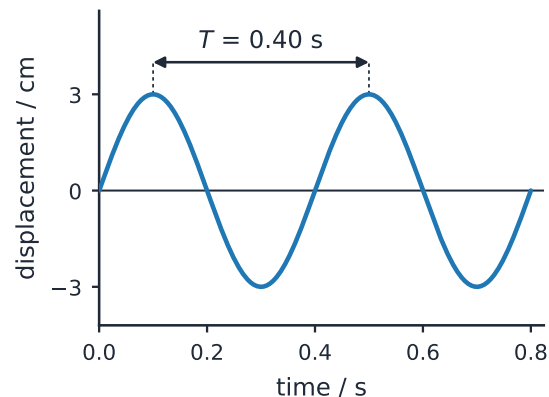
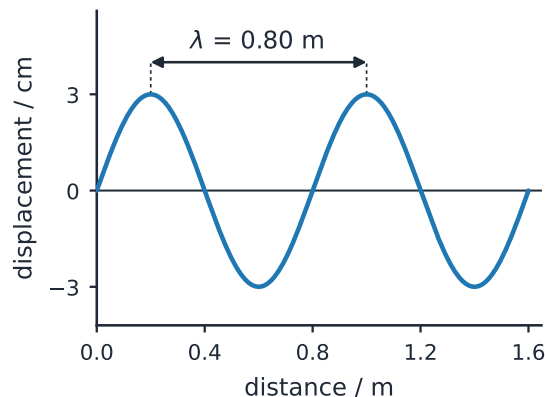
Exercise 2.6

2.6 A progressive wave has amplitude 2.0 mm, wavelength 0.60 m and frequency 25 Hz. During three complete cycles, find the particle's total distance, the distance travelled by the wave and the elapsed time. Describe how its profile changes after a quarter period.[5]



Exercise 2.6

2.6 A progressive wave has amplitude 2.0 mm, wavelength 0.60 m and frequency 25 Hz. During three complete cycles, find the particle's total distance, the distance travelled by the wave and the elapsed time. Describe how its profile changes after a quarter period.[5]



2.6

$D = 4nA = 4 \times 3 \times 2.0 = 24 \text{ mm}$; $s = n\lambda = 3 \times 0.60 = 1.8 \text{ m}$; $t = n/f = 3/25 = 0.12 \text{ s}$.
The profile shifts by $\lambda/4 = 0.15 \text{ m}$ in the propagation direction; particles oscillate about fixed equilibrium positions.

Exercise 3.1

3.1 A cork floats on water as a wave passes. Which statement is correct? [1]

☐

A The cork moves along with the wave at the wave speed.

B The cork oscillates about a fixed position while the wave transfers energy past it.

C The cork stays still because water waves transfer no energy.

D The cork moves in the direction of the wave for half of each cycle and stays still for the other half.



Exercise 3.1

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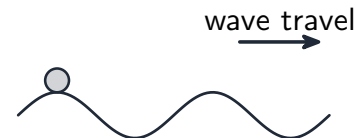
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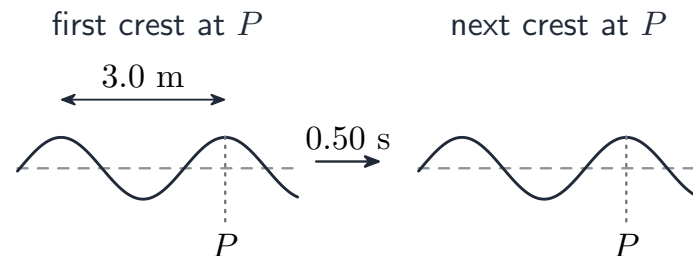
3.1 B

- a progressive wave transfers energy but not matter: the cork oscillates about its rest position
- **A** describes the matter moving with the wave, which does not happen

Exercise 3.2

3.2 The time between neighbouring crests passing a point is 0.50 s and the distance between neighbouring crests is 3.0 m. What is the speed of the wave? [1]

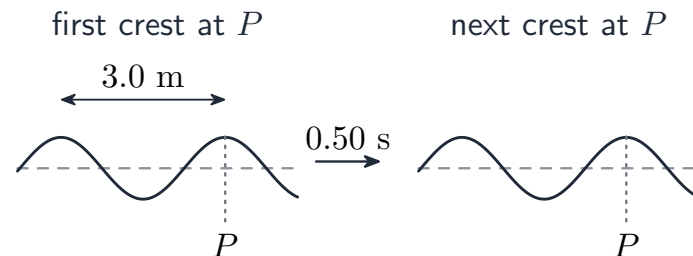
- ☐ **A** $1.5 \frac{\text{m}}{\text{s}}$
- B** $3.0 \frac{\text{m}}{\text{s}}$
- C** $6.0 \frac{\text{m}}{\text{s}}$
- D** $12 \frac{\text{m}}{\text{s}}$



Exercise 3.2

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- ☐ **A** $1.5 \frac{\text{m}}{\text{s}}$
- B** $3.0 \frac{\text{m}}{\text{s}}$
- C** $6.0 \frac{\text{m}}{\text{s}}$
- D** $12 \frac{\text{m}}{\text{s}}$



3.2 C

- $v = \frac{\lambda}{T} = \frac{3.0}{0.50} = 6.0 \frac{\text{m}}{\text{s}}$
- **A** multiplies instead of dividing

Exercise 3.3 (a)

3.3 A wave travels along a stretched rope. The wave has a wavelength of 1.20 m, and a point on the rope completes 15 oscillations in 6.0 s. The greatest displacement of the point from its rest position is 4.0 cm.

(a) State the amplitude of the wave.

[1]

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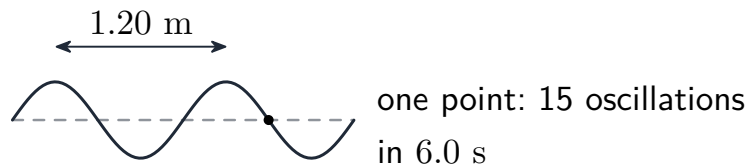
(a) **4.0** cm

Exercise 3.3 (b)

3.3 A wave travels along a stretched rope. The wave has a wavelength of 1.20 m, and a point on the rope completes 15 oscillations in 6.0 s. The greatest displacement of the point from its rest position is 4.0 cm.

(b) Calculate the frequency of the wave.

[2]

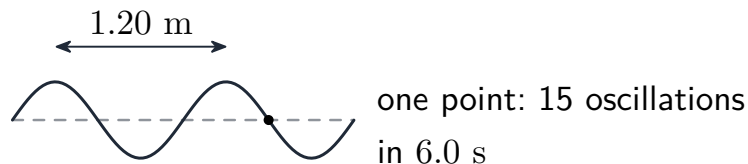


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(b) Calculate the frequency of the wave.

[2]



$$(b) f = \frac{\text{number of oscillations}}{\text{time}}$$

$$f = \frac{\text{number of oscillations}}{\text{time}} = \frac{15}{6.0 \text{ s}} = \mathbf{2.5 \text{ Hz}}$$

Exercise 3.3 (c)

3.3 A wave travels along a stretched rope. The wave has a wavelength of 1.20 m, and a point on the rope completes 15 oscillations in 6.0 s. The greatest displacement of the point from its rest position is 4.0 cm.

(c) Using the definitions of speed, frequency and wavelength, **show that** $v = f\lambda$. [2]

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(c) Using the definitions of speed, frequency and wavelength, **show that** $v = f\lambda$. [2]

(c) in one period T the wave travels one wavelength, so $v = \frac{\lambda}{T}$

- $f = \frac{1}{T}$, so $v = f\lambda$

Exercise 3.3 (d)

3.3 A wave travels along a stretched rope. The wave has a wavelength of 1.20 m, and a point on the rope completes 15 oscillations in 6.0 s. The greatest displacement of the point from its rest position is 4.0 cm.

(d) Calculate the speed of the wave.

[1]

Exercise 3.3 (d)

3.3 A wave travels along a stretched rope. The wave has a wavelength of 1.20 m, and a point on the rope completes 15 oscillations in 6.0 s. The greatest displacement of the point from its rest position is 4.0 cm.

(d) Calculate the speed of the wave.

[1]

$$(d) \ v = f\lambda = 2.5 \times 1.20 = \mathbf{3.0} \frac{\text{m}}{\text{s}}$$

Exercise 3.3 (e)

3.3 A wave travels along a stretched rope. The wave has a wavelength of 1.20 m, and a point on the rope completes 15 oscillations in 6.0 s. The greatest displacement of the point from its rest position is 4.0 cm.

(e) State the distance along the rope between a crest and the nearest trough. [1]

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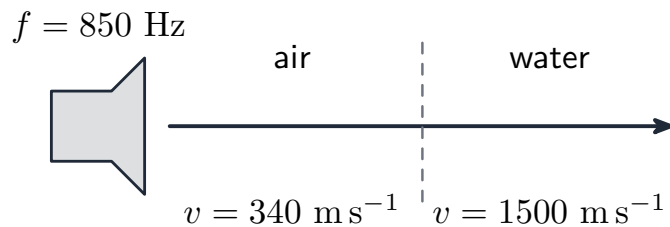
(e) half a wavelength, **0.60** m

Exercise 3.4 (a)

3.4 A loudspeaker emits sound of frequency 850 Hz into air, where the speed of sound is $340 \frac{\text{m}}{\text{s}}$.

(a) Calculate the wavelength of the sound.

[2]

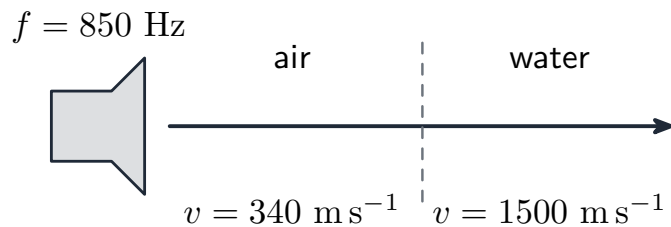


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(a) Calculate the wavelength of the sound.

[2]



(a) from $v = f\lambda$: $\lambda = \frac{v}{f}$

$$\lambda = \frac{v}{f} = \frac{340}{850} = \mathbf{0.40 \text{ m}}$$

Exercise 3.4 (b)

3.4 A loudspeaker emits sound of frequency 850 Hz into air, where the speed of sound is $340 \frac{\text{m}}{\text{s}}$.

(b) Calculate the period of the sound.

[1]

Exercise 3.4 (b)

3.4 A loudspeaker emits sound of frequency 850 Hz into air, where the speed of sound is $340 \frac{\text{m}}{\text{s}}$.

(b) Calculate the period of the sound.

[1]

$$(b) T = \frac{1}{f} = \frac{1}{850} = \mathbf{1.2 \times 10^{-3} \text{ s}}$$

Exercise 3.4 (c)

3.4 A loudspeaker emits sound of frequency 850 Hz into air, where the speed of sound is $340 \frac{\text{m}}{\text{s}}$.

(c) The same sound passes into water, where it travels at $1500 \frac{\text{m}}{\text{s}}$. State which of the frequency and the wavelength changes, and calculate its new value. [3]

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(c) the frequency stays the same, set by the source; the **wavelength** changes

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

$$\lambda = \frac{v}{f} = \frac{1500}{850} = \mathbf{1.8 \text{ m}}$$