# AS Level Physics

Chapter 4 – Waves

4.4.2 Stationary Waves

Worked Examples

# Stationary Waves

## Exam Style Question 1

(a) When used to describe stationary (standing) waves explain the terms:

(i) Node

(ii) Antinode

(b) Fig. 5.1 shows a string fixed at one end under tension. The frequency of the mechanical oscillator close to the fixed end is varied until a stationary wave is formed on the string.

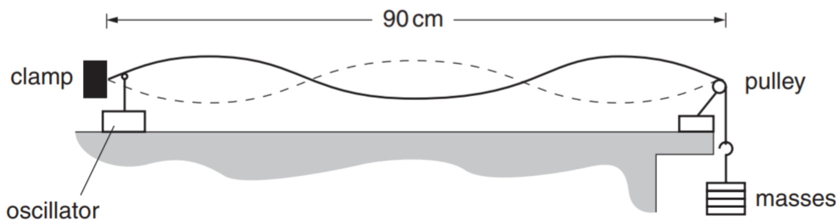


**Fig. 5.1**

(i) Explain with reference to a progressive wave on the string how the stationary wave is formed.

(ii) On Fig. 5.1 label one node with the letter N and one antinode with the letter A.

(iii) State the number of antinodes on the string in Fig. 5.1.

(iv) The frequency of the oscillator causing the stationary wave shown in Fig. 5.1 is $120\ Hz$. The length of the string between the fixed end and the pulley is $90\ cm$. Calculate the speed of the progressive wave on the string.

(c) The speed $v$ of a progressive wave on a stretched string is given by the formula

$$v = k\sqrt{W}$$

where $k$ is a constant for that string. $W$ is the tension in the string which is equal to the weight of the mass hanging from the end of the string.

In (b) the weight of the mass on the end of the string is $4.0\ N$. The oscillator continues to vibrate the string at $120\ Hz$. Explain whether or not you would expect to observe a stationary wave on the string when the weight of the suspended mass is changed to $9.0\ N$.



# Stationary Waves

## Exam Style Question 1

**(a) When used to describe stationary (standing) waves explain the terms:**

**(i) Node**

Node occurs where the amplitude (or displacement) is zero.

**(ii) Antinode**

Antinodes occur where the amplitude of the stationary wave takes the maximum possible value.

**(b) (i) Explain with reference to a progressive wave on the string how the stationary wave is formed.**

Stationary waves are created when a progressive wave is reflected at a boundary. The reflected wave interferes (or superposes) with the incident wave. The incident and reflected waves superpose destructively at certain points, resulting in nodes, and constructively at other points, resulting in antinodes.

**(b) (ii) On Fig. 5.1 label one node with the letter N and one antinode with the letter A.**

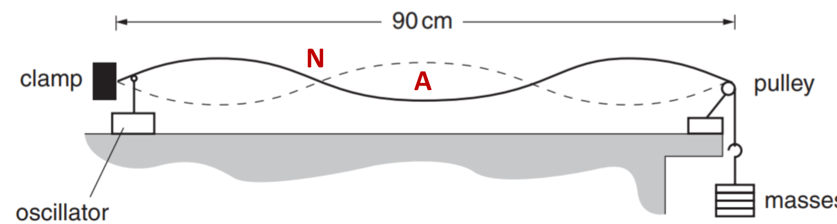


**Fig. 5.1**

# Stationary Waves

## Exam Style Question 1

(a) When used to describe stationary (standing) waves explain the terms:

(i) Node

(ii) Antinode

(b) Fig. 5.1 shows a string fixed at one end under tension. The frequency of the mechanical oscillator close to the fixed end is varied until a stationary wave is formed on the string.

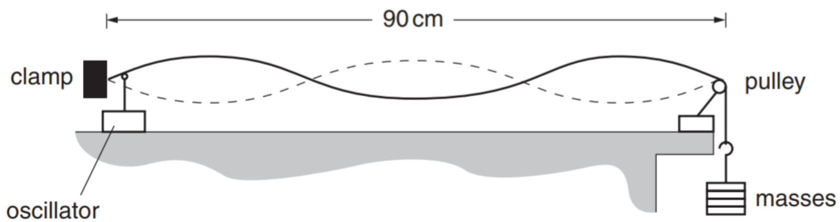


**Fig. 5.1**

(i) Explain with reference to a progressive wave on the string how the stationary wave is formed.

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(iv) The frequency of the oscillator causing the stationary wave shown in Fig. 5.1 is $120\ Hz$. The length of the string between the fixed end and the pulley is $90\ cm$. Calculate the speed of the progressive wave on the string.

(c) The speed $v$ of a progressive wave on a stretched string is given by the formula

$$v = k\sqrt{W}$$

where $k$ is a constant for that string. $W$ is the tension in the string which is equal to the weight of the mass hanging from the end of the string.

In (b) the weight of the mass on the end of the string is $4.0\ N$. The oscillator continues to vibrate the string at $120\ Hz$. Explain whether or not you would expect to observe a stationary wave on the string when the weight of the suspended mass is changed to $9.0\ N$.



# Stationary Waves

## Exam Style Question 1

**(b) (iii) State the number of antinodes on the string in Fig. 5.1.**

Three

**(b) (iv) Calculate the speed of the progressive wave on the string.**

$$30\ cm = \frac{\lambda}{2}$$
$$\lambda = 60\ cm$$
$$v = f\lambda = (120\ Hz)(60 \times 10^{-2}\ m)$$
$$v = 72\ m\ s^{-1}$$

**(c) Answer to question (c) is on the next page.**



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# Stationary Waves

## Exam Style Question 1

(a) When used to describe stationary (standing) waves explain the terms:

(i) Node

(ii) Antinode

(b) Fig. 5.1 shows a string fixed at one end under tension. The frequency of the mechanical oscillator close to the fixed end is varied until a stationary wave is formed on the string.

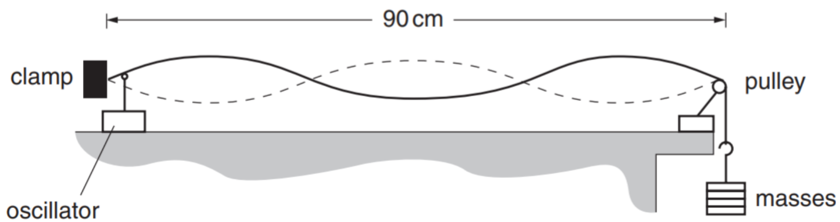


**Fig. 5.1**

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(iv) The frequency of the oscillator causing the stationary wave shown in Fig. 5.1 is $120\ Hz$. The length of the string between the fixed end and the pulley is $90\ cm$. Calculate the speed of the progressive wave on the string.

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$$v = k\sqrt{W}$$

where $k$ is a constant for that string. $W$ is the tension in the string which is equal to the weight of the mass hanging from the end of the string.

In (b) the weight of the mass on the end of the string is $4.0\ N$. The oscillator continues to vibrate the string at $120\ Hz$. Explain whether or not you would expect to observe a stationary wave on the string when the weight of the suspended mass is changed to $9.0\ N$.





# Stationary Waves

## Exam Style Question 1



**(c) Explain whether or not you would expect to observe a stationary wave on the string when the weight of the suspended mass is changed to $\mathbf{9.0\ N}$.**

In (b) the weight of the mass at the end of the string is $4.0\ N$, therefore:

$$v = k\sqrt{W} = k\sqrt{4} = 2k$$
$$v = 2k$$

Now we need to find the value of constant, $k$.

We know that $v = 72\ m\ s^{-1}$

Hence:

$$k = \frac{72\ m\ s^{-1}}{2} = 36$$

Now the weight suspended is changed to $9.0\ N$. Therefore:

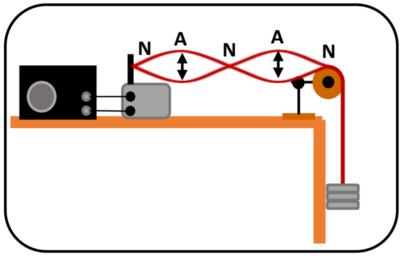
$$v = k\sqrt{W} = k\sqrt{9.0} = 3k$$
$$v = (3)(36) = 108\ m\ s^{-1}$$

Thus $v$ increases by $\frac{108\ m\ s^{-1}}{72\ m\ s^{-1}} = \frac{3}{2}$ and as $v \propto \lambda$, $\lambda$ also increases by $\frac{3}{2}$.

We know the $\lambda = 60\ cm$ for when the weight is $4.0\ N$ so for $9.0\ N$ the wavelength is $60\ cm \times \frac{3}{2} = 90\ cm$.

So for an increased weight we get a wavelength of $90\ cm$.

This means a standing wave can be formed as a complete wavelength fits on this string which is 90cm long. You would get a standing wave like the one below:



### Exam Style Question 2

Fig. 5.1 shows a uniform string which is kept under tension between a clamp and a pulley. The frequency of the mechanical oscillator close to one end is varied so that a stationary wave is set up on the string.

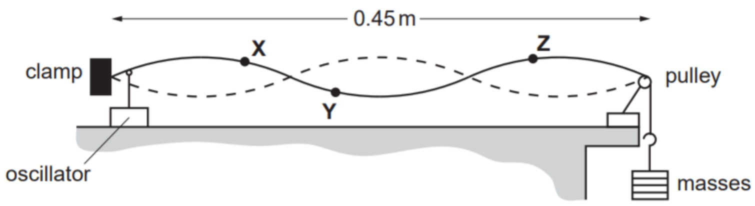



**Fig. 5.1**

(a) State two features of a stationary wave.

(b) Explain how the stationary wave is formed on the string.

(c) The distance between the clamp and the pulley is $0.45\ m$. $X$, $Y$ and $Z$ are three points on the string. $X$ and $Y$ are each $0.040$ m from the nearest node and $Z$ is $0.090\ m$ from the pulley. State, giving a reason for your choice, which of the points $Y$ or $Z$ or both oscillate

(i) with the same amplitude as $X$

(ii) with the same frequency as $X$

(iii) in phase with $X$.



## Stationary Waves

### Exam Style Question 2

**(a)State two features of a stationary wave.**

1) Standing waves have no net transfer of energy (because the two waves which make them up are carrying equal energy in opposite directions).

2) Stationary waves also have nodes (which has a zero amplitude) and antinodes with maximum amplitude.

**(b) Explain how the stationary wave is formed on the string.**

The stationary wave is formed when an incident wave is reflected at the fixed end of the string, and the reflected wave interferes (or superposes) with the incident wave.

**(c) State, giving a reason for your choice, which of the points $Y$ or $Z$ or both oscillate**

**(i) with the same amplitude as $X$**

Points which are the same distance from the nodes will have the same amplitude

So $Y$ has the same amplitude as $X$.

**(ii) with the same frequency as $X$**

All points on the string oscillate with the same frequency

So $Y$ and $Z$ have the same frequency as $X$.

**(iii) in phase with $X$.**

All points in alternative segments of the string oscillate in phase

So $Z$ is in phase with X.

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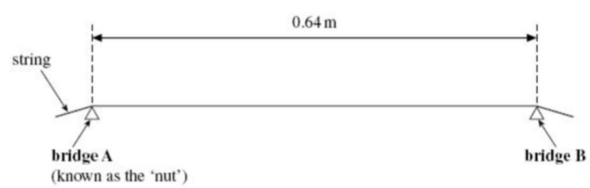
# Stationary Waves

## Exam Style Question 3

Figure 1 shows a side view of a string on a guitar. The string cannot move at either of the two bridges when it is vibrating. When vibrating in its fundamental mode the frequency of the sound produced is $108\ Hz$.

(a) (i) On Figure 1, sketch the stationary wave produced when the string is vibrating in its fundamental mode.

Figure 1



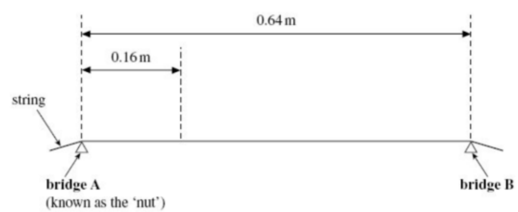

(ii) Calculate the wavelength of the fundamental mode of vibration.

(iii) Calculate the speed of a progressive wave on this string.

(b) While tuning the guitar, the guitarist produces an overtone that has a node $0.16\ m$ from bridge A.

(i) On Figure 2, sketch the stationary wave produced and label all nodes that are present.

Figure 2




(ii) Calculate the frequency of the overtone.

(c) The guitarist needs to raise the fundamental frequency of vibration of this string. State one way in which this can be achieved.

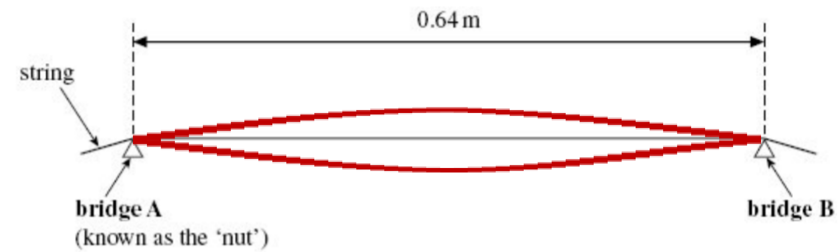


# Stationary Waves

## Exam Style Question 3

**(a)(i) On Figure 1, sketch the stationary wave produced when the string is vibrating in its fundamental mode.**

Figure 1




**(a) (ii) Calculate the wavelength of the fundamental mode of vibration.**

Use $\lambda_0 = 2L$

$$\lambda_0 = 2(0.64\ m) = 1.28\ m$$

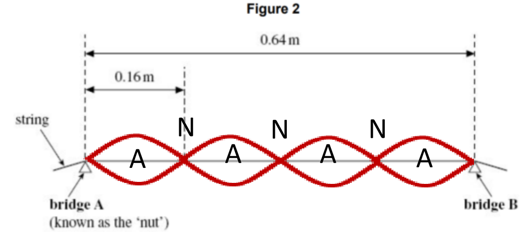
**(a) (iii) Calculate the speed of a progressive wave on this string.**

Use $v = f\lambda$

$$v = (108\ Hz)(1.28\ m) = 138\ m\ s^{-1}$$

**(b) (i) On Figure 2, sketch the stationary wave produced and label all nodes that are present.**

Figure 2




At 0.16 m, the first node is found. As a result, half a wavelength can fit into 0.16 m. The string is 0.64 m long, and half a wavelength can fit into 0.16m, so $\frac{0.64\ m}{0.16\ m} = 4$. Therefore 4 half wavelengths can fit onto this string.

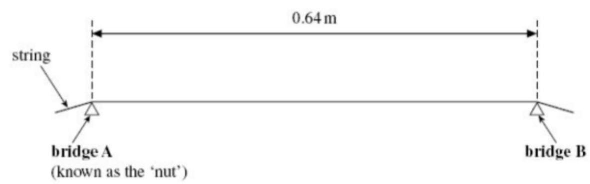
# Stationary Waves

## Exam Style Question 3

Figure 1 shows a side view of a string on a guitar. The string cannot move at either of the two bridges when it is vibrating. When vibrating in its fundamental mode the frequency of the sound produced is $108\ Hz$.

(a) (i) On Figure 1, sketch the stationary wave produced when the string is vibrating in its fundamental mode.

Figure 1



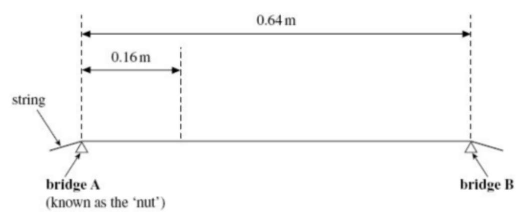

(ii) Calculate the wavelength of the fundamental mode of vibration.

(iii) Calculate the speed of a progressive wave on this string.

(b) While tuning the guitar, the guitarist produces an overtone that has a node $0.16\ m$ from bridge A.

(i) On Figure 2, sketch the stationary wave produced and label all nodes that are present.

Figure 2




(ii) Calculate the frequency of the overtone.

(c) The guitarist needs to raise the fundamental frequency of vibration of this string. State one way in which this can be achieved.




# Stationary Waves

## Exam Style Question 3


**(b) (ii) Calculate the frequency of the overtone.**

$$4f_0 = 4(108\ Hz) = 430\ Hz$$

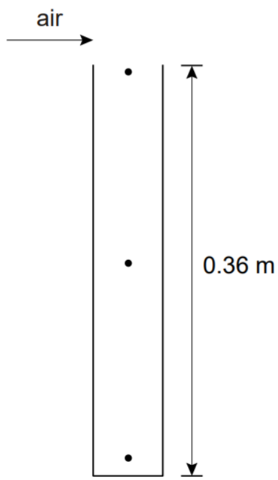
**(c) The guitarist needs to raise the fundamental frequency of vibration of this string. State one way in which this can be achieved.**

- Decrease the length
- Increase the tension
- Tighten the string.

# Stationary Waves

## Exam Style Question 4

A standing sound wave can be produced in an air column by blowing across the open end of a tube as shown in the diagram below.




The length of the tube is 0.36 m. The air column in the tube is sounding its lowest (fundamental) frequency note.

(i) Add arrowed lines to the dots in the diagram above to show the direction of movement and relative amplitudes of the air at these positions.

(ii) Calculate the wavelength of the sound produced.

(iii) The speed of sound in air is 330 $m\ s^{-1}$. Determine the frequency of this standing wave.

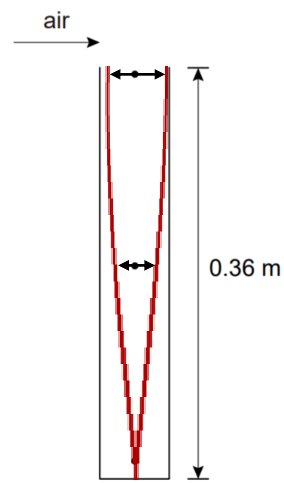
(iv) Determine the value of the lowest frequency of the note produced in a tube of this length but open at both ends. Show your reasoning.



# Stationary Waves

## Exam Style Question 4

**(i) Add arrowed lines to the dots in the diagram above to show the direction of movement and relative amplitudes of the air at these positions.**




We know that the fundamental mode of vibration generates a wave similar to the one seen in red. This indicates that the particles are oscillating vertically. Because it's a closed pipe, the amplitude is greatest at the open top end, and so the arrows are wide. The amplitude decreases (and the arrows become smaller) as you get closer to the middle. As you get to the end the amplitude becomes very small.

**(ii) Calculate the wavelength of the sound produced.**

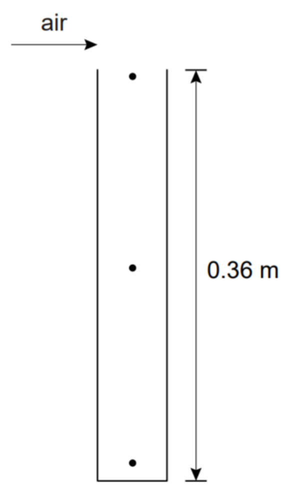
At the fundamental mode $L = \frac{\lambda_0}{4}$. So, use that formula and rearrange for $\lambda_0$:

$$\lambda_0 = L \times 4 = 0.36\ m \times 4 = 1.44\ m$$

# Stationary Waves

## Exam Style Question 4

A standing sound wave can be produced in an air column by blowing across the open end of a tube as shown in the diagram below.




The length of the tube is 0.36 m. The air column in the tube is sounding its lowest (fundamental) frequency note.

(i) Add arrowed lines to the dots in the diagram above to show the direction of movement and relative amplitudes of the air at these positions.

(ii) Calculate the wavelength of the sound produced.

(iii) The speed of sound in air is 330 $m\ s^{-1}$. Determine the frequency of this standing wave.

(iv) Determine the value of the lowest frequency of the note produced in a tube of this length but open at both ends. Show your reasoning.



# Stationary Waves

## Exam Style Question 4

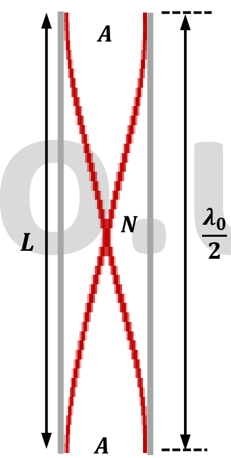
**(iii) The speed of sound in air is 330 $m\ s^{-1}$. Determine the frequency of this standing wave.**

Use $v = f\lambda$ and rearrange for $f$

$$f = \frac{v}{\lambda} = \frac{330\ m\ s^{-1}}{1.44\ m} = 299\ Hz$$

**(iv) Determine the value of the lowest frequency of the note produced in a tube of this length but open at both ends. Show your reasoning.**

If the pipe has open ends on both sides the wave changes to:




So now the formula becomes:

$L = \frac{\lambda_0}{2}$ and the wavelength changes. Rearrange for $\lambda_0$ to find out the new wavelength:

$$\lambda_0 = 2L = (2)(0.36\ m) = 0.72\ m$$

Therefore, using $f = \frac{v}{\lambda}$ we get:

$$f = \frac{330\ m\ s^{-1}}{0.72\ m} = 458\ Hz$$

Please see **‘4.4.1 Stationary notes’** pack for revision notes.

For more revision notes, tutorials and worked examples please visit **www.tutorpacks.co.uk.**