Checkpoints Chapter 17

Interference, diffraction, standing waves.

Multiple choice questions

Question 1

Your ear can hear sounds from a variety of sources at the same time. You are able to clearly distinguish the different sounds, eg you can hear someone speaking to you over the background noise of a stereo. The sound waves from both sources pass through each other without altering.
But you need to consider that the movement of the air molecules is a vector, so when the two waves are actually passing through each other their effects will add like vectors.
So the more complete answer is C, not A. In the exam you will always give the **best** answer. There will only be one answer, unless the question specifically says, 'one or more answers'.

∴ C (ANS)

Question 2

When the frequency of the sound is the same as the natural frequency of the pipe, we get 'amplification' of the sound which is called resonance. This occurs when the wavelength of the sound is a multiple of the length of the pipe. For a pipe open at both ends end the frequencies that will resonate are given by

$f = \frac{nv}{2L}$ where n = 1, 2, 3, 4 etc.

These frequencies are the natural frequencies of the pipe and a standing wave is set up in the pipe.
This standing wave is the superposition of the two waves travelling in opposite directions due to the reflections from the ends of the pipe.
This standing wave allows us to transfer more energy into the pipe easily. Hence we get 'amplification' of the sound.

∴ C (ANS)

Question 3

The person at B should be able to hear all frequencies, but the people at A and C will only here the lower frequencies, because the higher frequencies won't diffract enough to be heard.
If $v = f\lambda$ and $v = 320$ m s^{-1}, and f = 400 Hz.

Then $\lambda = 320 \div 400$
$= 0.80$ m

So $\frac{\lambda}{w} = \frac{0.80}{0.80} = 1$

The amount of diffraction (bending) is given by the value of the ratio $\frac{\lambda}{w}$ where w is either the width of the object or the width of the opening.

If the ratio $\frac{\lambda}{w} = 1$, then it is complete diffraction, i.e. bending through 180^0.

When $\frac{\lambda}{w} = 1$, the door opening is actually acting like a point source and so the waves spread out in all directions. This occurs when λ is greater than 0.8, which is when the frequency is less than 400Hz.

∴ A (ANS)

Question 4

Diffraction is given by $\frac{\lambda}{d}$. The wavelength of the light from the stars is fixed, so increasing "d" will decrease the spread of the light through the narrow gap. This will give a clearer image.

∴ B (ANS)

Question 5

The sound will diffract at the sound barrier.

Since the amount of diffraction is given by $\frac{\lambda}{d}$, and as 'd' is fixed the diffraction depends on λ.
∴ the larger λ, the more diffraction.
Large λ → lower frequency.
This means that the long wavelength sounds will diffract more at the barrier, and so they will be heard louder on the other side of the barrier. This means that the barrier is more effective at reducing the noise from the short wavelength (i.e. high frequency) sounds.

∴ A and D (ANS)

Question 6

The diffraction (bending) of the photon path varies as $\frac{\lambda}{d}$. So the pattern spreads more as λ increases and the pattern spreads more as ‘d’ (the size of the aperture/hole) decreases.

The stem of this question is confusing. It states that the circular hole has a larger diameter. So none of the answers are consistent with this. The answer C is a correct statement, but it what the question is asking.

Question 7 **(2015 Q10, 71%)**

The diffraction (bending) varies as $\frac{\lambda}{d}$,

If the frequency is increased the wavelength will decrease in the same ratio. Therefore the pattern will be less spread.

∴ **B** **(ANS)**

Question 8 **(2015 Q10, 62%)**

Reflections will interact with the sound waves, obscuring diffraction effects.

∴ **D** **(ANS)**

Question 9 **(2013 Q4, 84%)**

The diffraction is expressed as the ratio $\frac{\lambda}{d}$

Since the width of the door is fixed, the lower frequencies (longer wavelengths) will diffract more, so they will be louder

∴ **C** **(ANS)**

Question 10

The aperture (opening) will introduce some diffraction in the beam.

∴ **B** **(ANS)**

Question 11

The two car headlights are acting as two point sources, that are a long way away from the observer, but are close to each other. They will behave like light passing through two narrow slits, except that the diffraction pattern will be circular.

The diffraction (spreading) is expressed as the ratio $\frac{\lambda}{d}$

To minimise the spreading of the beam (from each headlight) use light with a shorter wavelength. (in this example the screen is actually your eyes, so you are seeing the image as if it was being seen on a screen. If there is less diffraction

∴ **A** **(ANS)**

Question 12

The diffraction (bending) varies as $\frac{\lambda}{d}$, so an decrease in the frequency will result in a increase in λ, hence, an increase in the diffraction. An increase in the aperture size, will lead to decrease in the diffraction.

These can be modelled as linear, so doubling the frequency change will result in doubling the size of the pattern, whilst doubling the size of the whole will result in a halving of the pattern. The net effect is zero change

∴ **B** **(ANS)**

Question 13

Assuming that the period is the only variable that is changed, then this will result in an increase in the frequency. This will result in a decrease in the wavelength and since the diffraction is expressed as the ratio $\frac{\lambda}{d}$, this will result in a decrease in the amount of diffraction.

∴ **C** **(ANS)**

Question 14

This is called diffraction.

∴ **A** **(ANS)**

Question 15 **(2014 Q11, 79%)**

John will hear the sound via two methods. Firstly, he will hear the sound as the musicians move past the end of the lane. The sound will travel directly to him. Once the band has moved on, the lower frequencies will diffract more and exist for longer down the laneway.

∴ **B** **(ANS)**

Question 16

When you pluck a guitar string, you set up a transverse wave in the string. It reflects from both ends, so you get a standing wave

$\therefore$ **B (ANS)**

Question 17

For resonance to occur the driving frequency needs to correspond to the natural vibration frequency

$\therefore$ **D (ANS)**

Question 18

The distance from the central maximum to the first anti-node is given by $x \approx \frac{n\lambda L}{d}$, where L is the distance between the slits and the screen and d is the distance between the two slits. An increase in 'd' will result in a decrease in 'x'. Therefore the pattern will be less spread out.

$\therefore$ **A (ANS)**

Question 19

If the refractive index of the medium changes, then the wavelength will change. An increase in refractive index will lead to a decrease in speed, (the frequency will remain constant) so the wavelength will decrease. (from $v = f \times \lambda$). This decrease in wavelength will result in less diffraction.

$\therefore$ **A, D (ANS)**

Question 20

Diffraction is the bending of the waves, this results in the spreading of the sound. Sound will diffract through the doorway, but light, with its much shorter wavelength, wont.

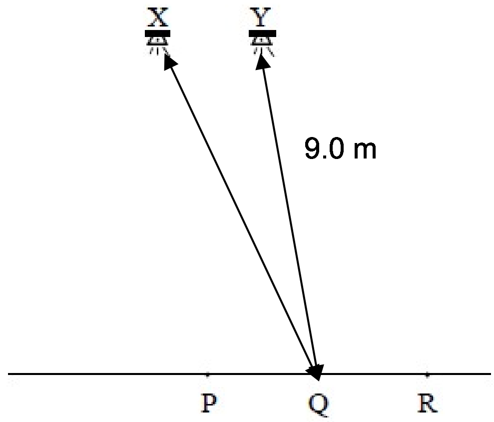
$\therefore$ **D (ANS)**

Extended answers

Question 21 (2012 Q8, 68%)

The 500 Hz sound will diffract and so will be heard relatively strongly, therefore the 5000 Hz will sound softer.

Question 22 (1999 Q12, 4m.57%)



The point Q is the first nodal point from the central maximum at P. So the path difference between XQ and YQ must 0.5 λ.

$\therefore$ 0.5 λ = 0.1 m

$\therefore$ if YQ = 9.0 m then XQ = 9.1 m

$\therefore$ **XQ = 9.1 m (ANS)**

Question 23 (2014 Q5, 67%)

The resonance is when the standing wave exists. This is identified as the note persisting, i.e. remaining loud.

Question 24a (1998 Q5, 4 m)

The sound intensity at P is a result of the interference between the waves emitted from S_1 and S_2.

For a minimum of sound intensity at point P the path difference of P from S_1 and S_2 needs to have a phase difference of one-half wavelength.

Point P is a point of destructive interference, arising from the superposition of crest and trough, trough and crest, half-crest and half trough etc.

Point P is a minimum at all times because S_1 and S_2 are producing waves of the same frequency, resulting in a stationary wave pattern.

Question 24b

S_1P = 4 m, S_1S_2 = 3.0 m,
Use Pythagoras, S_2P = 5.0 m
So path difference = 5.0 – 4.0 = 1.0 m

This is $(n - \frac{1}{2})\lambda$.
This question has been modified from the 1998 paper, and I don't think that you can get an answer from this point. We don't know which nodal line the point P is on.
Syd has assumed that it is on the first nodal line, therefore $(n - \frac{1}{2})\lambda = 1.0$ m
∴ $\lambda = 2.0$ m.
The logic in the book is correct but I'm not sure that we can assume that it is on the first nodal line.

Question 24c

Since Q is a local maximum, the path difference to Q = $n\lambda$.
This question has been modified from the 1998 paper, and I don't think that you can get an answer from this point. We don't know which anti-nodal line the point Q is on.
If you assume that P is on the first nodal line, (as in the previous question), then Q must be on the central maximum, as there is not a local maximum between the central maximum and the first nodal line.
Syd has assumed that point Q is on the first anti-nodal line, so $n\lambda = 2.0$ m.

Question 25a

This is a local minimum which is due to destructive interference of the waves from both speakers. The path difference for the waves from the two sources, is $\frac{1}{2}\lambda$.

Question 25b

$\frac{1}{2}\lambda = 1.0$ m, as Jan is 4.5 m from the left speaker and 5.5 m from the right speaker.
∴ **λ = 2 m (ANS)**

Question 25c

Use $v = f \times \lambda$
∴ $v = 175 \times 2$
∴ **$v = 350$ m s^{-1} (ANS)**

Question 25d

Both speakers are producing the same sound wave, so the two waves will interfere with each other and form a standing wave between the two speakers.

Question 26

The head is acting as an obstacle to the sound. Dan's head will cause a 'sound shadow' for the high frequencies. The low frequency (long wavelength) sounds will diffract around the head and be equally loud in both ears.
Dan can locate the source of the sound, by comparing the intensities in both ears. If they are both the same, Dan can't easily locate the source of the sound.

Question 27a

The two dippers produce travelling waves at regular intervals. These travelling waves move away from their source. At certain points (where the path difference is a multiple of $(n - \frac{1}{2})\lambda$, there will be destructive interference of the waves from the two separate sources. This will create nodal lines, which are the flat water in the tank.

Question 27b

The point A is on second nodal line to the right of the central maximum. This means that the path difference is 2λ. (λ = 1.0 cm)
∴ **2 cm (ANS)**

Question 27c

There is a standing wave formed between the two sources. (i.e. along the line XY). This is because two equal waves are travelling in the opposite direction. They will interfere and create a standing wave. There will be a node every $\frac{1}{2}\lambda$.

Question 27d

Use $v = \frac{\lambda}{t}$
∴ $5 = \frac{1}{t}$
∴ **t = 0.2 s (ANS)**

Question 27e

The distance from the central maximum to the first anti-node is given by $x \approx \frac{n\lambda L}{d}$. Reducing the distance XY (d) would spread the pattern (of nodal lines and anti-nodal lines) more.
Increasing the frequency, will reduce the wavelength, this will reduce the spread of the pattern

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Question 28

The diffraction (bending) varies as $\frac{\lambda}{d}$, so a decrease in the gap will spread the diffraction pattern further. The wave energy that entered the harbour would be reduced if the gap was reduced, as more would be reflected by the longer barriers.

Question 29a

The path difference is given by the difference between the length of the two paths. To go directly from A to B, the length is 2r. To take the longer route, the distance is given by

$d = \frac{2 \times \pi \times r}{2}$

$\therefore d = 3.14\ r$

$\therefore \Delta d = 3.14\ r - 2r$

$\therefore \Delta d = 1.14\ r$ **(ANS)**

Question 29b

Use $v = f \times \lambda$, where $v = 340\ m\ s^{-1}$, $f = 372$ Hz.

$\therefore 340 = 372 \times \lambda$

$\therefore \lambda = 0.914$ m

$\therefore PD = 1.14 \times 0.80$ m

$= 0.912$ m.

Therefore the path difference is close to 1 λ, therefore it will be a local maximum intensity.

Question 30a

Use $v = f \times \lambda$

$\therefore 6.0 = 3.0 \times \lambda$

$\therefore \lambda = 2.0$ cm **(ANS)**

Question 30b

The reflected wave has the same v, f and λ as the original. Therefore there are two wave that are travelling in opposite directions. They will set up a standing wave pattern in the tank. The distance between nodes will be $\frac{1}{2}\lambda$, i.e 1 cm. The amplitude of the standing wave will be double the original.

Question 31a

The reflection of the wave from both fixed ends results in two identical waves travelling in opposite directions. These two waves combine together and superimpose themselves on the other wave. This is because the transverse motions of both waves combine as vectors.

Question 31b

Use $t = \frac{1}{f}$

$\therefore t = \frac{1}{900}$

$\therefore$ **t = 0.001 s (ANS)**

Question 31c

Use $v = f \times \lambda$

$\therefore v = 900 \times 0.20$

$\therefore$ **v = 180 m s^{-1} (ANS)**

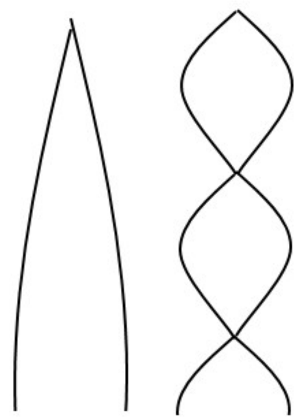
Question 31d

These notes will occur when there is a node at each end and one or two antinodes in between. The fundamental will be when there is a node at each end and an antinode in the middle. Here the wavelength will be 90 cm, so the frequency will be 300 Hz.
The second harmonic has a frequency of twice the fundamental, 600 Hz

$\therefore$**300 Hz, 600 Hz (ANS)**

Question 32a

The standing wave patterns need to have a node at the top and an antinode at the bottom.



Question 32b

If the original wave had a frequency of 150 Hz, the fundamental is 50 Hz, and the fifth harmonic is 250 Hz.
Waves free at one end only create the odd harmonics.

Question 32c

Use $v = f \times \lambda$

Form the stem we get f = 150 Hz, $\frac{3}{4}\lambda = 45$ cm

∴ λ = 60 cm.
∴ v = 150 × 0.60
∴ v = 90 m s^{-1} (ANS)

Question 33a

Take two points that are identical along the spring. It is probably easiest to use the transition point from the compressed to the stretched.

∴ 8.4 – 1.1 = 7.3 cm (ANS)

This answer is different to the one in the back of the book.

Question 33b

The nodes will be $\frac{1}{2}$ λ apart.

∴ 3.7 cm (ANS)

This answer is different to the one in the back of the book.

Question 33c

Use v = f × λ
∴ 15 = f × 7.3
∴ 2 Hz (ANS)

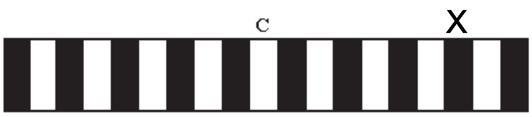
This answer is different to the one in the back of the book.

Question 34a (2012 Q2b, 2m, 60%)

The laser provides a coherent light source. Therefore the path difference for the two beams reaching the central point is zero. They will interfere constructively, so there will be a local maximum, which is seen as a bright band.

Question 34b (2012 Q2c, 3m, 60%)

The path difference is $\frac{2.142 \times 10^{-6}}{612 \times 10^{-9}}$ = 3.5 λ.
Therefore the point X will be on the 4th dark band to the right of C. Each dark band indicates destructive interference, where the path difference is a multiple of ½λ.



Question 34c (2012 Q2d, 2m, 40%)

With the new wavelength, 2λ must be the same as 1½λ in the original wavelength.
∴ $2\lambda_{new}$ = 1.5 x 612
∴ λ_{new} = 459 nm (ANS)

Question 35a (2013 Q22a, 2m, 50%)

Bright or a local maximum.
The path difference from the double slits to the **centre** of the pattern is zero, therefore constructive interference will occur.
You needed to be specific about the pattern in the centre.

Question 35b (2013 Q22b, 1m, 60%)

Lower frequency means a longer wavelength, therefore it is further to each maximum and minimum, i.e. the pattern is more spread out. So the second dark band will be further from te central maximum.

Question 35c (2013 Q22c, 3m, 33%)

Determine the wavelength of the light, (in metres).
Use:
The second bright band has a path difference of 2λ
∴ 2λ = 1.4 ×10^{3} nm
= 1.4 × 10^{-6} m
So λ was 7 × 10^{-7} m.
The PD to the first dark band is λ/2,
∴ 3.5 × 10^{-7} m (ANS)

Question 36a (2014 Q19a, 1m, 60%)

The path difference to the second bright band is 2λ.
∴ 2 × 420 = **840 nm (ANS)**

Question 36b (2014 Q19b, 2m, 45%)

If the point P is now on the second dark band, this means that the path difference is now 1.5λ.
∴ 840 = 1.5 λ_{new}
∴ $\lambda_{new} = \frac{840}{1.5}$
∴ λ_{new} = 560 nm (ANS)

Question 36c

The distance from the central maximum to the first anti-node is given by $x \approx \frac{n\lambda L}{d}$,
The wavelength λ, is increased by the factor
$\frac{520}{420}$ = 1.238
L is increased by a factor of 2

d is increased by a factor of 1.5,

∴ x will change by the factor

× 1.238 × 2 ÷ 1.5

∴ x = 3.0 × 1.238 × 2 ÷ 1.5

∴ x = 4.95

∴ x = 5.0 mm (ANS)

Question 36d

White light is made up from the colours in the spectrum, which have different wavelengths. The different wavelengths will all have their own interference pattern. These will all overlap in the middle, to give a white central maximum, but there will be coloured bright and dark bands on either side.

Question 37a

Increasing the distance between the aperture and the screen will give a proportionally larger image. The image is scaled up.

Question 37b

The diffraction (bending) is expressed as the ratio $\frac{\lambda}{d}$. If d is smaller the distance between the interference bands will increase.

Question 37c

This question is difficult at this stage, but $E = \frac{hc}{\lambda}$, so an increase in E will result in a decrease in λ. The diffraction (bending) is expressed as the ratio $\frac{\lambda}{d}$.

∴ The diffraction pattern is less spread out.

Question 38a

The beam of light will diffract as it passes through the small aperture. This will give a bright central region surrounded by a series of bright and dark bands. The bright and dark bands are due to interference effects.

Question 38b

If the screen is moved towards the slit, the pattern will not spread out as far. So the bright and dark bands will be closer together.

Question 38c

The diffraction (bending) is expressed as the ratio $\frac{\lambda}{d}$. If the wavelength is shortened, then the pattern will not be as spread out. So the interference bands come closer together.

Question 38d

White light is made up from the colours in the spectrum, which have different wavelengths. The different wavelengths will all have their own interference pattern. These will all overlap in the middle, to give a white central maximum, but there will be coloured bright and dark bands on either side.

Question 39a (2016 Q18a, 2m, 59%)

X is on the second dark band, therefore the path difference is given by $1\frac{1}{2}\lambda$.

∴ $1\frac{1}{2}\lambda = 750$ nm

∴ λ = 500 nm (ANS)

Question 39b (2016 Q18b, 2m, 60%)

The path difference to the 2nd bright band is 2 λ.

∴ $S_2P - S_1P = 2 \times 500$ nm

∴ 1 000 nm (ANS)

Question 39c (2016 Q18c, 2m, 58%)

As the width of the slit increases the spread of the diffraction pattern decreases. Therefore the central band needs to reduce in width.

Question 40a (2016 Sound Q7, 2m, 37%)

The middle between the two speakers will be a local maximum, as the waves from both speakers will interfere constructively. The speakers will create a standing wave which will have a wavelength of half of the wavelength of the original sound. Half a wavelength either side of the centre will be a local minimum. This will be 4.75 m from B, as the standing wave wavelength is 0.5 m. Yasmin will move another 0.5 metre towards B for the next local minimum. She will be 4.25 m from B.
