Physics 1901 Advanced
Solutions to Tutorial 8: Waves

Solutions

A. Qualitative Questions:

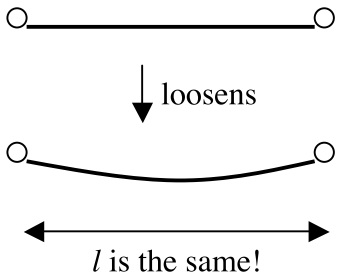
1. ***Shattering Glass***

a. A wine glass may shatter if the frequency of the note is equal to the resonant frequency of the glass. This is because the sound waves will set up standing waves in the glass and as long as the note is held at this frequency the sound waves will transfer energy to the standing waves. At some point the standing waves will become big enough to break the glass.

b. The explosion will generate a shock wave, which is an abrupt wave that can carry a large amount of energy. So, when the shock wave hits a barrier, (e.g. a window) it can impart a lot of energy in a short space of time. If the energy is great enough then the barrier will break. The cause of the breakage in part **a** was due to resonance whereas here the cause is a collision so the two situations are quite different.

c. Sound needs a medium to be transmitted, so no, you couldn't hear an explosion in space. The explosion could produce sound in another ship if bits of shrapnel hit the hull of the other ship.

2. ***Guitar***



a. The length l does not change, because the ends are fixed.

b. The wave velocity is given by:

$$\mathbf{v} = \sqrt{\frac{T}{m/L}}$$

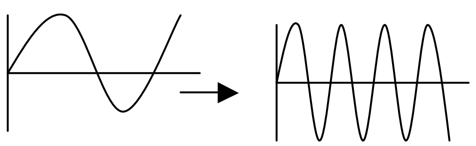
So a change in tension causes a change in velocity of the wave. The change in velocity causes a change in frequency, since $f = v / \lambda$ and λ is fixed by l.

c. The vocal cords are like the strings of a violin; they vibrate when driven to produce sound. They require a resonant cavity (like the wooden case of a violin), or in this case more than one (throat, sinuses, etc) to produce an audible sound.

Demonstration Questions:

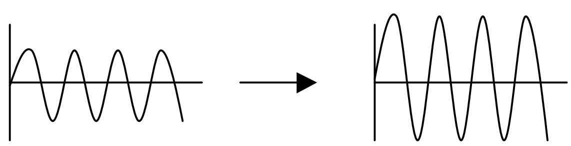
1. ***Look and listen.***

Increasing frequency



Increasing the frequency increases the pitch of the sound

Increasing amplitude (volume)



Increasing the amplitude increases the volume of the sound

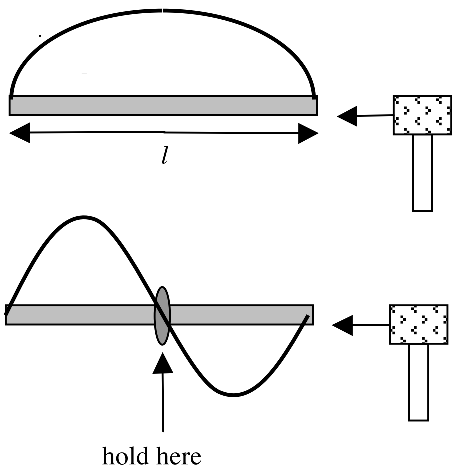
2. ***Visualising speech.***

When you speak the noise you make is made up of many different frequencies. Thus the wave you see on the CRO is quite complex (the wave generate in question **1** had only one frequency).

Speaking loudly or softly will mainly just affect the amplitude of the wave. By singing or whistling you are more able to control the frequencies of your voice and thus you should be able to generate a less complex wave form.

The microphone has a diaphragm (transducer) that converts vibrations in the air (sound) into an electrical si this diaphragm is vibrated by other means, such as tapping it, it still produces an electrical signal.

3. ***Waves in a rod.***

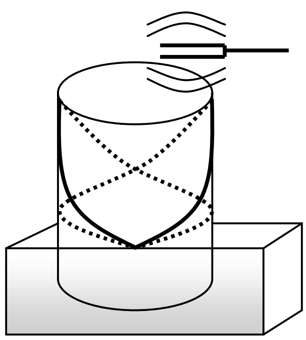


Longitudinal waves are produced by striking the rod 'end-on' (as in the diagram). Transverse waves are produced by striking the side of the rod.

Similarly to a guitar string (Q**A.2**), the wavelengths of the standing waves in the rod are determined by how much of the rod is allowed to oscillate. If you hold the rod at the end then the whole rod will be able to vibrate and thus a large wavelength (low frequency) standing wave can be generated (i.e. $\lambda/2 = l$). If you hold the rod firmly at the centre then you force a node at that point. This prevents the $\lambda/2 = l$ standing wave from forming making the $\lambda = l$ the largest wavelength standing wave able to form. Thus the frequency of the wave gets higher.

A traffic jam is similar to a longitudinal wave in that the particles (i.e. the cars) travel in the same dimension as the wave. However in a traffic jam there is slowly (but eventually) a net movement of particles. In a genuine wave there is no net movement of matter. The particles oscillate, but their average position does not change.

4. ***Resonance in a tube.***



When the tube is the right length, the air column inside it will resonate with the tuning fork, producing a louder sound.

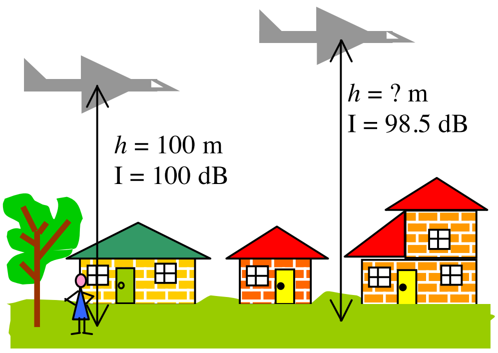
(See diagram opposite.)

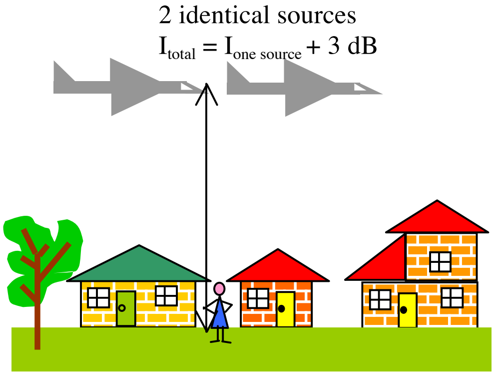
The open end of the tube is an antinode and the other end is a node.

A trombone produces different notes when its tube length is varied.

C. Quantitative Questions:

1. *Plane noise*





a. When the plane is at 100 m it produces a sound intensity of 100 dB. The maximum allowable is 98.5 dB, 1.5 dB lower, what is the height h for this intensity?

Using the decibel scale:

I (in dB) $= 10 \log_{10}(I / I_0)$

Where I_0 is a reference intensity.

The difference in dB is then:

$= 10 \log_{10}(I_{100} / I_0) - 10 \log_{10}(I_h / I_0)$

$= 10 \log_{10}(I_{100} / I_h)$

Intensity obeys the $1 / r^2$ law, so the ratio of the intensity at h to that at 100 m is:

$I_h / I_{100} = (100 \text{ m})^2 / h^2$

We know that the difference in intensity in dB is 1.5 dB, so:

$10 \text{ dB} \log (h / 100 \text{ m})^2 = 1.5 \text{ dB}$

Rearragning to find h:

$$20 \text{ dB} \log (h / 100 \text{ m}) = 1.5 \text{ dB}$$

$$h / 100 \text{ m} = 10^{1.5/20}$$

$$= 1.19$$

$$\therefore \quad h = 100 \text{ m} \times 1.19$$

$$= 119 \text{ m}$$

b. If two identical aircraft fly overhead at 119 m the intensity will double. So the increase in dB will be:

$= 10 \log_{10}(2I_h / I_h)$

$= 3$ dB

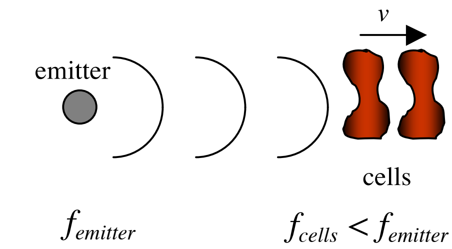
So the new intensity in dB

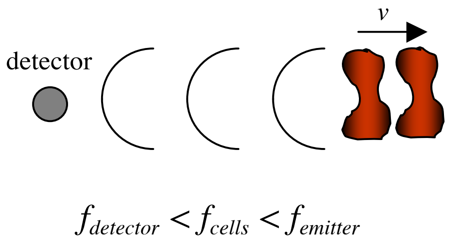
$= 98.5 \text{ dB} + 3 \text{ dB}$

$= 101.5$ dB.

(i.e. the intensity at 101.5 dB is twice that at 98.5 dB)

2. ***Doppler effect***





a. If the cells are moving away from the emitter then the distance between a cell and the emitter is increasing. Thus the frequency received by the cells will be lower. Inversely if the cells are moving towards the emitter the frequency received will be higher.

b. The cells are now acting as the source. If they are moving away from the detector (the machine) then the distance between the source and the detector will be increasing and thus the detector will detect a lower frequency. Inversely if the cells are moving towards the detector it will detect a higher frequency.

c. The sound is emitted by the machine, reflected by the red blood cells and then detected by the machine. We can break this down into two parts. In the first part the cells are the observer and the machine the source and in the second the cells are the source and the machine the observer. Thus we have,

$$f_{cells} = \left(\frac{v}{v+v_s}\right) f_{emitter}$$

$$f_{detector} = \left(\frac{v}{v+v_s}\right) f_{cells}$$

[Note: we are taking the case of cells moving away from the machine. The other case would be equally valid.]

We don't have a value for f_{cells} so we eliminate it from our equation and then rearrange to find v_s (which is the velocity of the blood relative to the machine)

$$f_{detector}\left(\frac{v+v_s}{v}\right) = f_{emitter}\left(\frac{v}{v+v_s}\right)$$

$$(v+v_s)^2 = \frac{f_{emitter}}{f_{detector}} v^2$$

$$v_s = v\left(\sqrt{\frac{f_{emitter}}{f_{detector}}} - 1\right)$$

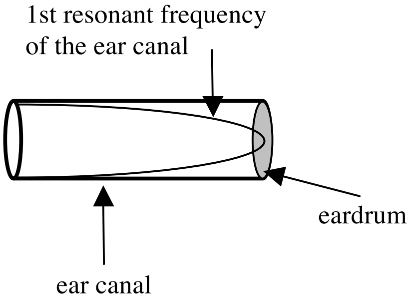
$$= 1570m/s\left(\sqrt{\frac{5000000Hz}{4999860Hz}} - 1\right)$$

$$= 0.02m/s$$

d. The wave speed does not depend on the particle speed. *[See last week's tute]*

Extra Questions:

1. *Ear drum*

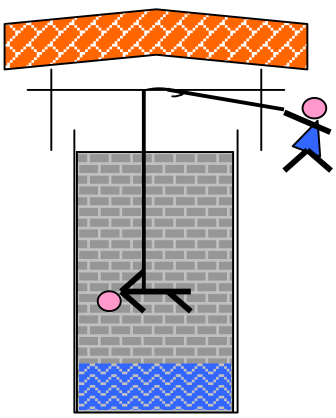


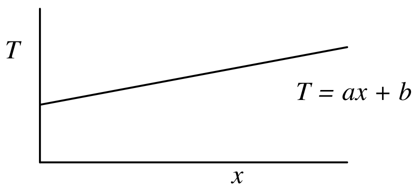
An object will have the greatest response to driving oscillations that have frequency equal to the objects natural frequency. Thus as the driving frequency moves further away from this natural frequency then the response of the object will decrease.

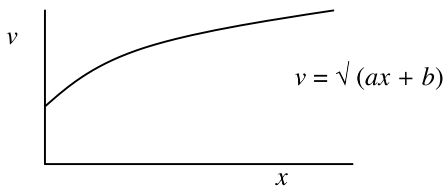
The eardrum behaves like a spring which is being driven by the oscillations of the air in the ear canal. The eardrum has a natural frequency of only a few Hz and thus will not oscillate very much in response to driving frequencies which are very much higher (or lower) than this. Hence human hearing is limited.

Note: Even if the eardrum did oscillate at high frequencies, the cochlear (where sound is converted into nerve impulses) would not respond to frequencies above about 20 kHz anyway.

2. *Brother down a well*







a. The linear density of the rope is:

$\mu = 2.0 \text{ kg} / 80 \text{ m}$

$= 0.025 \text{ kg/m}$

Measuring x from the bottom, the tension at any point is

T = mass hanging from that point × g

$T = (\mu \times x + m_{\text{brother}}) \times \text{g}$

$= 0.25 \text{ N/m} \times x + 590 \text{ N}$

b. The velocity at any point is:

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

$$= \sqrt{\frac{0.25N/m \times x + 590N}{0.025kg/m}}$$

$$= \sqrt{10m/s^2 \times x + 24000m^2/s^2}$$

c. $v = \mathrm{d}x / \mathrm{d}t$

Integrate over x to get the time:

$\mathrm{d}t = (1 / v)\,\mathrm{d}x$

$$t = \int_{0m}^{80m} \frac{1}{\sqrt{10\ m/s^2 \times x + 24000m^2/s^2}}\,dx$$

$$= \left[\frac{2}{10m/s^2}\sqrt{10\ m/s^2 \times x + 24000m^2/s^2}\right]_{0m}^{80m}$$

$$= \frac{1}{5m/s^2}\left(\sqrt{800m^2/s^2 + 24000m^2/s^2} - \sqrt{24000m^2/s^2}\right.$$

$$= 0.51s$$