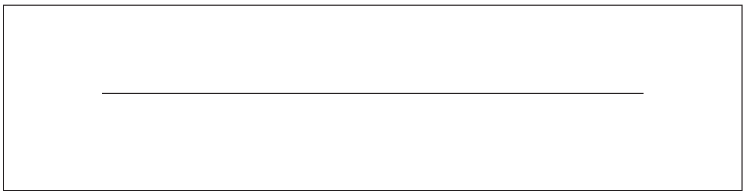
WAVES: STANDING WAVES QUESTIONS

QUESTION ONE (2019;1)

Sarah builds a simple guitar using a hollow wooden box as a resonator, and three strings on a wooden fretboard. She fixes the strings between two bridges that are separated by 0.736 m.

(a) In the space below, sketch the 4th harmonic (3rd overtone) that is formed when a string is plucked.



(b) The speed of the wave through the string is 289 m s^{-1}. Calculate the wavelength and frequency of this harmonic.

(c) The three strings of the box guitar produce different fundamental frequencies when played, even though the strings are the same length, and are made of the same material. Use this equation to explain how this is possible.

$$v_{\text{wave on string}} = \sqrt{\frac{\text{tension}}{\text{mass per unit length}}}$$

QUESTION TWO (2019;2)

The speed of sound in air is 338 m s^{-1}.

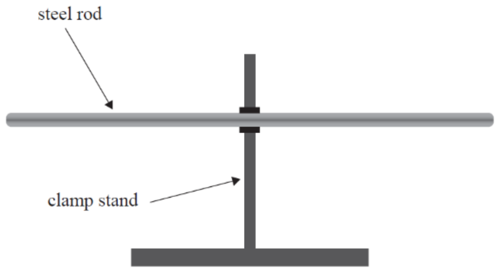
Sam and Miracle are experimenting with a 0.446 m length of plastic pipe that is open at both ends. When the wind blows across the top of the pipe, Sam and Miracle hear a sound. They assume the sound is made by air inside the pipe resonating at the fundamental frequency.

(a) Show that the frequency of the sound is 379 Hz.

(b) Sam places his hand over the end of the pipe, and the frequency of the sound coming out of the pipe changes. Describe and explain the changes in the frequency of the pipe. Draw diagrams to support your answer.

(c) Sam removes his hand so the pipe is open at both ends again. A strong gust of wind blows across the top of the pipe and causes a much higher pitched sound to be produced. Miracle uses an app on her phone to determine that the frequency of the sound is 1138 Hz. Draw the new standing wave formed in the pipe on the diagram below. Identify the harmonic that is resonating in the air column.

QUESTION THREE (2018;3)

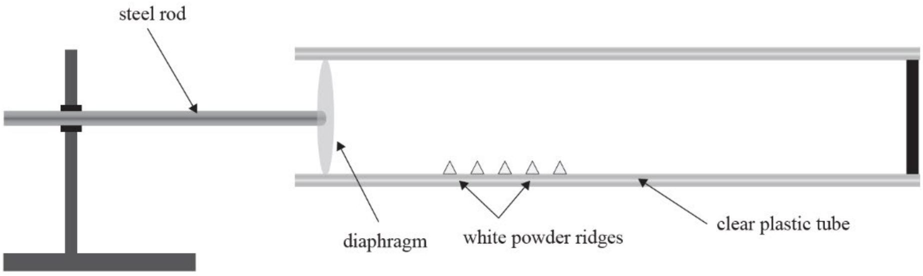


Speed of sound in air = 344 m s^{-1}

Clara wants to investigate the properties of a 0.400 m length of solid steel rod. The bar is clamped rigidly at the centre, and the ends are free to vibrate. The rod is struck in such a way as to produce a fundamental longitudinal standing wave.

(a) Show that the wavelength of the wave is 0.800 m. A diagram should be included in your answer.

One end of the rod is attached to a diaphragm that can move freely inside a clear plastic tube. The clear plastic tube is closed at the opposite end. On the bottom of the clear plastic tube is a fine white powder. When the steel rod is struck, the white powder forms into ridges that are λ/2 apart. The steel rod still vibrates at the fundamental frequency.



(b) The frequency of vibrations in the air in the tube is the same as the frequency of the vibrations in the steel rod. Explain why this is true for the frequency, but not for the wavelength of the two vibrations.

(c) Clara measures the ridges to be 2.30×10^{-2} m apart. Calculate the speed of sound in the rod.

(d) The clamp stand is adjusted, and the steel rod is struck in such a way as to produce a standing wave of the second harmonic in the rod. Explain the effect this will have on the air inside the tube.

QUESTION ONE (2017;1)

In 1845, Dutch physicist Buys Ballot demonstrated the Doppler effect by listening to musicians playing their instruments on a train as it passed by him. One musician played a note on a clarinet with all the finger holes closed. A clarinet can be modelled as a pipe that is open at one end and closed at the other. The length of the clarinet is 0.613 m. The speed of sound is 341 m s^{-1}.

(a) On the diagram, draw the 1st harmonic (fundamental) standing wave, AND label the nodes and antinodes.

(b) The clarinet produces the fundamental frequency and several harmonics. Explain why the clarinet does not produce any even harmonics.

QUESTION TWO (2017;2)

Mike and Kate are on a tramping trip and are crossing a suspension bridge. They realise that by jumping up and down in a particular way, they can set up a standing wave in the bridge. The bridge is 24.0 m long.

(a) Describe one difference between a standing wave and a travelling wave.

(b) A bridge can oscillate at many harmonics. Show that the frequency of the 3rd harmonic mode is: $f = 3v/2L$, where L is the length of the bridge.

(c) The bridge oscillates at the fundamental frequency mode with a period of 1.80 s. Calculate the speed of the waves in the bridge.

(d) Mike is 6 m from one end and Kate is 6 m from the other end. Give a comprehensive explanation of how it is possible for Mike and Kate to cause the bridge to oscillate in the 2nd harmonic mode. In your explanation you should:

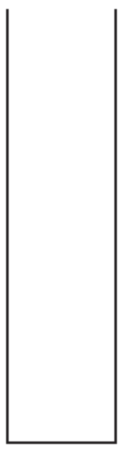
- draw a labelled diagram of the bridge oscillating in the 2nd harmonic mode
- explain how they set up a standing wave
- explain why they choose to stand in the positions stated
- explain the phase relationship between their oscillations.

PAN FLUTES (2016;1)

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 draw the standing wave Maria is producing in the pipe. Label the displacement nodes and antinodes.



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.

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.

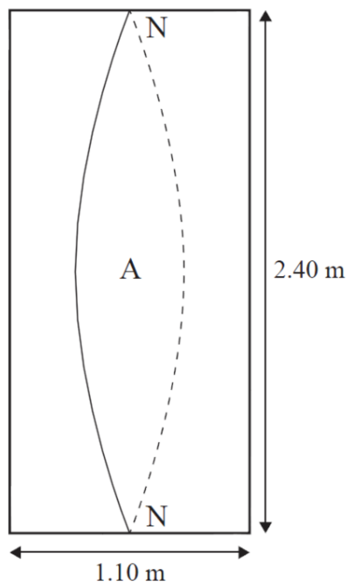
(b) State the name of this phenomenon and explain how it causes Maria to hear a variation in loudness.

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

STANDING WAVES AND PLUMBING (2015;1)

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.

(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.

(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. 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.

(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:

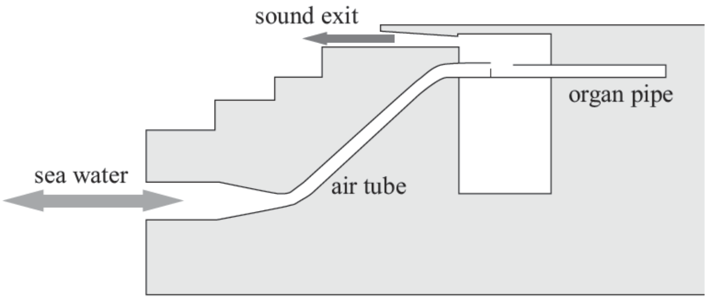
- describe how the water affects the speed of the sound wave
- explain why the sound in the waste pipe no longer resonates at 3.00×10^{2} Hz
- calculate one of the resonant frequencies

THE SEA ORGAN (2014;1)

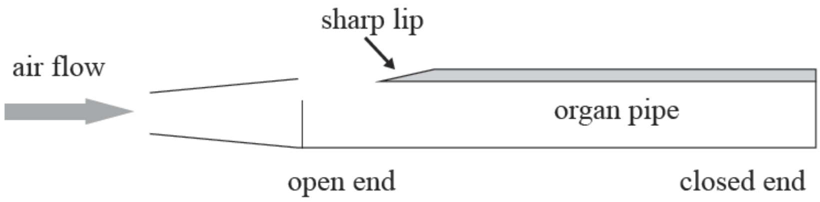
The Sea Organ in Zadar, Croatia, is a musical instrument that creates its musical notes through the action of sea waves on a set of pipes that are located underneath the steps shown in the picture. The sound from the pipes comes out through the regular slits in the vertical part of the top step.

To produce a sound, the organ pipes must have air blown into them, so each organ pipe is connected to the top end of a tube, as shown in the diagram on the right.

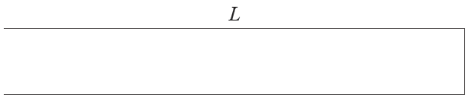
The action of the waves pushes water in and out of a tube, creating a flow of air at the upper end of the tube.



The diagram shows the inside of an organ pipe. These organ pipes have one closed end.



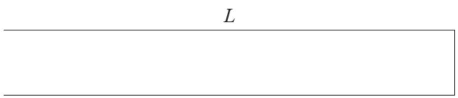
(a) Calculate the length, L, of an organ pipe, with one closed end, that produces a fundamental standing wave of wavelength 2.60 m. You may find the diagram on the right useful.



(b) Air is driven against a sharp lip, producing oscillations in the air, with a range of frequencies. Explain why not all frequencies produce standing waves in the pipe.

(c) The Sea Organ contains organ pipes of several different lengths. Explain why the differences in length of the organ pipes affect the sounds that are heard.

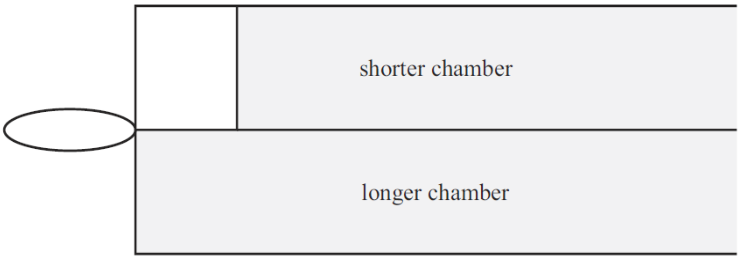
(d) The speed of sound in cold air is slower than it is in warm air. The speed of sound in air at 35°C = 353 m s^{-1} and the speed of sound in air at –2°C = 330 m s^{-1}. Calculate the difference between the 3rd harmonic frequency (1st overtone) heard in summer (35°C), and the 3rd harmonic frequency heard in winter (–2°C).



THE POLICE WHISTLE (2013;1)

Some police forces have used whistles that have two chambers of different lengths.

A model of the whistle chamber is shown in the diagram below.



(a) On the above diagram, draw the fundamental standing wave in the shorter chamber, AND label any displacement nodes and antinodes.

The fundamental frequencies for the two chambers are 2136 Hz and 1904 Hz. The speed of sound in air is 343 m s^{-1}.

(b) Calculate the length of the longer chamber.

(c) Explain how a standing wave is produced in a pipe that is closed at one end.

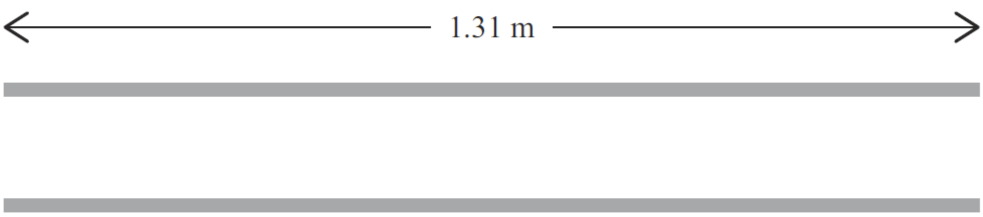
(d) When the whistle is blown, the sound made is quite different to a pure sound of either 2136 Hz or 1904 Hz. Calculate the value of TWO other frequencies produced, AND explain why these other frequencies are produced, and what effect they have on the sound.

BOOM PIPE (2012;1)

(a) A boom pipe is a simple musical instrument made from a plastic drain pipe. Instructions for making a boom pipe say that a pipe 1.31 m long will make the musical note 'C'. A tuning fork is labelled "261.6 Hz, middle C". Jan strikes the fork, holds it over the end of a 1.31 m boom pipe, and hears the sound of the tuning fork amplified by the pipe. The speed of sound in the air is 343 m s^{-1}.

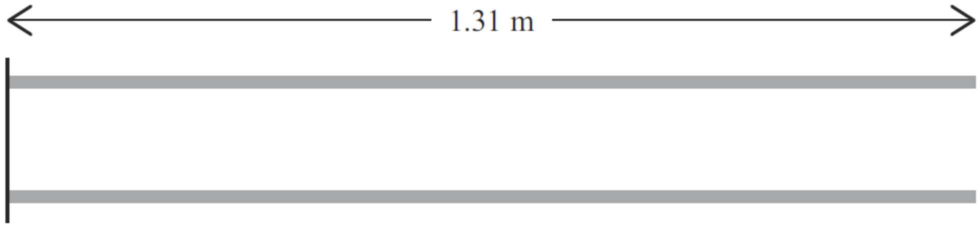
(i) Calculate the wavelength of middle C in air.

(ii) Draw and label a sketch to identify the positions of nodes and antinodes for middle C. Add arrows to show the direction of the vibration at these positions.



(iii) Describe how the amplitude and phase of the vibrating air particles vary along the pipe. Your answer may use words or a labelled sketch.

(b) Jan closes one end of the pipe and holds the same tuning fork over the other end. Explain why the tuning fork will no longer cause resonance in the pipe. You may include a sketch as part of your answer.

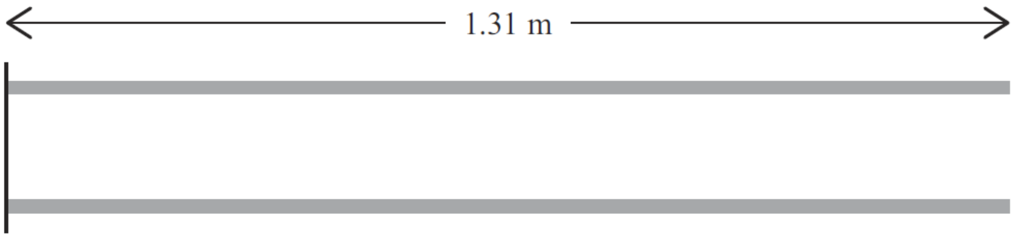


Closed pipe

(c) Jan adds carbon dioxide from an old fire extinguisher into the **closed** pipe. She wants to investigate whether the closed pipe can be made to resonate using the "261.6 Hz" tuning fork. The speed of sound in pure carbon dioxide gas is 259 m s^{-1}.

(i) Explain how adding carbon dioxide will affect the resonant frequencies in the pipe.

(ii) By carrying out appropriate calculations, determine whether Jan's plan is likely to work and describe what resonance might occur in the pipe. You may include a sketch as part of your answer.



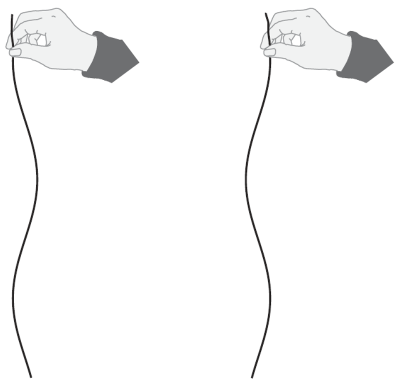
STANDING WAVES (2011;1)

A piece of string is held fixed between finger and thumb and allowed to hang vertically downwards.

(a) When the string is rolled between the finger and thumb, a wave is sent down the string and a standing wave is set up.

(i) Describe how waves travelling down the string result in a standing wave being set up.

(ii) Explain why the standing wave will have a node at the top, but not at the bottom.



(b) The length of the string below the point that is held fixed by the finger and thumb is 12 cm. If the speed of the wave in the string is 2.5 m s^{-1}, calculate the frequency of the standing wave that has 2 nodes (including the node at the top).

(c) The standing wave that has the lowest possible frequency is called the 1st harmonic (often called the fundamental). In the string, the next lowest frequency standing wave is called the 3rd harmonic, because it has 3 times the frequency of the 1st harmonic. Calculate the frequency that is twice the frequency of the 1st harmonic and discuss why the string cannot resonate at a 2nd harmonic frequency.

STEAM WHISTLE (2010;1)

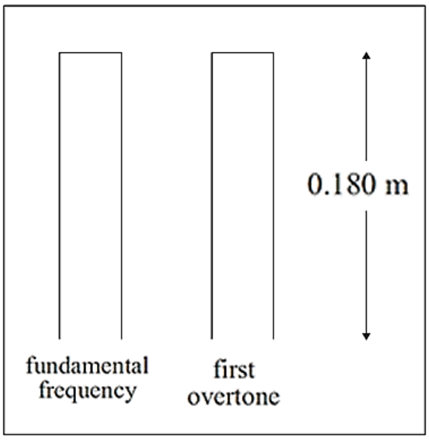
Data to use:

Speed of sound in dry air at 20°C = 343 m s^{-1}

Speed of sound in steam at 200°C at a pressure of 7 MPa = 523 m s^{-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).

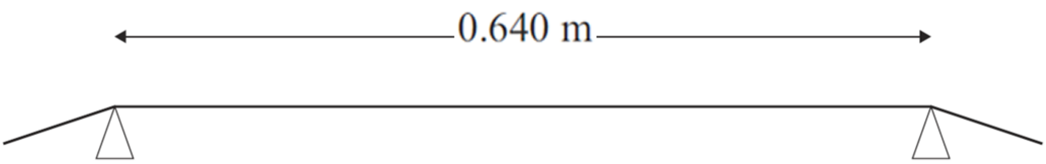


(b) In this part of the question assume that the whistle is full of steam at 200°C, at a pressure of 7 MPa, and surrounded by dry air at 20°C. Calculate the frequency of the fundamental (1st harmonic).

(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.

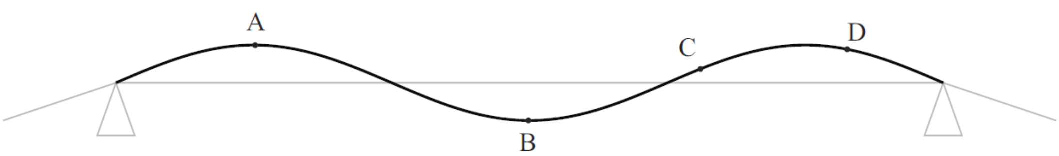
TUNING A GUITAR (2010;2)

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)

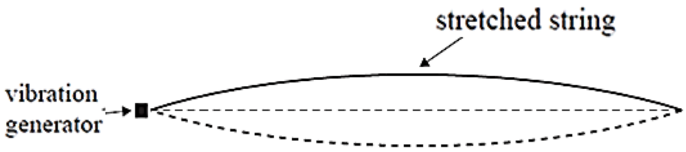
Sarah has a six-stringed guitar. Each string is tuned to a different pitch. She finds that when she places a tuning fork of frequency 512 Hz on the bridge of her guitar, ONE of the strings starts to make a sound at the same frequency as the tuning fork. She looks at the string very carefully and sees 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 m s^{-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.

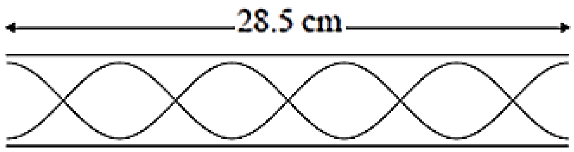
(d) Explain why a standing wave does not occur when the string is tightened.

(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 m s^{-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:

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

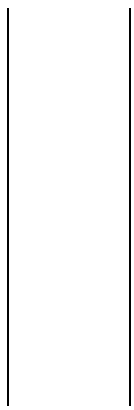
where T is the tension force and μ is the mass per unit length of the string.

(c) By finding the mass per unit length, show that the wave speed on this string is 296 m s^{-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 m s^{-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, sketch the standing wave in the pipe for the note that is heard.
(c) On the diagram, 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.

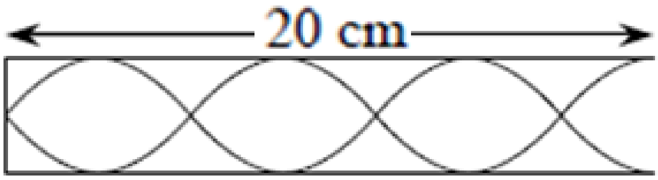
(g) Joe swung a similar pipe at the same time as Jessica was swinging hers, and his pipe also produced the 3rd harmonic frequency note. There was a 9.0 Hz beat in the sound they heard. Show that the difference in the length of the two pipes is 1 cm.

QUALITY OF THE SOUND (2004;2)

Use $v = 3.40 \times 10^2$ m s^{-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.