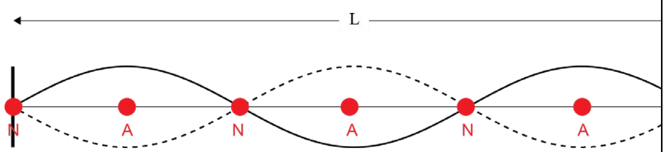
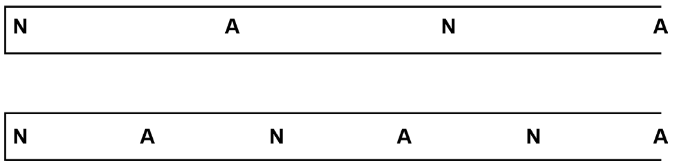
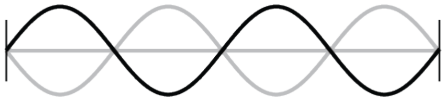
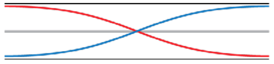
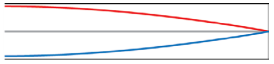
Level 3 Physics: Demonstrate understanding of Waves –Standing Waves - Answers

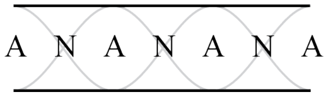
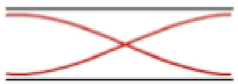
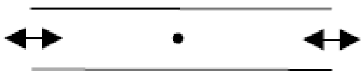
Question	Evidence	Achievement	Merit	Excellence
2022(1) (a)	Third harmonic (or 2nd overtone). 	Third harmonic (or 2nd overtone) AND Node and antinode labelled correctly.		
(b)	$\boldsymbol{\lambda = 0.43\ m}$ $L = 0.645\text{ m}$ $L = 1.5\lambda$ $\lambda = \frac{0.645}{1.5}$ $\lambda = 0.43\text{ m}$ $v = f\lambda$ $v = \frac{0.645 \times 995}{1.5}$ $v = 427.8$ $v = 428\text{ m s}^{-1}$ (3sf)	Correct wavelength. OR Correct working (incorrect λ).	Correct answer for speed of sound along the string.	
(c)	Since the speed of sound along the string increases when Mele tightens the string, and since the length of the string does not change, the wavelength does not change, the frequency of the note will increase: $v = f\lambda$. Mele's original frequency was 995 – 5 = 990 Hz.	f increases. OR 990 Hz	v increases, $v = f\lambda$, (L const), OR λ const, f increases. AND 990 Hz	

(d)	Higher harmonics are multiples of the 1st harmonic. The flute can be modelled as an open pipe, (as waves reflect at the open end with no phase change) only waves that form **antinodes at both ends** will form standing waves (with alternating nodes and antinodes). As higher harmonics are **all multiples of half wavelengths,** all harmonics meet the end conditions and are able to form and fit the length of the flute. Since the clarinet has one end closed, it can be modelled as a closed pipe, (as waves reflect at the fixed end with a 180-degree phase change) only waves that result in **nodes at the closed end** and **antinodes at the open end** will only form standing waves (with alternating nodes and antinodes). Hence only **odd multiples of ¼ wavelengths** can be formed that fit the length of the clarinet.	Either a diagram or a statement. Closed pipe end condition (A-N) open pipe end condition (A-A) OR To show odd multiples of ¼ wavelengths formed on the clarinet. OR Multiples of half wavelengths on the flute. Note: “Can only form odd harmonics” is NOT sufficient.	Explanation of why 2[nd] harmonic in closed pipe (clarinet) cannot form OR Explanation of why 2nd harmonic in open pipe (flute) **can** form.	Explanation of why 2nd harmonic in closed pipe (clarinet) cannot form. AND Explanation of why 2nd harmonic in open pipe (flute) **can** form.
2021(2) (a)	$\lambda = 4L = 4 \times 1.20 = 4.80 \text{ m}$	Correct answer.		
(b)	 These have frequencies of $3f_0$ and $5f_0$. **Nodes and antinodes are equally spaced**	One diagram correct. OR One correct harmonic noted.	Complete correct answer. Note: f_0 = 71.14 $3f_0$ = 213.125 $5f_0$ = 355	

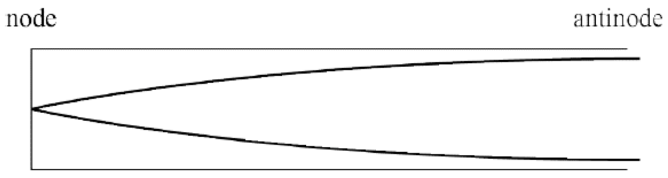
(c)	Marc's lips produce many frequencies. The sound waves travel down the tube and **reflect** off the closed end (with a π phase change, destructively interfering with itself) and the open end (with no phase change, constructively in interfering with itself). If the wavelength is such that it fits the pipe (odd multiples of ¼ wavelengths) so that the open end is always an antinode and the closed end a node, the multiple reflections will produce a standing wave with nodes (destructive interference) and antinodes (constructive interference) in fixed positions, as the energy of the wave builds, the amplitude increases causing the pipe to resonate. Those frequencies (/wavelengths) that do not meet the end conditions, are not able to build in energy and so no sound is heard.	Only the resonant frequencies having wavelengths **fitting** the pipe by. Mentions ONE of: Reflections at the ends. OR Interference pattern. OR End conditions / odd multiples of ¼ λ	Any valid reason leading to the resonant frequencies having wavelengths fitting. Mentions TWO of: Reflections at the ends. OR Interference pattern. OR End conditions / odd multiples of ¼ λ	Complete answer that refers to the resonant frequencies having wavelengths **fitting** by: Full answer: **Reflection** at the end with incident and reflected waves **interfering** to produce standing wave with (**end conditions)** A at the open end and N at the closed.
(d)	$v = f\lambda$ λ of all the harmonics are determined by the length of the pipe, so are unchanged (constant). As v increases, f must increase for all the resonant frequencies.	Frequency increases.	Complete answer. λ constant (as L is constant) v increases f increases.	
2020(1) (a)	4th harmonic.	Correct answer.		
(b)	$v = 340\ \text{m s}^{-1}$ $L = 0.155$ m $\lambda = 0.155/2 = 0.0775$ m $f = 340/0.0775 = 4387$ Hz	Correct wavelength or correct method with incorrect harmonic.	Correct frequency.	

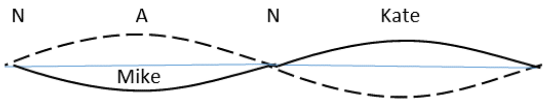
(c)	Opening the hole effectively reduces the length of the pipe. Hence wavelength of the fundamental is shorter. The wave speed stays the same. Since v = f λ, the frequency of the fundamental note played with the hole open will be higher. For the fundamental note, opening the hole causes an antinode to form atthe hole, effectively reducing the length of the pipe. Hence the fundamental wavelength decreases. As v = f λ, (and the wave speed stays the same) the frequency of thenote will increase.	Either point: For opening the hole • λ decreases • f increases.	Both points.	
(d)	When blowing air into the pipe, vibrations are produced (a whole range of sounds of different frequencies are generated in the pipe). • These travel down the length of the pipe and are reflected at the openend. • The reflected wave will interfere / superimpose with the incident wave(to produce nodes (destructive) and antinodes (constructive)). • (At the open end, there is no phase change with the reflection, so thetwo waves are always in phase and hence produce an antinode.) Only those waves that 'fit' the pipe (or $2L = nl$, or diagram) having antinodes at both ends (being in phase with the driving vibrations),will resonate to form a standing wave (with stationary nodes and antinodes).	One bullet point. • Reflected • Interference - Constructive – A - Destructive – N • Fit E.g. A each end, formula, resonant *f*.	TWO (linked / justified) bullet points. • Reflected • Interference - Constructive – A - Destructive – N • Fit E.g. A each end, formula,resonant *f*.	THREE bullet points.

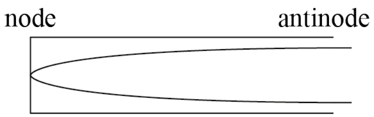
2019(1) (a)	 Third overtone, 4th harmonic.	Correct diagram. *(Count 4 antinodes.)*		
(b)	3rd overtone = 4th harmonic $\text{wavelength} = \frac{L}{2} = 0.368\text{ m}$ • $f(\text{4th harmonic}) = \frac{v}{\lambda} = \frac{289}{0.368} = 785.326\text{ Hz}$	Correct wavelength (*of 4th harmonic).* OR Correct calculation of frequency using an incorrect wavelength (formula & substitution).	Correct frequency.	
(c)	The tension α velocity α Frequency. as $v = f\lambda$ (fixed wavelength) *(Accept thickness argument, only if stating thicker/thinner & clear understanding.)*	One point.	Both points.	
2019(2) (a)	$v = 338\text{ m s}^{-1}$ $L = 0.446\text{ m}$ $\lambda = 2L = 0.892\text{ m}$ $f = \frac{v}{\lambda} = \frac{338}{0.892} = 378.92\text{ Hz}$	Correct frequency with working. NB this is a SHOW question.		
(b)	  Open pipe $\lambda = 2L$. Closed pipe $\lambda = 4L$. As $v = f\lambda$, velocity const, L const, the closed pipe has a larger (twice) wavelength, so the frequency will be less (half) than the open pipe *(f = 189.46 Hz)*	Correct diagrams OR Description to justify that frequency will be less.	Correct diagrams. AND Description to justify that frequency will be less.	

(c)	 *(Count 3 nodes.)* n = 1138/379 = 3.0026 Third harmonic or second overtone.	Identifies correct harmonic or overtone. OR Draws waveform with correct nodes and antinode positions (no labels required).	Correct diagram and harmonic / overtone stated.	
2018(3) (a)	 OR  $L = \frac{\lambda}{2}$ $\lambda = 2L = 2 \times 0.400 = 0.800$ m	Correct drawing OR $L = \frac{\lambda}{2}$ $\lambda = 2L = 2 \times 0.400 = 0.800$ m		
(b)	Each time the rod vibrates, the vibration is transferred to the air. So the frequency of the rod will be the same as the frequency of vibration in the air. The wavelength is determined by how far a vibration is able to move away from the source before the next vibration is made. Since the wave speed is different in the air than it is in the rod, the wavelengths will be different as well.	Identifies the rod as the source of vibration for the air, thus frequencies will be the same. OR Links wavelength as being dependent on speed of wave travel in the medium.	Identifies the rod as the source of vibration for the air, thus frequencies will be the same. AND Links wavelength as being dependent on speed of wave travel in the medium.	

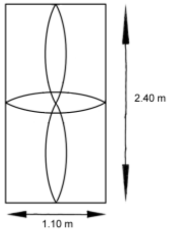
(c)	$\lambda = 2 \times 0.0230\text{ m} = 0.0460\text{ m}$ In tube / air: $v = f\lambda,\ f = \dfrac{344\text{ m s}^{-1}}{0.0460\text{ m}} = 7478.26\text{ s}^{-1}$ In steel rod: $v = f\lambda = 7478.26\text{ Hz} \times 0.800\text{ m}$ $= 5982.61\text{ m s}^{-1}$ $= 5980\text{ m s}^{-1}$	Correct wavelength in air. OR Correct velocity calculation for steel using an incorrect wavelength in air. E.g. gets 11960 m s^{-1}	All correct. Unrounded answer OK Can use $\dfrac{\lambda_{rod}}{\lambda_{air}} = \dfrac{v_{rod}}{v_{air}}$.	
(d)	Second harmonic in the rod will have double the frequency of the fundamental. The increase in frequency in the metal rod causes the same increase in frequency in the tube. The wavelength in the tube decreases, while wave velocity in the tube is unchanged. The tube is an open-closed pipe, and so must have a displacement antinode at one end, and a displacement node at the other end. Doubling the frequency of an odd harmonic produces an even harmonic frequency. Even harmonic frequencies cannot form standing waves in the tube.	Frequency will be increased OR New frequency will not be a resonant frequency for the length of the tube. OR Standing wave will not form in the tube. OR Even harmonics cannot form in the tube.	Recognises the increase in frequency in the metal rod causes the same increase in frequency in the tube and calculates the new wavelength in the tube/states wavelength in the tube decreases.	Recognises the change in frequency in the metal rod causes the same change in frequency in the tube, but the tube will not form the same standing wave pattern because: the pipe is an open-closed pipe. OR Recognises the increase in frequency in the metal rod causes the same increase in frequency in the tube and calculates the new wavelength in the tube/states that wavelength in the tube decreases. Must also either state that wave velocity in the tube is unchanged, or state that the powder piles will be closer together.

2017(1) (a)		Correct labelled diagram. (line doesn't curve back or become parallel, continues to the end of the pipe, in not straight. Only one side needs to be correct)		
(b)	The clarinet is open / closed, so has a node and an antinode at the two ends. The tube can sustain only odd harmonics because the tube "fits" only an odd number of quarter wavelengths (OR $\frac{\lambda}{4}, \frac{3\lambda}{4}, \frac{5\lambda}{4}$). OR The fundamental has a pipe length of λ/4. The pipe length for even harmonics would require an even number of quarter wavelengths etc. $L = \frac{\lambda}{2}, \lambda, \frac{3\lambda}{2}$ This requires a node / node OR antinode / antinode.	Open end must be an antinode and closed end must be a node. OR standing wave has odd number of ¼ wavelengths. OR explanation good for only second harmonic OR Even harmonics require nodes at both ends/antinodes at both ends.	node at closed end and antinode at open end requires odd number of quarter wavelengths OR even harmonics need nodes at both ends or antinodes at both ends because length is an even number of quarter wavelengths	
2017(2) (a)	Travelling waves transfer energy, standing waves don't. OR The amplitude is the same at different places on a travelling wave. The amplitude is different at different places on a standing wave. OR Standing waves have nodes and antinodes but travelling waves do not. OR Travelling waves have one source but a standing wave requires 2 sources. OR Standing waves require interference but travelling waves do not.	Correct answer.	Answers must be comparative, relevant and not wrong Not: Travelling waves move but standing waves stay still Standing wave has a reflected wave/reflects back on itself *(Note from nb2s editor – this was incorrectly left in the Excellence column*)	.

(b)	$f=\frac{v}{\lambda}$ for 3rd harmonic, $L=\frac{3\lambda}{2}\to\lambda=\frac{2L}{3}$ $f=\frac{v}{\frac{2L}{3}}$ $f=\frac{3v}{2L}$ OR 1st harmonic: $L=\frac{\lambda}{2}$ $f=\frac{v}{2L}$ 3rd harmonic $=3f_1=\frac{3v}{2L}$	Correct relationship between L and λ for 1st or 3rd harmonic.	working linking wavelength to L, substituted into the wave equation, 3rd harmonic.	
(c)	$f=\frac{1}{T}=\frac{1}{1.8}$ Hz $\lambda=2L=48.0$ m $v=f\lambda$ $v=\frac{1}{1.8}\times 48.0=26.7\text{ m s}^{-1}$	Correct frequency, wavelength or distance travelled in one period.	Correct answer and unit (at least 3sf).	
(d)	 By jumping up and down, they send (transverse) waves along the bridge. These waves hit a closed end and reflect inverted. The two sets of waves interfere and set up a standing wave. They must stand at the ¼ and ¾ positions because this is where the antinodes are for the second harmonic. They must jump up and down 180° out of phase (because adjacent antinodes are out of phase). Mike and Kate must jump at the correct frequency (1.11 Hz or T = 0.9s).	Mike and Kate are at antinodes OR Mike and Kate in antiphase OR Description of standing wave formation. OR 2nd harmonic correctly drawn including labelling of nodes and antinodes. OR Mike and Kate must jump at the correct frequency(1.11Hz). OR Initially the amplitude/energy of the standing wave increases each cycle.	2nd harmonic correctly drawn including labelling of an antinode/ (Mike and Kate drawn at antinodes and statements that they are at antinodes). AND Mike and Kate are at antinodes. OR Mike and Kate in antiphase. OR Mike and Kate must jump at the correct frequency (1.11Hz or T = 0.9s). OR Initially the amplitude / energy of the standing wave increases each cycle.	2nd harmonic correctly drawn including labelling of an antinode / (Mike and Kate drawn at antinodes and statements that they are at antinodes). AND Mike and Kate are at antinodes. AND Mike and Kate in antiphase. AND Mike and Kate must jump at the correct frequency (1.11 Hz or T = 0.9 s)

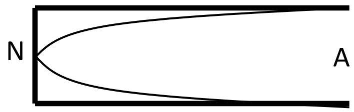
2016(1) (a)		Correct diagram and labels.		
(b)	The first pipe produces a lower frequency, so it has a longer wavelength and a longer pipe length. The wave speed is constant. $\lambda = \frac{v}{f}$ so a lower frequency means a longer wavelength. The wavelength of a standing wave in a pipe is proportional to the pipe length.	Lower frequency pipe / 350 Hz / first pipe is longer AND one of correct description of relationship between frequency and wavelength OR Longer pipes have longer wavelengths	Statement relating wavelength to pipe length. AND Statement relating wavelength to frequency to explain that the first pipe is longer.	
(c)	The phenomenon is called beating (beats). The two pipes produce similar but different frequencies. At one time, two waves arrive in phase and add constructively (loud), a short time later two waves arrive out of phase and add destructively (quiet).	Beating occurs / beats occur. AND ONE of: Links loudness to phase or type of interference	Explanation linking phase and interference to loudness changing over time to produce beats	

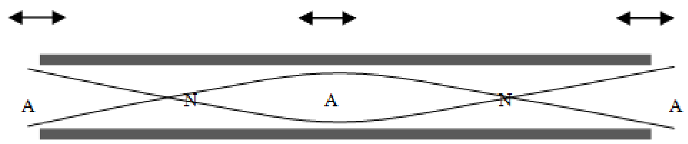
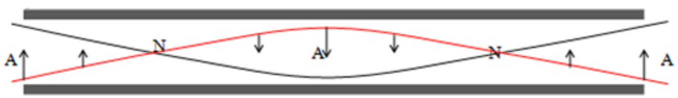
(d)	$f_1 = 762$ Hz beat frequency $= 4$ Hz $\therefore f_2 = 766$ Hz 3rd harmonic $= 766$ Hz so $\lambda = \frac{v}{f} = \frac{343}{766} = 0.4478$ m 3rd harmonic....pipe length $= \frac{3\lambda}{4}$ $L = \frac{3\lambda}{4} = \frac{3 \times 0.4478}{4} = 0.336$ m ALTERNATE SOLUTION $f_3 = 762$ Hz $f_3' = f_3 + 4 = 766$ Hz $(f_1 - f_2 = f_{\text{beat}})$ $3f_0 = 766$ Hz $f_0 = \frac{766}{3}$ $\lambda = \frac{v}{f_0}$ $L = \frac{\lambda}{4} = \frac{v}{4f_0} = \frac{343 \times 3}{4 \times 766} = 0.336$ m	Correct value for 2nd pipe frequency.	Correct value for 2nd pipe frequency AND realisation that 2nd pipe contains $\frac{3\lambda}{4}$. OR Correct calculation of *L* with incorrect frequency.	Correct answer and working.

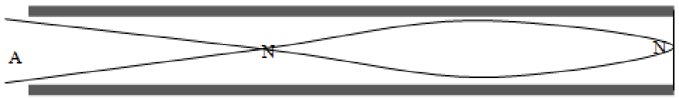
2015(1) (a)	$\lambda = 2L = \mathbf{4.80\,m}$ $f = \frac{v}{\lambda} = \frac{343}{4.80}$ $f = 71.5\,\text{Hz}$	f = 343/4.80		
(b)	Vertically: $\lambda = \frac{v}{f} = \frac{343}{143} = \mathbf{2.40\,m}$ so one λ would have a fundamental note of 143 Hz.  Horizontally: $\lambda = \frac{v}{f} = \frac{343}{156} = \mathbf{2.20\,m}$ so half λ would have a fundamental note of 156 Hz.	Correct diagram for one of the waves A correct calculation	Correct diagram for both of the waves and both calculations correct.	
(c)	f_3 = 180 Hz and f_5 = 300 Hz so the fundamental would be 60 Hz. The fundamental is 4L so the blockage is 1.43m from the open end. f_3 = 180 Hz, λ = $\frac{343}{180}$ =1.91 m, $L = 3\times\frac{1.91}{4}$ = 1.43 m f_5 = 300 Hz, λ = $\frac{343}{300}$343/300 = 1.14 m, $L = 5\times\frac{1.14}{4}$ =1.43 m.	Fundamental frequency is 60 Hz $\lambda = 4L$ or $\lambda = \frac{4L}{3}$ or $\lambda = \frac{4L}{5}$ OR 1 correct drawing	1.43m found using $\lambda = \frac{343}{60} = 5.72$ $L = \frac{5.72}{4} = 1.43$ OR $\lambda = \frac{343}{180} = 1.91$ $L = 3\times\frac{1.91}{4} = 1.43$ OR $\lambda = \frac{343}{300} = 1.14$ $L = 3\times\frac{1.91}{4} = 1.43$	

(d)	300 Hz is no longer a resonant frequency because the sound wave is now travelling faster. $f \propto v$, so the possible resonant frequencies increase. At a speed of 1.49×10^3 m s^{-1}, a 300Hz sound has the wrong wavelength (4.97 m) to place an antinode at the open end of the pipe, as the antinode must be λ/4 (1.24m) from the node but the pipe is 1.43 m long. The 1.43 m pipe resonates at frequencies of $f_0 = \frac{v}{\lambda} = \frac{1490}{5.71} = 261\,(260)$ Hz, $f_3 = \frac{v}{\lambda} = \frac{1490}{1.90} = 783\,(780)$ Hz, $f_5 = 1305\,(1300)$ Hz, etc. Which corresponds to wavelengths of 5.72 m, 1.91 m, 1.14 m.	Sound waves travel faster in water. $\lambda = 4L$ or $\lambda = \frac{4L}{3}$ or $\lambda = \frac{4L}{5}$ (Replacement only)	$\lambda \propto v$, so wavelength increases for the same frequency (to 4.97 m). *OR* $f \propto v$ so the possible resonant frequencies increase for the same pipe (same λ). At least one correct frequency: f_0 = 261 Hz, f_3 = 783 Hz, f_5 = 1305 Hz	Proves that 300 Hz is not a resonant frequency by finding 260Hz and 783 Hz and making a statement comparing to 300Hz OR finding 1.91m and 5.72m and comparing to 4.97m OR using $n = \frac{4L}{\lambda} = 4 \times \frac{1.43}{4.97} = 1.15$ which is not an odd whole number. OR At this speed a 300Hz sound has the wrong wavelength to place an antinode at the open end of the pipe / node at one end and antinode at the other. AND States that changing the frequency to 261 Hz / 783 Hz / 1305 Hz will produce a standing wave.

2014(1) (a)	L = ¼ λ = ¼ × 2.6 = 0.650 m	*L* = λ/4 or λ = 4*L* 0.650 m		
(b)	The wavelength of the standing sound wave forming in the pipe must allow a position of permanent constructive interference (antinode) to occur at the open end. There will be a position of permanent destructive interference (node) at the closed end because the waves reflect back out of phase/particles can't move. *The sharp lip generates sound waves that have a large range of different frequencies*, and some of these will produce a wavelength (length of the pipe is an odd number of quarter λ) that will meet the condition above. *Answers can describe wavelengths that <u>don't</u> meet conditions <u>not</u> creating standing waves*	Wavelength must 'fit'. There must be a node at the closed end of the pipe. There must be an antinode at the open end of the pipe. Driving frequency equals the natural/resonant frequency. Only odd harmonic frequencies will produce standing waves	Position of node and antinode linked to type of interference occurring. Only frequencies that create waves of the correct length to place a displacement node at the closed end and an antinode at the open end will form standing waves. L must be equal to an odd number of quarter wavelengths OR λ=4L/(2n-1) or equivalent	Answer that only those frequencies that create waves of the correct length to place a displacement node at the closed end and an antinode at the open end linked to why the type of interference that is permanently occurring at these positions occurs.
(c)	The length of the pipe is proportional to the wavelength of the sound wave produced. As the frequency (pitch) of the sound produced depends inversely on its wavelength ($v = f\lambda$), the longer the pipe the lower the frequency.	Longer pipes produce longer wavelengths of sound. Longer wavelengths have a lower pitch / frequency. Pipe length affects / changes the wavelength which affects the frequency / pitch.	Pitch of the sound linked to the wavelength and the length of the pipe.	
(d)	$\lambda = \frac{4L}{3} = \frac{4 \times 0.65}{3} = 0.8666\ \text{m}$ $f_{\text{cold}} = \frac{330}{0.8666} = 380.77\ \text{Hz}$ $f_{\text{hot}} = \frac{353}{0.8666} = 407.31\ \text{Hz}$ $\text{Difference} = 407.31 - 380.77 = 26.5\ \text{Hz}$	$\lambda = \frac{4L}{3}$ OR Diagram drawn correctly for the 3rd harmonic. Correct frequency for any odd harmonic using *L* = 2.6 or consequential from 1(a).	One correct frequency found (380.77 or 407.31 Hz). Correct working and answer for the 5th harmonic (44 Hz). Correct answer using L = 2.6 m or consequential from1(a).	Correct working and answer: 26.5 Hz (accept 26 or 27 Hz if rounded too soon).

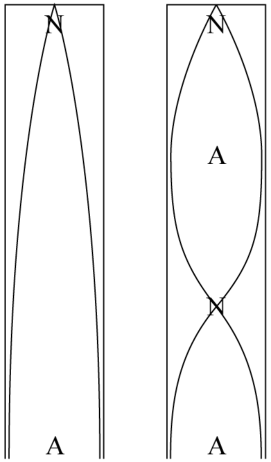
2013(1) (a)		Correct shape and labels drawn		
(b)	λ=v/f 343 / 1904=0.18 m. 0.18 / 4=0.045m 0.045m = 45mm	Correct wavelength. Divides calculated wavelength by four.	0.045m / 45mm	
(c)	Sound waves enter at the open end, travel along the pipe and reflect from the closed end. Reflected waves are out of phase making the closed end a place of permanent destructive interference (a node). Reflected waves of the correct wavelength reflect from the open end in phase with incident waves, producing a position of permanent constructive interference (an antinode) . Amplitude at antinode is larger than amplitude of the wave	Node is destructive interference (zero amplitude)/ antinode is constructive interference (maximum amplitude). System is forced to vibrate at its natural frequency (driving frequency = natural frequency). λ/4 (or 3λ/4) fits in the pipe wave changes phase/inverts after reflection at the closed end. *(BOTH of Closed end is a node: Open end is an antinode replacement evidence for 1a only).*	Position of node and antinode linked to type of interference occurring. Position of node and antinode linked to phase of the wave after reflection	Complete correct answer linking position of antinode and node to phase change upon reflection of waves with the correct wavelength/frequency/λ/4 fits in the pipe

(d)	Overtones in shorter chamber produced at 6408Hz and 10680Hz. Overtones in longer chamber produced at 5712Hz, and 9520Hz. Mixture of overtones produces distinctive sound (timbre) of the whistle. Difference tones/beats can be produced between fundamental frequencies	Two frequencies correctly calculated. Timbre is the distinctive sound. Describes beats at 232Hz	Shows understanding that only odd harmonics of the frequencies of each chamber are produced. E.g. deliberately leaving out even multiples Fundamental /overtone frequencies interfere/combine to produce a different sound.	Complete answer linking the timbre/quality/unique sound produced to combination/interference of correct odd multiples of the fundamental frequencies of each of the two chambers.
2012(1) (a)(i)	$v = f\lambda$ $\lambda = \frac{v}{f} = \frac{343}{261.6} = 1.31(1)\,\text{m}$	Correct answer.		
(ii)		Identifies nodes and antinodes or direction.	Identifies both nodes / antinodes and direction.	
(iii)	The particles at the ends and in the middle vibrate with maximum amplitude. The particles at the nodes (N) do not vibrate (due to the sound wave). From A to N, amplitude steadily decreases. Particles between two nodes are all in phase with one another. Either side of a node they are an antiphase (so the particles at the end are in phase with each other) – or diagram which shows this. E.g.  OR 	Identifies maximum amplitude at antinodes, zero / minimum at nodes.	Identifies maximum amplitude at antinodes, zero at nodes, identifies variation between A and N (could be shown on diagram). OR Particles between two nodes are all in phase with one another. Either side of a node they are an antiphase (so the particles at the end are in phase with each other).	Identifies maximum amplitude at antinodes, zero at nodes. AND Particles between two nodes are all in phase with one another. Either side of a node they are an antiphase (so the particles at the end are in phase with each other).

(b)	When the pipe is sealed, there must be a node at the sealed end. There are no resonant frequencies with the right wavelength so the pipe will not make a sound. Alternative to diagrams candidate could provide calculations:  Wavelength of middle C (1.31m) is too short to do this.  Wavelength of middle C (1.31m) is too long to do this.	Any of: 261.6Hz is not the natural frequency or a harmonic for this pipe. Identifies node at the sealed end The resonant frequencies have changed / different than for an open pipe. Sealing the end changes the λ of the standing wave. There is a node at one end and an antinode at the other.	Any of: 1 diagram as shown with correct explaining text If a node at sealed end, λ =1.31 m does not put an antinode at the open end. If an antinode at open end, λ =1.31 m does not put a node at the sealed end. 261.6 Hz is not the natural frequency or a harmonic for this pipe with explanation The resonant frequencies have changed / different than for an open pipe with explanation Sealing the end changes the λ of the standing wave that can form with explanation	Complete answer: Closed end pipe must have a node at the sealed end: must have antinode at open end therefore the standing wave will have an odd number of quarter wavelengths in the pipe: λ =1.31 m fails to meet this condition.

(c)(i) (ii)	The wavelengths of the resonant frequencies are fixed, but the speed changes. $v = f\lambda$ So, if v decreases, f decreases As CO_2 is mixed in, the wavelength decreases from 1.31 m to the wavelength for pure carbon dioxide: $\lambda = \frac{v}{f} = \frac{259}{261.1} = 0.992 \text{ m}$ The closest harmonic is the 5th harmonic (2nd overtone).  (Neglecting end correction) for resonance at the second overtone the speed needs to be $\frac{5}{4}\lambda = 1.31 \text{ m}$ $\lambda = \frac{4}{5} \times 1.31 \text{ m} = 1.048$ $v = f\lambda = 261.6 \times 1.048 = 274 \text{ m s}^{-1}$ So, by decreasing the speed of sound in the mix to 274 m s^{-1}, the pipe will resonate. With a mixture of almost pure carbon dioxide and a tiny bit of air, this speed is possible, so the plan could work.	Identifies decrease in frequency.	Appropriate calculations which show that the second overtone is the only one which might work (for pure CO_2), with a conclusion. 2nd overtone won't resonate because 0.99m ≠ 1.048 m. 2nd overtone won't resonate because 1.32 wavelengths in pipe not 1.25. 2nd overtone won't resonate because 4L is not an odd multiple of λ. 2nd overtone may resonate because 1.31m ≈ 5/4 λ.	Appropriate calculations which show that for the second overtone a gas of air / carbon dioxide which has a very high proportion of carbon dioxide is needed.
2011(1) (a)(i)	The incident wave is reflected at the bottom, and so the reflected wave travels up through the incident wave.	Correct answer. Must give the idea of reflected wave travelling up and interfering or combining with the incident wave		

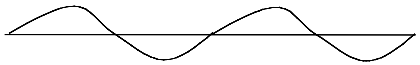
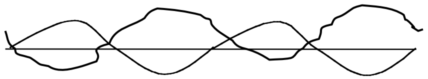
(ii)	At a node the medium is fixed. The top of the string is fixed. The bottom of the string is free to move, and so will not be a node, The top end is a node because the two waves combine destructively, and the bottom end is an antinode because the two waves combine constructively.	Answer describes how the restriction on the movement of the string at the top causes a node. AND the bottom end is free to move/ not fixed, so will not be a node/be an antinode	Achievement + since the top end is fixed so destructive interference (or crest on a trough) happens making it a node. OR Achievement + since the bottom end is free so constructive interference (or crest on a crest) happens making it an antinode.	
(b)	$\frac{3\lambda}{4} = 12 \Rightarrow \lambda = 16$ cm $v = f\lambda \Rightarrow f = \frac{2.5}{0.16} = 15.625 = 16$ Hz	Correct wavelength. 16 cm. OR Incorrect wavelength is used to calculate the frequency but λ must be in metres.	Correct answer. 16 Hz.	
(c)	f (2nd) = 2 × f (1st) = 2 × (15.625 ÷ 3) 10.526 Hz $\Rightarrow \lambda(\text{2nd}) = \frac{v}{f} = \frac{2.5}{10.526} = 0.2375 = 24$ cm The string is 12 cm long, which is half of the wavelength of the second harmonic (λ_2 = 24cm). The top end of the string has to be a node and 12 cm from the top will be another node and as the bottom of the string has to be an antinode, it is not possible to fit a wave of this length into the string.	Correct fundamental = 5.2Hz OR Correct answer for the wavelength of the second harmonic wave can supply replacement evidence. ONE idea is described correctly.	Correct answer, 10 Hz or consequential to 1(b). BOTH ideas are linked correctly. OR Some other correct and valid explanation Do not accept closed pipe has only odd harmonics.	Correct frequency and correct explanation.

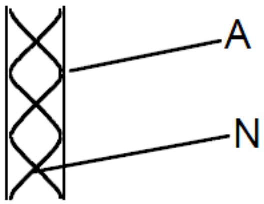
2010(1) (a) (i) & (ii)		Correct answer – allow schematic diagrams and/or labels.		
(b)	$f = \frac{v}{\lambda} = \frac{523}{4 \times 0.18} = 726 \text{ Hz}$	Correct answer.		
(c)	As it heats and becomes more humid *v* increases, and for steam *v* again increases. *l* remains the same, so λ is the same (for the fundamental and all the overtones). since $f = \frac{v}{\lambda}$, it increases with *v*. If *f* increases, pitch increases.	Pitch gets higher / frequency increases.	Explains that the change in *v* causes: Change in pitch due to change in *f*. OR Change in pitch as λ is constant. OR Change in *f* as λ is constant.	Complete answer.

2010(2) (a)	$f = \frac{v}{\lambda} = \frac{563}{2 \times 0.64} = 439.8 \text{ Hz}$	Correct method.		
(b)(i) (ii)	They are exactly in antiphase and have the same amplitude. They are in phase but the amplitude of D is much greater than C.	EITHER ONE part completely correct OR BOTH correct for amplitude (no confusion with displacement) OR BOTH correct for phase.	BOTH correct.	ALL correct.
(c)	Shorter string produces higher frequency. Frequency of the new string. $f_2 = f_1 + f_{\text{beat}} = 440 + 20 = 460 \text{ Hz}$ $l = \frac{\lambda}{2} = \frac{v/f}{2} = \frac{563}{2 \times 460} = 0.612$ $\Delta l = 0.640 - 0.612 = 0.028 \text{ m}$	Correct f_2.	Correct length.	Correct answer.
2009(1) (a)	Fundamental = 512/3 =171 Hz	Correct working.		
(b)	The string moves because it has a natural oscillation at that frequency, so it resonates. The other strings don't have a natural oscillation at that frequency, so they don't move. Resonance results in standing wave forming on that string. This is when the wave reflects at the ends of strings in way that the incoming and reflected waves interfere to produce nodes at both ends. This string has this natural frequency because of the tension and mass per unit length, which change the wave speed in the string. The result is that the wavelength of this frequency in the string has a whole number of half wavelengths, so it resonates.	Mentions resonance/formation of standing wave/ frequency match.	Answer that explains movement of one string and not others in terms of tension being such that wave speed/frequency results in standing wave / vibration at the natural frequency establishes a standing wave.	Detailed answer that includes reasons for resonance in terms of the natural frequency match/energy and the build-up of a standing wave.

(c)	$\lambda = .635 \times 2/3 = 0.423$ m $f = 512$ Hz $v = f\lambda = 512 \times 0.423 = 217$ m s^{-1} OR $\lambda = .635 \times 2 = 1.27$ m $f = 171$ Hz $v = f\lambda = 171 \times 1.27 = 217$ m s^{-1}	Correct wavelength calculated.	Correct answer.	
2008(1) (a)	$v = f\lambda$, $\lambda = 2.4$ m $\Rightarrow v = 35 \times 2.4 = 84$ m s^{-1}	Correct answer		
(b)	$f = 3 \times 35 = 105$ Hz	Correct answer.		
(c)	Wavelength has been decreased to ⅓ its original length.	Wavelength decreased.	Correct factor for the decrease in wavelength.	
(d)	Tightening the string changes the speed of the wave. Changing the speed (at fixed frequency) changes the wavelength. Thus a whole number of half-wavelengths no longer fit into the string length. OR Tightening the string changes the speed of the wave. Changing the speed (at fixed string and hence wavelength) changes the required frequency. Thus the generator frequency is no longer the resonant frequency.	The speed of the wave changes / wavelength changes / resonant frequency changes.	Lack of fit linked to a change in speed or a change in wavelength / lack of resonance linked to a change in the required frequency for resonance	Lack of fit linked to a change in wavelength caused by a change in speed / lack of resonance linked to a change in the required frequency for resonance caused by a change in speed.
(e)	$v = f\lambda$ = (answer to (b)) $\times$ 1.8 = $105 \times 1.8 = 190$ m s^{-1}	Correct wavelength.	Correct answer consequential with (b).	
2007(1) (a)	2½ waves in the pipe $\Rightarrow 28.5 = \frac{5\lambda}{2} \Rightarrow \lambda = 11.4$ cm OR 0.114 m	Correct answer		

(b)	5th harmonic OR 4th overtone	Correct answer		
(c)	$\lambda(\text{fundamental}) = 2L = 0.570$ m $f = \dfrac{v}{\lambda} = \dfrac{340}{0.570} = 596.49$ $= \mathbf{596\ Hz}$ **OR 596 $\mathbf{s^{-1}}$** OR $f(\text{5th harmonic}) = 5 \times f(\text{fundamental})$ $f(\text{5th H}) = \dfrac{v}{\lambda(\text{5th } H)}$ $\Rightarrow f(\text{fund}) = \dfrac{340}{5 \times 0.114} = 596.49 = \mathbf{596\ Hz}$		Correct answer	
(d)	When particular incident waves that have the fundamental frequency (wavelength) are reflected at the pipe ends, they superpose (interfere) with the waves travelling in the opposite direction, to produce a standing wave.	Idea of incident and reflected waves combining to produce standing waves. OR Idea of vibration of air at the right frequency causing resonance to produce a standing wave.	Achievement plus clear implication that the wave has to "fit" the pipe. OR The driving frequency matches the length of the pipe causing resonance.	
(e)	Opening the last hole makes the pipe shorter. This means the note will have a shorter wavelength and so a higher frequency.	Change in pipe length changes wavelength (frequency). OR Opening the air hole causes the wavelength to decrease which causes the frequency to increase	Decrease in pipe length linked to decrease in wavelength and hence increase in frequency. OR Achieved plus speed of the wave stays the same.	Merit plus speed of the wave stays the same.
2006(2) (a)	$\lambda = 2 \times 43.2 = 86.4$ cm or 0.864m	Correct answer.		

(b)	 Or 	Correct shape.		
(c)	This is a SHOW question $\mu = \dfrac{4.62\times10^{-4}}{0.578} = 7.993\text{x}10^{-4}$ $= 7.993 \times 10^{-4}$ kg m^{-1} $v = \sqrt{\dfrac{70}{7.993\times10^{-4}}} = 295.933 = 296$ m s^{-1}		Correct mass per unit length. AND Correct substitution shown.	
(d)	When the string is tighter, the wavelength is the same and the frequency is higher.	Wavelength unchanged AND frequency increased.		
(e)	While the fundamental note may be the same, the instruments produce different overtones and with differing strengths for the overtones. What is heard is the combination of the fundamental and overtones. The combined wave shape, which gives a diagrammatic representation of the combined waves, is different for the two instruments. The ear is able to detect this difference.	Idea that musical instruments produce overtones (or harmonics resonances). OR Reasonable resultant wave shapes. Accept closed pipe arguments (like only odd harmonics in flute but all harmonics in harp).	Recognition that different instruments have different (combinations of) overtones, i.e. have different strengths or number of overtones. Allow difference in sound production. E.g. attack (M_1)	Recognition that the timbre (difference) of a note is determined by the combination of the fundamental and its overtones (all harmonics). AND That the overtones in different instruments differ in number or strength. OR Merit plus the resultant wave(form) are different for each instrument. (Pictures OK.)

(f)	Lowest frequency is the longest wavelength – hence the fundamental. For an open pipe $\lambda = 2L = 2 \times 0.61$ = 1.22 m $f = \frac{v}{\lambda} = \frac{340}{1.22}$ = 278.69 = 280 Hz	Recognition that wavelength is 2 × pipe length. (1.22m). 4 × pipe length and gets 139.344 Hz Max of A_2 only.	Correct answer 278.69 (280Hz)	
2005(1) (a) (i)	$v = f\lambda$ $\Rightarrow \quad \lambda = 340 \div 685 = \ 0.49635$	Correct substitution and rearranging.		
(a) (ii)	2 significant figures because the lowest number of s.f. in the substituted data is 2.	Units and Sig fig: 3 correct units given from 1e, 2c, 2d, 2g plus 2sf in 1(a)(ii) correctly justified.		
(b) (c)	 Accept other diagrams (e.g. arrow displacement diagram) that clearly understanding.	Antinodes at both ends of the pipe. 1 antinode and 1 node correctly labelled.	Correct wave shape.	
(d)	A closed pipe must have a node at the closed end. / A closed pipe can only fit an odd number of $^1/_4\ \lambda$ whereas an open pipe fits an even number of $^1/_4\ \lambda$.	Correct answer.		
(e)	$L = 1\frac{1}{2}\lambda$ $= 1.5 \times 0.49635$ $= 0.74453 \quad = 0.74$ m	Correct consequential answer if the incorrect answer to (b) shows a half or one full wavelength.	Correct answer or correct consequential answer if the incorrect answer to (b) shows a wavelength other than half or one full wavelength.	

In 2013, AS 91523 replaced AS 90520.

The Mess that is NCEA Assessment Schedules….

In AS 90520 there was an Evidence column with the correct answer and Achieved, Merit and Excellence columns explaining the required level of performance to get that grade. Each part of the question (row in the Assessment Schedule) contributed a single grade in either Criteria 1 (Explain stuff) or Criteria 2 (Solve stuff). From 2003 to 2008, the NCEA shaded columns that were not relevant to that question.

In 91523, from 2013 onwards, each part of a question contributes to the overall Grade Score Marking of the question and there are no longer separate criteria. There is no shading anymore. There is no spoon. At least their equation editor has stopped displaying random characters over the units.