3

SUPERVISOR'S USE ONLY

91523

915230

NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

QUALIFY FOR THE FUTURE WORLD
KIA NOHO TAKATŪ KI TŌ ĀMUA AO!

Level 3 Physics, 2015

91523 Demonstrate understanding of wave systems

9.30 a.m. Friday 20 November 2015
Credits: Four

Achievement	Achievement with Merit	Achievement with Excellence
Demonstrate understanding of wave systems.	Demonstrate in-depth understanding of wave systems.	Demonstrate comprehensive understanding of wave systems.

Check that the National Student Number (NSN) on your admission slip is the same as the number at the top of this page.

You should attempt ALL the questions in this booklet.

Make sure that you have Resource Booklet L3–PHYSR.

In your answers use clear numerical working, words and / or diagrams as required.

Numerical answers should be given with an SI unit, to an appropriate number of significant figures.

If you need more room for any answer, use the extra space provided at the back of this booklet.

Check that this booklet has pages 2–8 in the correct order and that none of these pages is blank.

YOU MUST HAND THIS BOOKLET TO THE SUPERVISOR AT THE END OF THE EXAMINATION.

Excellence

TOTAL 24

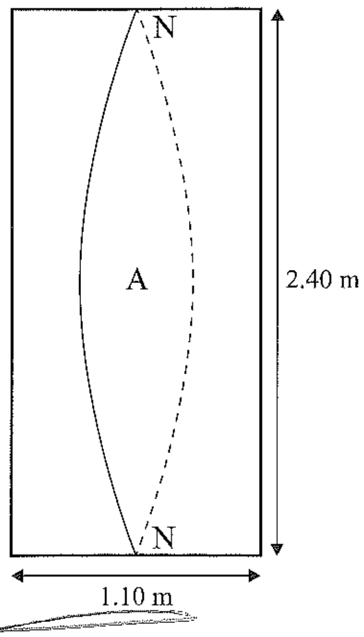
ASSESSOR'S USE ONLY

QUESTION ONE: STANDING WAVES AND PLUMBING

ASSESSOR'S USE ONLY

Speed of sound in air = 3.43×10^2 m s^{-1}
Speed of sound in water = 1.49×10^3 m s^{-1}

A shower acts like a closed pipe with a node at both ends. Matthew's shower has a height of 2.40 m, with a square base of width 1.10 m. The diagram shows a side view of the shower with one of the standing sound waves that can be set up in the shower. The displacement antinode (A) and nodes (N) are shown on the diagram.



(a) Show that the frequency of the vertical standing sound wave drawn is 71.5 Hz.

$\lambda = 2.4 \times 2 = 4.8\,m$

$f = \frac{v}{\lambda} = 71.458\dot{3}$

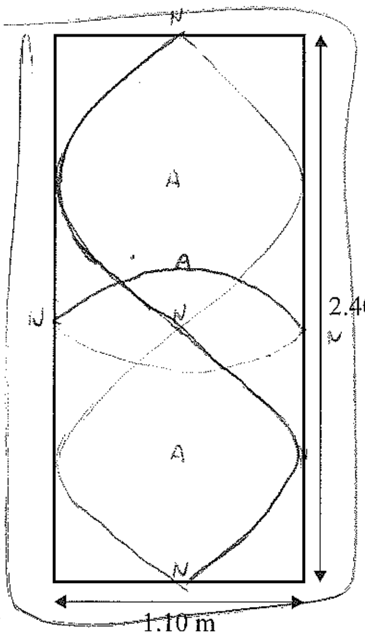
$= 71.5$ Hz (3sf)

(b) Matthew loves singing in the shower. Although Matthew is a talented singer he cannot sing a note to resonate at this low a frequency. However, Matthew can produce two resonant frequencies:

- a vertical standing wave at 143 Hz
- a horizontal standing wave at 156 Hz.

Draw these two standing waves in the box on the right.

Show the calculations you used, in order to draw the two waves.



Vertical: $\lambda = \frac{v}{f} = 2.40\,m$ (3sf)

$\Rightarrow L = \lambda$

Horizontal: $\lambda = \frac{v}{f} = 2.20\,m$ (3sf)

$\lambda = 2L \quad L = \frac{1}{2}\lambda$

(c) One day, Matthew finds his shower is filling with water because the shower waste pipe is blocked. Matthew drains water from the waste pipe, and attempts to locate the position of the blockage.

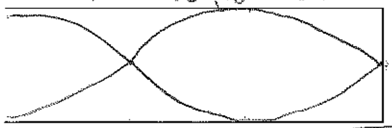
With a loudspeaker, Matthew detects the fundamental frequency, and then detects the next two adjacent resonant frequencies at 1.80×10^2 and 3.00×10^2 Hz. Matthew uses these resonant frequencies to estimate that the pipe is blocked 1.43 m from the open end.

ASSESSOR'S USE ONLY

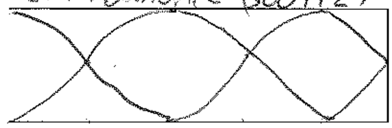
Show how Matthew calculated that the pipe is blocked 1.43 m from the open end.

You may want to draw waveforms in the diagrams below to help you.

3rd harmonic (180Hz)



5th harmonic (300Hz)



u

i

~~3rd~~ The next two adjacent resonant frequencies after the fundamental:

- 3rd harmonic at 180 Hz $\lambda = \frac{V}{f} = 1.9055...$ m

  $L = \frac{3}{4}\lambda \Rightarrow L = 1.429.. = 1.43m$ (3sf)

- 5th harmonic at 300 Hz $\lambda = \frac{V}{f} = 1.14\dot{3}$ m

  $L = \frac{5}{4}\lambda \Rightarrow L = 1.429... = 1.43m$ (3sf)

$\therefore$ the length of pipe from open end to blockage is 1.43 m //

(d) With the loudspeaker still set at 3.00×10^2 Hz, Matthew fills the waste pipe with water. He uses his loudspeaker to make sound waves in the water, and puts his ear in the water and listens, but the sound no longer resonates.

Calculate one of the frequencies that Matthew should set the loudspeaker to in order to get resonance again.

In your answer you should:

- describe how the water affects the speed of the sound wave
- explain why the sound in the waste pipe no longer resonates at 3.00×10^2 Hz
- calculate one of the resonant frequencies.

Water is denser than air $\therefore V_{water} > V_{air}$ and is 1490 ms^{-1}.

$\lambda = \frac{1490}{300} = 4.9\dot{6}$ m at 300Hz

Frequencies only resonate in the closed pipe if there is a node at the closed end and an antinode at the open end. For a frequency to "fit" the pipe, this means that the pipe length must be an odd number of quarter wavelengths i.e. $L = \frac{n}{4}\lambda$, $n = 1, 3, 5, 7, ...$, $\Rightarrow \frac{L}{\lambda} \times 4$ must = an odd +ve integer. For f = 300 Hz, $\frac{L}{\lambda} \times 4 = 0.288$ (3sf), which isn't an odd integer, implying that this ~~wave~~ frequency no longer results in the wave fitting the pipe and causing resonance. One resonant frequency would be if $L = \frac{1}{4}\lambda \Rightarrow \lambda = 5.72$m

$f = \frac{v}{\lambda} = \frac{1490}{5.72} = 260.489... = 260$ Hz (3sf) //

u

i

c

E8

QUESTION TWO: INTERFERENCE

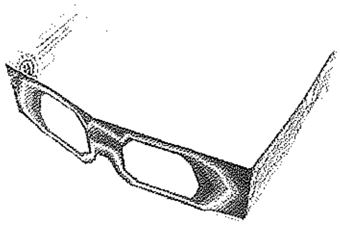
ASSESSOR'S USE ONLY

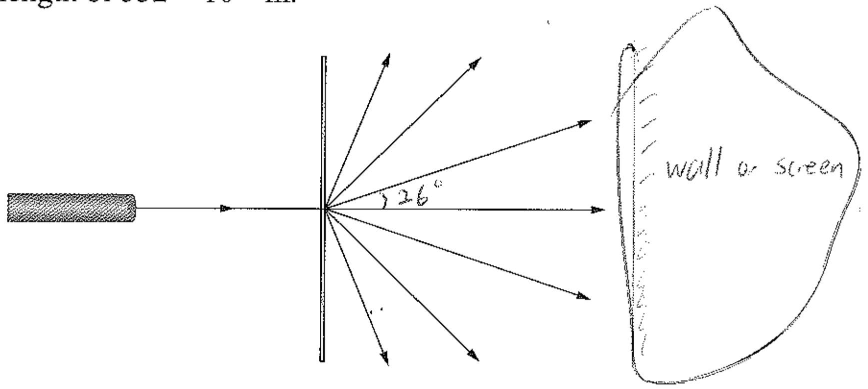
Rianne uses a pair of novelty glasses to produce a laser show.

When she shines a laser through the centre of one of the eyepieces, the laser light splits up into a number of beams.

She suspects that the novelty glasses contain a diffraction grating.

Rianne measures the angle between the bright central beam of light and the 1st order maximum in the horizontal direction to be 26.0°. The laser light has a wavelength of 532×10^{-9} m.





(a) Calculate the slit spacing of the novelty glasses.

$d \sin\theta = n\lambda \Rightarrow d \sin 26° = 1 \times 532 \times 10^{-9}$

$\Rightarrow d = \frac{532 \times 10^{-9}}{\sin 26°}$

$d = 1.2135... \times 10^{-6}$

$= 1.21 \times 10^{-6}$ m (3sf)

A4

(b) Rianne experiments by shining her laser light through different parts of the glasses. There are more lines per metre in the middle of each eyepiece (smaller slit spacing) than there are at the edges.

Describe the differences in the patterns Rianne would see when she shines the laser light through the two different sections of the glasses.

In the middle, d is smaller with the same λ, it means than $\sin\theta$ is greater than when shone through the edges. For $\theta < 90°$ (for rays to hit the wall or screen), greater $\sin\theta$ means greater θ. This means that light rays shone through middle will be diffracted by a greater angle than the edges, as a result, adjacent maxima will be spaced further apart, and less number of maxima will be observed on the wall/screen

(c) Rianne visits a physics laboratory where she replaces the novelty glasses with a 600 000 lines per metre diffraction grating.

ASSESSOR'S USE ONLY

n=0, θ=0 n=2

Calculate the spacing in degrees between the central maximum and the 2nd order maximum for her laser light when it passes through the diffraction grating.

$d = \frac{1}{600\,000} = 1.6 \times 10^{-6}$ m

$\sin\theta = \frac{2\lambda}{d} = \frac{2 \times 532 \times 10^{-9}}{d}$

$= 0.6384$

$\theta = \sin^{-1}(0.6384)$

$= 39.672..$

$= 39.7^{\circ}$ (3sf)

u
i

(d) Rianne wonders whether it would be possible to use the diffraction grating to create a laser light show, where a blue laser light with a wavelength of 460×10^{-9} m creates a pattern that overlaps with a pattern created by a red laser light with a wavelength of 690×10^{-9} m.

Explain what the complete pattern would look like.

In your answer you should:

- calculate the number of maxima for blue laser light
- calculate the number of maxima for red laser light
- explain why there will be a limit to the number of maxima for each laser light
- show that one of the red maxima is at the same angle as one of the blue maxima.

There is a limit as θ must be less than 90°, or the rays won't hit the screen (eg. diffracted parallel to the screen instead)

$d\sin\theta = n\lambda$ $n < \frac{d\sin 90^{\circ}}{\lambda}$ i.e $n < \frac{d}{\lambda}$ (nearest whole number $< \frac{d}{\lambda}$)

blue: $n < \frac{1}{600000 \times 460 \times 10^{-9}}$ red: $n < \frac{1}{600000 \times 690 \times 10^{-9}}$

$n < 3.62..$ $n < 2.415...$

$n = 3$ on each side (above/below) $n = 2$

$3 \times 2 + 1 = 7$ maxima in total $2 \times 2 + 1 = 5$ maxima in total

central maxima n=0

3rd order blue $\theta = \sin^{-1}\left(\frac{3 \times 460 \times 10^{-9}}{\frac{1}{600000}}\right) = 55.9^{\circ}$ (3sf)

2nd order red $\theta = \sin^{-1}\left(\frac{2 \times 690 \times 10^{-9}}{\frac{1}{600000}}\right) = 55.9^{\circ}$ (3sf)

i.e. they are at the same angle

u
i
c

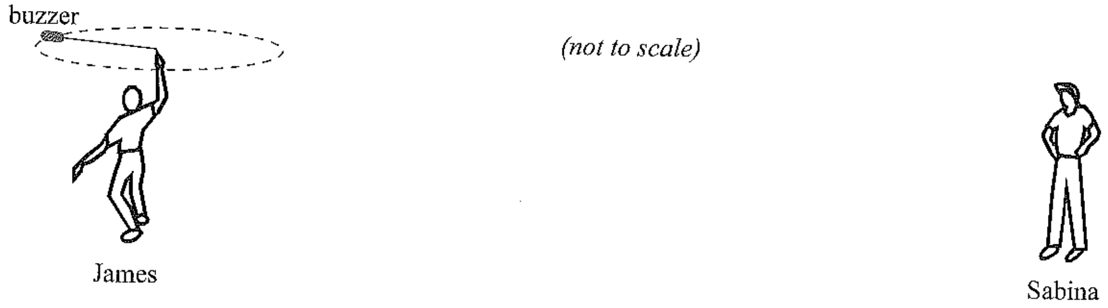
E8

QUESTION THREE: THE WHIRLING BUZZER

ASSESSOR'S USE ONLY

Speed of sound in air = 3.43×10^2 m s^{-1}

James attaches a buzzer to the end of a piece of string. James whirls the buzzer above his head in a horizontal circle of radius 1.02 m at a constant speed of 16.0 m s^{-1}.



Sabina stands a long distance away and listens.

(a) Describe the motion of the buzzer when Sabina receives sound waves with the shortest wavelength.

The buzzer is travelling directly towards Sabina i.e. all of V_s, not just a component

u

(b) If the frequency emitted by the buzzer is 512 Hz, show that the lowest frequency heard by Sabina is 489 Hz.

lowest f' is when $V_s = 16\,ms^{-1}$ directly away from Sabina

$$f' = f\frac{V_w}{V_w + V_s}$$

$$= 512 \times \frac{343}{343 + 16}$$

$$= 489.181\ldots$$

$$= 489\ Hz\ (3sf)$$

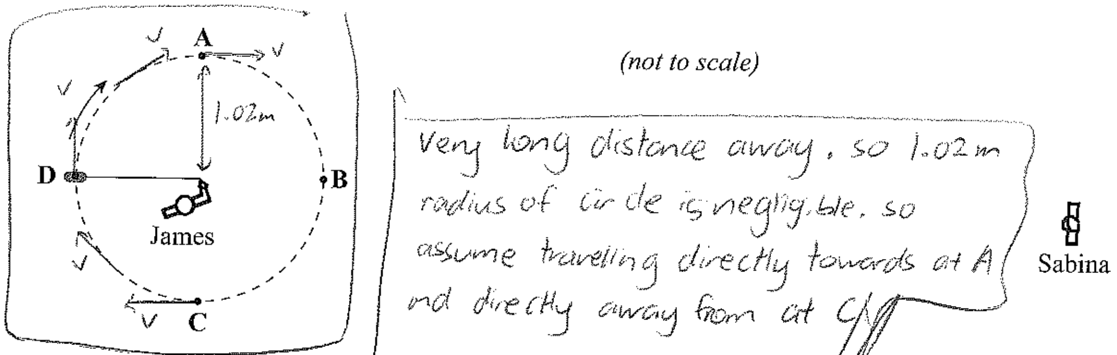
u

(c) Sabina stands a very long way away from James and listens to the buzzer. The sound appears to be increasing in frequency as the buzzer travels from point C to point A.

ASSESSOR'S USE ONLY

Explain why Sabina hears an increasing frequency between point C and point A.

You may want to use calculations to assist your answer.



The instantaneous velocity of the buzzer is always at a tangent to the circular path. At C, Sabina hears the lowest frequency of 489 Hz. This gradually increases as only a component of V_s is directly away, until at D, where V_s is not directly towards or away from, so 512 Hz (emitted f) is heard P8 BACK

u i

(d) James wants Sabina to hear beats. He puts a second buzzer, which is also emitting a sound of frequency 512 Hz, on the ground. James again whirls the original buzzer above his head, but at a different speed. When the buzzer is at point A, James lets go of it, so the buzzer flies towards Sabina.

Sabina hears a 10 Hz beat as James releases the string.

Calculate the velocity of the buzzer at the point of release.

When the spinning buzzer is at A, Sabina is hearing the highest apparent frequency as V_s is directly towards. $\therefore f' > 512$ Hz. Theres a beat frequency of 10 Hz, so

$f' = 512 + 10 = 522$ Hz

$f' = f \frac{V_w}{V_w - V_s}$

$522 = 512 \times \frac{343}{343 - V_s}$

$V_s = 343 - \frac{512 \times 343}{522}$

$= 6.5708...$

$= 6.6\ ms^{-1}$ (2sf)

u i c

E8

Excellence exemplar for 91523, 2015		Total score	24
Q	**Grade score**	**Annotation**	
1	E8	1d There is a small mathematical error however there is adequate evidence that this candidate understands the physics of this situation and can prove mathematically that 300 Hz will not resonate in the pipe in this situation.	
2	E8	2b has a statement that attributes the difference in the direction of the bright beams to a difference in the amount of diffraction, which is incorrect. The remaining evidence on this question is complete and accurate.	
3	E8	3c has a comprehensive explanation of the link between the component of the buzzer's velocity towards or away from Sabina, and the effect on the frequency she hears as this component gradually changes. 3d is also correct so E8 has been awarded.	