WAVES: STANDING WAVES QUESTIONS

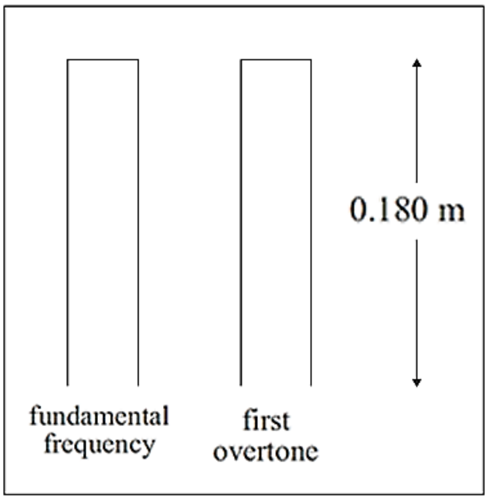
STEAM WHISTLE (2010;1)

Data to use:
Speed of sound in dry air at 20°C = 343 ms^{-1}
Speed of sound in steam at 200°C at a pressure of 7 MPa = 523 ms^{-1}

Steam-powered trains use loud whistles for signals. The whistles work like pipes that are closed at one end. Instead of air, steam from the boiler makes the sound.

One such whistle acts as a pipe closed at one end, with a length of 0.180 m. It produces a sound with many overtones (harmonics).

(a) Label the diagrams to show the positions of displacement nodes (N) and antinodes (A) of the standing waves that are set up in the pipe when it vibrates
 (i) at its fundamental frequency (1st harmonic)
 (ii) with its first overtone (3rd harmonic).

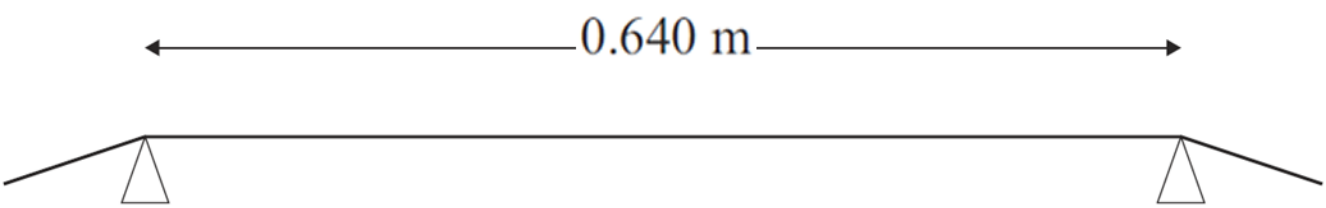


(b) In this part of the question assume that the whistle is full of steam at 200°C, at a pressure of 7 MPa, and surrounded by dry air at 20°C. Calculate the frequency of the fundamental (1st harmonic).

(c) The whistle is initially full of dry air at 20°C. It is blown with a jet of steam and as it whistles it is gradually filled with steam, changing the sound of the whistle. Describe what you might expect to hear and explain any changes.

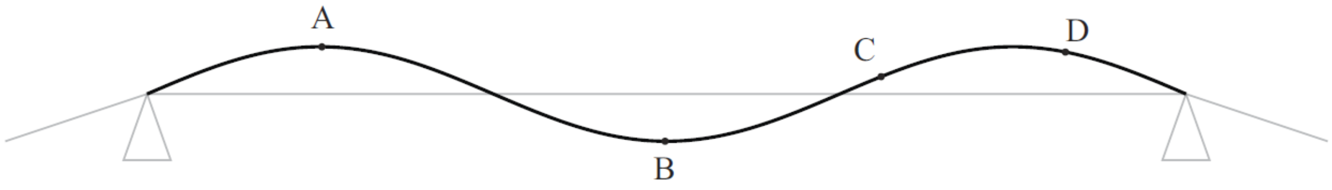
TUNING A GUITAR(2010;2)

The 'A' string on a guitar has a weight and a tension which means that waves travel along the string at 563 ms^{-1}. The length of the string that is free to vibrate is 0.640 m.



(a) Show that the fundamental frequency (1st harmonic) of the string is 440 Hz.

(b) The diagram shows the shape of the string at one moment while it is oscillating in a standing wave at the frequency of its second overtone (3rd harmonic). Particles in the string at A, B, C and D are all oscillating with simple harmonic motion.



(i) Compare the phase difference and amplitude of the particles of string at antinodes A and B.
(ii) Compare the phase difference and amplitude of particles of string at C and D.

STRINGS AND STANDING WAVES (2009;1)

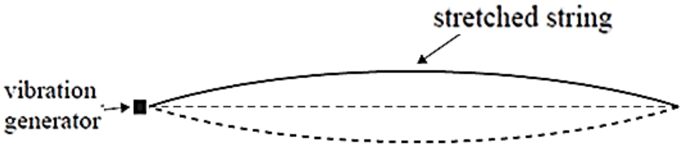
Sarah has a six-stringed guitar. Each string is tuned to a different pitch. She finds that when she places a tuning fork of frequency 512 Hz on the bridge of her guitar, ONE of the strings starts to make a sound at the same frequency as the tuning fork. She looks at the string very carefully and sees that it is oscillating with THREE antinodes, as shown in the diagram (on the next page).

(a) Show that the natural fundamental frequency of the string is 171 Hz.
(b) Explain why energy from the tuning fork appears to be transferred only to this string.
(c) The string has a length (between the two fixed ends) of 0.635 m. Calculate the velocity of the travelling wave in the string.

STANDING WAVES (2008;1)

Speed of sound in air = 3.40×10^2 ms^{-1}

When a guitar string is plucked, a standing wave is set up. Standing waves can be demonstrated in the laboratory by vibrating one end of a stretched elastic string with the other end fixed. The end that is vibrated can also be considered fixed, because the vibration generator oscillates with very low amplitude.



(a) The vibration generator is set at a frequency of 35 Hz. When the string is stretched to a length of 1.2 m, a 1st harmonic (fundamental) standing wave is produced. Calculate the speed of the wave in the string.

The string is fixed at this length and the frequency of the generator is increased until the 3rd harmonic (2nd overtone) standing wave is produced.

(b) Calculate the new frequency of the generator.
(c) How does this increase in frequency change the wavelength of the wave on the string, and by what factor?

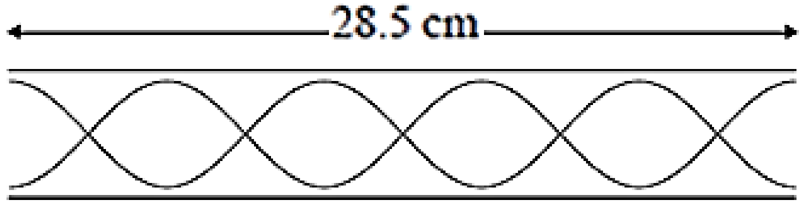
With the generator still set at the higher frequency (producing the 3rd harmonic), the string is tightened, keeping the length the same, and the standing wave disappears.

(d) Explain why a standing wave does not occur when the string is tightened.
(e) The string is now stretched, and when its length reaches 1.8 m, a 2nd harmonic (1st overtone) standing wave is produced by the vibration generator, which is still at the higher setting. Calculate the new speed of the wave.

STANDING WAVES (2007;1)

The speed of sound in air is 3.40×10^{2} ms^{-1}.

Carlie plays the recorder. The recorder can be modelled as an open pipe. On one occasion, the note Carlie plays has the following standing wave pattern for one of its overtones (harmonics). The length of the pipe when she plays this note is 28.5 cm.



(a) Calculate the wavelength of the standing wave shown in the diagram.
(b) Which harmonic (or overtone) is shown in the diagram above?
(c) By first calculating the wavelength that the fundamental standing wave would have in this length of pipe (or otherwise), calculate the frequency of the fundamental standing wave.
(d) Explain how the fundamental standing wave is produced in this pipe.

Opening or closing holes along the length of the pipe can produce different frequency notes. Carlie first plays a note with all holes closed. She then opens the last hole.

(e) Explain how the frequency of the note produced will change.

IRISH HARP (2006;2)

Speed of sound in air = 3.40×10^{2} ms^{-1}

An Irish harp is an instrument that is played by plucking the strings. One of the strings of the harp is 43.2 cm long.
(a) Calculate the wavelength of the fundamental note produced on this string when it is plucked.
(b) On the line below sketch the 3rd overtone (4th harmonic) on this string.

Another harp string is 57.8 cm long and has a mass of 4.62×10^{-4} kg. The tension force in the string is 70.0 N. The wave speed on this string can be calculated using the formula:

$$v = \sqrt{\frac{T}{\mu}}$$

where T is the tension force and μ is the mass per unit length of the string.

(c) By finding the mass per unit length, show that the wave speed on this string is 296 ms^{-1}.

(d) The tension force in the harp string is now increased. State what happens to the size of the wavelength AND frequency of the wave on the string.

(e) During a concert, a flute is played alongside the harp. Explain why the same note played on a flute sounds different to that played on the harp.

(f) A particular flute can be modelled as an open pipe of length 0.61 m. Calculate the lowest possible frequency note that could be played on this flute.

USING A PIPE TO MAKE MUSIC (2005;1)

A child's toy consists of a long, flexible, plastic pipe, open at both ends. Holding the pipe at one end, the other end can be swung around so that a standing wave is set up in the pipe, and a musical note heard. If the pipe is swung slowly the 1st harmonic (fundamental) frequency is heard. If the pipe is swung at a faster speed, the note changes to the 2nd harmonic (1st overtone) frequency. Even faster swinging produces the 3rd harmonic (2nd overtone).

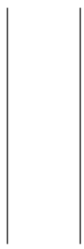
Jessica swings her pipe in such a way that the 3rd harmonic (2nd overtone) is heard. The frequency of the note is 685 Hz. The speed of sound in air is 3.4×10^2 ms^{-1}.

(a)

(i) Show that the wavelength of the note heard has an unrounded value of 49.635 cm.

(ii) Justify the number of significant figures this answer should be rounded to.

(b) On the diagram below, sketch the standing wave in the pipe for the note that is heard.



(c) On the diagram above, label one antinode (A) and one node (N).

(d) What aspect of the standing wave in a closed pipe makes it impossible for it to have the same wavelength as the standing wave in an open pipe of the same length?

(e) Calculate the length of the pipe that Jessica was swinging.

Swinging the pipe causes waves with a range of frequencies to be generated in the pipe.

(f) Explain how a standing wave is set up in the pipe.

(g) Joe swung a similar pipe at the same time as Jessica was swinging hers, and his pipe also produced the 3rd harmonic frequency note. There was a 9.0 Hz beat in the sound they heard. Show that the difference in the length of the two pipes is 1 cm.

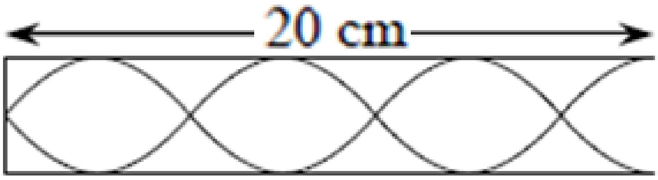
QUALITY OF THE SOUND (2004;2)

Use v = 3.40×10^2 ms^{-1} for the speed of sound.

An air horn is a type of wind instrument and so can be modelled by a pipe. The length of the horn the students used was 20 (2 s.f.) cm and the sound it produced had a frequency of 426 Hz.

(a) Show by calculation that this data indicates that a closed pipe, not an open pipe, models an air horn. (Note: a closed pipe is closed at one end; an open pipe is open at both ends.)

When the students were matching the sound from the recording with the sound from the speaker, they noticed that although the frequencies were the same, the quality (timbre) of the notes was different. They knew that this is because the horn produces many higher harmonics (overtones), as well as the 1st harmonic (fundamental), all of which add together. The diagram below shows the shape of a higher harmonic.



(b) Show that the wavelength of the harmonic is 0.11 m.

(c) Calculate the frequency of the harmonic. Give your answer to the correct number of significant figures.

Harmonics are numbered in such a way that the frequency of the n^{th} harmonic
has n x the frequency of the 1st harmonic (e.g. the 3rd harmonic has 3 x the frequency of the 1st harmonic).

(d) Which harmonic is illustrated above?

As well as pitch, the loudness (or intensity) of sound is an important property. Intensity, I, is directly proportional to the power, P, (rate at which energy is) transmitted by the wave, and inversely proportional to the area, A, over which the energy is spread. The constant of proportionality is dimensionless.

(e) Use this information to derive a unit for intensity of sound.