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Level 3 Physics, 2016

91523 Demonstrate understanding of wave systems

2.00 p.m. Tuesday 15 November 2016
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 23

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QUESTION ONE: PAN FLUTES

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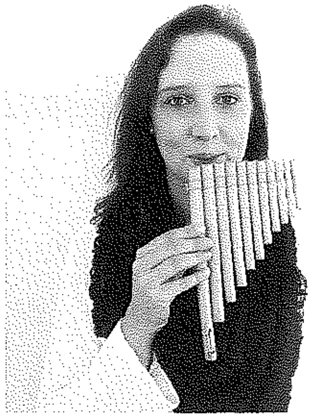
Assume the speed of sound in air is 343 m s^{-1}.

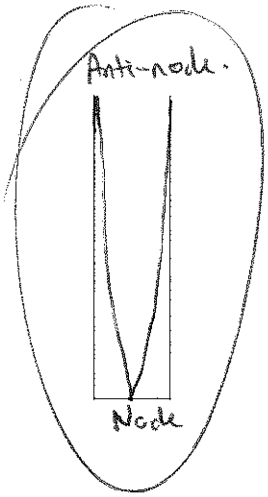
A pan flute is a musical instrument made of a set of pipes that are closed at one end. Maria produces different frequency notes by blowing air across the top of different pipes.



Maria is producing the fundamental frequency (first harmonic) in one pipe.

(a) On the diagram below draw the standing wave Maria is producing in the pipe.

Label the displacement nodes and antinodes.



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(b) Maria blows across one pipe and a fundamental frequency of 350 Hz is produced. A second pipe produces a fundamental frequency of 395 Hz.

Explain which pipe is longer.

$v = f\lambda$

The pipe ~~t~~ with the fundamental frequency of 350 Hz is longer. This is because the length of a pipe is directly proportional to the wavelength of the harmonic frequencies for that pipe. ~~For the first~~ A pipe with one closed and one open end ~~must have an~~ will have an antinode at the open end and a node at the closed end for each harmonic frequency. For this type of pipe, the wavelength for the fundamental frequency is $\lambda = 4L$. The 350 Hz wave ~~with~~ will have a longer wavelength than the 395 Hz wave, as $v = f\lambda$, and so the first pipe, with the 350 Hz wave, is longer.

$L = \frac{\lambda}{4}$

u

Maria blows air across one of her pipes and it produces a third harmonic with a frequency of 762 Hz. At the same time, her friend Sophie blows air across a similar pipe and also produces a third harmonic. They both hear a sound of 764 Hz, which is the average of the two frequencies. The sound varies in loudness, at a frequency of 4.00 Hz.

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(c) State the name of this phenomenon, and explain how it causes Maria to hear a variation in loudness.

This ~~ph~~ phenomenon is called beats. It occurs when ~~two~~ multiple waves with frequencies that are not the same but only have a small difference, ≤20 Hz, reach the same point. This will cause a regular variation to the loudness of the sound heard, as ~~the~~ waves will vary regularly between in phase and out of phase. When the waves are in phase constructive interference occurs and the sound heard will be louder, and when the waves are out of phase ~~the~~ destructive interference occurs and the sound is quieter. This occurs on a regular interval.

(d) Calculate the length of Sophie's pipe.

For third harmonic.

$\Rightarrow L = \frac{3\lambda}{4}$

~~$\lambda = \frac{v}{f}$~~ Average of sounds is 764.

~~$\lambda = 343 \Rightarrow f_s$ ... let f~~

let f_s be sophie's frequency and f_M be maria's frequency.

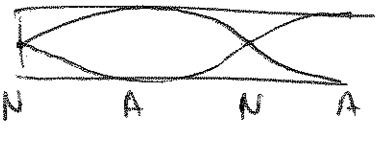
$\Rightarrow$ as $f_{avg} > f_M$

$f_s > f_M$

$f_B = |f_1 - f_2|$

$\Rightarrow f_B = f_s - f_M$

$f_s = f_M + f_B$



$f_s = 762 + 4$

$= 766$ Hz.

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

$\lambda_s = \frac{343}{766}$

$\lambda_s = 0.448$ m.

for third harmonic of this pipe, $L = \frac{3\lambda}{4}$

$\Rightarrow L_s = \frac{3 \times 0.448}{4}$

$= 0.336$ m (3sf).

C

E7

QUESTION TWO: A RADIO CONTROLLED PLANE

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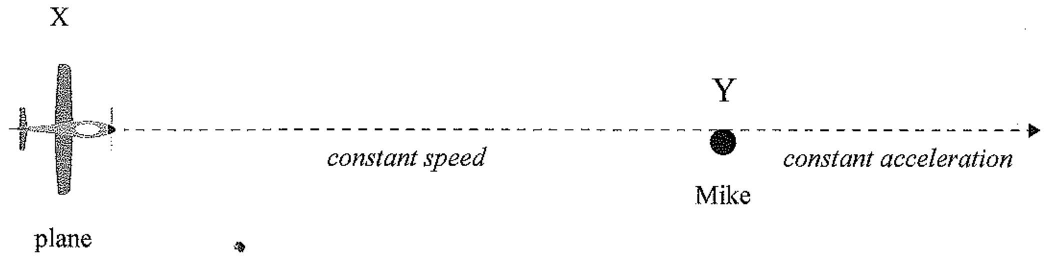
Mike is flying his radio controlled plane. The plane flies towards him at constant speed, and then away from him with constant acceleration, as shown in the diagram below.

The plane is producing a constant frequency of 185 Hz.

Assume the speed of sound in air is 343 m s^{-1}.



(a) Describe and explain the frequency of the sound Mike hears when the plane is at position X.

Mike hears a frequency higher than 185Hz when the plane is at X. This is because the Doppler effect causes the wavelength heard by Mike to be ~~longer~~ shorter, and therefore the frequency larger as $v = \overset{\uparrow}{f}\overset{\downarrow}{\lambda}$. The wavelength is shorter because ~~each crest~~ the plane is flying toward Mike, and so each crest emitted by the ~~plane~~ plane that Mike hears is emitted closer to Mike than the previous crest, and so the effective wavelength of the ~~wave~~ sound is lower. Therefore f is greater.

(b) Describe the frequency of the sound Mike hears when the plane is at position Y.

At point Y, ~~M~~ Mike hears the original frequency of 185Hz. This is because the Doppler effect only affects crests emitted in front of and behind the plane, not to the sides. At point Y the plane will be directly beside Mike flying past him. The waves ~~heard a~~ crest heard were all emitted with the original effective wavelength

(c) Describe and explain the frequency of the sound Mike hears as the plane gradually accelerates away from him.

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When a point source is travelling away from a person, the frequency heard is lower, also due to the Doppler effect. In this case each crest is emitted further away from Mike, extending the effective wavelength and decreasing frequency. As the plane is accelerating, each crest is emitted further and further from the previous, meaning the effective wavelength of the sound is getting longer and longer, and the frequency heard therefore lower and lower. This is shown by the equation $f_1 = f_0\left(\frac{v_w}{v_w + v_s}\right)$

i

(d) Calculate the speed of the plane when the sound waves being produced behind it have a wavelength of 2.00 m.

$f_1 = \frac{v}{\lambda}$

$f_1 = \frac{343}{2}$

$f_1 = 171.5\text{ Hz}$

$f_1 = f_0\left(\frac{v_w}{v_w + v_s}\right)$

$\cancel{\frac{f_1}{f_0} = \frac{v_s}{v_w + v_s}}$

$f_1(v_w + v_s) = f_0 v_w$

$f_1 v_w + f_1 v_s = f_0 v_w$

$f_1 v_s = f_0 v_w - f_1 v_w$

$v_s = \frac{f_0 v_w - f_1 v_w}{f_1}$

$\Rightarrow v_s = \frac{185 \times 343 - 171.5 \times 343}{171.5}$

$v_s = 27.0\text{ ms}^{-1}$

C

E8

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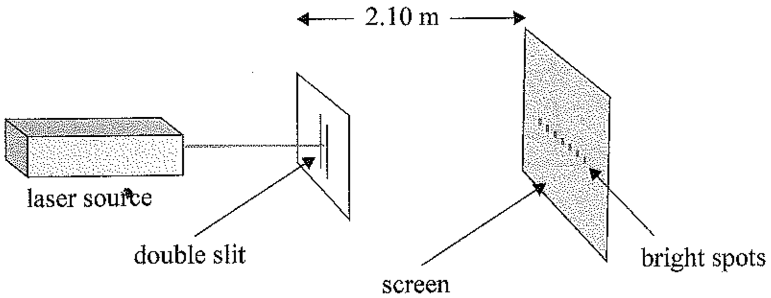
QUESTION THREE: DIFFRACTION GRATINGS

Moana is doing an experiment in the laboratory. She shines a laser beam at a double slit and observes an interference pattern on a screen. The diagram below shows the experiment. Moana measures the distance between adjacent bright spots (maxima) and finds they are 0.0100 m apart.

The slits are 1.28×10^{-4} m apart.

The screen is 2.10 m from the slits.



(a) Show that the wavelength of the laser light is 6.10×10^{-7} m.

$n\lambda = \frac{dx}{L}$

$\lambda = \frac{dx}{Ln}$

$\Rightarrow \lambda = \frac{1.28\times10^{-4} \times 0.01}{2.1 \times 1}$

$\lambda = 6.09523 \times 10^{-7}$

$\lambda = 6.10 \times 10^{-7}$ m (3sf) QED.

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Moana replaces the double slit with a diffraction grating in the same position. The diffraction grating has 500 lines per mm.

(b) Calculate the angle between the central antinodal line and the first antinodal line.

$d\sin\theta = n\lambda$

$d = \frac{1\times10^{-3}}{500}$

$d = 2\times10^{-6}$ m

$\theta = \sin^{-1}\left(\frac{n\lambda}{d}\right)$

$\theta = \sin^{-1}\left(\frac{1 \times 6.10\times10^{-7}}{2\times10^{-6}}\right)$

$\theta = 17.8°$ (3sf)

i

(c) Explain what would happen to the distance between the bright spots on the screen if the laser source is changed to one with a shorter wavelength.

$d\sin\theta = n\lambda$ $\quad n\lambda = \frac{dx}{L}$

The distance between the ~~fringes would~~ bright spots would decrease with a shorter wavelength. This is because the path difference between the waves that come from the grating, which acts as a series of point sources, will decrease with a lower wavelength and so the ~~fringes~~ areas of constructive interference, the bright spots, will be closer together.

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(d) Moana then shines white light through a diffraction grating. The pattern she sees is shown below.

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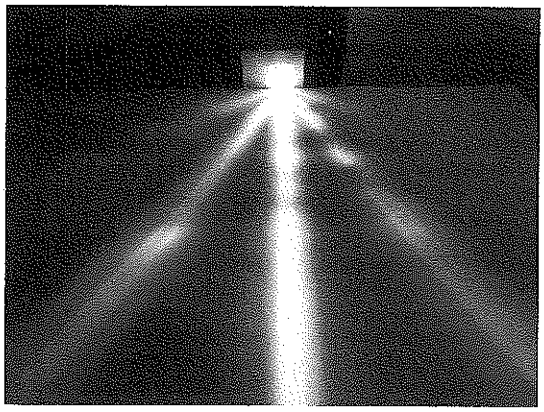

Explain the pattern Moana observes.

Your explanation should include:

- why the centre of the pattern is white
- why there is a coloured spectrum on each side
- why there are dark regions between the white and coloured regions.

A diffraction grating splits up the wavelengths that make up white light, red, green, and blue, due to their different wavelengths

The centre, the central antinodal line, is white because all of the different wavelengths ~~are constructively~~ that make up white light are constructively interfering, producing white light. The coloured spectrum is because the colours of light that make up white light ~~are~~ have different wavelengths, and so the angle between the central line and the following antinodal lines is different for each wavelength. The path difference for the light colour with the smaller wavelength is smaller than the others, so the area constructive interference is closer to the centre. Blue light has a smaller wavelength than red or green light, so angle between its first antinodal line is smaller and therefore the area of blue is closer to the white on the screen, than the other colours. Green has the next smallest wavelength, which is why it is closer to the centre than the area of red light on the screen.

see back

$d\sin\theta = n\lambda$

$n\lambda = \frac{dx}{L}$

C

E8

Extra paper if required.
Write the question number(s) if applicable.

QUESTION NUMBER

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3d) The dark region is present because this is where all the wavelengths present arrive out of phase, and so destructive interference occurs leaving no or little light waves present, so the area on the screen is dark.

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Annotated Exemplar 91523 2016

Excellence exemplar 2016

Subject:	Physics	Standard:	91523	Total score:	23

Q	Grade score	Annotation
1	E7	The explanation in 1b doesn't have a written statement that the wavelength of the fundamental standing wave in the pipe is inversely proportional to the frequency. The explanation in 1c explains beats as a variation in loudness **over time** linked to the **phase** difference and **type of interference** needed to make the sound louder (and softer)
2	E8	In part c the explanation clearly describes the frequency heard by Mike changing over time. The dropping frequency is explained by the wavelengths of the waves travelling towards Mike getting longer and longer.
3	E8	White light will only be seen where all wavelengths are constructively interfering. Dark regions will only be seen where all visible wavelengths are destructively interfering. Antinodal lines for each colour will be in a position determined by their wavelengths, separating the colours into a spectrum. All of these points are explained so excellence is awarded.