Waves – Notes

$v = f\lambda$

$f = \frac{1}{T}$

$\lambda \propto \frac{1}{n}$

Standing waves/strings/open pipes produce integer multiple of halves of wavelengths.

Closed pipes produce odd multiples of quarters of wavelengths.

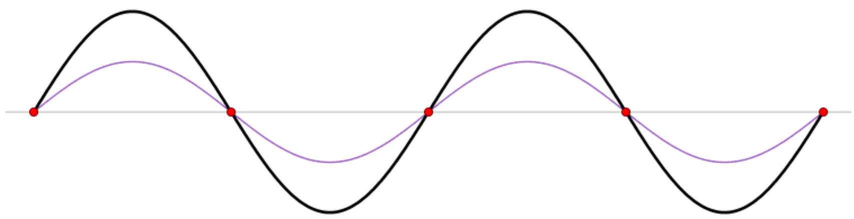
Standing waves / strings:

Order number = number of antinodes.

Ends are always displacement nodes / pressure antinodes.

Overtone number = order number minus one.

Harmonic number = order number.



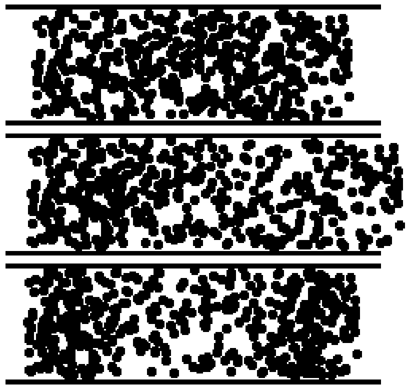
Open pipes:

Order number = number of pressure antinodes / displacement nodes.

Ends are always pressure nodes / displacement antinodes.

Order number = overtone number + 1.

Order number = harmonic number.



Closed pipes:

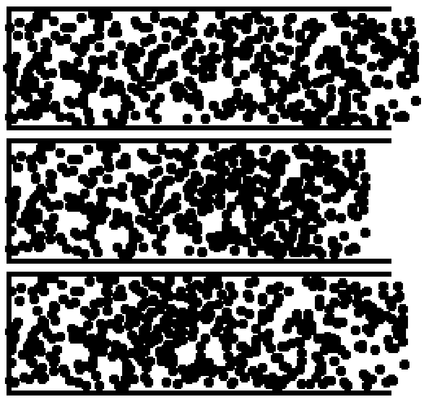
Order number = number of pressure nodes and antinodes.

Closed ends are always displacement nodes / pressure antinodes.

Open ends are always displacement antinodes / pressure nodes.

n = $\frac{\text{Harmonic number} + 1}{2}$

Order number = overtone number + 1.



Reflection results when the wave bounces off a surface.

Refraction results when waves bend as they pass from one medium to another.

The change in direction results from a change in speed of the wave as it enters a new medium.

Diffraction occurs when a wave passes through a narrow opening (aperture).

The greatest diffraction results when the width of the opening that the wave passes through is similar to the wavelength of the wave.

Diffraction also occurs at the edges of an obstacle. In this case, waves of greater wavelength tend to diffract more noticeably.

Forced vibration occurs when an oscillating energy source forces an object to vibrate in time with the source (e.g., loudspeakers).

Resonance occurs when the frequency of forced vibration matches a body's natural frequency. The result is a much larger amplitude of vibration than the forced vibration at other frequencies.

Q: A fisherperson has a small float that's moving up and down with the motion of the sea. He's curious as to why the float doesn't appear to move along with the waves as they move past his float. Explain his observation.

The waves are transverse, that is the molecules move in a direction perpendicular to the direction of the flow of energy, and so the bob moved up and down with the particles in the medium (the ocean) as the wave moves past, rather than moving along the flow of energy.

Q: In a transverse wave, the molecules of the medium move in a plane that's 90 degrees to the direction of energy flow. In what plane do the molecule in a longitudinal wave flow?

The molecules in a longitudinal wave move in the direction of the energy flow.

Q: Water can move in both a transverse and longitudinal at the same time. The Earth after a large seismic event can do the same. Identify which type of wave arrives first and which type usually does the most damage to structures.

Longitudinal waves travel faster and so will arrive first but do much less damage. Transverse waves are slower, and so arrive later, but instead of particles moving sideways (as in longitudinal waves) they move up and down like ripples, so they do more damage to rigid structures, forcefully moving them up and down (or side to side).

Q: When you use a microphone to connect to a digital CRO or other analysis system the signal will often be a sound pressure vs time graph or voltage vs time graph. Explain.

The microphone measures the compressions and rarefactions against time and converts this to an electric signal. This means the output of the microphone will be against time and so the CRO shows the voltage vs time which directly correlates to a sound pressure vs time graph (the voltage changes according to the sound pressure in the microphone).

Q: In a major athletics event having a staggered start, loudspeakers connected to the starter's gun are placed in each lane just behind each competitor. Explain.

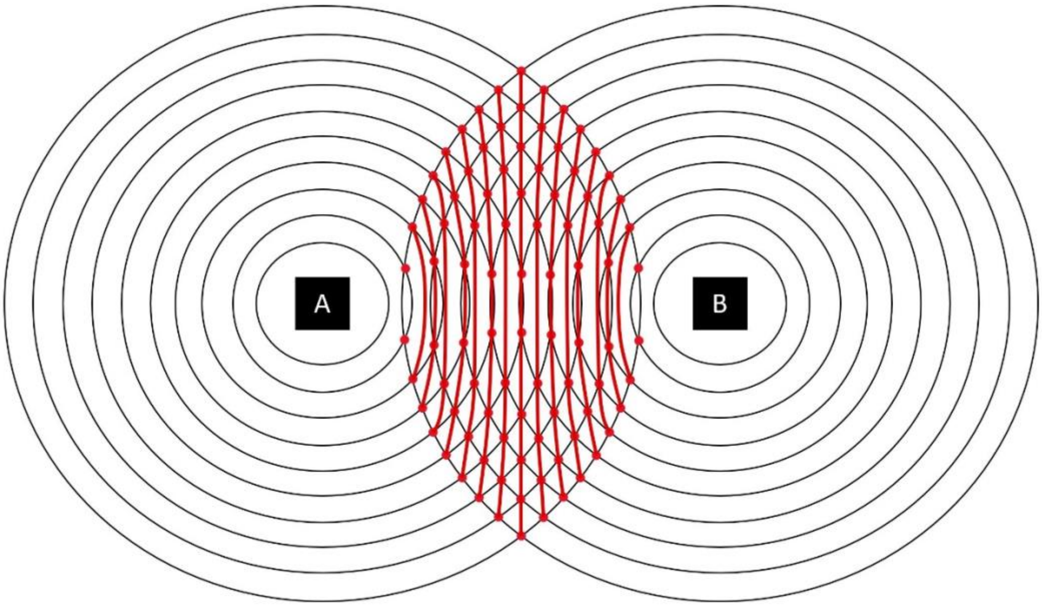
Loudspeakers are connected behind each athlete so as to not give the closer racers a head start. If this were not done, the farthest athletes would be disadvantaged by the amount of time it takes the sound to reach them.

Q: A group of researchers perform a sensitive experiment. They find that sound travels slightly faster on hot days than on cold days. Explain.

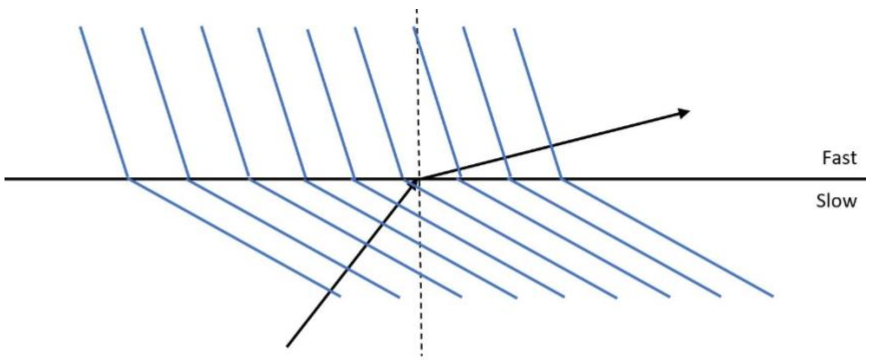
Sound travels faster in hotter gases: changes in temperature change the density of air (decreases) without changing its elasticity.

Q: Why do ships and lighthouses usually use low frequency warning sounds?

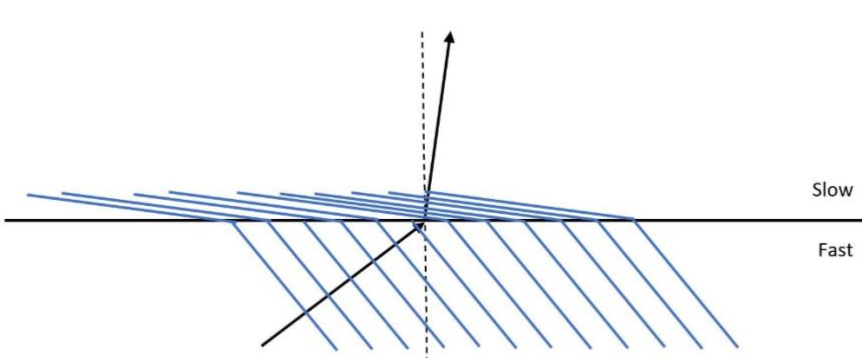
Lower frequencies have larger wavelengths and are diffracted more, so more likely to be transmitted around barriers.



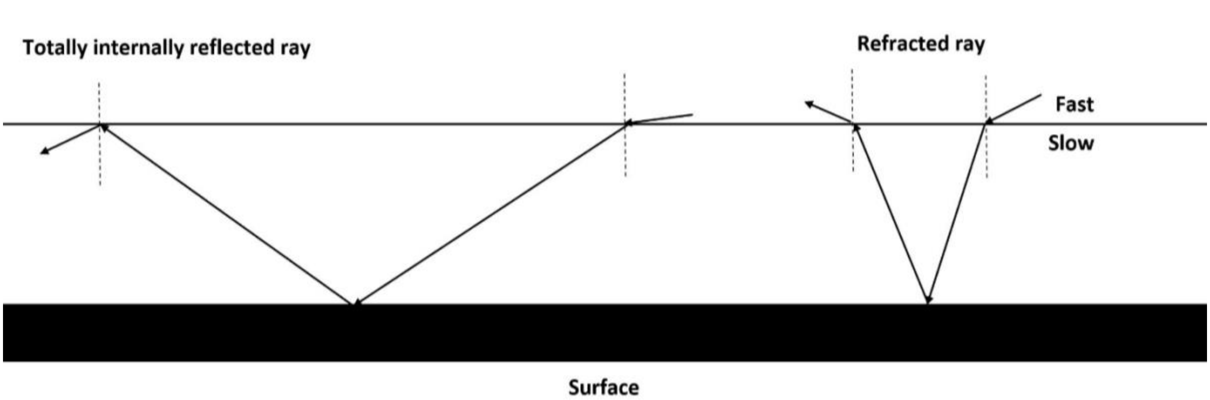
A
B



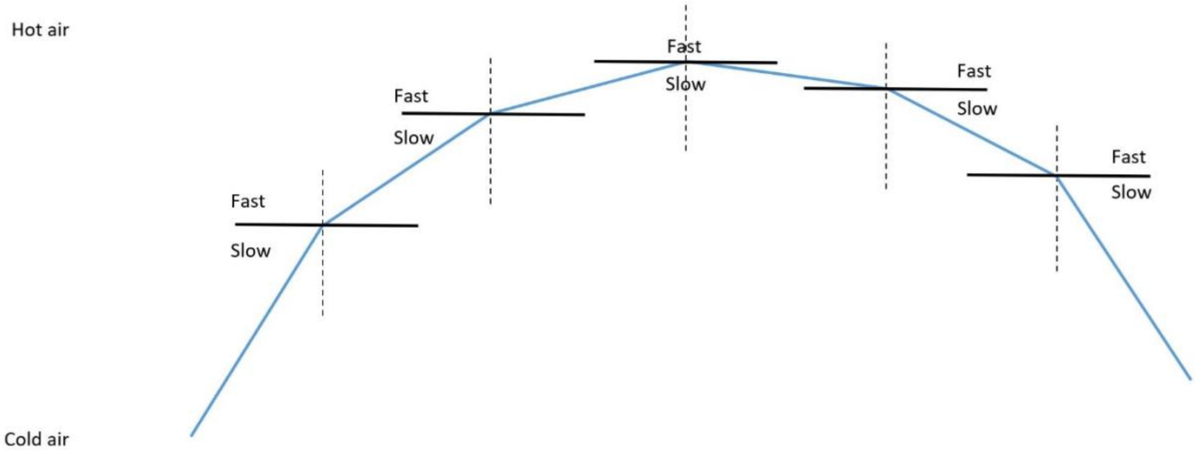
Fast
Slow

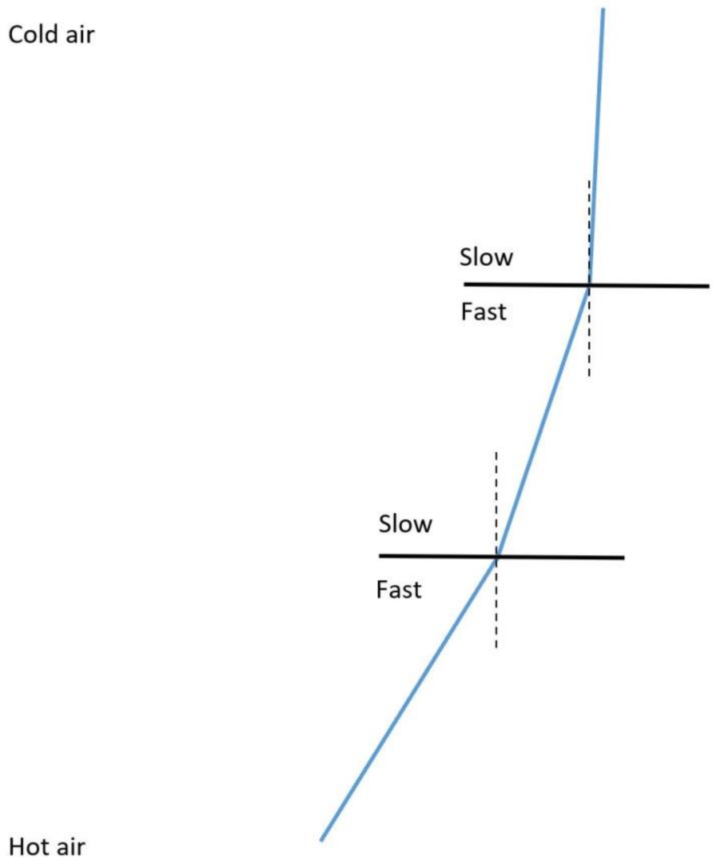


Slow
Fast

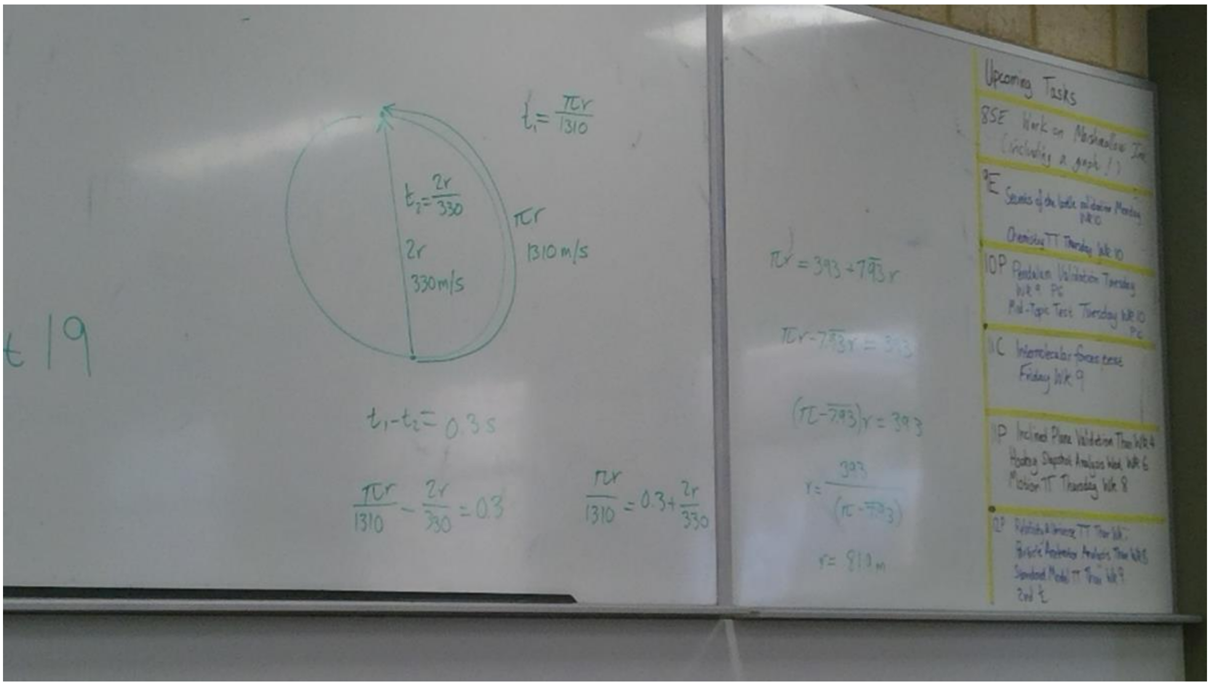


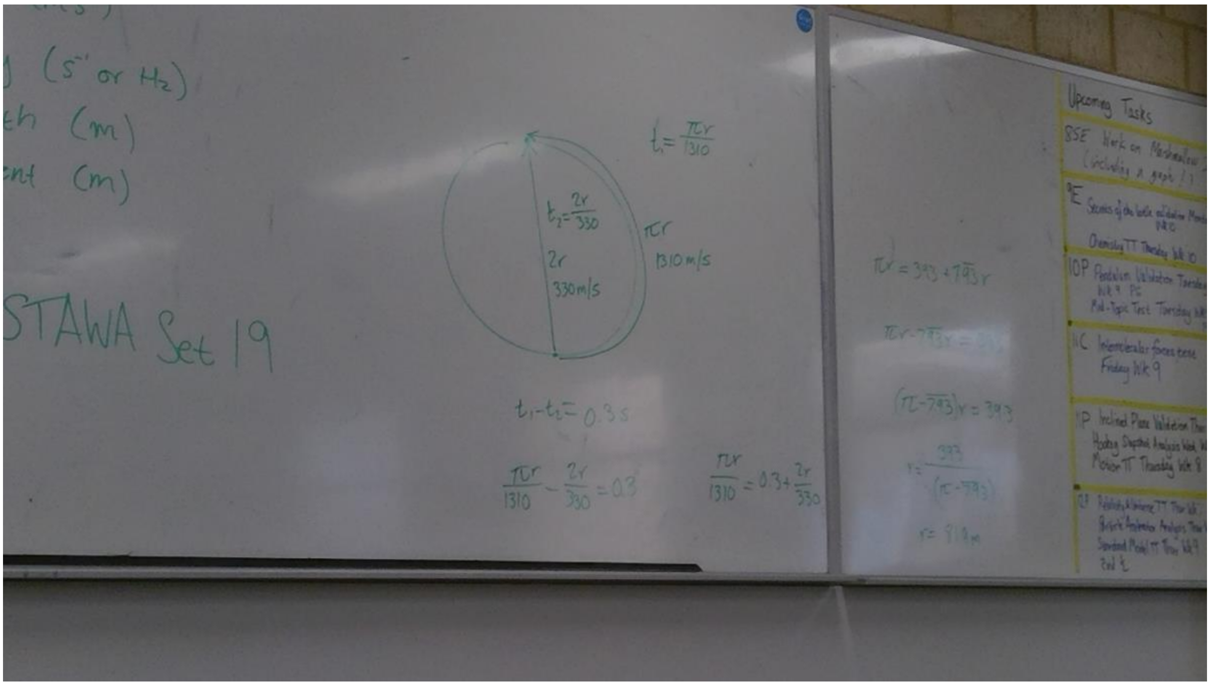
Totally internally reflected ray
Refracted ray
Fast
Slow
Surface





Q: A park has a circular fence around it. The top rail of the fence is a metal pipe. A physics teacher sets a group of students the task of finding the radius of the fence by using their knowledge of sound. One member of the group hits the pipe with a hammer giving a sound of 350Hz. A second student, standing directly opposite on the other side of the park, detects 2 sound, 0.300s apart. If the speed of sound is 330ms^{-1} in air and 1310ms^{-1} in this metal pipe, calculate the radius of the fence.





For sound travelling around the fence: $1310\ ms^{-1} = \frac{\pi r}{t}$

For sound travelling across the circle: $330\ ms^{-1} = \frac{2r}{t+0.3}$

Rearrange equation one to give: $t = \frac{\pi r}{1310ms^{-1}}$

Substitute for t into the second equation: $1037r + 129690 = 2620$

r = 82 m

The wavelength of a reflected wave remains unchanged.

The frequency of a transmitted wave remains unchanged.

A lower frequency has a longer wavelength and are diffracted more so travel over more of the ocean.

Waves getting closer together means the water is getting shallower.

Q: Timmy stands 3m in front of a speaker, before walking 5m back from it. By what factor does the sound intensity change?

3m → 8m

3m x $\frac{8}{3}$ = 8m

I x $\frac{1}{(\frac{8}{3})^2}$

Factor of 0.141

Q: Alan stands 40m away from a speaker and walks 24m towards it. By what factor does the intensity change?

40m → 16m

40 x $\frac{16}{40}$ = 16

I x $\frac{1}{(\frac{16}{40})^2}$

Factor of 6.25

Q: Why can you hear a tuning fork better if you hold the stem in contact with a solid surface?

By placing the tuning fork in contact with a larger object this causes the other object to vibrate in sympathy (forced vibration). Because the other object has a larger surface area it can radiate a larger mass of air, which produces a louder sound as more energy is dissipated.

Q: Explain how a singer is supposed to smash a wine glass by singing certain notes close to the glass.

The wine glass has its own natural frequency at which it vibrates if struck (e.g. flicked with a finger). Sound waves coming from the singer cause regular air compressions to arrive and hit the glass. If the frequency of these compressions matches the natural frequency of the glass, they cause resonance to occur, where the amplitude of vibration builds up to a point where the glass can shatter.

Q: Why do engineers build in devices that reduce resonance and limit the effect of forced vibrations?

In structures such as bridges, cables and chimneys the effect of winds can be to cause resonance in the structure which can be destructive. By adding mechanical systems that absorb the wind energy (damping) the amplitude of the vibrations can never build up to a destructive resonance level.

Q: Why do some parts of a car's body vibrate excessively at a certain speed?

Rattles in cars at a particular speed are caused by resonance in components of the body (body shell, springs etc.) The forcing frequency usually comes from unbalanced wheels which give regular pulses that can match the natural frequency of the components at a particular rotational frequency.

Q: What could cause dead spots?

'Dead spots' are areas where sound levels are very soft and are caused by the destructive interference of two sound waves arriving at that area. One wave comes to a point straight from the instrument and the other wave arrives out of phase because it has travelled a greater distance due to reflection off a wall. Because the path difference between these two waves is an odd number of half wavelengths the sound pressure is cancelled at that point.

Q: How could you minimise dead spots?

By adding an absorbing surface, any sound waves striking the walls is partially absorbed which means that reflection is much less likely to occur and so the 'dead spots' problem is greatly reduced.

Q: Explain the shape of a resultant waveform of 2 waves half a wavelength out of phase.

The resultant wave is a "beat frequency". It is the result of the constructive and destructive interference. It is at its loudest when there is constructive interference and at its softest when there is destructive interference (amplitude is 0). Since the 2 waves are only slightly different frequencies the interference results in a waveform that 'beats' at this difference in frequencies.

Q; Explain why a pipe shatters in the middle if both ends are struck simultaneously by soft rubber gloves.

As both waves reach the middle, constructive interference occurs as the two waves are superimposed. This much larger wave has the combined energy of the two smaller waves and so can shatter the pipe, but only in the very middle where the constructive interference occurs.

Q: Paula timed Beth at 14.2s for a 100m sprint. What's the more likely correct time for this sprint? Assume velocity of sound to be 244ms^{-1}.

$t = \frac{100}{344} = 0.291s \rightarrow t = 14.2 + 0.291 = 14.5s$

Q: Dolphins can locate objects by emitting sounds of up to 150 kHz in short pulses.

[a] Assuming the velocity of sound in sea water is to be $1530 ms^{-1}$, determine the wavelength of these sounds.

$\lambda = \frac{1530}{150 \, x \, 10^3} = 1.02 \text{ x } 10^{-2}$ m

[b] What would be the minimum sized object the dolphins could easily detect by this method? Explain.

Objects about 10cm or greater would be most easily detected.

Q: Modern cameras determine the distance of the subject from the camera by measuring the time delay between emitting the sound and detecting an echo. What would be the time delay for a subject 10.0m from the cameras?

$t = \frac{2 \, x \, 10}{346} = 0.0578s$

Q; 3 similar tuning forks, X, Y and Z, are sounded together in pairs in order to determine the unknown frequency of one of them. The frequencies of X and Y are 440 Hz and 445 Hz respectively. When Z is sounded with X, 10 beats are heard in 5 seconds. When it's sounded with Y, 15 beats are heard in 5 seconds. What's the frequency of tuning fork Z?

X: $2 = |440 – f| \rightarrow f = 438, 442$

Y: $3 = |445 – f| \rightarrow f = 442, 448$

f = 442 Hz

Similarities and differences between the 2 wave motions causing beats and standing waves:

Similarities:	**Differences**:
Same velocity.	Same direction for beats and opposite directions for standing waves.

Same medium.	Slightly different frequencies for beats but same frequency for standing waves.
Same type.	

Q: 2 speakers, A and B, are emitting sound waves in the same direction. The wavelengths are 1.40m and 1.50m, respectively. Assume the velocity of sound is $340ms^{-1}$.

[a] What will be the distance between successive in phase positions?

λ_A = 1.40m, λ_B = 1.50m → $\Delta\lambda$ = 1.10m

Therefore, you need 14, 1.5m waves for in phase position 21m.

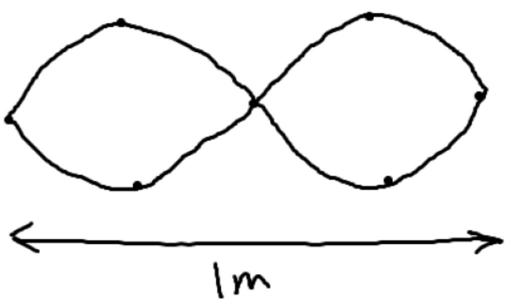
[b] What will be the time difference between the occurrence of maximum sound intensities at any given point?

$f_A = \frac{340}{1.4}$ = 243 Hz, $f_B = \frac{340}{1.5}$ = 227 Hz

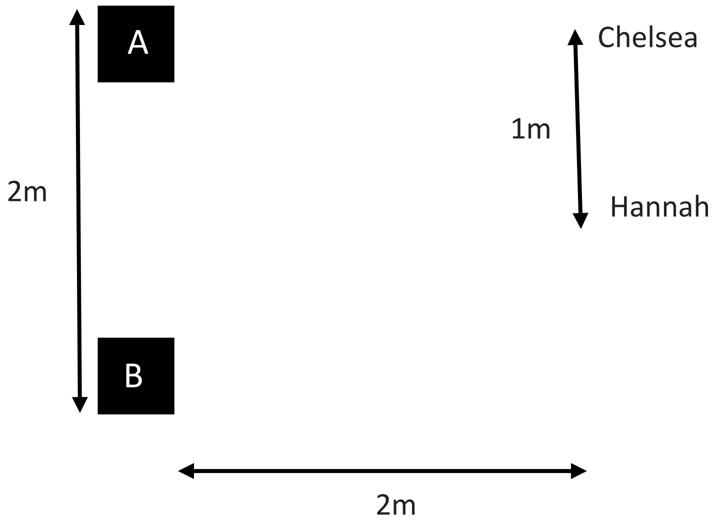
f_{beat} = 243 – 227 = 16.2 Hz → $T = \frac{1}{16.2}$ = 0.0518s

If someone is equally distant from both speakers, the <u>sounds will be in phase</u> and so a person will hear a sound of maximum intensity.

Q: Simon walks from the midpoint of 2 speakers (A and B) 4m apart towards B and encounters 2 points of minimum and 2 points maximum sound intensity. Determine the sound being used.



λ = 1.00m



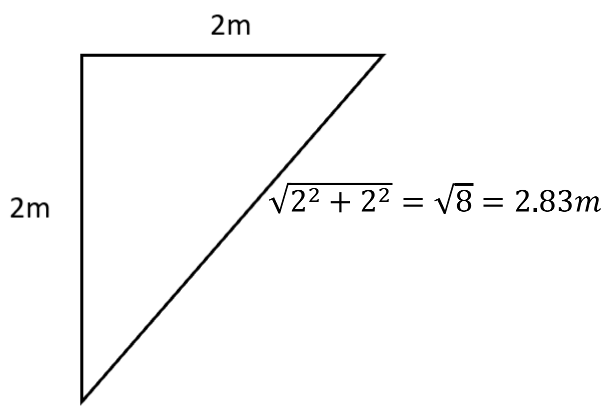
[a] If Hannah begins to walk towards Chelsea, in what way will the sound that she hears vary? Explain.

Hannah is walking away from a maximum loudness point. She'll encounter a series of loud and quiet spots. This is due to constructive and destructive interference from the 2 speakers.

[b] Chelsea, who's standing directly in front of speaker A, can't hear any sound at this position. Determine the minimum frequency of the sound being emitted by the 2 speakers (assume the speed of sound is $340ms^{-1}$).

$\Delta\lambda = 0.83 = n\lambda \rightarrow n = 0.5 \rightarrow \lambda = \frac{0.83}{0.5} = 1.66m$

$f = \frac{340}{1.66} = 205$ Hz



Q: Samuel plucks a harp string 1.25m long so that it's vibrating at its fundamental frequency.

[a] What name is given to this type of wave pattern?

Standing wave pattern.

[b] What's the maximum wavelength that this string can have when vibrating?

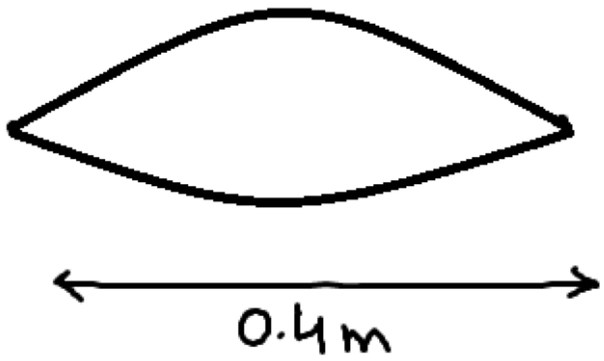
$\lambda = 1.25 \times 2 = 2.50\text{m}$

Q: Rebecca and Pamela set up a resonating air column in the laboratory sing a 440 Hz tuning fork. The pipe was 1.20m in length. Beginning at one end of the pipe they found:

[i] Maximum intensity at 0m, 0.4m and 0.8m.

[ii] Minimum intensity at 0.2m and 0.6m.

[a] Determine the wavelength of the sound.



$\lambda = 0.4 \times 2 = 0.800\text{m}$

[b] Determine the speed of sound in this experiment.

$v = 440 \times 0.8 = 352\text{ms}^{-1}$

[c] Did the 2 students use an open or closed pipe as a resonating air column? Explain.

They used an open pipe since the next antinode would occur at the other end of the pipe.

Speed of a wave will only change when there's a transfer between media.

When sound travels from cool air to warm air:

[a] Velocity: Increases.

[b] Direction: Away from the normal.

[c] Wavelength: Increases.

[d] Frequency: Unchanged.

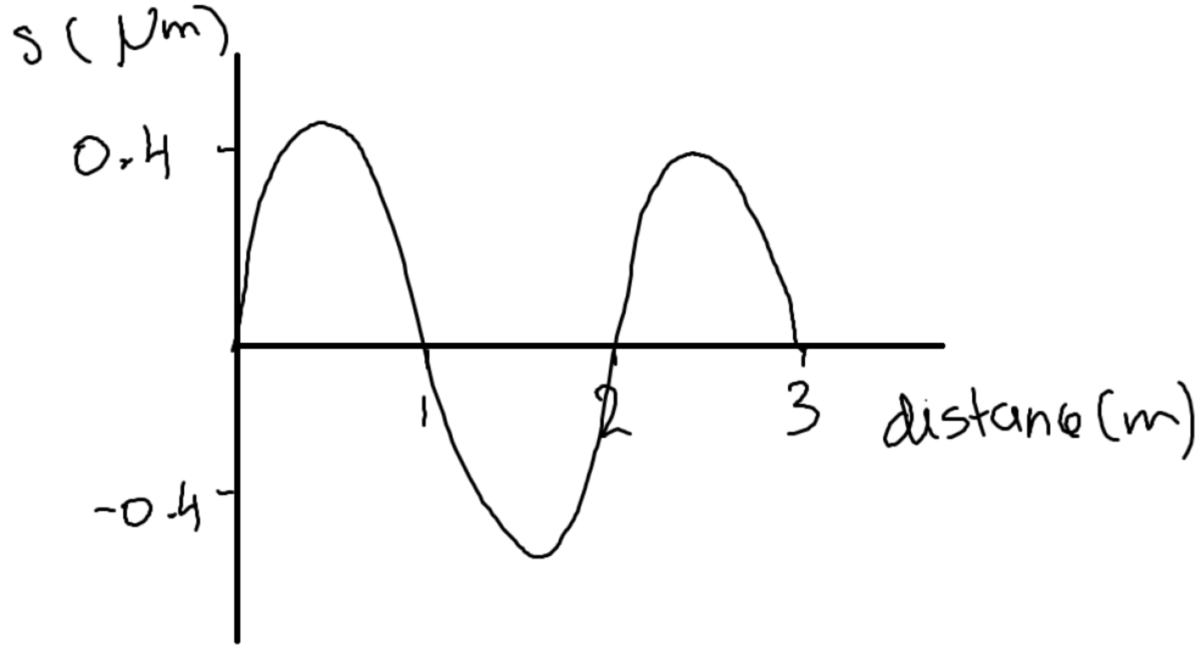
Q: Echo sounding devices are often used to determine the depth of oceans and rivers. These devices emit short pulses of ultrasound (50 kHz) towards the ocean floor and then detect the reflected sound.

[a] How can you calculate the depth of the ocean?

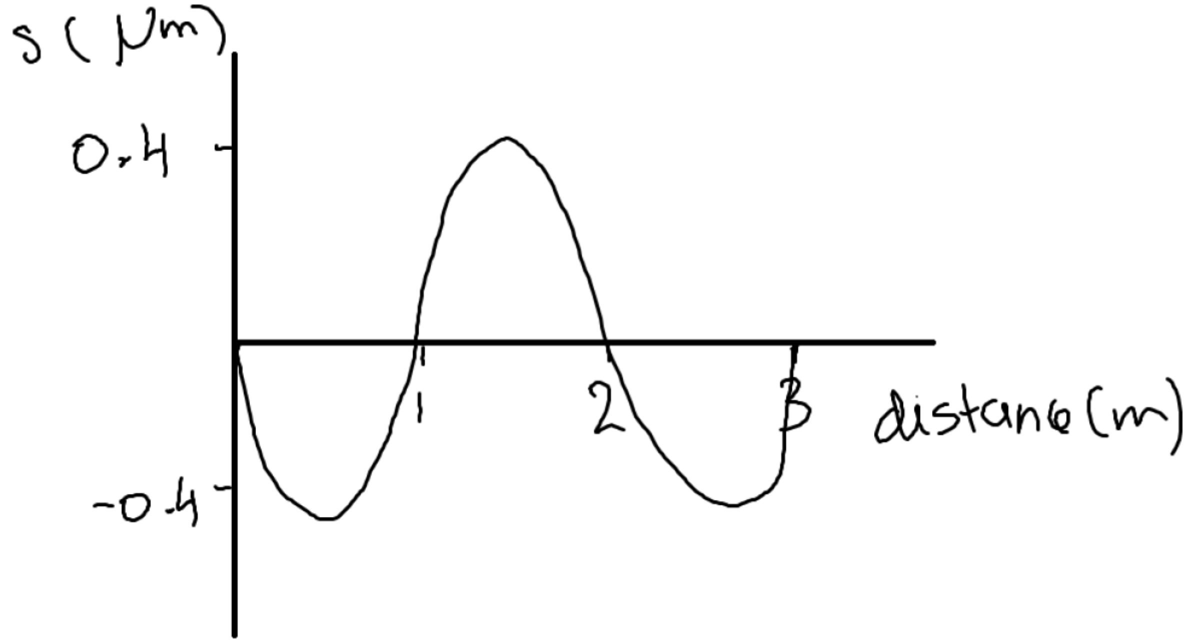
Since the velocity of sound in water is known, the time delay between sending a signal and receiving an echo can be used to calculate depth.

[b] If the time delay between sounding and receiving a signal is 110 ms, what's the depth of the water?

s = 1530 x $\frac{0.110}{2}$ = 8.42 = 84.2m



Redraw the diagram above to show how it will look at t = $\frac{T}{2}$.

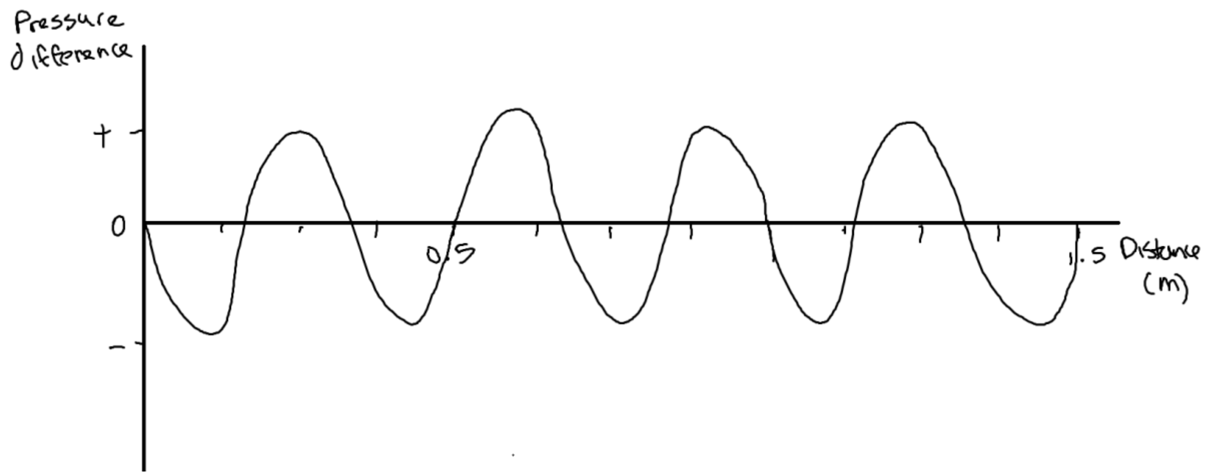


Q: A loudspeaker emits a sound of 1.00 kHz towards a microphone. The microphone is 2.00m from the speaker. Assume the speed of sound is 340ms^{-1}.

[a] Determine the wavelength of the sound being emitted.

$\lambda = \frac{340}{1000} = 0.340\text{m}$

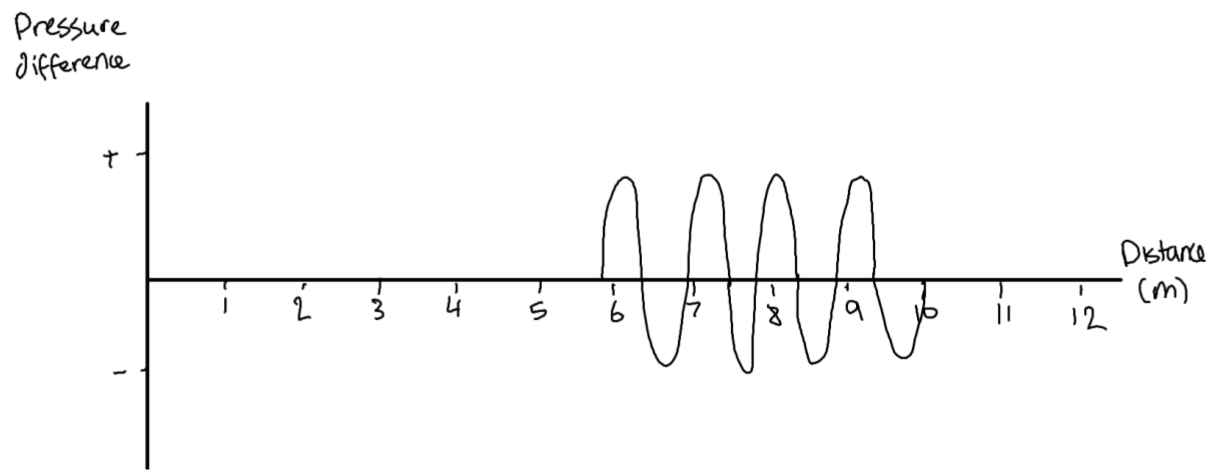
[b] Draw a graph to show how air pressure varies with distance from the microphone 4.00ms after the commencement of the sound. Assume that initially a compression wave leaves the cone. Pressure levels are arbitrary.



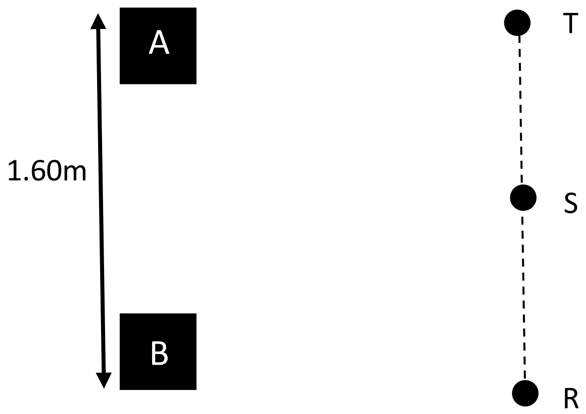
[c] How long will it take sound to reach the microphone after the commencement of the sound?

$t = \frac{2}{340} = 5.88 \times 10^{-3}$ s

[d] Sketch a pressure difference versus time graph as would be recorded at the microphone for the first 0.010 seconds of sound emitted by the speaker.



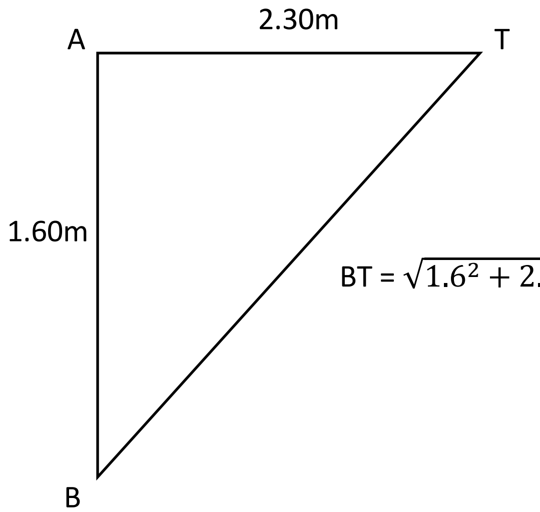
Q: Paula and Jake use a frequency of 685 Hz. Paula walks along the line from R to T and notices that maximum sound intensities occur at R and T (directly in front of the speakers) and at S (a point equidistant from each speaker). Quiter spots are noticed in between.



[a] What's the cause of this effect? Explain clearly.

Constructive and destructive interference causing loud and quiet spots.

[b] From the diagram, determine the difference in the distance between AT and BT.



BT = $\sqrt{1.6^2 + 2.3^2} = 2.80m$

[c] Use your result in (b) to determine the velocity of sound during this experiment.

Since point T is a maximum, then BT > AT by one wavelength.

v = fλ = 685 x 0.5 = 342ms^{-1}

P waves are longitudinal waves like sound. When they reach the Earth's surface, they travel through the air as sound waves and so can be heard and felt. S waves are transverse waves and can only travel through solids, and so they can only be felt.

Q: The nearest air molecule moving in phase with molecule X is 1.40m away. What's the wavelength of this sound wave?

$\lambda = 1.40m$

Q: Describe the motion of particles within a medium as a mechanical wave passes through a medium.

Particles oscillate perpendicular to or parallel to the direction of propagation of the wave. They oscillate around a mean/average position and pass on the energy carried by the wave. They don't move along with the wave.

Longitudinal waves occur when the direction of oscillation of particles is parallel to the direction of propagation of the wave.

Transverse waves occur when the direction of oscillation of particles is perpendicular to the direction of propagation of the wave.

Q: Describe how energy from a tuning fork is transferred.

The tuning fork vibrates back and forth, creating a series of compressions and rarefactions in the air as the energy is transferred.

Q: Describe how particles A and B have moved from their equally spaced undisturbed positions to form a compression.

The forward motion of the source pushes particles together so that particle A goes to the right, forming a compression. The backward motion of the source creates a rarefaction as particle B goes to the left.

If the speed of a police car and a runaway vehicle are the same and there's no relative motion of the medium, the frequency observed would be the same.

When water waves travelling through deep water reach a region of shallow water and refract, the following change:

- Wavelength,
- Direction.
- Speed.

As pulses pass through each other, the interaction doesn't permanently alter the characteristics of each pulse.

Q: Explain why resonance can result in damage to built structures.

An object subjected to forces with a forcing frequency matching its natural oscillating frequency will oscillate with increasing amplitude as there's a maximum transfer of energy. This could continue until the structure can no longer withstand the internal forces and fails.

Q: Is the standing transverse wave produced using a rope actually standing still? Explain.

It's only the nodes from the pattern made by the amplitude along the rope that stay still. The rope is still moving, especially at the antinodes where there's maximum movement.

Q: Describe how superposition and interference are related to the formation of standing waves in a stretched slinky spring.

A transverse wave moving along a slinky spring is reflected at a fixed end with a phase change. The interference that occurs during the superposition of the reflected wave and the original wave creates a standing wave.

4x frequency → $\frac{1}{4}$ wavelength.

Q: A pipe produced a fundamental frequency of 450Hz and subsequent resonant frequencies of 900Hz, 1350Hz and 1800Hz. Is this an open or closed pipe? Explain.

Each of the subsequent frequencies are integer multiples of the fundamental frequency. Therefore all the harmonics are formed and it's an open pipe.

Q: A pipe produces a fundamental wavelength of 3m and subsequent resonances at 1m and 0.6m. Is this an open or closed pipe? Explain.

The next resonance wavelength is $\frac{1}{3}$ that of the fundamental and the following is $\frac{1}{5}$. This means the frequencies would be 3x and 5x that of the fundamental frequency. Each of the subsequent frequencies are odd multiples of the fundamental frequency. Therefore only odd harmonics are formed and it's a closed pipe.

Q: High-intensity sound waves are used in treating sports injuries. Explain.

At high intensity, the vibrations of the tissues as the sound is propagated produces heat which can promote faster healing.

A diffuser is a corrugated surface that allows reflections to occur in multiple directions, thus reducing echoes and preventing standing waves from forming.

Q: Explain 2 ways to reduce sound pollution.

A high, solid barrier can be used to reflect sound and vegetation can be used to absorb sound.

Q: Describe the movement of water particles as a stone is dropped into water.

The particles on the surface of the water oscillate perpendicular to the direction of propagation of the wave as the waves radiate outwards, carrying energy away from the point where the stone entered the water.

Transverse waves vs longitudinal waves:

Similarities:	Differences:
Both are waves. Both carry energy away from the source. Both are caused by vibrations. Both require a medium to travel through.	Transverse waves involve particle displacement perpendicular to the direction of propagation of the waves whilst longitudinal waves involve particle displacement parallel to the direction of propagation of the wave.

Q: Explain how sound waves carry energy and not matter from one place to another.

Sound waves are longitudinal mechanical waves where the particles oscillate parallel to the direction of propagation of the wave. When these particles move in the direction of the wave, the collide with adjacent particles and transfer energy to the particles in front of them. This means kinetic energy is transferred between aprticles in the direction of the wave through collisions. Therefore the particles can't move along with the wave form the source as they lose their kinetic energy to the particles inf ront of them during the collisions.

Q: Describe the concept of resonance and why it would need to be considered when designing structures.

All substances have a resonating frequency. If the substance is forced to vibrate at this frequency, the amplitude of the substance's vibrations will increase with time. If a building or bridge was subjected to wind that made it vibrate at its natural frequency, this vibration may increase in amplitude so much that the structure is damaged or collapses.

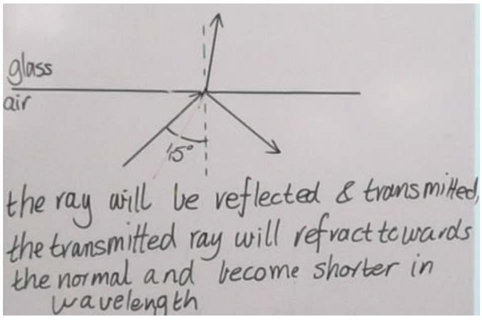
The condition for total internal reflection to occur is when the wave goes from a slow-speed medium to a higher-speed medium.

Q: The third harmonic for an open pipe produced a frequency of 400Hz. Assuming he speed of sound is 330ms^{-1}, calculate the length of the pipe.

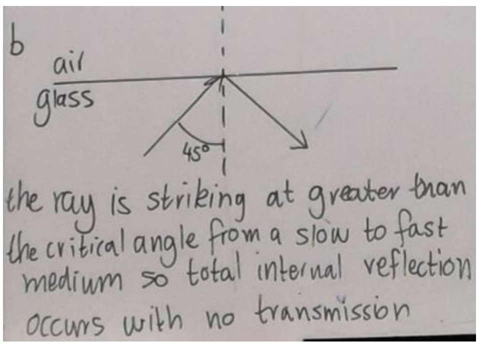
$\lambda = \frac{2l}{3} = \frac{330}{400} \rightarrow l = 1.24\text{m}$

Q: If the critical angle between air and glass is 30°, use a diagram to explain what happens when:

[a] A ray of light strikes a block of glass at a 45° angle.



[b] A ray of light in glass strikes the edge of the glass at a 45° angle.



Q: Explain in detail how bowing a violin string can produce sound of a specific frequency that can easily be heard across the room.

The bow physically disturbs the string. The string will preferentially vibrate at its resonant frequency while all other frequencies rapidly lose energy. The vibrating string forces the body to vibrate at the same frequency. The large surface area of the body transfers a large amount of energy to the air, creating vibrations at the same frequency as the string.