Volume

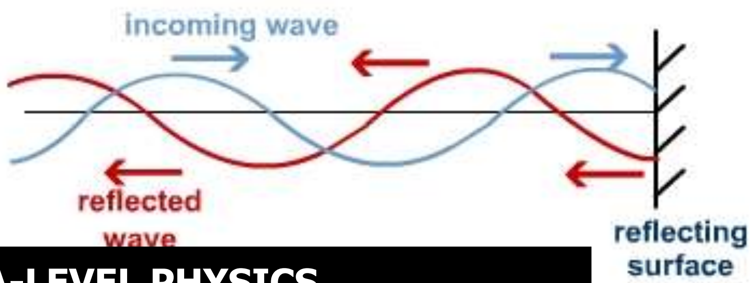
One

ST MARY'S SCIENCE DEPARTMENT:

PHYSICS

A LEVEL PHYSICS YEAR 1
STUDENT INDEPENDENT WORK BOOK
WAVES
3.3.1: PROGRESSIVE AND STATIONARY WAVES

NAME	
PHYSICS CLASS	
MODULE TEACHER	
ALPS GRADE	



A-LEVEL PHYSICS

TOPIC 3

INDEPENDENT WORK BOOK

THIS MUST BE BROUGHT TO ALL PHYSICS LESSONS.

Contents

Overview

GCSE studies of wave phenomena are extended through a development of knowledge of the characteristics, properties, and applications of travelling waves and stationary waves.
Topics treated include refraction, diffraction, superposition and interference.

IMPORTANT NOTE
This book contains all of the activities you can carry out independently in your study periods to enhance your understanding in A-Level Physics.

You may work through the activities in this book and mark this work yourself. You work will then be reviewed by your teacher in KS5 file checks. This work is in addition to the class work and homework you carry out.

This book may also be used as a revision resource for intervention, internal assessments and external assessments.
Please keep this in your student file.

As part of this course you are expected to **read through this preparatory reading book** and **complete the independent study tasks**.

This work will not be assessed but will be monitored by your class teacher.

This must be completed by the deadline set by your class teacher.

SECTION 1

INDEPENDENT STUDY TASK

Instructions

Read through the information from the student preparatory book and then produce revision posters on the key points highlighted on the following pages.

These notes should be used as a revision resource for assessments.

INDEPENDENT STUDY TASK 1

Produce an **information sheet** on wave properties.

This is an independent study task to carried out outside of lesson.

This work will not be assessed but will be monitored by your class teacher.

This must be completed by the deadline set by your class teacher

INDEPENDENT STUDY TASK 2

Produce an **information sheet** on standing waves.

This is an independent study task to carried out outside of lesson.

This work will not be assessed but will be monitored by your class teacher.

This must be completed by the deadline set by your class teacher

INDEPENDENT STUDY TASK 3

Produce an **information sheet** on polarisation.

This is an independent study task to carried out outside of lesson.

This work will not be assessed but will be monitored by your class teacher.

This must be completed by the deadline set by your class teacher

INDEPENDENT STUDY TASK 4

Produce an **information sheet** on the equations of this module.

This is an independent study task to carried out outside of lesson.

This work will not be assessed but will be monitored by your class teacher.

This must be completed by the deadline set by your class teacher

SECTION 2

KNOWLEDGE CHECKER

Instructions

Read through the information from the student preparatory book and then answer the following questions from the different parts of the topics.

These questions are designed to introduce the different parts of this module.

Use the mark schemes to review your knowledge and understanding.

QUESTIONS

Use the preparatory reading notes to answer these questions.

A1. Write down the relationship between the frequency of a wave and its time period.

[1 Mark]

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A2. Give the units of frequency, displacement and amplitude.

[1 Mark]

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A3. Give an example of a transverse wave and a longitudinal wave.

[1 Mark]

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A4. What is a polarised wave?

[1 Mark]

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A5. How do you polarise a wave?

[1 Mark]

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A6. What happens when a crest meets a trough.

[1 Mark]

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Use the preparatory reading notes to answer these questions.

A7. What is meant by the path difference of two waves?

[1 Mark]

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A8. How do stationary waves form?

[1 Mark]

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A9. How does the displacement of a particle at one anti-node compare to that of a particle at another anti-node?

[1 Mark]

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ADVANCED SECTION

Questions **A22 – A23** refer to the following statement.
A buoy floating on the sea takes 6.0 seconds to rise and fall once (complete a full cycle). The difference in height between the buoy at its highest and lowest points is 1.2m and waves pass it at a speed of $3.0 ms^{-1}$

A10. Calculate the wavelength.

[1 Mark]

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A11. State the amplitude of the waves.

[1 Mark]

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Use the preparatory reading notes to answer these questions.

A12. Light travelling through a vacuum has a wavelength of 7.1×10^{-7}m. Calculate its frequency.

[1 Mark]

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A13. Explain how Polaroid sunglasses help to reduce the glare caused by reflections.

[1 Mark]

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A14. Explain why sound waves cannot be polarised.

[1 Mark]

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A15. Two wave sources are coherent. Explain what this means.

[1 Mark]

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A16. A stationary wave at the first harmonic frequency, 10Hz is formed on a stretched string of length 1.2m. Calculate the wavelength of the wave.

[1 Mark]

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Use the preparatory reading notes to answer these questions.

ANSWERS

A1. Write down the relationship between the frequency of a wave and its time period.

[1 Mark]

Frequency = 1 / Time Period

A2. Give the units of frequency, displacement and amplitude.

[1 Mark]

Frequency = Hertz
Displacement = Metres
Amplitude = Metres

A3. Give an example of a transverse wave and a longitudinal wave.

[1 Mark]

Transverse waves include water waves, electromagnetic waves, seismic S-waves and string waves.
Longitudinal waves include sound waves and seismic P-waves.

A4. What is a polarised wave?

[1 Mark]

A polarised wave is a wave which only vibrates in one direction.

A5. How do you polarise a wave?

[1 Mark]

A wave is polarised after being passed through a polarising filter – this removes the vibrations in the incorrect directions.

A6. What happens when a crest meets a trough.

[1 Mark]

The two waves cancel each other out and no wave is formed.

A7. What is meant by the path difference of two waves?

[1 Mark]

The difference in displacement or vibration between the two waves.

A8. How do stationary waves form?

[1 Mark]

The superposition of two progressive waves with the same frequency (or wavelength) moving in opposite directions such as reflecting a wave off a surface.

A9. How does the displacement of a particle at one anti-node compare to that of a particle at another anti-node?

[1 Mark]

They have the same displacement. They may be acting in opposite directions. They may be acting in the same direction.

A10. Calculate the wavelength.

[1 Mark]

$c = f\lambda$
$f = 1/T$
$\lambda = cT$
$\lambda = 3.0 \times 6.0 = 18$m

A11. State the amplitude of the waves.

[1 Mark]

The trough to peak distance is twice the amplitude, so the amplitude is 0.6m.

A12. Light travelling through a vacuum has a wavelength of 7.1×10^{-7}m. Calculate its frequency.

[1 Mark]

$f = c / \lambda = (3.00 \times 10^8) / (7.1 \times 10^{-7}) = 4.225 \times 10^{14} = 4.2 \times 10^{14}$Hz

A13. Explain how Polaroid sunglasses help to reduce the glare caused by reflections.

[1 Mark]

Polaroid material only transmits vibrations in one direction.
Reflected light mostly vibrates in one direction, so Polaroid sunglasses filter out that direction, reducing glare.

A14. Explain why sound waves cannot be polarised.

[1 Mark]

Sound is a longitudinal wave. The vibrations are in the same direction as the energy transfer, so it cannot be polarised.

A15. Two wave sources are coherent. Explain what this means.

[1 Mark]

The frequency and wavelengths of the two sources are equal and the phase difference is constant.

A16. A stationary wave at the first harmonic frequency, 10Hz is formed on a stretched string of length 1.2m. Calculate the wavelength of the wave.

[1 Mark]

The length of the string for a stationary wave at the fundamental frequency is half the wavelength of the wave.

$\lambda = 2 \times 1.2 = 2.4$m

SECTION 3

QUESTIONS

Instructions

Read through the information from the student preparatory book and then answer the following questions from the different parts of the topics.

Use the mark schemes to review your knowledge and understanding.

TOPIC: 3.3.1.1 Progressive Waves
SPEC CHECK

Specification	Completed?
Oscillation of the particles of the medium;	
amplitude, frequency, wavelength, speed, phase, phase difference, $c = f\lambda$, $f = 1/T$	
Phase difference may be measured as angles (radians and degrees) or as fractions of a cycle.	
Laboratory experiment to determine the speed of sound in free air using direct timing or standing waves with a graphical analysis.	

SUPPORT

When looking at a graph showing a progressive wave always check carefully what has been plotted on the *x*-axis: is it distance or time? This makes a big difference with respect to what you can measure or calculate. Remember to use any scale provided correctly and be prepared to measure the amplitude or wavelength using a ruler if no scale is provided.

In the graphs in Figure 1 the waves are travelling from left to right. Energy is being transferred as the waves travel. They are **progressive waves**.

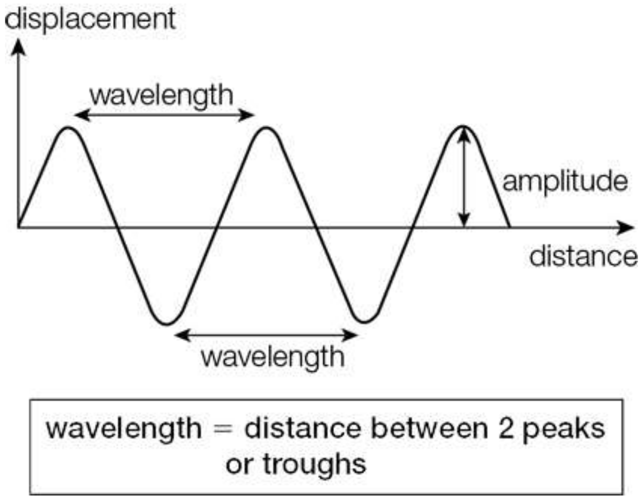

Figure 1a

From the displacement–distance graph in Figure 1a you can:

- measure the amplitude
- measure the wavelength
- calculate the phase difference between two points.

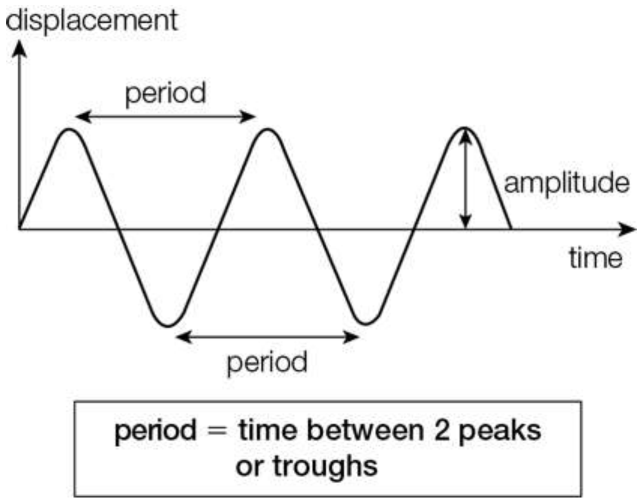

Figure 1b

From the displacement–time graph in Figure 1b you can:

- measure the amplitude
- calculate the period, and hence the frequency.

Note that if you know the frequency and can calculate the wavelength from a graph, you can calculate the wave speed using the wave equation:

$$\text{wave speed } c\,(\text{ms}^{-1}) = \text{frequency } f\,(\text{Hz}) \times \text{wavelength } \lambda\,(\text{m})$$

$$c = f\lambda$$

Figure 2 is a displacement–distance graph for a progressive wave. You should see that OE and AB = one complete wave cycle. You need to know what one wave cycle looks like so that you can visualise it when looking at a wave graph. Look at the shape of OE and remember it.

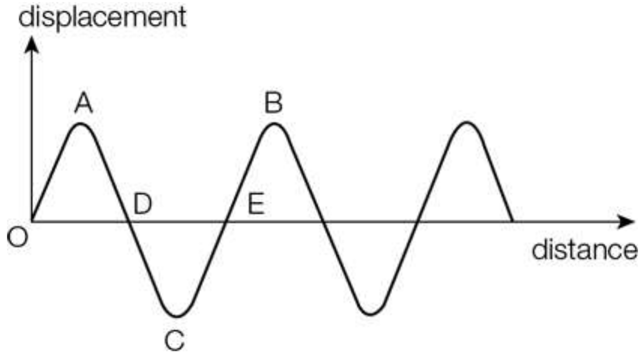

Figure 2 *Displacement–distance graph for a progressive wave*

In Figure 2, AB = λ and OE = λ, this means that:

- A is $\frac{\lambda}{4}$ from O
- D is $\frac{\lambda}{2}$ from O
- C is $\frac{3\lambda}{4}$ from O
- E is λ from O.

We can also express this in degrees or radians, as shown in Table 1.

Table 1

	OA	OD	OC	OE
Distance in wavelengths	$\frac{\lambda}{4}$	$\frac{\lambda}{2}$	$\frac{3\lambda}{4}$	λ
Distance in degrees	90	180	270	360
Distance in radians	$\frac{\pi}{2}$	π	$\frac{3\pi}{2}$	2π

Exam questions frequently ask for the phase difference between two points further along the wave, for example, between A and B, or A and C, or A and D in Figure 2.

- A and B
  - Point B is one wave cycle after A, or there is **one wavelength** between A and B.
  - Points A and B are **in phase**, that is, B is at the same point on one cycle of the wave as A is on the previous cycle.
  - The phase difference between A and B = 360° or 2π radians.
- A and C
  - Point C is half a wave cycle after A, or there is half a wavelength between A and C.
  - Points A and C are totally out of phase, or in **antiphase**.
  - The phase difference between A and C = 180° or π radians.

- A and D
  - Point D is a quarter of a wave cycle after A, or there is one quarter of a wavelength between A and D, and similarly between E and B.
  - Phase difference between A and D = 90° or $\frac{\pi}{2}$ radians. The same phase difference exists between E and B.

Worked example

Question

Figure 3 shows a rope that is being used to demonstrate the motion of a progressive transverse wave. The wave is travelling from left to right. There is a knot in the rope at point A.

Describe what will happen to the vertical displacement of the knot during the next cycle.

(You should be prepared to be presented with either a progressive or stationary wave diagram with a point marked on it and asked to describe what happens to a particle at that point over the next complete cycle.

If this is a progressive wave the easiest way to answer this type of question is to add successive waves to the original diagram, and then look at what is happening at the point in question.)

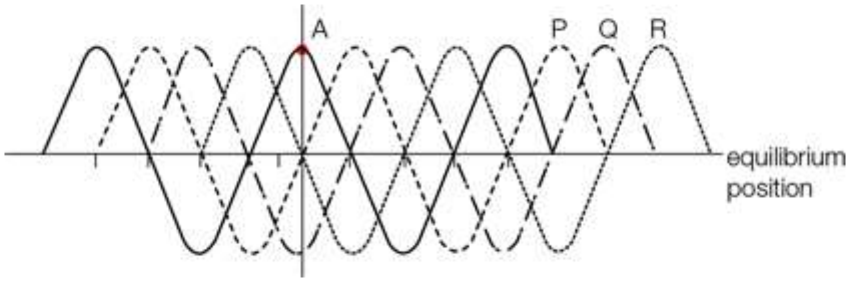

Figure 3

Answer

The knot moves from the maximum upwards displacement down through the equilibrium position ($\frac{1}{4}$ of a cycle later) to the maximum downward displacement (after $\frac{1}{2}$ cycle), and then up through the equilibrium position (after another $\frac{1}{4}$ cycle) and back to maximum upward displacement (after a whole cycle).

(You can see on Figure 3 that the student has drawn on the progressive wave positions P, Q, and R at each following quarter cycle. They then used the vertical line through A to see what happens as the particles in a transverse wave vibrate perpendicular to the direction of travel of the wave.)

QUESTIONS

Before answering wave questions decide whether the diagram represents:

- a progressive transverse wave
- a progressive longitudinal wave.

Remember, values may be presented through scales on graphs, not just in the words of the question.

Be prepared to add to a diagram to assist you in describing the motion of the particles of the wave.

1 Look at the two graphs in Figure 4, which refer to the same wave.

a) State the amplitude of the wave. (*1 mark*)

b) Calculate the speed of the wave. (*3 marks*)

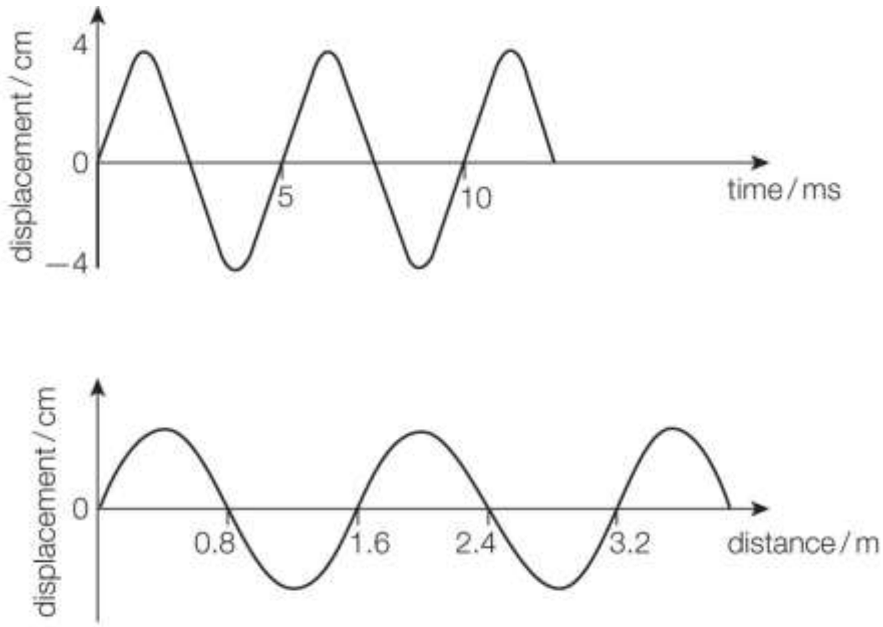

Figure 4

2 Figure 5 shows a transverse wave.

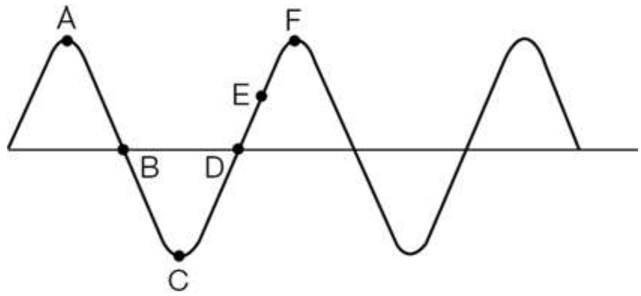

Figure 5

State the phase difference between the following points on the wave in degrees and radians.

- A and F
- B and C
- C and F
- D and E

(*4 marks*)

3 In Figure 6 there is a knot at point P of the rope, which is showing a transverse progressive wave travelling from left to right.

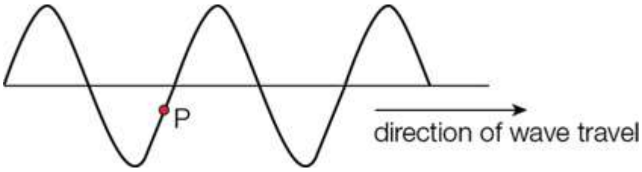

Figure 6

Describe what will happen to the vertical displacement of the knot in the next complete cycle.(*4 marks*)

ANSWERS

1 **a** Amplitude = 4 cm (*1 mark*)

b Wavelength = 1.6 m

Period = 5 ms (*1 mark*)

Frequency = $\frac{1}{T}$ = 200 Hz (*1 mark*)

Wave speed = 1.6 × 200 = 320 ms^{-1} (*1 mark*)

2 Award *1 mark* for each correct row in the table.

	Degrees	**Radians**
AF	360	2π
BC	90	$\frac{\pi}{2}$
CF	180	π
DE	45	$\frac{\pi}{4}$

3 Downwards to maximum negative displacement. (*1 mark*)

Upwards through equilibrium position to maximum positive displacement. (*1 mark*)

Downwards through equilibrium position and back to P. (*1 mark*)

The knot passes through the equilibrium position. (*1 mark*)

If the student has not stated that the knot passes through the equilibrium position, award a maximum of *3 marks*.

PRACTICAL SKILLS

Complete the following practical skills-based task to improve your experimental understanding of this part of the course in preparation for the Physics Paper 3 questions.

The frequencies of different coloured light were recorded. Knowing the wavelengths you will analyse the data below to find the speed of light in a vacuum, c.

Experimental Data

Here are the frequencies recorded for light of seven different colours.

Light Colour	Wavelength, λ (nm)	$1/\lambda$ (m^{-1})	Frequency, f ($\times 10^{14}$ Hz)			Mean Frequency, f ($\times 10^{14}$ Hz)
Violet	415		7.22	7.21	7.26	
Blue	463		6.41	6.50	6.53	
Cyan	489		6.15	6.16	6.09	
Green	532		5.61	5.70	5.61	
Yellow	580		5.11	5.24	5.16	
Orange	608		4.98	4.89	4.91	
Red	685		4.38	4.38	4.38	

Analysis

A1. Calculate the mean frequency of each coloured light.
A2. Calculate the uncertainty in the frequency of blue light.
A3. What is this as a percentage of the mean frequency?
A4. Calculate the uncertainty in the frequency of blue light.
A5. What is this as a percentage of the mean frequency?
A6. Calculate the uncertainty in the frequency of red light.
A7. What is this as a percentage of the mean frequency?
A8. What is the precision of the wavelength measurements?
A9. Calculate the percentage uncertainty in the value of wavelength for cyan light.
A10. Calculate the percentage uncertainty in the value of wavelength for yellow light.
A11. Calculate the value of $1/\lambda$ for each coloured light. Ensure your units are per metre (m^{-1}).
A12. Plot a graph of f (on the y axis) against $\frac{1}{\lambda}$ (on the x axis).
A13. Calculate the gradient of your line of best fit.
A14. The gradient should be equal to c, 3×10^8. What is the difference between your gradient and the accepted value?
A15. Calculate the percentage difference from the accepted value.
A16. Does your line pass through the origin? Should it?
A17. Use these calculations and your graph to comment on the reliability, precision and accuracy of the experiment.
A18. Use the equation $c = f\lambda$ to calculate the value of c for each coloured light.
A19. Calculate your mean value for the wave speed c.

A20. What is the uncertainty in the wave speed?

A21. Calculate the percentage difference between your mean value and the accepted value.

ANSWERING SPACE

ANSWERING SPACE

TOPIC: 3.3.1.2 Longitudinal and Transverse Waves

SPEC CHECK

Specification	Completed?
Nature of longitudinal and transverse waves.	
Examples to include: sound, electromagnetic waves, and waves on a string.	
Students will be expected to know the direction of displacement of particles/fields relative to the direction of energy propagation and that all electromagnetic waves travel at the same speed in a vacuum.	
Polarisation as evidence for the nature of transverse waves.	
Applications of polarisers to include Polaroid material and the alignment of aerials for transmission and reception.	
Students can investigate the factors that determine the speed of a water wave.	

PRACTICAL SKILLS

Complete the following practical skills-based task to improve your experimental understanding of this part of the course in preparation for the Physics Paper 3 questions.

A speaker was attached to the top of an open ended glass cylinder. The other end was placed in a trough of water so that the column of air between the speaker and the water is 15 cm. The speaker is attached to a signal generator which is adjusted until each harmonic is heard

Experimental Data

Here are the frequencies recorded for the first five harmonics.

Harmonic	**Frequency, f (Hz)**			**Wavelength, λ (m)**
First	1134	1131	1125	
Second	2288	2282	2291	
Third	3387	3407	3406	
Forth	4838	4841	4850	
Fifth	5639	5666	5645	

Harmonic	**Mean Frequency, f (Hz)**	**Wavelength, λ (m)**	$\frac{1}{\lambda}$ **(m⁻¹)**	**Wave Speed, v (m/s)**
First				
Second				
Third				
Forth				
Fifth				

Analysis

A1. Calculate the mean frequency for each harmonic.

A2. Calculate the uncertainty in the frequency of the first harmonic.

A3. What is this as a percentage of the mean frequency?

A4. Calculate the uncertainty in the frequency of the third harmonic.

A5. What is this as a percentage of the mean frequency?

A6. Calculate the uncertainty in the frequency of the fifth harmonic.

A7. What is this as a percentage of the mean frequency?

A8. Calculate the wavelength of the standing wave for each harmonic.

A9. Complete the column in the table labelled $\frac{1}{\lambda}$.

A10. Plot a graph of f on the y axis against $\frac{1}{\lambda}$ on the x axis.

A11. Draw a line of best fit and calculate the gradient.

A12. Calculate the percentage difference between the gradient and the accepted value of 343 m/s.

A13. Use the equation $v = f\lambda$ to complete the last column of the table.

A14. Calculate your mean value for the wave speed v.

A15. What is the uncertainty in the wave speed?

ANSWERING SPACE

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ANSWERING SPACE

TOPIC: 3.3.1.3 Principle of Superposition of Waves and Formation of Stationary Waves

SPEC CHECK

Specification	Completed?
Stationary waves.	
Nodes and antinodes on strings. $f = 1/2l \times \sqrt{T/\mu}$ for first harmonic.	
The formation of stationary waves by two waves of the same frequency travelling in opposite directions.	
A graphical explanation of formation of stationary waves will be expected.	
Stationary waves formed on a string and those produced with microwaves and sound waves should be considered.	
Stationary waves on strings will be described in terms of harmonics. The terms fundamental (for first harmonic) and overtone will not be used.	
Students can investigate the factors that determine the frequency of stationary wave patterns of a stretched string.	

SUPPORT

Superposition is the resultant displacement caused by two waves arriving at a point; it is the vector sum of the individual displacements caused by each wave at that instant.

Figure 1a shows **constructive interference**, which occurs when two identical waves are in phase, creating double-height peaks and troughs (**supercrests** and **supertroughs**) as the two waves reinforce each other.

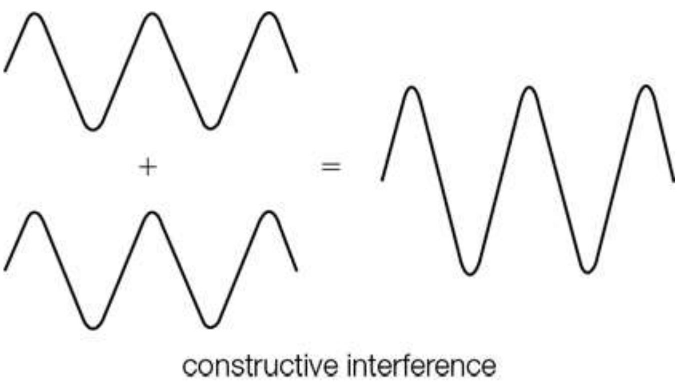


Figure 1a

Figure 1b shows **destructive interference**, which occurs when two identical waves are 180° out of phase, creating a resultant displacement of zero as the waves cancel each other out.

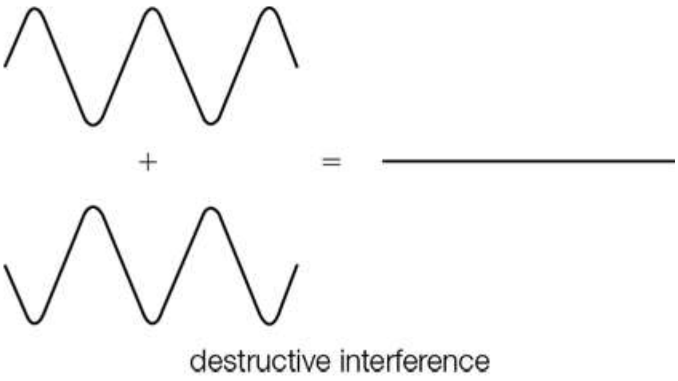


Figure 1b

Stationary waves

Stationary waves are formed when two progressive waves travelling in opposite directions pass through each other. The two waves must have the same or similar amplitudes, and equal and opposite velocities. This causes a fixed pattern of vibration where no energy is transferred along the waves. Figure 2 shows a stationary wave.

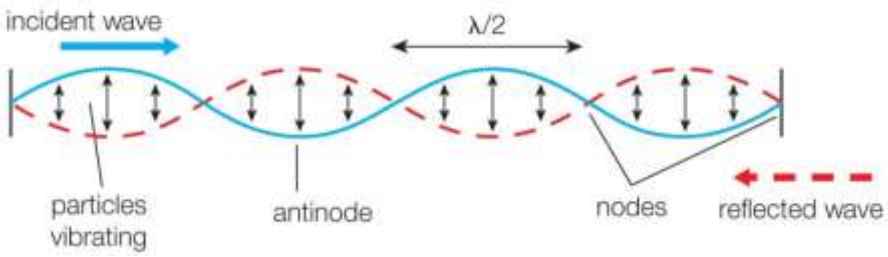


Figure 2

- At the **nodes,** the two waves are 180° out of phase and cancel each other out. The particles at the nodes do not vibrate at all: they have **zero displacement**.
- At the **antinodes,** the two waves are in phase and reinforce each other. The particles at the antinodes always vibrate at **maximum displacement**.
- The distance between adjacent nodes or adjacent antinodes = $\frac{\lambda}{2}$. This means that the wavelength of a stationary wave can be calculated.
- Vibrating particles between two adjacent nodes, or separated by an even number of nodes, are in phase.
- Vibrating particles that are separated by an odd number of nodes are out of phase, so have a phase difference of 180 ° or π radians.

Worked Example

Question

Figure 3 represents successive positions of a string exhibiting a stationary wave. Describe what will happen to the vertical displacement of a particle that's part of the string that starts at maximum amplitude during the next cycle.

(You should be prepared to be presented with either a progressive or stationary wave diagram with a point marked on it and asked to describe what happens to a particle at that point over the next complete cycle.)

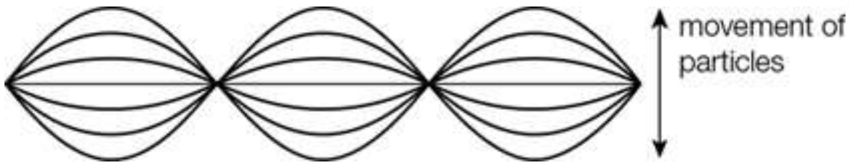


Figure 3

Answer

The particle moves from the maximum upwards displacement down through the equilibrium position ($\frac{1}{4}$ of a cycle later) to the maximum downward displacement (after $\frac{1}{2}$ cycle), and then up through the equilibrium position (after another $\frac{1}{4}$ cycle) and back to maximum upward displacement (after a whole cycle).

Since the wave is stationary, the particle oscillates about a fixed point and moves neither left nor right. In the case of a particle found at a node, this does not oscillate but remains at a fixed position.

(If you are given the frequency of the wave you can calculate the period and then work out where the wave will be after a particular time.)

QUESTIONS

Before answering wave questions decide whether the diagram represents:

- a progressive transverse wave
- a progressive longitudinal wave
- a stationary wave.

Be prepared to add to a diagram to assist you in describing the motion of the particles of the wave.

1. Figure 4 shows two waves, A and B. Determine the phase difference between them. Express your answer in terms of both degrees and radians.

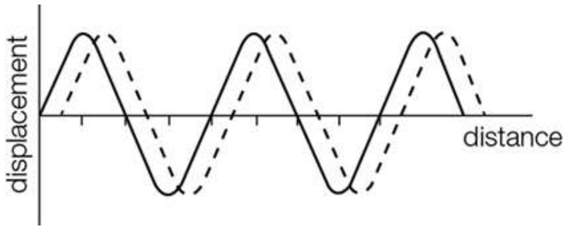


Figure 4

(*2 marks*)

2. A stationary wave is shown in Figure 5.

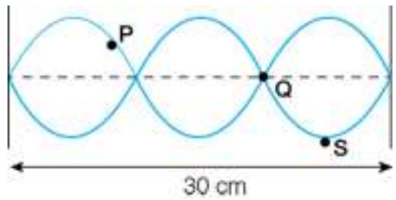


Figure 5

a) Label a node **and** an antinode. (*2 marks*)

b) Explain how a node is formed.

(*4 marks*)

c) State the wavelength of the wave.

(*1 mark*)

d) If the frequency of the wave is 250 Hz, calculate the speed of the wave.

(*2 marks*)

e) Describe the movement of the particle at point Q during the next cycle.

(*1 mark*)

f) Draw on the diagram the position of the particle at P 3 ms after the position shown. (*2 marks*)

g) Compare the amplitude **and** phase of particles P and S.

(*2 marks*)

ANSWERS

1. Phase difference = $\frac{\lambda}{8}$

In degrees = 45° (*1 mark*)

In radians = $\frac{\lambda}{4}$ (*1 mark*)

Exam-style question

2 a Node = Q or a similar point. (*1 mark*)

Antinode = S or a similar point above or below mean position. (*1 mark*)

b Award a maximum of *4 marks*.

- two waves of same amplitude travelling in opposite directions (*1 mark*)
- superpose / destructive interference (*1 mark*)
- cancel each other out / 180° out of phase (*1 mark*)
- minimum / zero displacement (*1 mark*)

c Wavelength = 20 cm (*1 mark*)

d Speed = 0.2 × 250 (*1 mark*)

= 50 ms^{-1} (*1 mark*)

e The particle at Q does not move as it is at a node. (*1 mark*)

f Frequency = 250 Hz

Period = $\frac{1}{250}$ = 4 ms (*1 mark*)

So after 3 ms particle P will have completed $\frac{3}{4}$ cycle and will at the equilibrium position. (*1 mark*)

g P has a smaller amplitude than S. (*1 mark*)

P has the same phase as S. (*1 mark*)

EXTENSION

Waves on a vibrating string

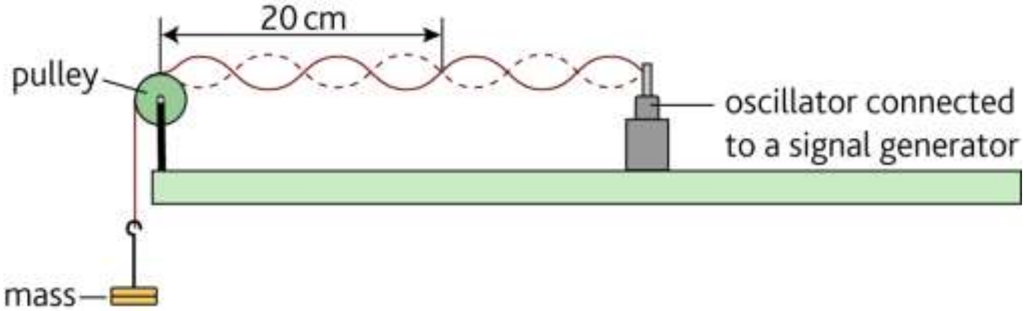


Figure 1

The string is vibrating at 42 Hz; this is the 7th harmonic. It is not the fundamental frequency.

Questions

1 a Explain what is meant by the **fundamental** frequency and draw a diagram to show what the string looks like when it is vibrating at its fundamental frequency.

(*2 marks*)

b How you can tell that the string is vibrating at its 7th harmonic?

(*2 marks*)

c What is the fundamental frequency of vibration of the string?

(*1 mark*)

d Calculate the wavelength of the wave.

(*2 marks*)

e Calculate the speed of the wave along the string.

(*1 mark*)

2. Suggest how the apparatus can be used to measure the speed of the wave along the string.

Decide what measurements should be made make sure you state clearly:

- how each actual measurement is made
- any extra apparatus that is used in each measurement
- how the speed is calculated from the actual measurements.

(*6 marks*)

3. The formula for the speed *c* of a wave on a string is $c = \sqrt{\frac{T}{\mu}}$ where *T* is the tension in the string, and μ is the mass per unit length of the string. The units on both sides of an equation must be equal.

a Show that the units are equal on both sides of the wave equation $c = f\lambda$. (*1 mark*)

b Show that the units are equal on both sides of the equation $c = \sqrt{\frac{T}{\mu}}$

(Hint: $F = ma$ enables you to express the N in more basic units.)

(*3 marks*)

c The tension in the string is increased by a factor of four while the oscillator vibrates at the same frequency as in Figure 1.

State what happens to the speed and the wavelength of the wave, and explain why the string does not now show a standing wave pattern.

(*2 marks*)

4. Someone says to you, 'The wave on the string creates a sound. The speed of sound is the speed of the wave on the string'.

Why are they wrong? What wave property is the same for the string and the sound that is created?

(*3 marks*)

ANSWERS

1 a. The fundamental frequency is the simplest mode of operation with only one antinode on the string and the string vibrates at the lowest frequency. (*1 mark*)

Award *1 mark* for a correct diagram.

b. There are seven antinodes, so the string has a length of $7\lambda / 2$ (*1 mark*)

The wavelength of the standing wave is one-seventh the wavelength of the fundamental and thus seven times the frequency. This makes the vibration the 7th harmonic. (*1 mark*)

c. 6 Hz (*1 mark*)

d. Four sections of the string cover 20 cm so $\lambda / 2 = 5$ (*1 mark*) and $\lambda = 10$ cm (*1 mark*).

e. $v = f\lambda = 42 \times 0.10 = 4.2\ \text{m s}^{-1}$ (*1 mark*)

2 Frequency is measured by either attaching a frequency meter to the a.c. signal from the signal generator **or** by attaching an oscilloscope to the signal generator (*1 mark*).

Using the oscilloscope, the time for one wave is measured by multiplying the distance along the *x*-axis of one oscillation by the number of seconds per division (*1 mark*).

The frequency = 1 / time period (*1 mark*).

The wavelength is measured by measuring the distance between adjacent nodes with a metre rule (*1 mark*).

For accuracy more than one node-to-node distance can be measured (*1 mark*).

The wavelength $\lambda = 2 \times$ node-to-node distance and $v = f\lambda$ (*1 mark*).

3a. Units of $f\lambda$ = Hz × m = 1 / s × m = m s^{-1}

Units of $c = \text{m s}^{-1}$ (*1 mark*)

b. Units of T = N = kg m s^{-2} (*1 mark*)

Units of $T / \mu = \text{kg m s}^{-2} / \text{kg m}^{-1} = \text{m}^2\,\text{s}^{-2}$. (*1 mark*)

Taking the square root gives m s^{-1}, which is the same as for the velocity. (*1 mark*)

c. The speed doubles; the wavelength doubles (the frequency is constant). (*1 mark*)

The string (of length 20 × 7 / 4 = 35 cm) is not now a multiple of $\lambda / 2$ (which is now 10 × 2 = 20 cm). (*1 mark*)

4. The string vibrates up and down making the air molecules vibrate with the same frequency as the string (*1 mark*).

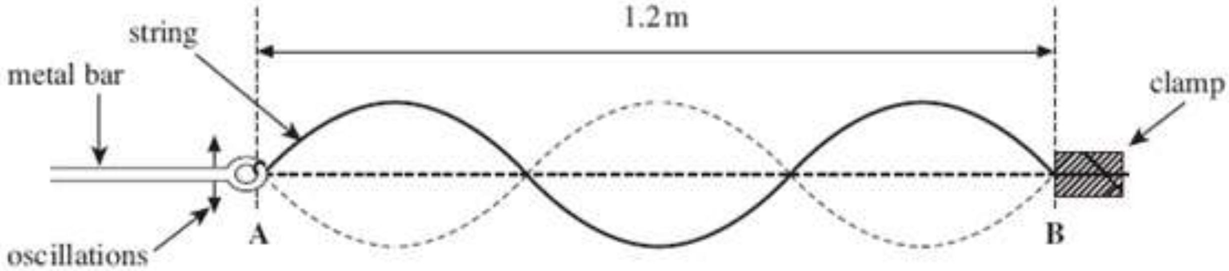
The sound has the same frequency as the wave on the string but since the speed of sound (340 m s^{-1}) is different (*1 mark*),

The wave on the string and the sound wave have different wavelengths (*1 mark*).

EXTENDED WRITING

To enhance your skills in answering examination questions for the A-Level examinations, complete the following task…

The diagram below shows a stationary wave on a string. The string is tied onto a thin metal bar at **A** and fixed at **B**. A vibration generator causes the bar to oscillate at a chosen frequency.



Explain how a stationary wave is formed. You answer should include the following:

- A description of the key features of the standing wave in the diagram
- The conditions necessary for stationary waves to form
- A definition of the terms node and antinode
- An explanation of how nodes and antinodes form
- An explanation of how a standing wave with four 'loops' would be formed.

ANSWERING SPACE

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MARK SCHEME

P	**Praise. What were the positive aspects of the work? What did they do well? What skills did they demonstrate?**						
I	**Improvements. What were the literacy issues in the piece of work?**		*Write in ink.*		*Draw in Pencil.*		*Use a ruler.*
	Always use capital letters at the beginning of a sentence.		Learn the spellings identified in your work.				
	Always use capital letters for proper nouns.		Ensure sentences make sense.				
	Make sure you write on the line and not above or below it.		Use correct punctuation.				
	Use scientific vocabulary appropriate to the task.		Vary your sentences to demonstrate your understanding.				

D answer		**B answer**		**A* answer**	
The standing wave shown is one and a half wavelengths long or contains three 'loops' (owtte).		The standing wave has 4 nodes and 3 antinodes…		…the wavelength of the wave is 0.8 m.	
		All points between twoadjacent nodes are in phase with each other…		…and out of phase with points between the next two nodes (owtte).	
Standing waves are formed when two waves travel in opposite directions meet…		…the waves have the same wavelength (or frequency) …		…and similar (or the same) amplitude.	
Node is a point of minimum (or zero) movement…		…the word amplitude is used instead of movement…		…the amplitude between a node and antinode is described as increasing (owtte) (accept opposite).	
Antinode is a point of maximum movement…					
Nodes are formed when a peak and a trough overlap or cancel out.		Nodes are formed when two waves arrive at the same point, travelling in opposite directions and completely out of phase…		…the term 'destructive interference' is used.	
				…the term 'superposition' is used.	
Antinodes are formed when two peaks (or 2 troughs) overlap or add together.		Antinodes are formed when two waves arrive at the same point, travelling in opposite directions and completely in phase…		…the term 'constructive inference' is used.	
A standing wave of four loops would be formed by increasing the frequency (of the metal bar).		A standing wave of four loops would be formed when the frequency in increased and two wavelengths fit on the string (owtte).		The frequency needs to be increased by ⅓ (of the previous) or to 4 times the fundamental frequency.	
				The wavelength of the standing wave will be 0.6 m.	

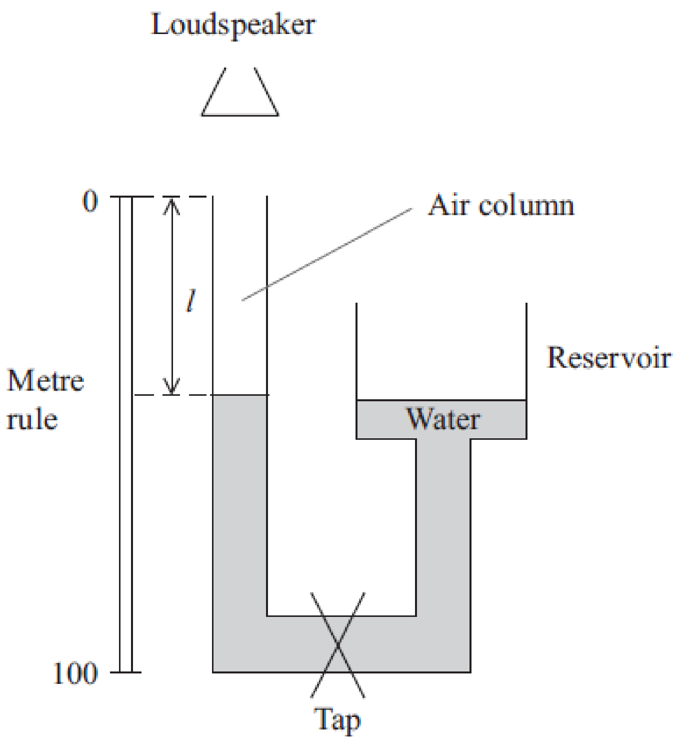
N	**Next Steps. How can they move their work onto the next grade? What didn't they include?**	**Grade**	**Effort**

EXPERIMENTAL TECHNIQUE

Experimental technique and analysis questions are common on A Level Paper 3. To practice these keys skills, answer the following questions.

A student determines the speed of sound using standing waves in an air column.

A diagram of the apparatus is shown.



He moves the reservoir up and down to change the length l of the air column.

When a standing wave is formed a louder sound is heard. He records the readings on the metre rule when this happens.

Reading on metre rule /mm	36	192	356	516

(a) Criticise these results.

(2)

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(b) The distance between successive readings on the metre rule should be half the wavelength.

Calculate a mean value for the wavelength of the sound with a suitable uncertainty.

(4)

Wavelength = ... ± .... mm

(c) Use your value of the mean wavelength to calculate a value for the velocity of sound in air.

The frequency of the sound is 1024 Hz.

(2)

Velocity = ...

Reference: IAL Edexcel Physics Unit 3 June 2012 Examination

Mark Scheme

8(a)	**Max 2** Only 4 sets of readings No repetition Small range [ignore comments about not equally spaced, or sig figs]	 **(1)** **(1)** **(1)**	**2**
8(b)	Subtraction of values (may be implicit) Averages their results $\lambda = 320$ mm Uncertainty 8 mm (allow 16 mm) OR $\lambda = 322$ mm Uncertainty 2 mm (allow 4 mm) <u>Example of calculation</u> Av distance between antinodes = (156 + 164 + 160)/3 = 160 mm Wavelength = 2 x 160 (mm) = 320 mm Uncertainty = 8 mm (which is double the range for $\lambda/2$ x 2 as measurement doubled)	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	**4**
8(c)	Use of $v = f\lambda$ (allow ecf) $v = 328$ ms^{-1} with correct unit and 3 sf <u>Example of calculation</u> $v = 1024$ (Hz) x 0.32 (m) = 328 ms^{-1}	**(1)** **(1)**	**2**

A group of students is asked to determine the unknown concentration of a sugar solution by measuring the rotation of the plane of polarisation. The students have taken the following measurements using known concentrations of sugar solution.

Concentration of sugar solution / %	**Angle of rotation of the plane of polarisation / °**
0	0
20	16
33	26
43	34

(a) Criticise these measurements.

(3)

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(b) Plot a graph of the angle of rotation of the plane of polarisation against the concentration of sugar solution.

(6)

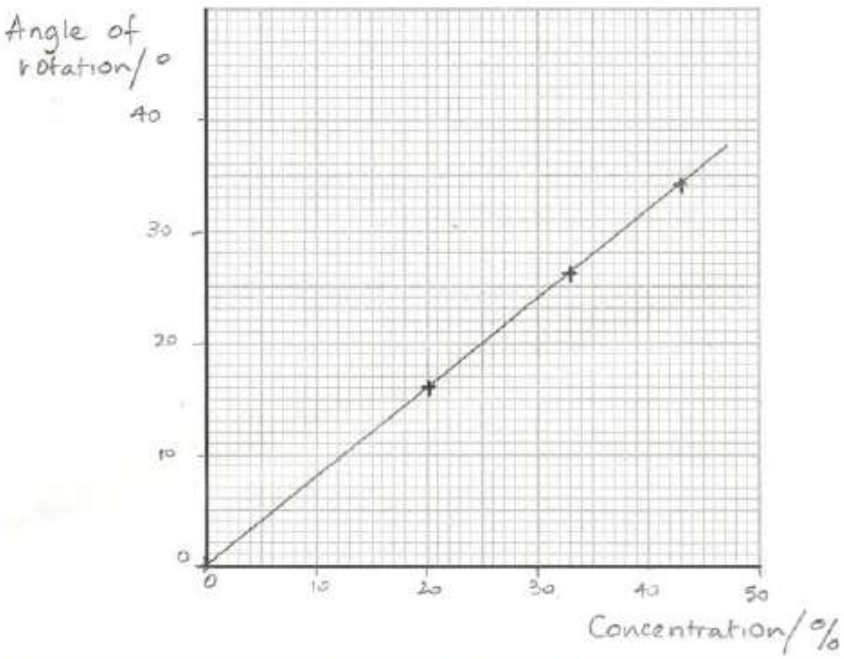
(c) The students measure the angle of rotation for the unknown concentration of sugar solution as 20°.

Use your graph to determine a value for this concentration.

(2)

Reference: IAL Edexcel Physics Unit 3 January 2013 Examination

Mark Scheme

Question Number	Answer		Mark
8 (a)	**Max 3** No repetition Too few results Concentration values not evenly spaced **Or** large gap between 0 – 20 Range too small **Or** Higher values of concentration should have been used [Ignore reference to precision]	 (1) (1) (1) (1)	 3
(b)	Axes labelled with quantities (Allow symbols e.g. θ and C. Must be a clear reference to an angle or rotation i.e. **not** just polarisation) Axes labelled with units Sensible scales Origin marked (0,0) and plotted Correct plotting of other 3 points Best fit line <u>Example of graph</u> (would gain all 6 marks) 	(1) (1) (1) (1) (1) (1)	 6
(c)	Value of concentration read correctly from candidate's graph with % sign and 2 or 3 sig figs (Value to within ½ of a small square. Candidates may change % to a decimal. For example if read correctly from the graph a value of 0.25 would score 2 marks, but 25 would score the first mark only.)	(1) (1)	 2
	Total for question 8		**11**

REVISION CHECKLIST

Specification reference	Checklist questions	
3.3.1.1	Can you explain oscillation of particles in terms of amplitude, frequency, wavelength, speed, phase, and phase difference?	☐
3.3.1.1	Can you explain that phase difference may be measured as angles (radians and degrees) or as fractions of a cycle?	☐
3.3.1.2	Can you explain the nature of longitudinal and transverse waves, including sound, electromagnetic waves, and waves on a string?	☐
3.3.1.2	Can you describe the direction of displacement of particles/fields relative to the direction of energy propagation?	☐
3.3.1.2	Can you recall that all electromagnetic waves travel at the same speed in a vacuum?	☐
3.3.1.2	Can you explain polarisation as evidence for the nature of transverse waves?	☐
3.3.1.2	Can you apply your knowledge of polarisers to explain the function of Polaroid material and the alignment of aerials for transmission and reception?	☐
3.3.1.3	Can you define stationary waves?	☐
3.3.1.3	Can you describe nodes and antinodes on strings?	☐
3.3.1.3	Can you use the formula $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$ for first harmonic?	☐
3.3.1.3	Can you describe the formation of stationary waves by two waves of the same frequency travelling in opposite directions?	☐
3.3.1.3	Can you draw a diagram to explain the formation of stationary waves?	☐

Specification reference	**Checklist questions**	
3.3.1.3	Can you describe stationary waves formed on a string and those produced with microwaves and sound waves?	☐
3.3.1.3	Can you describe stationary waves on strings in terms of harmonics?	☐
3.3.1.3	Have you carried out an investigation into how the frequency of stationary waves on a string varies with length, tension, and mass per unit length of the string?	☐

DATASHEET

DATA – FUNDAMENTAL CONSTANTS AND VALUES

Quantity	Symbol	Value	Units
speed of light in vacuo	c	3.00×10^{8}	$\mathrm{m\,s^{-1}}$
permeability of free space	μ_0	$4\pi \times 10^{-7}$	$\mathrm{H\,m^{-1}}$
permittivity of free space	ε_0	8.85×10^{-12}	$\mathrm{F\,m^{-1}}$
magnitude of the charge of electron	e	1.60×10^{-19}	C
the Planck constant	h	6.63×10^{-34}	J s
gravitational constant	G	6.67×10^{-11}	$\mathrm{N\,m^{2}\,kg^{-2}}$
the Avogadro constant	N_A	6.02×10^{23}	$\mathrm{mol^{-1}}$
molar gas constant	R	8.31	$\mathrm{J\,K^{-1}\,mol^{-1}}$
the Boltzmann constant	k	1.38×10^{-23}	$\mathrm{J\,K^{-1}}$
the Stefan constant	σ	5.67×10^{-8}	$\mathrm{W\,m^{-2}\,K^{-4}}$
the Wien constant	α	2.90×10^{-3}	m K
electron rest mass (equivalent to 5.5×10^{-4} u)	m_e	9.11×10^{-31}	kg
electron charge/mass ratio	$\frac{e}{m_e}$	1.76×10^{11}	$\mathrm{C\,kg^{-1}}$
proton rest mass (equivalent to 1.00728 u)	m_p	$1.67(3) \times 10^{-27}$	kg
proton charge/mass ratio	$\frac{e}{m_p}$	9.58×10^{7}	$\mathrm{C\,kg^{-1}}$
neutron rest mass (equivalent to 1.00867 u)	m_n	$1.67(5) \times 10^{-27}$	kg
gravitational field strength	g	9.81	$\mathrm{N\,kg^{-1}}$
acceleration due to gravity	g	9.81	$\mathrm{m\,s^{-2}}$
atomic mass unit (1u is equivalent to 931.5 MeV)	u	1.661×10^{-27}	kg

ALGEBRAIC EQUATION

quadratic equation $$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

ASTRONOMICAL DATA

Body	Mass/kg	Mean radius/m
Sun	1.99×10^{30}	6.96×10^{8}
Earth	5.97×10^{24}	6.37×10^{6}

GEOMETRICAL EQUATIONS

arc length	$= r\theta$
circumference of circle	$= 2\pi r$
area of circle	$= \pi r^2$
curved surface area of cylinder	$= 2\pi rh$
area of sphere	$= 4\pi r^2$
volume of sphere	$= \frac{4}{3}\pi r^3$

Particle Physics

Class	Name	Symbol	Rest energy/MeV
photon	photon	γ	0
lepton	neutrino	ν_e	0
		ν_μ	0
	electron	$e^\pm$	0.510999
	muon	$\mu^\pm$	105.659
mesons	π meson	$\pi^\pm$	139.576
		π^0	134.972
	K meson	$K^\pm$	493.821
		K^0	497.762
baryons	proton	p	938.257
	neutron	n	939.551

Properties of quarks

antiquarks have opposite signs

Type	Charge	Baryon number	Strangeness
u	$+\frac{2}{3}e$	$+\frac{1}{3}$	0
d	$-\frac{1}{3}e$	$+\frac{1}{3}$	0
s	$-\frac{1}{3}e$	$+\frac{1}{3}$	-1

Properties of Leptons

		Lepton number
Particles:	e^-, ν_e ; μ^-, ν_μ	$+1$
Antiparticles:	e^+, $\overline{\nu_e}$, μ^+, $\overline{\nu_\mu}$	-1

Photons and energy levels

photon energy $E = hf = hc/\lambda$

photoelectricity $hf = \phi + E_{k\,(max)}$

energy levels $hf = E_1 - E_2$

de Broglie wavelength $\lambda = \frac{h}{p} = \frac{h}{mv}$

Waves

wave speed $c = f\lambda$ *period* $f = \frac{1}{T}$

first harmonic $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$

fringe spacing $w = \frac{\lambda D}{s}$ *diffraction grating* $d \sin\theta = n\lambda$

refractive index of a substance s, $n = \frac{c}{c_s}$

for two different substances of refractive indices n_1 *and* n_2

law of refraction $n_1 \sin\theta_1 = n_2 \sin\theta_2$

critical angle $\sin\theta_c = \frac{n_2}{n_1}$ for $n_1 > n_2$

Mechanics

moments $\text{moment} = Fd$

velocity and acceleration $v = \frac{\Delta s}{\Delta t}$ $a = \frac{\Delta v}{\Delta t}$

equations of motion $v = u + at$ $s = \left(\frac{u+v}{2}\right)t$

$v^2 = u^2 + 2as$ $s = ut + \frac{at^2}{2}$

force $F = ma$

force $F = \frac{\Delta(mv)}{\Delta t}$

impulse $F\Delta t = \Delta(mv)$

work, energy and power $W = Fs\cos\theta$

$E_k = \frac{1}{2}mv^2$ $\Delta E_p = mg\Delta h$

$P = \frac{\Delta W}{\Delta t}$, $P = Fv$

$efficiency = \frac{useful\ output\ power}{input\ power}$

Materials

density $\rho = \frac{m}{V}$ *Hooke's law* $F = k\,\Delta L$

Young modulus $= \frac{\text{tensile stress}}{\text{tensile strain}}$ *tensile stress* $= \frac{F}{A}$ *tensile strain* $= \frac{\Delta L}{L}$

energy stored $E = \frac{1}{2}F\Delta L$

Electricity

current and pd	$I = \frac{\Delta Q}{\Delta t}$ $V = \frac{W}{Q}$ $R = \frac{V}{I}$
resistivity	$\rho = \frac{RA}{L}$
resistors in series	$R_T = R_1 + R_2 + R_3 + \ldots$
resistors in parallel	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$
power	$P = VI = I^2R = \frac{V^2}{R}$
emf	$\varepsilon = \frac{E}{Q}$ $\varepsilon = I(R + r)$

Circular motion

magnitude of angular speed	$\omega = \frac{v}{r}$
	$\omega = 2\pi f$
centripetal acceleration	$a = \frac{v^2}{r} = \omega^2 r$
centripetal force	$F = \frac{mv^2}{r} = m\omega^2 r$

Simple harmonic motion

acceleration	$a = -\omega^2 x$
displacement	$x = A\cos(\omega t)$
speed	$v = \pm\omega\sqrt{(A^2 - x^2)}$
maximum speed	$v_{max} = \omega A$
maximum acceleration	$a_{max} = \omega^2 A$
for a mass-spring system	$T = 2\pi\sqrt{\frac{m}{k}}$
for a simple pendulum	$T = 2\pi\sqrt{\frac{l}{g}}$

Thermal physics

energy to change temperature	$Q = mc\Delta\theta$
energy to change state	$Q = ml$
gas law	$pV = nRT$
	$pV = NkT$
kinetic theory model	$pV = \frac{1}{3}Nm(c_{rms})^2$
kinetic energy of gas molecule	$\frac{1}{2}m(c_{rms})^2 = \frac{3}{2}kT = \frac{3RT}{2N_A}$

Gravitational fields

force between two masses	$F = \frac{Gm_1m_2}{r^2}$
gravitational field strength	$g = \frac{F}{m}$
magnitude of gravitational field strength in a radial field	$g = \frac{GM}{r^2}$
work done	$\Delta W = m\Delta V$
gravitational potential	$V = -\frac{GM}{r}$
	$g = -\frac{\Delta V}{\Delta r}$

Electric fields and capacitors

force between two point charges	$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$
force on a charge	$F = EQ$
field strength for a uniform field	$E = \frac{V}{d}$
work done	$\Delta W = Q\Delta V$
field strength for a radial field	$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$
electric potential	$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$
	$E = \frac{\Delta V}{\Delta r}$
capacitance	$C = \frac{Q}{V}$
	$C = \frac{A\varepsilon_0\varepsilon_r}{d}$
capacitor energy stored	$E = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$
capacitor charging	$Q = Q_0(1 - e^{-t/RC})$
decay of charge	$Q = Q_0e^{-t/RC}$
time constant	RC

Magnetic fields

force on a current $F = BIl$

force on a moving charge $F = BQv$

magnetic flux $\Phi = BA$

magnetic flux linkage $N\Phi = BAN\cos\theta$

magnitude of induced emf $\varepsilon = N\dfrac{\Delta\Phi}{\Delta t}$

$N\Phi = BAN\cos\theta$

emf induced in a rotating coil $\varepsilon = BAN\omega\sin\omega t$

alternating current $I_{rms} = \dfrac{I_0}{\sqrt{2}}$ $V_{rms} = \dfrac{V_0}{\sqrt{2}}$

transformer equations $\dfrac{N_s}{N_p} = \dfrac{V_s}{V_p}$

$efficiency = \dfrac{I_s V_s}{I_p V_p}$

Nuclear physics

the inverse square law for γ radiation $I = \dfrac{k}{x^2}$

radioactive decay $\dfrac{\Delta N}{\Delta t} = -\lambda N,\ N = N_0 e^{-\lambda t}$

activity $A = \lambda N$

half-life $T_{½} = \dfrac{\ln 2}{\lambda}$

nuclear radius $R = R_0 A^{1/3}$

energy-mass equation $E = mc^2$

OPTIONS

Astrophysics

1 astronomical unit = 1.50×10^{11} m

1 light year = 9.46×10^{15} m

1 parsec = 206265 AU = 3.08×10^{16} m
= 3.26 light year

Hubble constant, H = 65 km s^{-1} Mpc^{-1}

$M = \dfrac{\text{angle subtended by image at eye}}{\text{angle subtended by object at unaided eye}}$

in normal adjustment $M = \dfrac{f_o}{f_e}$

Rayleigh criterion $\theta \approx \dfrac{\lambda}{D}$

magnitude equation $m - M = 5\log\dfrac{d}{10}$

Wien's law $\lambda_{max} T = 2.9 \times 10^{-3}$ m K

Stefan's law $P = \sigma A T^4$

Schwarzschild radius $R_s \approx \dfrac{2GM}{c^2}$

Doppler shift for v << c $\dfrac{\Delta f}{f} = -\dfrac{\Delta\lambda}{\lambda} = \dfrac{v}{c}$

red shift $z = -\dfrac{v}{c}$

Hubble's law $v = Hd$

Medical physics

lens equations $P = \dfrac{1}{f}$

$m = \dfrac{v}{u}$

$\dfrac{1}{f} = \dfrac{1}{u} + \dfrac{1}{v}$

threshold of hearing $I_0 = 1.0 \times 10^{-12}$ W m^{-2}

intensity level $intensity\ level = 10\log\dfrac{I}{I_0}$

absorption $I = I_0 e^{-\mu x}$

$\mu_m = \dfrac{\mu}{\rho}$

ultrasound imaging $Z = \rho c$

$\dfrac{I_r}{I_i} = \left(\dfrac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2$

half-lives $\dfrac{1}{T_E} = \dfrac{1}{T_B} + \dfrac{1}{T_P}$

Acknowledgements

This document has been produced by Mr J Turnbull.

All relevant information has been credited in the document.

This has been document has been produced for educational purposes only.

This document has been produced for the AQA A Level Physics Specification.

Student Voice

If you when using this document, you believe there is an improvement to made, please state this in the space below….

Only constructive and reasoned feedback will be considered.