Week 13

A-Level Physics

Homework bundle for this week

本周作业合集

exercises.lol

Contents 目录

A-Level Physics   Name: ____________   Score: ______

1. A progressive wave carries energy without moving matter along overall.

   ☐ True   ☐ False

2. In a transverse wave, the particles vibrate:

   ☐ perpendicular to the direction of travel

   ☐ parallel to the direction of travel

   ☐ in circles around the source

   ☐ not at all

3. As a sound source moves **toward** you, the pitch you hear is:

   ☐ higher than the source

   ☐ lower than the source

   ☐ the same as the source

   ☐ silent

4. All electromagnetic waves are transverse.

   ☐ True   ☐ False

5. Polarising a transverse wave means making it vibrate:

   ☐ in one plane only

   ☐ faster

   ☐ in all planes at once

   ☐ along the direction of travel

6. A wave has a period of 0.020 s. What is its frequency?

   ________________ Hz

7. Sound travelling through air is a longitudinal wave.

   ☐ True   ☐ False

8. A source moving toward an observer bunches the wavefronts ahead of it.

   ☐ True   ☐ False

9. In a vacuum, which EM wave travels the fastest?

   ☐ They all travel at the same speed

- ☐ gamma rays
- ☐ radio waves
- ☐ visible light

10. Sound waves can be polarised.

    ☐ True ☐ False

A-Level Physics

1. **True**

   Yes — the particles only oscillate about fixed points; the disturbance and its energy are what travel.

2. **perpendicular to the direction of travel**

   Transverse = vibration at right angles to the energy flow (a rope wave, light, water ripples).

3. **higher than the source**

   Moving toward you bunches the wavefronts, shortening the wavelength and raising the frequency you hear.

4. **True**

   Yes — every EM wave is transverse, and all travel at c in a vacuum.

5. **in one plane only**

   A polarising filter passes only the vibration lined up with its axis, leaving the wave in a single plane.

6. **50 Hz**

   $f = \frac{1}{T} = \frac{1}{0.020} = 50$ Hz.

7. **True**

   Yes — the air particles vibrate back and forth along the travel direction, making compressions and rarefactions.

8. **True**

   Yes — each new wavefront is sent from a point a little closer, so they crowd together in front.

9. **They all travel at the same speed**

   In a vacuum every EM wave travels at $c = 3.0 \times 10^8\ \frac{\text{m}}{\text{s}}$.

10. **False**

    No — sound is longitudinal (it vibrates along the travel), so there is no other plane to pick out.

7.1 Progressive waves

Name: ______________ Class: __________ Date: ____________ **Total: 26 marks**

KEY WORDS wave 波 • frequency 频率 • wavelength 波长 • progressive wave 行波 • speed 速率

Objective

Build the skills to answer exam questions on **progressive waves** — the wave terms, the wave equation, the CRO, and intensity.

You must be able to:

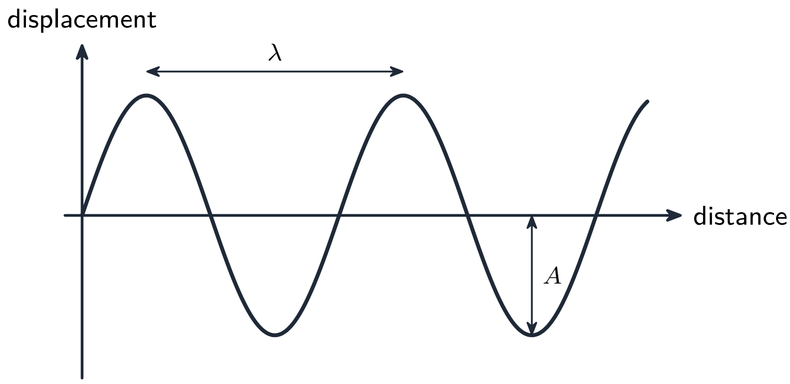
- use **displacement, amplitude, wavelength, period, frequency, phase difference**
- derive and use the **wave equation** $v = f\lambda$
- read a **CRO** trace and use **intensity** $\propto$ amplitude^2
- read two waves off one **displacement-distance** graph and superpose them
- say what a **progressive wave** transfers, and what it does not

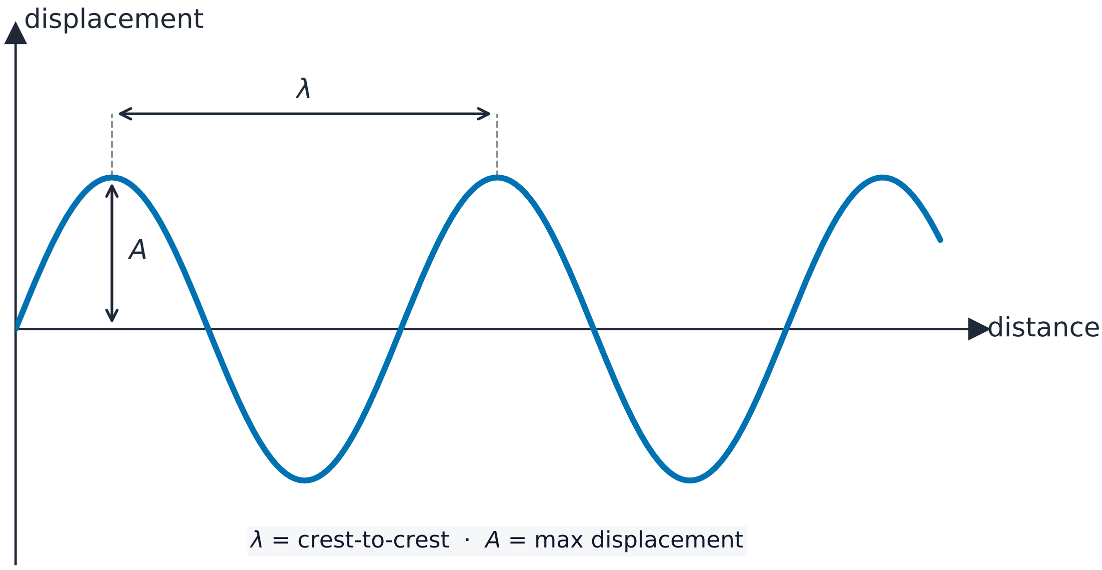
1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Wave terms

A progressive wave carries **energy** without moving matter overall:





A snapshot of a progressive wave

- **amplitude** A — maximum displacement; **wavelength** λ — distance between points in phase; **period** T — time for one cycle; **frequency** $f = 1/T$.
- points $\frac{1}{2}\lambda$ apart are **out of phase** (π); points λ apart are **in phase**.

What a wave is, and what it carries

A **progressive wave** is a disturbance that travels: each particle oscillates about its own rest position and passes the disturbance on to the next. Watch it three ways:

- a **rope** flicked at one end — a hump runs along the rope while every piece of rope only moves up and down;
- a stretched **spring** pushed along its length — compressions travel while each coil moves back and forth about the same place;
- a **ripple tank** — circular ripples spread out, but a floating cork bobs and does not travel with them.

So the wave transfers **energy** (and momentum) from one place to another, but **not matter**. That cork is the sentence the mark scheme wants.

Wave equation

In one period T the wave moves one wavelength, so $v = \lambda/T = f\lambda$.

CRO and intensity

Read the **period** from the screen: (cycles' width in divisions) × time-base. Then $f = 1/T$. **Intensity** $= \dfrac{\text{power}}{\text{area}}$ and intensity $\propto A^2$ — so doubling the amplitude makes the intensity **four times** larger.

2 Practice

Now apply the methods above.

2.1 Define **amplitude** and **wavelength**. [2]

2.2 A wave has frequency 50 Hz and wavelength 6.0 m. Find its **speed**. [2]

2.3 State the relationship between **period** and **frequency**. [1]

2.4 Two points on a wave are **half a wavelength** apart. State their **phase difference**. [1]

3 Exam-style questions

3.1 A wave travels at 340 m s^{-1} with frequency 170 Hz. Its wavelength is: [1]

- **A** 0.50 m
- **B** 2.0 m
- **C** 2.0 cm
- **D** 5.8×10^4 m

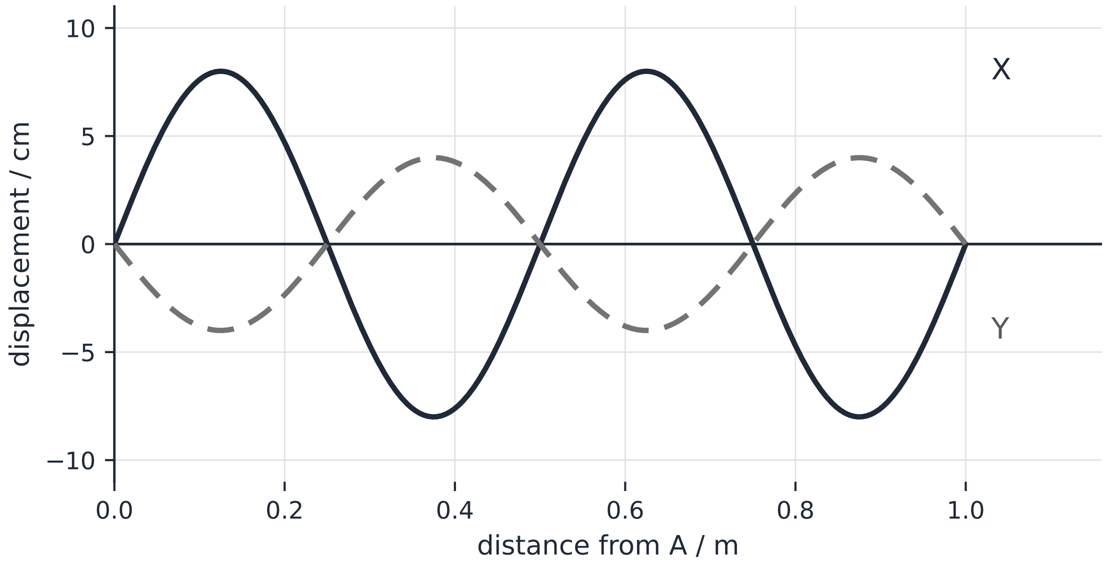
3.2 On a CRO the time-base is 5 ms per division, and one complete cycle of the trace spans 4 divisions. Calculate the **period** and the **frequency**. [3]

3.3 A wave travels forward exactly one wavelength during one complete oscillation of its source. Use this fact, with $f = 1/T$, to obtain an expression for the wave **speed**, and state what each symbol means. [2]

3.4 The amplitude of a wave is **doubled**. State what happens to its **intensity**. [1]

3.5 A cork floats on the surface of a pond as ripples pass under it. **State** what the ripples transfer past the cork, and what they do **not** transfer. [2]

3.6 Two progressive water waves, X and Y, travel along the same straight line from a point A. The graph shows the displacement of each wave against distance from A, at one instant. Both waves have a frequency of 12 Hz.

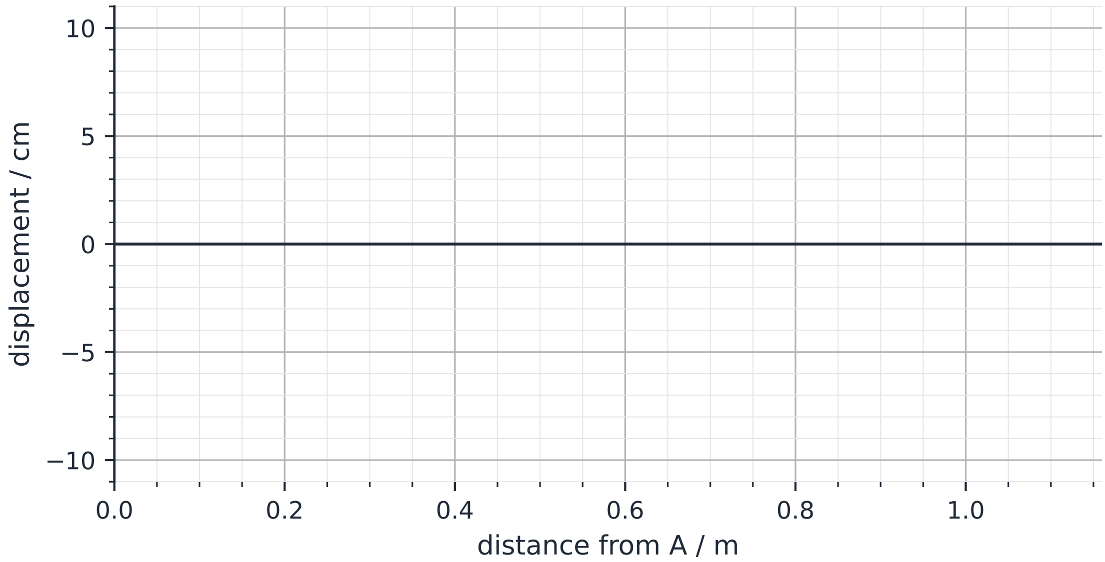


(a) **State** the amplitude and the wavelength of wave X. [2]

(b) **Determine** the speed of wave X. [2]

(c) **State and explain** whether X and Y are **coherent**. [2]

(d) The two waves superpose. On the grid below, **sketch** the displacement of the resultant wave against distance from A, at the same instant. [3]



(e) The intensity of wave X is I_X and that of wave Y is I_Y. **Determine** the ratio $\dfrac{I_X}{I_Y}$. [2]

Solutions

2.1 Amplitude — the maximum displacement from the rest position; **wavelength** — the shortest distance between two points oscillating **in phase**.

2.2 $v = f\lambda = 50 \times 6.0 = 300$ m s^{-1}.

2.3 $f = 1/T$.

2.4 π radians (or 180°) — exactly out of phase.

3.1 B — $\lambda = v/f = 340/170 = 2.0$ m.

3.2 $T = 4 \times 5$ ms $= 20$ ms $= 0.020$ s; $f = 1/T = 1/0.020 = 50$ Hz.

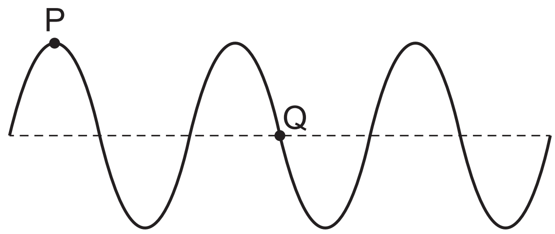
3.3 In one period T the wave moves one wavelength λ, so $v = \lambda/T$; since $f = 1/T$, $v = f\lambda$.

3.4 It becomes **four times** larger (intensity $\propto A^2$).

3.5 They transfer **energy** (the cork gains and loses energy as it bobs); they do **not** transfer matter — the cork oscillates about the same place and does not travel with the ripples.

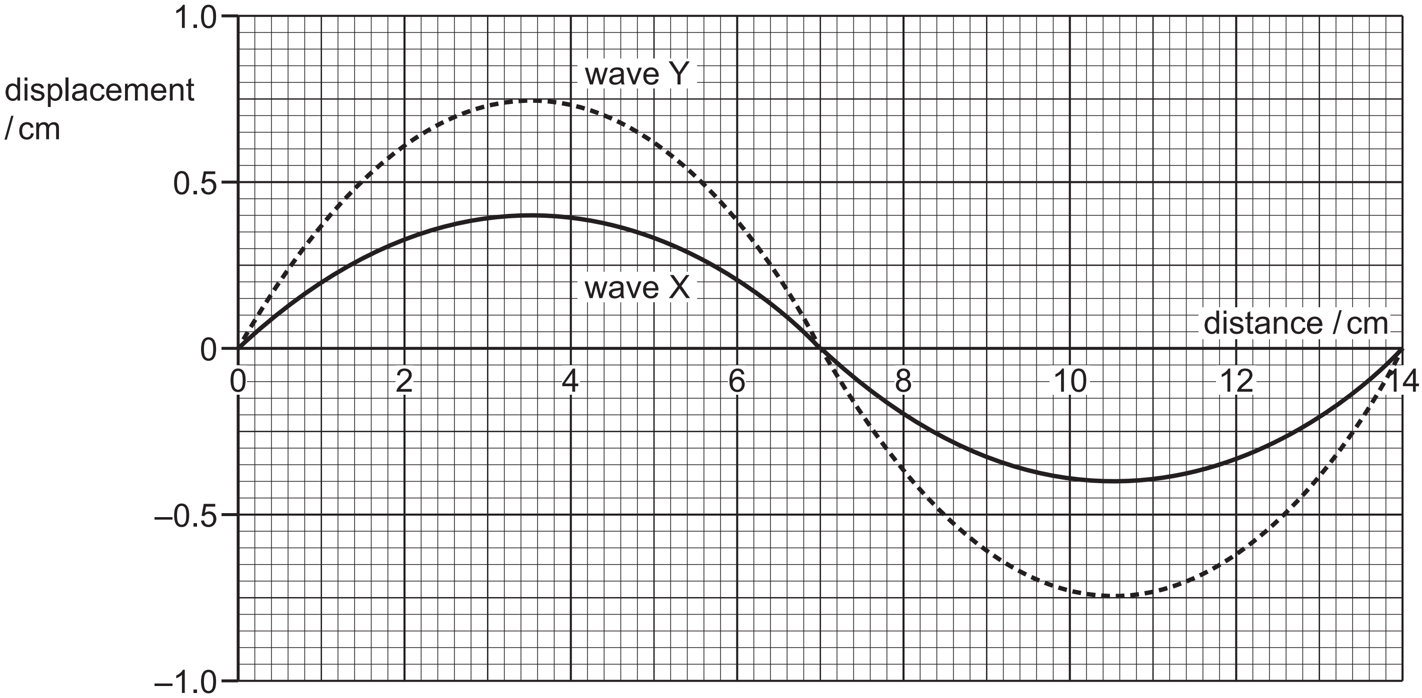
3.6 (a) Amplitude = 8.0 cm; wavelength = 0.50 m.
(b) $v = f\lambda = 12 \times 0.50 = 6.0$ m s^{-1}.
(c) **Coherent** — they have the same frequency and a **constant phase difference** (180°, i.e. π rad); coherence does not require equal amplitudes.
(d) A single wave of the same wavelength, 0.50 m, of amplitude 8.0 − 4.0 = 4.0 cm, in phase with **X** — a crest wherever X has a crest, because X is the larger of the two.
(e) Intensity $\propto$ (amplitude)^2, so $\dfrac{I_X}{I_Y} = \left(\dfrac{8.0}{4.0}\right)^2 = 4.0$.

25 What is the phase difference between points P and Q on the progressive wave shown in the diagram?



A 180° **B** 450° **C** 540° **D** 720°

26 The graph shows the variation of displacement with distance for two progressive waves X and Y of the same type in the same medium.



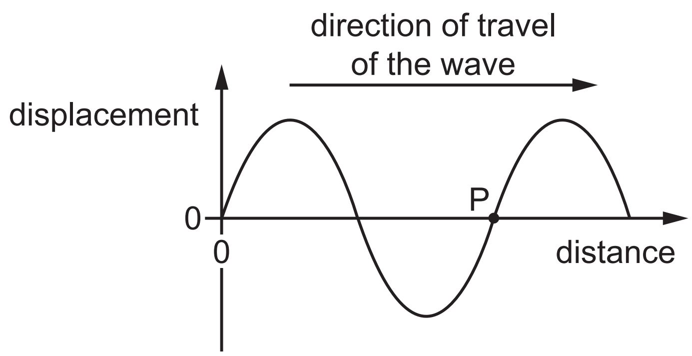
The intensity of wave X is I.

What is the intensity of wave Y?

A $0.28I$ **B** $0.53I$ **C** $1.9I$ **D** $3.5I$

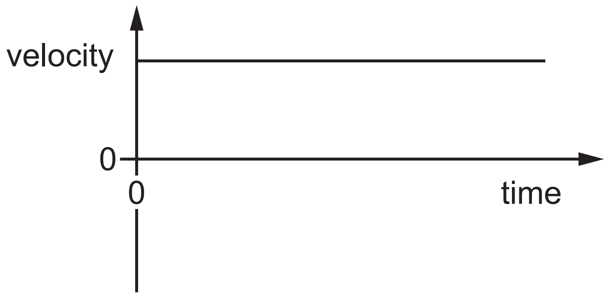
24 A transverse progressive wave travels along a string.

The graph shows the variation with distance of the displacement of the string at time $t = 0$.

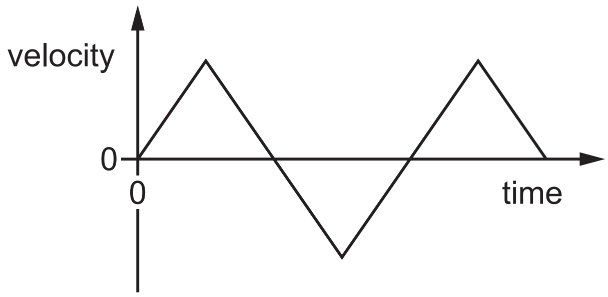


Which graph represents the variation with time of the velocity of point P on the string?

A



B



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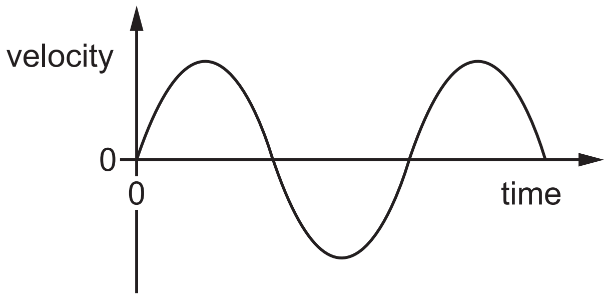
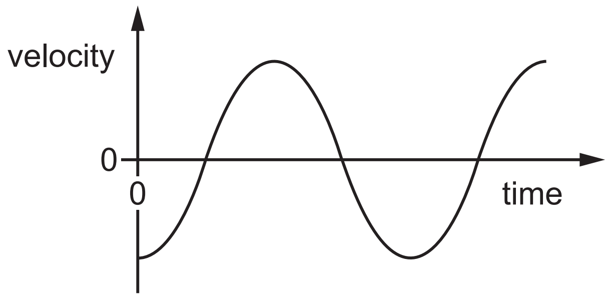


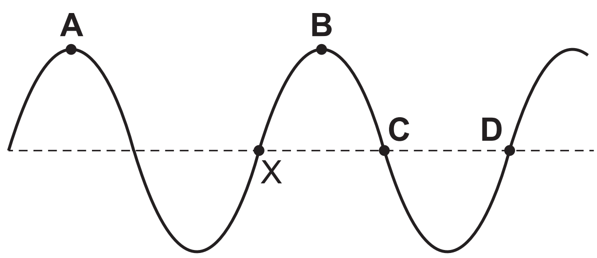
D



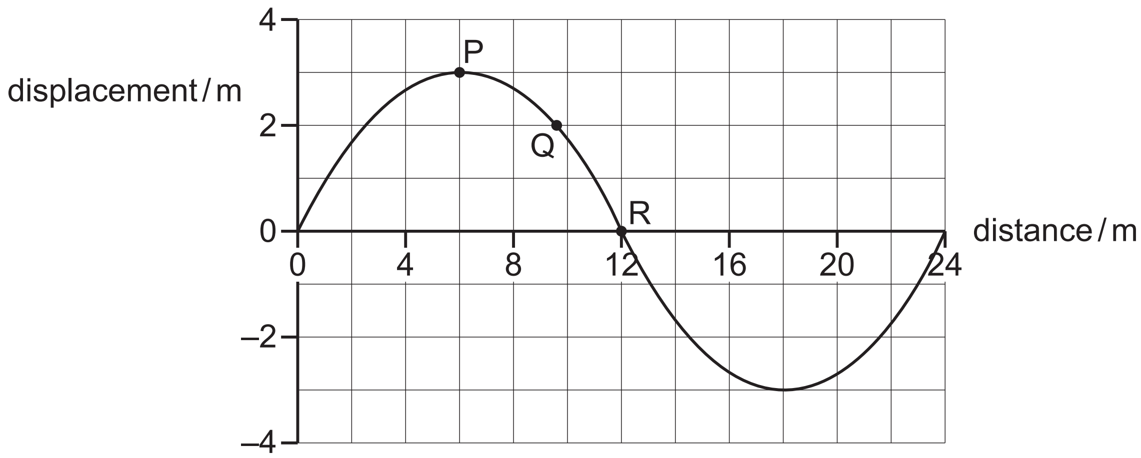
26 The diagram shows a progressive transverse wave on a stretched string at one instant in time.

One point on the string is labelled X.

Which point on the string is 270° out of phase with X?



24 The graph shows the variation with distance along the wave of the displacement of water particles at a particular instant in time for a transverse water wave.



P, Q and R show the positions of three water particles in the wave.

Which particle has the greatest speed at the instant shown?

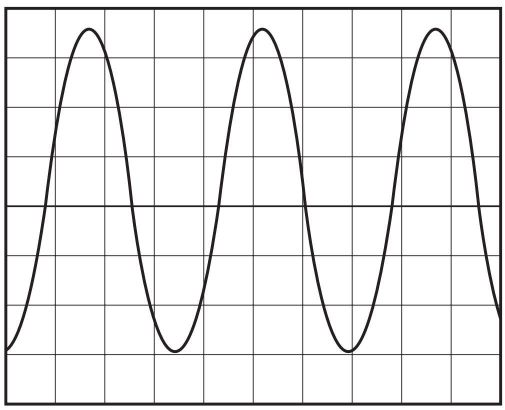
A all have the same speed

B particle P

C particle Q

D particle R

26 A wave is displayed on an oscilloscope.



The oscilloscope settings are:

time–base: $300\,\mu s\,div^{-1}$

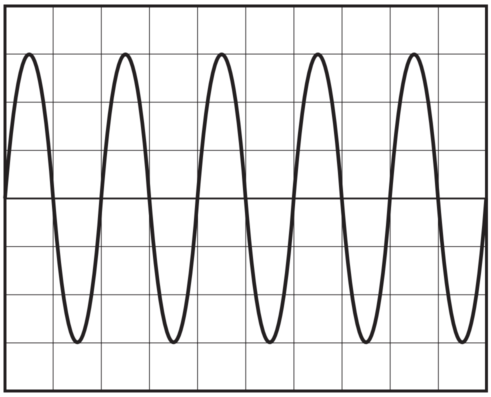
y-gain: $40\,\mu V\,div^{-1}$.

What is the frequency of the wave?

A 130 Hz **B** 950 Hz **C** 1100 Hz **D** 7100 Hz

20 A microphone is connected to a cathode-ray oscilloscope (CRO). The diagram shows the waveform on the display of the CRO when the microphone detects a sound.

The y-gain is set to $1\,V\,div^{-1}$. The time-base is set to $2.0\,ms\,div^{-1}$.



Which row gives the amplitude and frequency of the waveform?

	amplitude / V	frequency / Hz
A	3	125
B	3	250
C	6	125
D	6	250

5 **(a)** Use the definitions of speed v, frequency f and wavelength λ to derive the wave equation

$$v = f\lambda.$$

[2]

(b) A source of sound waves of frequency 236 Hz is travelling at a constant velocity of $20\,\mathrm{m\,s^{-1}}$.

A stationary observer has a microphone connected to a cathode-ray oscilloscope (CRO). The microphone detects the sound waves as the source moves directly towards the observer.

The resulting trace on the CRO is shown in Fig. 5.1.

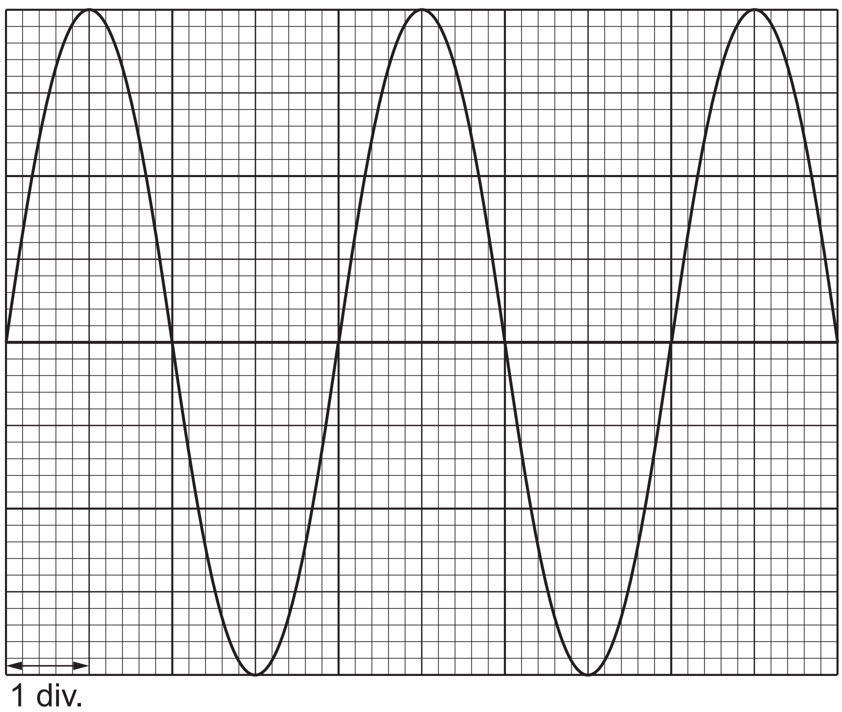


Fig. 5.1

The time-base on the CRO is set to $1.0\,\mathrm{ms\,div^{-1}}$.

(i) Calculate the frequency of the sound waves detected by the microphone.

frequency = ... Hz [2]

(ii) Determine the speed of the sound in air.

speed of sound = ... $m\,s^{-1}$ [2]

[Total: 6]

3 Two progressive water waves X and Y travel along a straight line from point A to point B. The variation of displacement of the waves with distance from A at an instant in time is shown in Fig. 3.1.

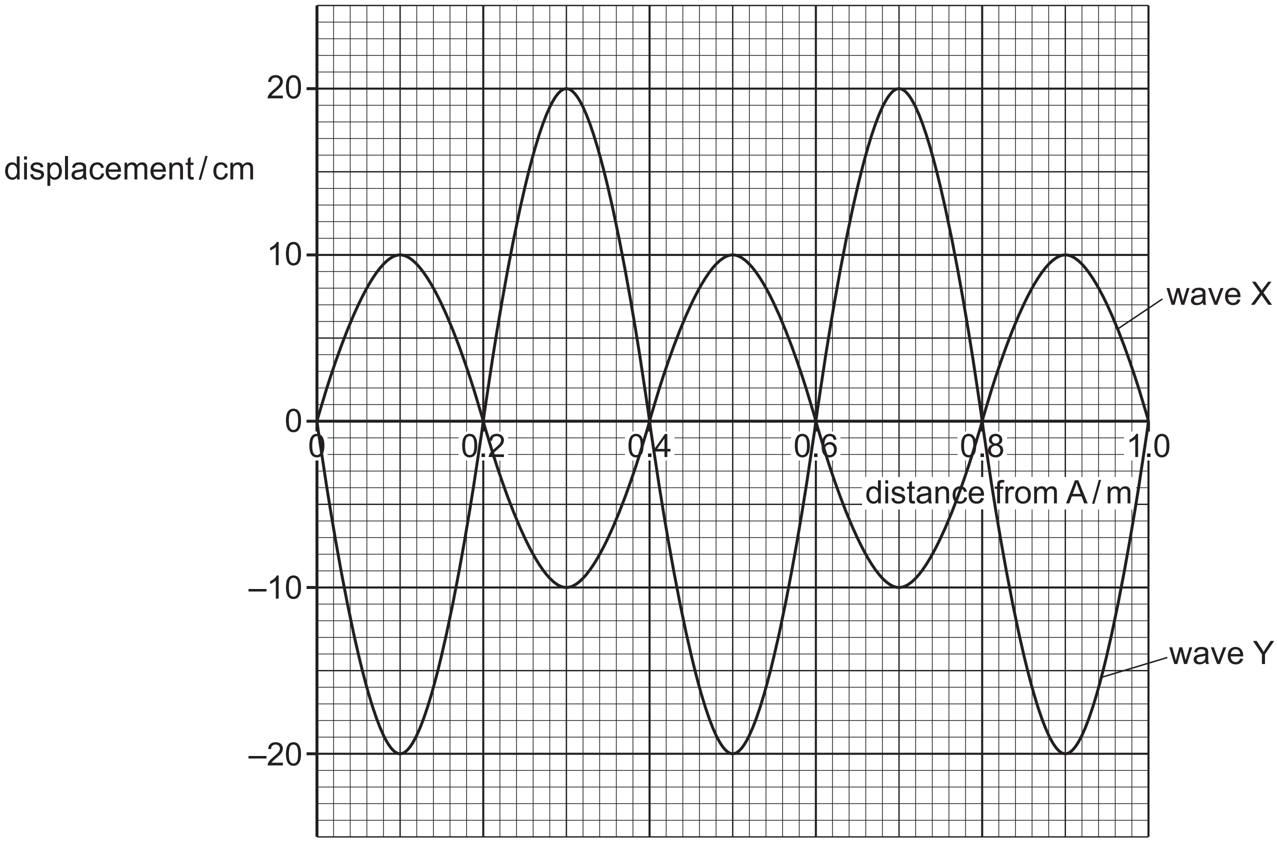


Fig. 3.1

(a) State the amplitude of wave X.

amplitude = ... cm [1]

(b) Both waves have frequency 16 Hz.

(i) Determine the speed of wave X.

speed = ... $m\,s^{-1}$ [2]

(ii) State and explain whether X and Y are coherent.

....

....

.... [1]

(c) Wave X and wave Y superpose to form a resultant wave.

On Fig. 3.2, sketch the variation of displacement of the resultant wave with distance from A at the instant of time shown in Fig. 3.1.

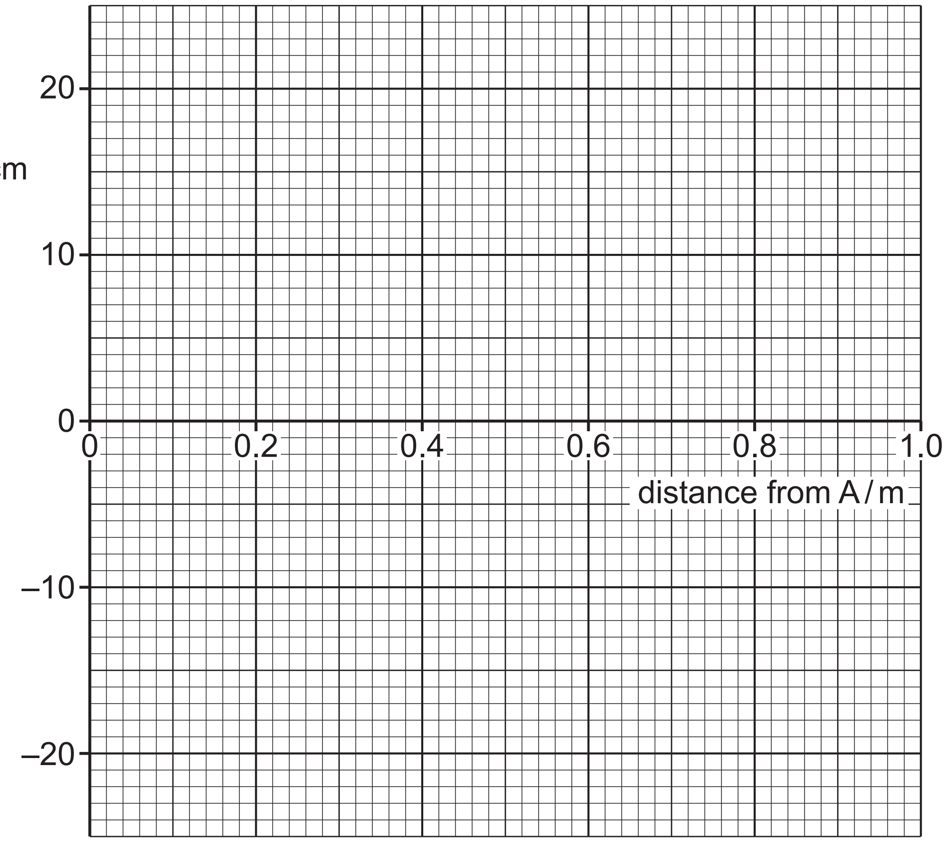


Fig. 3.2

[2]

(d) The intensity of wave X is I_X. The intensity of wave Y is I_Y.

Use Fig. 3.1 to determine the ratio $\frac{I_X}{I_Y}$.

ratio = ... [2]

[Total: 8]

A-Level Physics: **m25 12**

25 A progressive wave of frequency 300 Hz is travelling with a speed of 600 m s^{-1}.

What is the phase difference between two points on the wave that are a distance of 0.50 m apart?

A 45° **B** 90° **C** [illegible] **D** 360°

7.2 Transverse and longitudinal waves

Name: ____________ Class: ________ Date: __________ **Total: 14 marks**

KEY WORDS longitudinal 纵波 • transverse 横波 • electromagnetic wave 电磁波 • wave 波 • compression 压缩

Objective

Build the skills to answer exam questions on **transverse and longitudinal waves** — comparing them and reading their graphs.

You must be able to:

- compare **transverse** 横波 and **longitudinal** 纵波 waves
- give examples of each and identify **compressions** and **rarefactions**
- interpret displacement–distance and displacement–time graphs

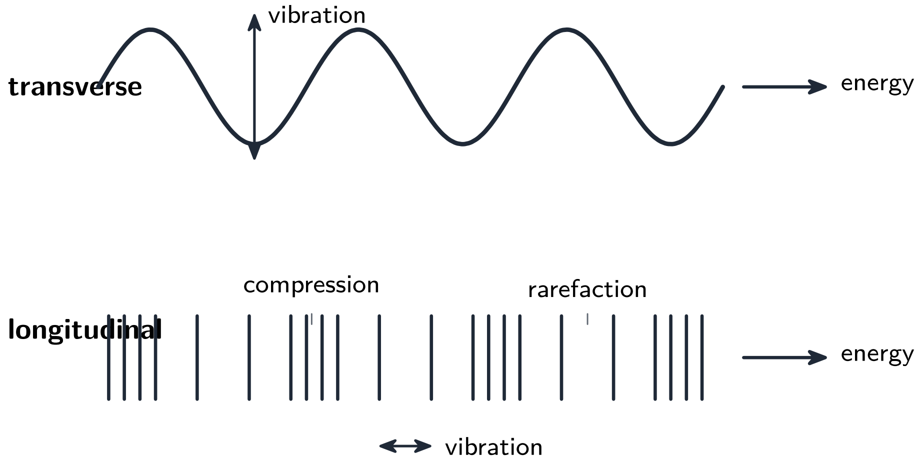
1 Worked examples

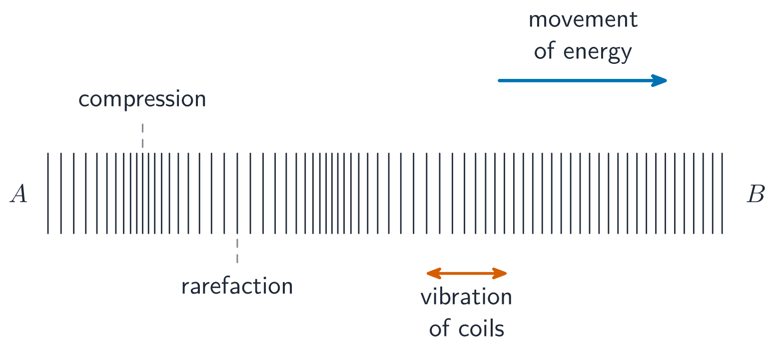
Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Transverse vs longitudinal

- **Transverse:** particles vibrate **perpendicular** to the energy travel (rope, all EM waves, water ripples).
- **Longitudinal:** particles vibrate **parallel** to the energy travel; the wave is **compressions** and **rarefactions** (sound, slinky squashes).

A key difference often tested: only **transverse** waves can be **polarised** (restricted to one plane of vibration); longitudinal waves **cannot** (covered fully in 7.5).





A longitudinal wave on a slinky

■ Graphs

Both look like a **sine curve**. A **displacement–distance** graph gives the **wavelength** λ; a **displacement–time** graph gives the **period** T (then $f = 1/T$).

2 Practice

Now apply the methods above.

2.1 State the difference between a **transverse** and a **longitudinal** wave. [2]

2.2 Give **one** example of a transverse wave and **one** of a longitudinal wave. [2]

2.3 Name the two features that make up a **longitudinal** wave. [1]

2.4 State what you read from a **displacement–time** graph and from a **displacement–distance** graph. [2]

3 Exam-style questions

3.1 Which of these is a **longitudinal** wave? [1]

- **A** light
- **B** a wave on a rope
- **C** sound
- **D** water ripples

3.2 Sound is a longitudinal wave. Describe how the **air particles** move as the wave passes. [2]

3.3 State whether **all electromagnetic waves** are transverse or longitudinal. [1]

3.4 A displacement–time graph for a wave shows a period of 0.020 s. Calculate the

frequency. [2]

3.5 State **one** property that a **transverse** wave has but a **longitudinal** wave does not. [1]

Solutions

2.1 In a **transverse** wave the particles vibrate **perpendicular** to the direction of energy travel; in a **longitudinal** wave they vibrate **parallel** to it.

2.2 Transverse — any one: light/EM wave, wave on a rope, water ripple. Longitudinal — sound, slinky compression wave.

2.3 Compressions and **rarefactions**.

2.4 Displacement–time → the **period** T (and so frequency); displacement–distance → the **wavelength** λ.

3.1 C — sound.

3.2 The air particles vibrate **back and forth parallel** to the wave's direction, forming regions of high pressure (**compressions**) and low pressure (**rarefactions**).

3.3 Transverse.

3.4 $f = 1/T = 1/0.020 = 50$ Hz.

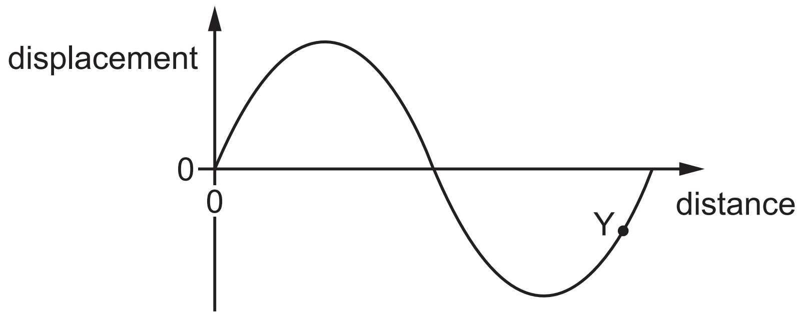
3.5 It can be **polarised** (restricted to one plane of vibration) — a longitudinal wave cannot.

24 Which row is correct for sound waves?

	can travel in a vacuum	can be polarised	can diffract through a gap
A	no	no	yes
B	yes	no	no
C	no	yes	no
D	no	yes	yes

25 A source emits a progressive sound wave in the horizontal direction. The wave travels away from the source in a direction towards the right.

The graph shows the variation of the displacement of the particles from their equilibrium positions with distance from the source at a particular instant in time. Displacements to the right of the equilibrium positions are shown as positive.



Position Y represents the displacement of a particle in the sound wave at a particular distance from the source at this instant.

Which statement about the motion of this particle is correct?

A The particle is moving away from the source.

B The particle is moving towards the source.

C The particle is moving upwards.

D The particle is moving downwards.

24 Which row describes a progressive longitudinal wave?

	transfers energy in a direction parallel to the oscillations	requires a medium to travel through	always travels at the same speed
A	false	false	true
B	false	true	true
C	true	false	false
D	true	true	false

A-Level Physics: **s25 11**

25 Which statement about longitudinal and transverse wave motion for a progressive wave is correct?

A All transverse and longitudinal waves require a medium for propagation.

B All transverse waves travel at the same speed, but longitudinal waves can travel at different speeds.

C In both transverse waves and longitudinal waves, a particle with zero displacement has a maximum speed.

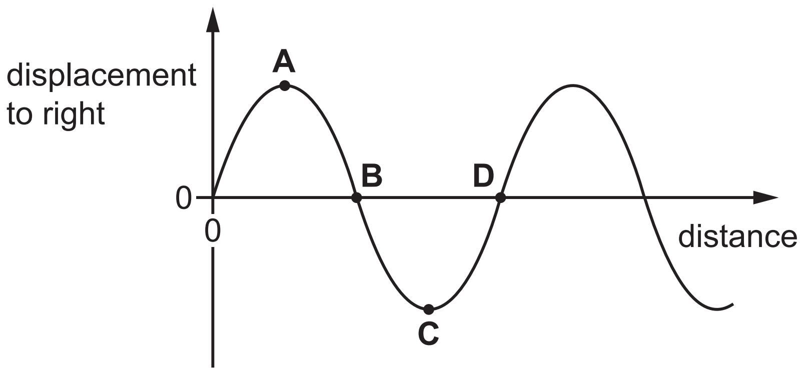
D In a longitudinal wave there is a net movement of particles in the direction of travel of the wave, but there is no net movement of particles in a transverse wave.

A-Level Physics: **s25 12**

25 A sound wave travels from the left to the right.

The graph shows the variation of the displacement to the right of particles in the sound wave with distance, at one instant.

Which letter represents the centre of a compression?



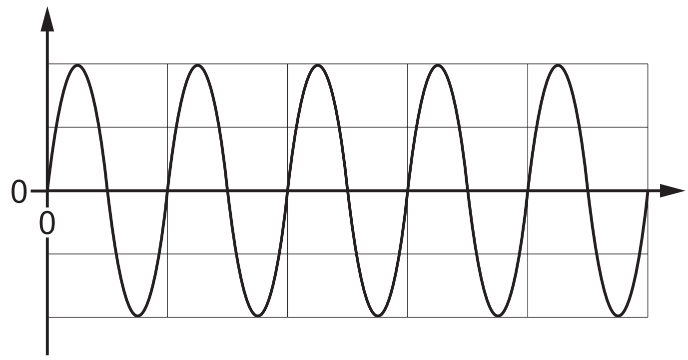
28 Which statement compares the behaviour of transverse and longitudinal waves?

- **A** Only longitudinal waves can be diffracted.
- **B** Only longitudinal waves can travel in free space.
- **C** Only transverse waves can be coherent.
- **D** Only transverse waves can be polarised.

A-Level Physics: **s25 14**

21 A progressive longitudinal wave is travelling horizontally from left to right.

A graphical representation of the wave at one instant in time is shown.



Which row could give the correct labels for the *x*-axis and *y*-axis of this graph?

	x-axis	*y*-axis
A	distance	displacement of particles to the right
B	distance	displacement of particles upwards
C	time	displacement of particles to the right
D	time	displacement of particles upwards

7.3 Doppler effect for sound waves

Name: ____________ Class: ________ Date: __________ **Total: 12 marks**

KEY WORDS frequency 频率 • wave 波 • source 波源 • stationary 静止 • observer 观察者

Objective

Build the skills to answer exam questions on the **Doppler effect** 多普勒效应 for sound (moving source, stationary observer).

You must be able to:

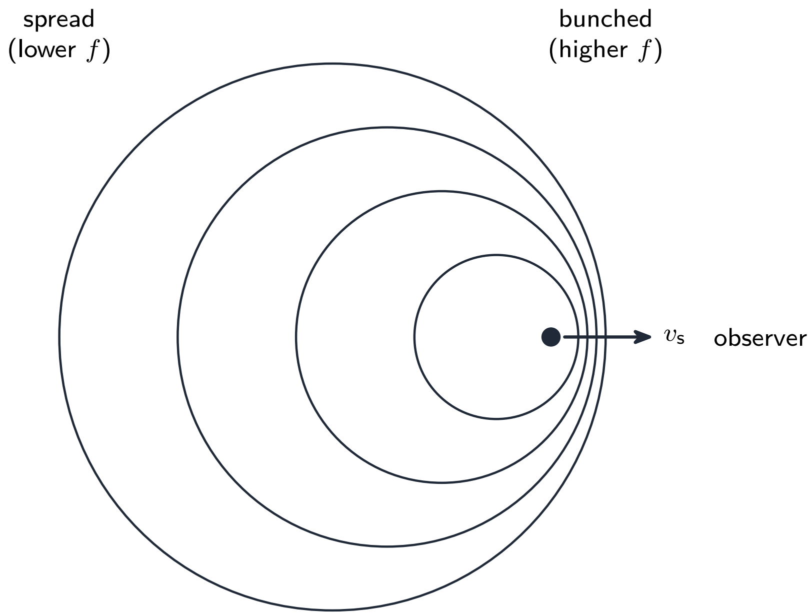
- explain why a moving source changes the observed frequency
- use $f_\mathrm{o} = \dfrac{v f_\mathrm{s}}{v \pm v_\mathrm{s}}$ with the correct sign

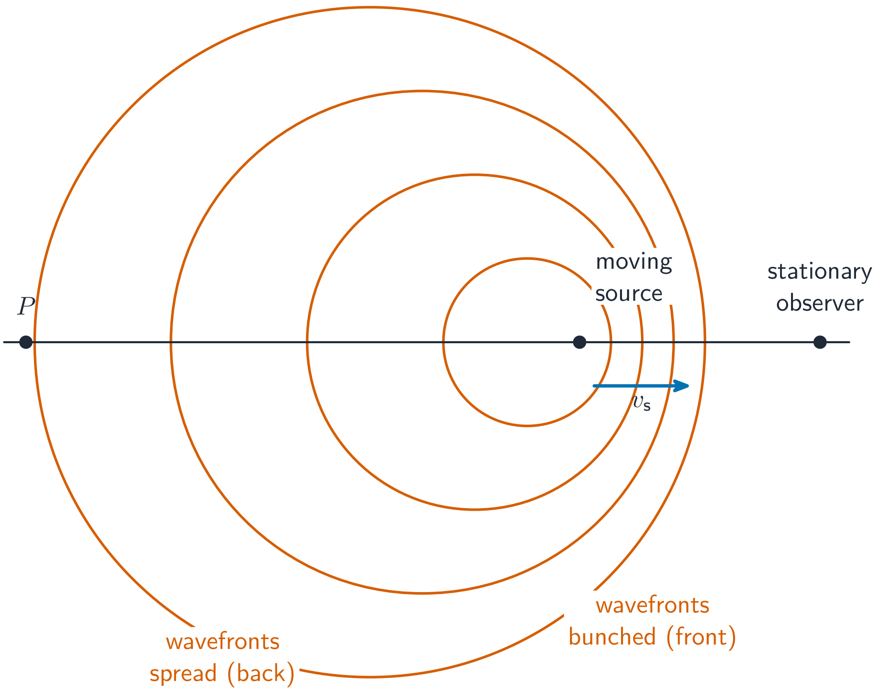
1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ The Doppler effect

When the source moves, the wavefronts **bunch up ahead** (shorter λ, **higher** f) and **spread behind** (longer λ, **lower** f):





The Doppler effect shifts observed frequency

■ The formula

$$f_o = \frac{v f_s}{v \pm v_s}$$

- **minus** sign $\rightarrow$ source moving **towards** observer ($f_o > f_s$);
- **plus** sign $\rightarrow$ source moving **away** ($f_o < f_s$).

Worked example. Horn $f_s = 800$ Hz at 30 m s^{-1} **towards** a listener, $v = 340$ m s^{-1}:

$$f_o = \frac{340 \times 800}{340 - 30} = \frac{272\,000}{310} \approx 877 \text{ Hz}.$$

2 Practice

Now apply the methods above.

2.1 State what the **Doppler effect** is. [1]

2.2 State whether the observed frequency **increases** or **decreases** as a source moves **towards** the observer. [1]

2.3 State which **sign** (+ or −) is used in the denominator when the source moves **towards** the observer. [1]

2.4 Explain why the wavelength is **shorter** ahead of an approaching source. [1]

3 Exam-style questions

For these, take the speed of sound as $v = 340$ m s^{-1}.

3.1 A horn of frequency 800 Hz moves at 30 m s^{-1} **towards** a stationary listener. Calculate the observed frequency. [3]

3.2 The same horn now moves **away** at 30 m s^{-1}. Calculate the observed frequency. [2]

3.3 A source moving **away** from an observer gives an observed frequency that is: [1]

- **A** higher than the source frequency
- **B** lower than the source frequency
- **C** the same as the source frequency
- **D** zero

3.4 Explain, in terms of **wavefronts**, why an approaching ambulance siren sounds **higher-pitched**. [2]

Solutions

2.1 The change in the **observed frequency** when the source of a wave **moves relative to** the observer.

2.2 It **increases**.

2.3 **Minus** $(-)$.

2.4 As the source moves forward, each new wavefront is emitted from slightly **closer** to the observer, so the wavefronts ahead are **closer together** (shorter λ).

3.1 Source moving towards $\rightarrow$ minus sign; $f_o = \dfrac{340 \times 800}{340 - 30} = \dfrac{272\,000}{310} \approx 877$ Hz.

3.2 Source moving away $\rightarrow$ plus sign; $f_o = \dfrac{340 \times 800}{340 + 30} = \dfrac{272\,000}{370} \approx 735$ Hz.

3.3 **B** — lower than the source frequency.

3.4 As the ambulance approaches, the wavefronts ahead are **bunched closer together**, giving a shorter wavelength and a **higher frequency** (higher pitch).

27 A dolphin is swimming at a speed of $16.0\,\text{m}\,\text{s}^{-1}$ directly towards a stationary underwater microphone.

The dolphin emits a sound of frequency 122 kHz. The speed of sound in water is $1480\,\text{m}\,\text{s}^{-1}$.

What is the frequency of sound detected by the microphone?

A 1300 Hz **B** 1330 Hz **C** 121 kHz **D** 123 kHz

A-Level Physics: **w25 12**

27 A moving source emits sound of frequency 1200 Hz.

A stationary observer hears sound of frequency 960 Hz. The speed of the sound is $340\,\text{m}\,\text{s}^{-1}$.

What could be the velocity of the source?

A $68\,\text{m}\,\text{s}^{-1}$ directly away from the observer

B $68\,\text{m}\,\text{s}^{-1}$ directly towards the observer

C $85\,\text{m}\,\text{s}^{-1}$ directly away from the observer

D $85\,\text{m}\,\text{s}^{-1}$ directly towards the observer

A-Level Physics: **w25 14**

27 An aircraft flies at a velocity v_s directly away from a stationary observer.

The aircraft emits a sound of constant frequency.

The speed of sound in air is v.

The frequency of the sound heard by the observer on the ground is 500 Hz.

The speed of the aircraft is increased so that it flies away from the observer at a greater velocity.

The observer now hears a sound of frequency 250 Hz.

Which expression gives the new velocity of the aircraft?

A $2(v + v_s)$ **B** $\dfrac{v + v_s}{2}$ **C** $2v_s + v$ **D** $2v_s - v$

24 An aircraft produces a sound at a frequency of 30.0 Hz.

The speed of sound in air is 330 m s^{-1}.

The aircraft is directly in front of the stationary observer and travels in a straight line towards or away from the observer.

The observer hears the sound from the aircraft at a frequency of 20.0 Hz.

What is the speed and direction of the aircraft?

	speed / m s^{-1}	direction
A	110	away from observer
B	110	towards observer
C	165	away from observer
D	165	towards observer

A-Level Physics: **s25 12**

26 A buzzer emitting sound of frequency 846 Hz is attached to a string and rotated in a horizontal circle. The linear speed of the buzzer is 25.0 m s^{-1}.

The speed of sound is 340 m s^{-1}.

What is the maximum frequency heard by the observer?

A 783 Hz **B** 788 Hz **C** 908 Hz **D** 913 Hz

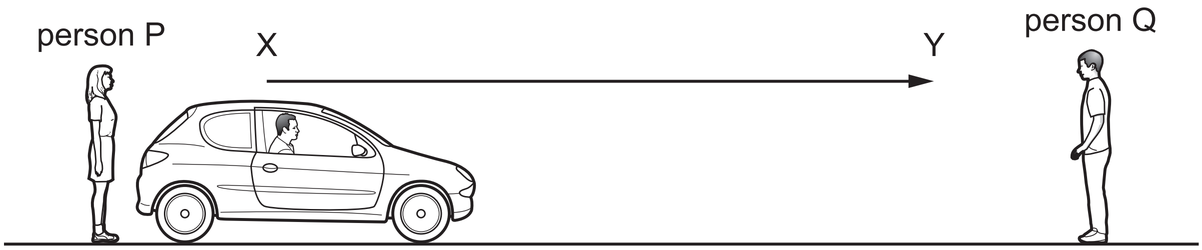
A-Level Physics: **s25 14**

22 A vehicle is moving with a speed of 30.0 m s^{-1} directly towards a stationary observer. The horn of the vehicle emits sound of frequency 440 Hz. The speed of sound in air is 340 m s^{-1}.

What is the frequency of the sound heard by the observer?

A 401 Hz **B** 404 Hz **C** 479 Hz **D** 483 Hz

24 The diagram shows a car travelling at a constant speed in a straight line between person P and person Q from point X to point Y.



The car sounds its horn continuously as it travels. The horn emits sound of constant frequency.

Which statements about what person P and person Q hear during the motion of the car are correct?

1 Person P hears a sound of increasing frequency.

2 Person Q hears a sound of decreasing frequency.

3 Person Q always hears a sound of higher frequency than person P.

A 1, 2 and 3

B 1 and 2 only

C 3 only

D none of them

7.4 Electromagnetic spectrum

Name: ______________ Class: __________ Date: ____________ **Total: 13 marks**

KEY WORDS electromagnetic spectrum 电磁波谱 • wave 波 • electromagnetic wave 电磁波 • vacuum 真空 • infrared 红外线

Objective

Build the skills to answer exam questions on the **electromagnetic spectrum 电磁波谱**.

You must be able to:

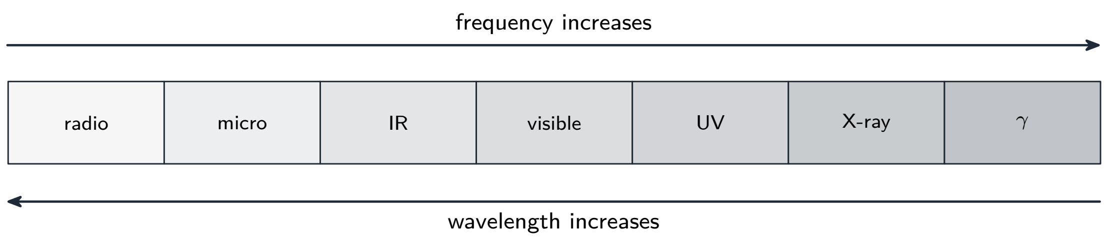
- state that all EM waves are **transverse** and travel at c in a vacuum
- order the regions from **radio** to **γ-rays** by wavelength/frequency
- use $c = f\lambda$ and recall visible light is 400–700 nm

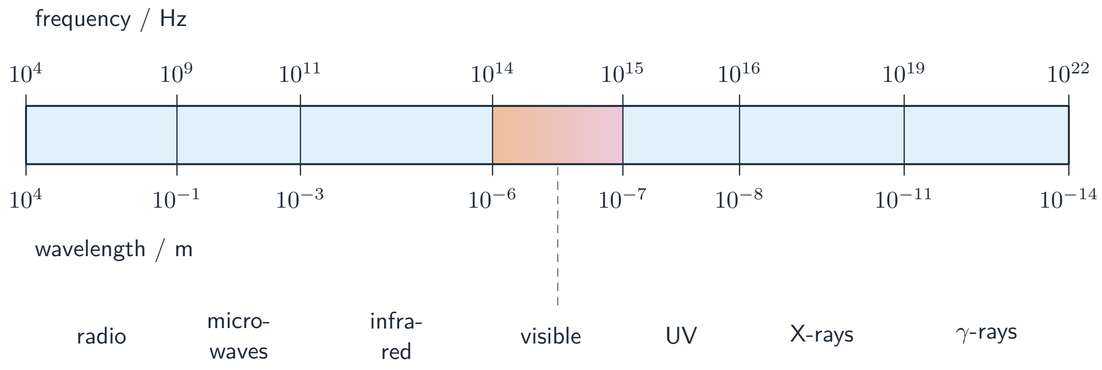
1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ EM waves and the spectrum

All EM waves are **transverse** and travel in a vacuum at $c = 3.00 \times 10^8$ m s^{-1}. In order:





The electromagnetic spectrum

Approximate wavelengths (learn the orders of magnitude): radio $> 10^{-1}$ m; microwaves 10^{-3}–10^{-1} m; IR up to $\sim 7 \times 10^{-7}$ m; **visible** 400–700 **nm**; UV $\sim 10^{-8}$–4×10^{-7} m; X-rays $\sim 10^{-11}$–10^{-8} m; γ-rays $< 10^{-11}$ m.

Use $c = f\lambda$ to convert between wavelength and frequency.

2 Practice

Now apply the methods above.

2.1 State **two** properties common to **all** electromagnetic waves. [2]

2.2 State the speed of EM waves in a **vacuum**. [1]

2.3 State the wavelength range of **visible** light. [1]

2.4 Put these in order of **increasing frequency**: X-rays, radio waves, visible light. [1]

3 Exam-style questions

3.1 Which EM wave has the **shortest** wavelength? [1]

- **A** radio waves
- **B** infrared

- **C** ultraviolet
- **D** γ-rays

3.2 A radio wave has frequency 100 MHz. Find its wavelength. ($c = 3.0 \times 10^8$ m s^{-1}.) [2]

3.3 A surveyor points a laser rangefinder at the far wall of a valley. The reflected pulse returns 8.4 μs after it was sent. **Determine** the width of the valley, and **state** the assumption you make about the path of the light. [3]

3.4 State whether **infrared** or **ultraviolet** has the higher frequency, and explain using the spectrum. [2]

Solutions

2.1 Any two: they are **transverse**; they travel at the **same speed** c in a vacuum; they can travel through a vacuum.

2.2 3.0×10^8 m s^{-1}.

2.3 400 nm to 700 nm.

2.4 radio waves $<$ visible light $<$ X-rays.

3.1 **D** — γ-rays.

3.2 $\lambda = c/f = (3.0 \times 10^8)/(100 \times 10^6) = 3.0$ m.

3.3 The pulse covers the width **twice**: $d_{\text{total}} = ct = 3.0 \times 10^8 \times 8.4 \times 10^{-6} = 2520$ m; width $= \frac{1}{2} \times 2520 = 1.3 \times 10^3$ m. Assumption: the light travels in a straight line at 3.0×10^8 m s^{-1} through the air, i.e. air is treated as a vacuum.

3.4 **Ultraviolet** has the higher frequency; on the spectrum UV is **closer to the high-frequency end** (shorter wavelength) than infrared.

25 Which statement about electromagnetic waves is correct?

A A wave of wavelength 5.0×10^{-6} m is invisible to the human eye.

B They can all travel at different speeds in free space.

C They **cannot** be polarised.

D They consist of vibrating atoms.

A-Level Physics: **s25 11**

27 Which wavelength of electromagnetic radiation in free space could be green light?

A 4.9×10^{-9} m **B** 6.6×10^{-9} m **C** 5.5×10^{-7} m **D** 8.6×10^{-7} m

A-Level Physics: **s25 12**

5 Radio waves can be used to measure the distance between Earth and the planet Jupiter.

A pulse of radio waves is emitted from the surface of Earth. The pulse reflects from the surface of Jupiter and is detected again on Earth.

The time between emitting and receiving the pulse is 3960 s.

What is the distance between Earth and Jupiter?

A 5.94×10^{8} km

B 1.19×10^{9} km

C 5.94×10^{11} km

D 1.19×10^{12} km

A-Level Physics: **s25 13**

27 An electromagnetic wave travelling in free space is **not** visible to the human eye.

What is a possible wavelength of the wave?

A 4.5×10^{-10} km

B 6.2×10^{-7} m

C 5.4×10^{-6} cm

D 4.2×10^{-4} mm

23 Which row could describe electromagnetic waves?

	type of wave	speed in free space
A	longitudinal	faster for shorter wavelengths
B	longitudinal	the same for all wavelengths
C	transverse	faster for shorter wavelengths
D	transverse	the same for all wavelengths

A-Level Physics: **m25 12**

22 Which row correctly identifies the properties of all electromagnetic waves?

	transverse wave	longitudinal wave	can travel in free space
A	✓	✗	✓
B	✓	✗	✗
C	✗	✓	✓
D	✗	✓	✗

key

✓ = property of an electromagnetic wave

✗ = **not** a property of an electromagnetic wave

23 What is the approximate range of wavelengths in free space for infrared radiation?

A 100 nm to 400 nm

B 300 μm to 30 cm

C 400 nm to 700 nm

D 800 nm to 1000 μm

A-LEVEL PHYSICS • EXERCISE SHEET

7.5 Polarisation

Name: __________ Class: ________ Date: __________ **Total: 20 marks**

KEY WORDS polarising filter 偏振片 • polarisation 偏振 • transverse 横波 • plane-polarised 平面偏振 • wave 波

Objective

Build the skills to answer exam questions on **polarisation 偏振** and **Malus's law**.

You must be able to:

- explain that only **transverse 横波** waves can be polarised
- use **Malus's law** $I = I_0 \cos^2 \theta$, and work **backwards** to find the angle
- sketch how the transmitted intensity varies as a filter is **rotated**
- link transmitted **intensity** to **amplitude 振幅** using $I \propto A^2$

1 Worked examples

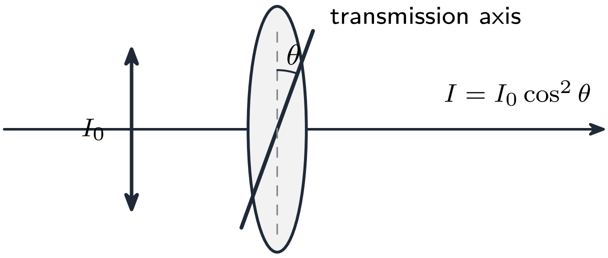
Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Polarisation

Polarisation makes a transverse wave oscillate in **one plane** only. Only **transverse** waves can be polarised (their oscillation is perpendicular to the travel direction, so different planes exist). **Longitudinal 纵波** waves such as sound **cannot** — so polarisation is a **test for a transverse wave**.

■ Malus's law

Plane-polarised light of intensity I_0 meets a filter whose **transmission axis 透射轴** is at angle θ to the plane of polarisation. The transmitted intensity is:



$$I = I_0 \cos^2\theta.$$

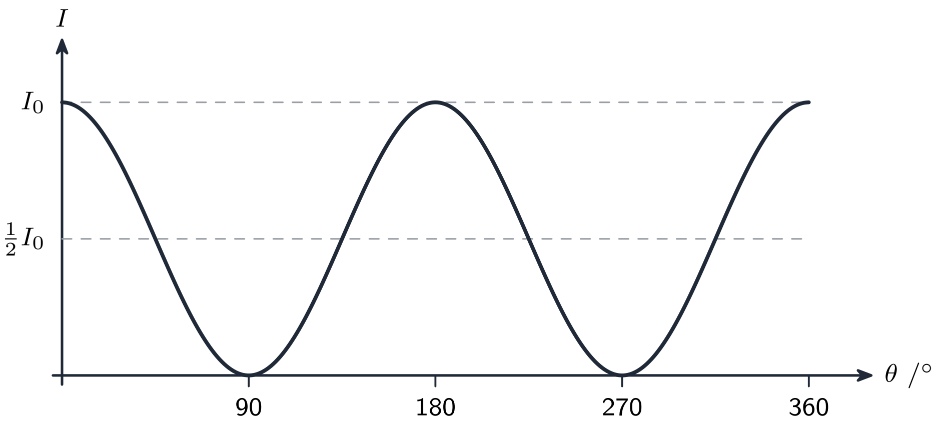
- $\theta = 0°$: $I = I_0$ (all passes); $\theta = 90°$: $I = 0$ (blocked); $\theta = 45°$: $I = \frac{1}{2}I_0$; $\theta = 60°$: $I = \frac{1}{4}I_0$.

Worked example (forward). $I_0 = 12$ W m^{-2}, $\theta = 30°$: $I = 12\cos^2 30° = 12 \times 0.75 = 9.0$ W m^{-2}.

Worked example (backwards). For what θ is the intensity **halved**? Set $\cos^2\theta = 0.5$, so $\cos\theta = \sqrt{0.5}$ and $\theta = 45°$.

Rotating the filter

If the angle θ between the axis and the polarisation is changed (by **rotating** the filter), the transmitted intensity traces a $\cos^2$ curve — maximum I_0 at $0°, 180°, 360°$ and zero at $90°, 270°$:



The "starts perpendicular" case. If the axis **begins perpendicular** to the polarisation and is then rotated by an angle ϕ, the angle in the formula is $\theta = 90° - \phi$. So $I = I_0\cos^2(90° - \phi) = I_0\sin^2\phi$: the intensity **starts at zero**, rises to I_0 after $\phi = 90°$, and so on.

Intensity and amplitude

Intensity is proportional to amplitude squared, $I \propto A^2$, so for a wave through a filter:

$$\frac{A}{A_0} = \sqrt{\frac{I}{I_0}}.$$

Worked example. If a filter transmits $I = 0.25\,I_0$, the amplitude is $A = A_0\sqrt{0.25} = 0.50\,A_0$ — the amplitude falls to **half**, even though the intensity falls to a **quarter**.

Two filters in series

Apply Malus's law **once per filter**; the second angle is measured from the **first** filter's axis. Two **crossed** filters (90° apart) transmit **nothing**.

2 Practice

Now apply the methods above.

2.1 State what **polarisation** means. [1]

2.2 State why **sound** cannot be polarised. [1]

2.3 Plane-polarised light meets a filter whose axis is at 60° to its plane. State the **fraction** of intensity transmitted. [1]

2.4 A filter transmits **half** the incident intensity. State the angle θ between its axis and the plane of polarisation. [1]

2.5 A filter transmits $I = 0.25\,I_0$. State the transmitted amplitude as a fraction of A_0. [1]

3 Exam-style questions

3.1 Which of these **can** be polarised? [1]

- **A** sound waves
- **B** all electromagnetic waves
- **C** longitudinal waves
- **D** all of these

3.2 Plane-polarised light of intensity 12 W m^{-2} meets a filter whose axis is at 30° to the plane of polarisation. Calculate the transmitted intensity. [2]

3.3 Plane-polarised light passes through **two** filters. The first axis is at 30° to the plane of polarisation; the second is a further 30° beyond the first. The light reaching the first filter has intensity 8.0 W m^{-2}. Calculate the intensity emerging from the **second** filter. [3]

3.4 A photographer looks at a shop window through a polarising filter. The light reflected from the glass is plane-polarised, of intensity I_0, and the filter's transmission axis starts **parallel** to the plane of polarisation. The filter is then rotated through 360° about the viewing direction.

(a) On the axes, sketch how the transmitted intensity I varies with the rotation angle ϕ. [2]

(b) Determine the smallest rotation ϕ that **halves** the transmitted intensity. [2]

(c) At that angle, find the transmitted **amplitude** as a fraction of the incident amplitude A_0, and explain why the photographer rotates the filter to cut the glare. [3]

3.5 Explain why the ability to **polarise** a wave shows that the wave is **transverse**. [2]

Solutions

2.1 Restricting the oscillations of a transverse wave to **one plane**.

2.2 Sound is **longitudinal** — its oscillation is along the direction of travel, so there is no other plane to restrict it to.

2.3 $\cos^2 60° = 0.25$, i.e. **one quarter**.

2.4 $\cos^2\theta = 0.5 \Rightarrow \cos\theta = \sqrt{0.5} \Rightarrow \theta = 45°$.

2.5 $A = A_0\sqrt{0.25} = 0.50\,A_0$ — **half** the amplitude.

3.1 **B** — all electromagnetic waves (they are transverse).

3.2 $I = I_0\cos^2\theta = 12\times\cos^2 30° = 12\times 0.75 = 9.0\ \mathrm{W\ m^{-2}}$.

3.3 First filter: $I_1 = 8.0\cos^2 30° = 8.0\times 0.75 = 6.0\ \mathrm{W\ m^{-2}}$. Second filter (a further 30°): $I_2 = I_1\cos^2 30° = 6.0\times 0.75 = 4.5\ \mathrm{W\ m^{-2}}$.

3.4 (a) A $\cos^2$-shaped curve: **starts at the maximum** I_0 (axis parallel), falls to zero at $\phi = 90°$, back to I_0 at 180°, zero at 270°, I_0 at 360°.

3.4 (b) $I = I_0\cos^2\phi = 0.5\,I_0$ gives $\cos^2\phi = 0.5$, so $\cos\phi = 0.707$ and $\phi = 45°$.

3.4 (c) Intensity $\propto$ amplitude^2, so $A = A_0\sqrt{0.5} = 0.71\,A_0$. Glare from the glass is polarised in one plane, so turning the axis towards 90° to that plane cuts the reflected light while the unpolarised light from inside the shop is only halved.

3.5 Polarisation restricts the oscillation to **one plane**; this is only possible if the oscillation is **perpendicular** to the direction of travel — i.e. the wave is transverse (a longitudinal wave oscillates along the travel direction, so it has only one possible plane).

26 Two polarising filters are placed next to each other so that their planes are parallel.

The first polarising filter has its transmission axis at an angle of 50° to the vertical.

The second polarising filter has its transmission axis at an angle of 20° to the vertical. The angle between the transmission axes of the two polarising filters is 30°.

A beam of vertically polarised light of intensity $8.0\,W\,m^{-2}$ is incident normally on the first polarising filter.

What is the intensity of the light that is transmitted from the second polarising filter?

A zero **B** $2.5\,W\,m^{-2}$ **C** $2.9\,W\,m^{-2}$ **D** $6.0\,W\,m^{-2}$

A-Level Physics: **w25 14**

28 What may be observed with light waves but **not** with sound waves?

A diffraction

B interference

C polarisation

D reflection

A-Level Physics: **s25 11**

28 Which group contains only waves that can be polarised?

A infrared waves, radio waves, sound waves

B visible light waves, microwaves, radio waves

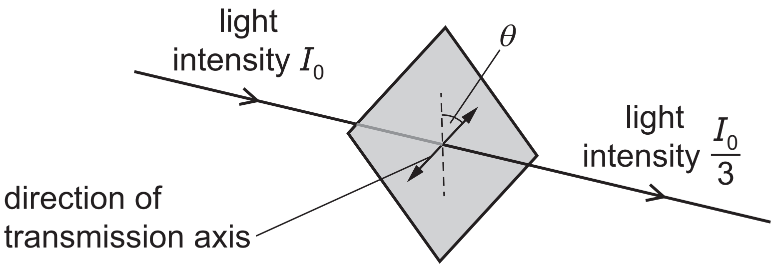
C visible light waves, radio waves, sound waves

D microwaves, visible light waves, sound waves

27 Vertically polarised light of intensity I_0 is incident normally on a polarising filter.

The transmission axis of the filter is at an angle θ to the plane of polarisation of the light.

The intensity of the light after passing through the filter is $\dfrac{I_0}{3}$.



What is θ?

A 8.4° **B** 55° **C** 71° **D** 84°

A-Level Physics: **s25 13**

25 Which phenomenon is only associated with transverse waves?

A diffraction

B interference

C polarisation

D reflection

A-Level Physics: **s25 14**

24 A horizontal beam of light is incident normally on a polarising filter. The incident light is vertically polarised and has an intensity of $24\,\mathrm{W\,m^{-2}}$. The direction of the transmission axis of the filter is at an angle of 30° to the vertical.

What is the intensity of the light in the transmitted beam?

A $18\,\mathrm{W\,m^{-2}}$ **B** $21\,\mathrm{W\,m^{-2}}$ **C** $28\,\mathrm{W\,m^{-2}}$ **D** $32\,\mathrm{W\,m^{-2}}$

5 **(a)** State why sound waves **cannot** be polarised.

....

.... [1]

(b) A plane-polarised light wave is incident on a polarising filter as shown in Fig. 5.1.

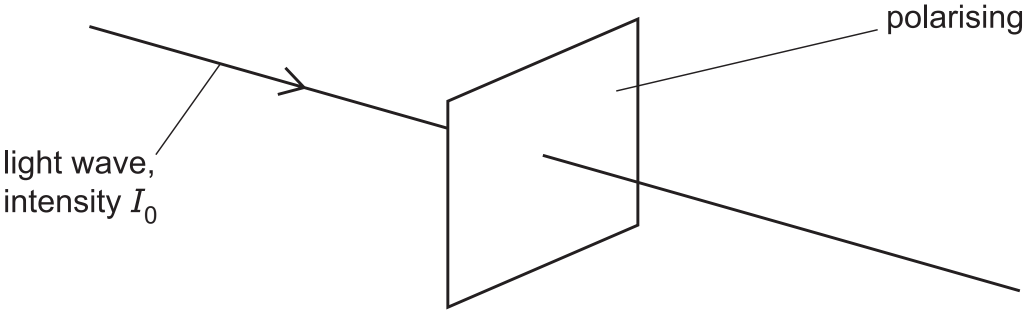


Fig. 5.1

The intensity of the light incident on the filter is I_0.

The light is incident normally on the filter and the transmission axis of the filter is initially perpendicular to the plane of polarisation of the light.

The filter is now rotated through 360° about the direction of travel of the light wave.

(i) On Fig. 5.2, sketch the variation of the intensity I of the transmitted light with the angle of rotation α as the filter is rotated through 360° from its initial position.

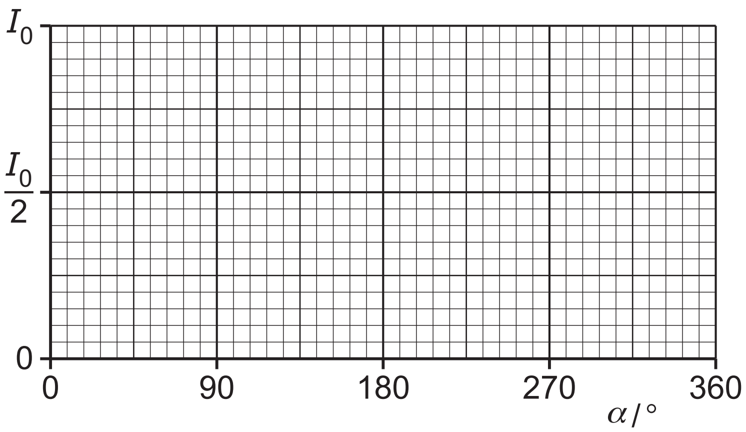


Fig. 5.2

[3]

(ii) The amplitude of the incident light wave is A_0 when the intensity of the wave is I_0.

Use Malus's law to determine, in terms of A_0, the amplitude of the transmitted wave when $\alpha = 20°$.

amplitude = ... A_0 [4]

[Total: 8]

A-Level Physics: **m25 12**

26 A polarised beam of light with intensity I is incident normally on a polarising filter.

The transmitted light has intensity I.

The filter is rotated about the normal axis through an angle θ.

The transmitted light has intensity $0.75I$.

What is the angle θ?

A 30° **B** 42° **C** 49° **D** 60°