	Study Design 2009 – 2012 **Unit 4 Detailed Study: Sound**
	describe sound as the transmission of energy via longitudinal pressure waves;
	analyse sound using wavelength, frequency and speed of propagation of sound waves , $v = f\lambda$;
	analyse the differences between sound intensity (W m^{-2}) and sound intensity level (dB);
	calculate sound intensity at different distances from a source using an inverse square law **(knowledge of acoustic power is not required**);
	explain resonance in terms of the superposition of a travelling sound wave and its reflection;
	analyse, for strings and open and closed resonant tubes, the fundamental as the first harmonic, and subsequent harmonics;
	describe in terms of electrical and electromagnetic effects, the operation of: – microphones, including electret-condenser, crystal, dynamic and velocity microphones – dynamic loudspeakers;
	describe the effects of baffles and enclosures for loudspeakers **in terms of the interference of sound due to phase difference;**
	interpret frequency response curves of microphones, speakers, simple sound systems and hearing, including loudness (phon);
	evaluate the fidelity of microphones and loudspeakers in terms of: – the intended purpose of the device – the frequency response of the system – construction (qualitative);
	describe diffraction as the directional spread of various frequencies in terms of different gap width or obstacle size including the significance of the magnitude of the λ/w ratio
	identify and apply safe and responsible practices when working with sound sources, and sound equipment

Concepts

<table>
<tr>
<td>What are the two different type of waves we have?</td>
<td>We have transverse and longitudinal waves</td>
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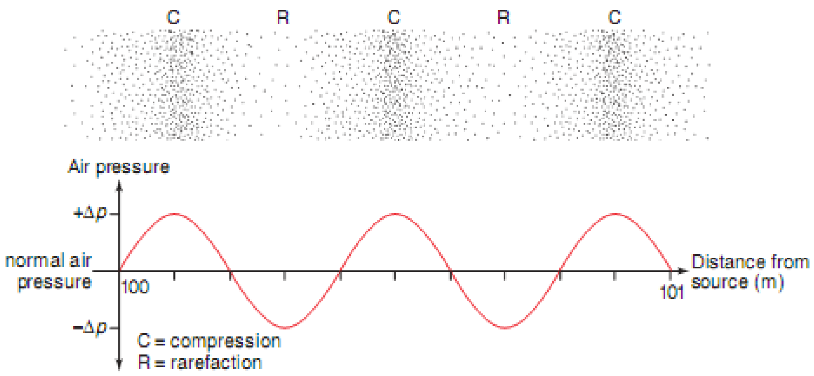
<tr>
<td>What are sound waves</td>
<td>Sound is a longitudinal wave of alternating pressure deviations, called compressions and rarefactions.
Unlike light/electromagnetic waves, sound requires a medium.



The wavefront is perpendicular to the direction of the wave</td>
</tr>
<tr>
<td>Some of the common properties of waves</td>
<td><u>Properties of waves</u>
Wavelength λ
Is the distance between adjacent compressions or rarefactions (or regions that are in phase) and is measured in metres
Period T
Is the time taken to produce one complete wave and is measured in seconds
Frequency f
Is the number of complete waves produced per second and is measured in Hertz
Velocity v
Is the speed at which the wavefront moves through the medium and is measured in metres per second
Amplitude
Can be described as either the relative magnitude of pressure variation or particle displacement

Extra points
1 complete Wave consists of 1 compression and 1 rarefaction
Period – time taken for a wave to pass a point (if given a graph of pressure vs time, simply find the time of one wave, gives period)
Frequency – number of compressions that pass a point</td>
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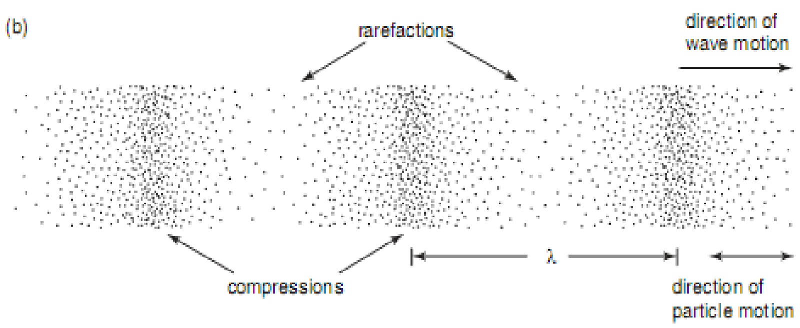
<tr>
<td>Example
The wavelength of a 256 Hz sound is:
A The distance between a compression and rarefaction
B The distance between two adjacent rarefactions
C The time taken for a compression to</td>
<td>



The answer is B</td>
</tr>
</table>

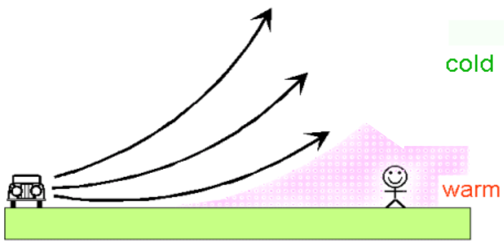
travel a complete cycle
D The position of the main compressions

Is the speed of sound constant?

MATERIAL	SPEED OF SOUND (m s^{-1})
Air (0°C)	331
Air (20°C)	343
Carbon dioxide	260
Helium	1005
Water	1440
Sea water	1560
Glass	≈4500
Iron and steel	≈5100

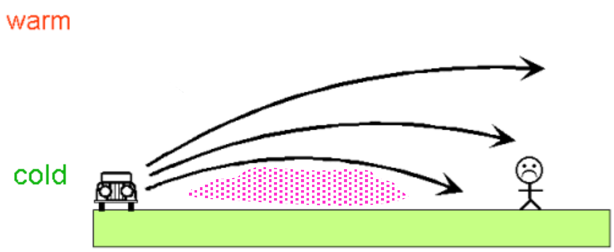
- The speed of sound is NOT constant.
- The speed is ONLY dependant on the medium (or material) that the wave is travelling through
- In air, speed of sound increases with temperature
- Does not vary with pressure

Refraction



During normal conditions

Refraction



During a temperature inversion, the sound will refract back toward the ground.

What is the wave equation?

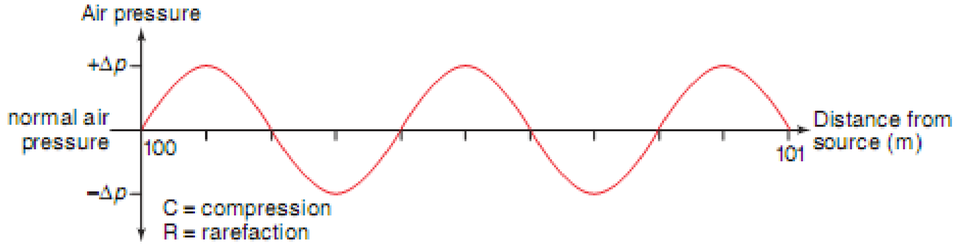
Wave Equation

$v = f\lambda$

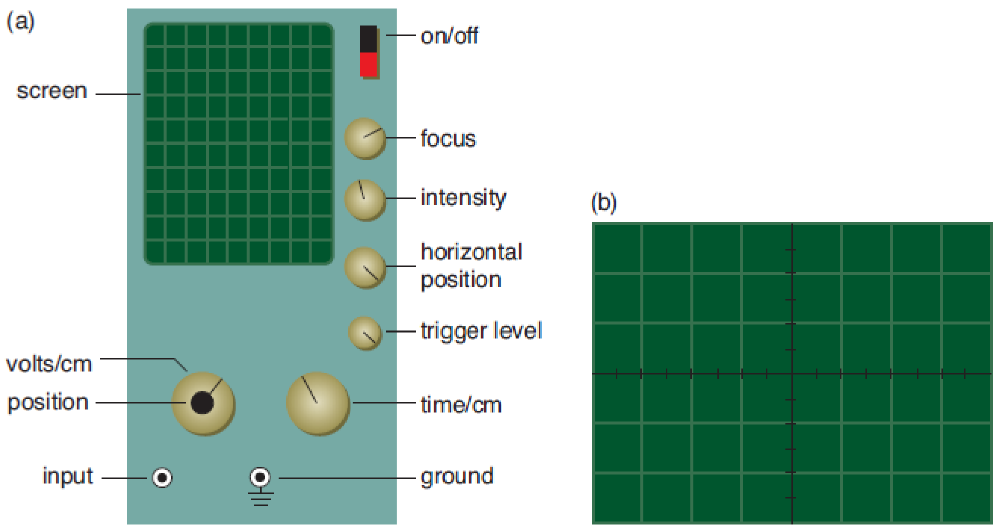
$v = \lambda / T$

- Frequency is constant
- If sound waves travel from one medium to another (eg. Air to water) where the speed of sound is different, the wavelength changes

$$\frac{v_2}{v_1} = \frac{\lambda_2}{\lambda_1}$$

<table>
<tr><td></td><td>


You can work out the wavelength for this graph by finding the distance between adjacent compressions or rarefactions
</td></tr>
<tr><td>Seeing sound waves</td><td>
A Cathode ray oscilloscope –CRO- is an electronic device that shows how voltage varies with time at a point in a circuit.
It screen is divided into 1 cm squares with axes marked. The vertical axis is the voltage axis and the horizontal axis is the time axis. Below is a picture



Sound can be shown by a graph of how pressure varies with time at a point near the sound source. This is basically what is shown on a screen on the cro. The period of the sound is the time for one complete cycle and it can be read directly from the graph. So we can work out the frequency.
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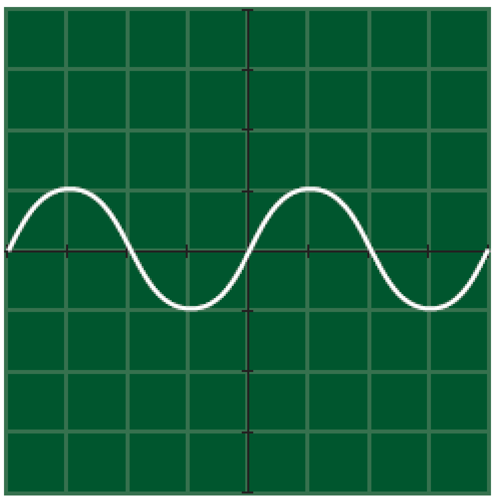
<tr><td>Example of CRO</td><td>
The figure below shows the trace on a CRO screen produced by a microphone detecting sound. The time scale is : 1cm = 2 ms



Question 1-What is the period of the sound?
Answer- One complete cycle is 4 cm on screen so $4 \times 2ms = 8ms$
Question 2- Sketch the trace produced by a sound of twice the frequency?
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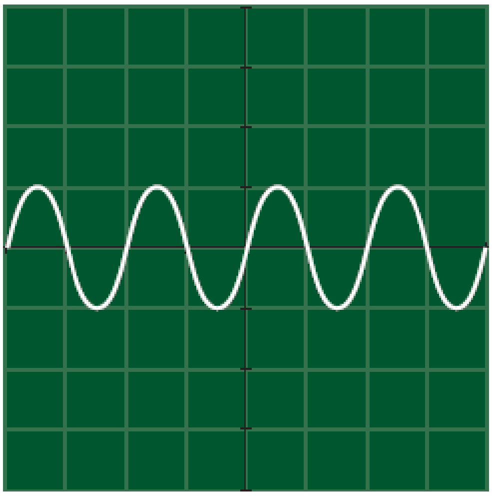
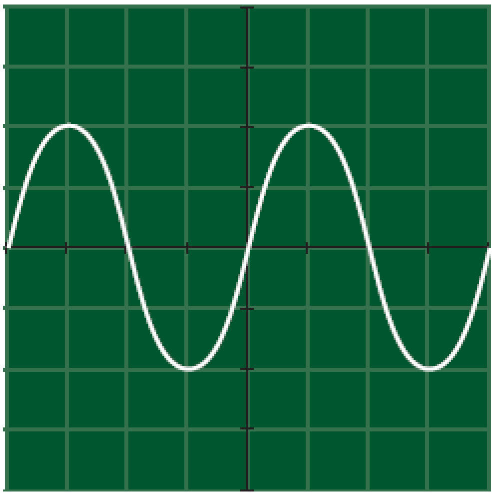
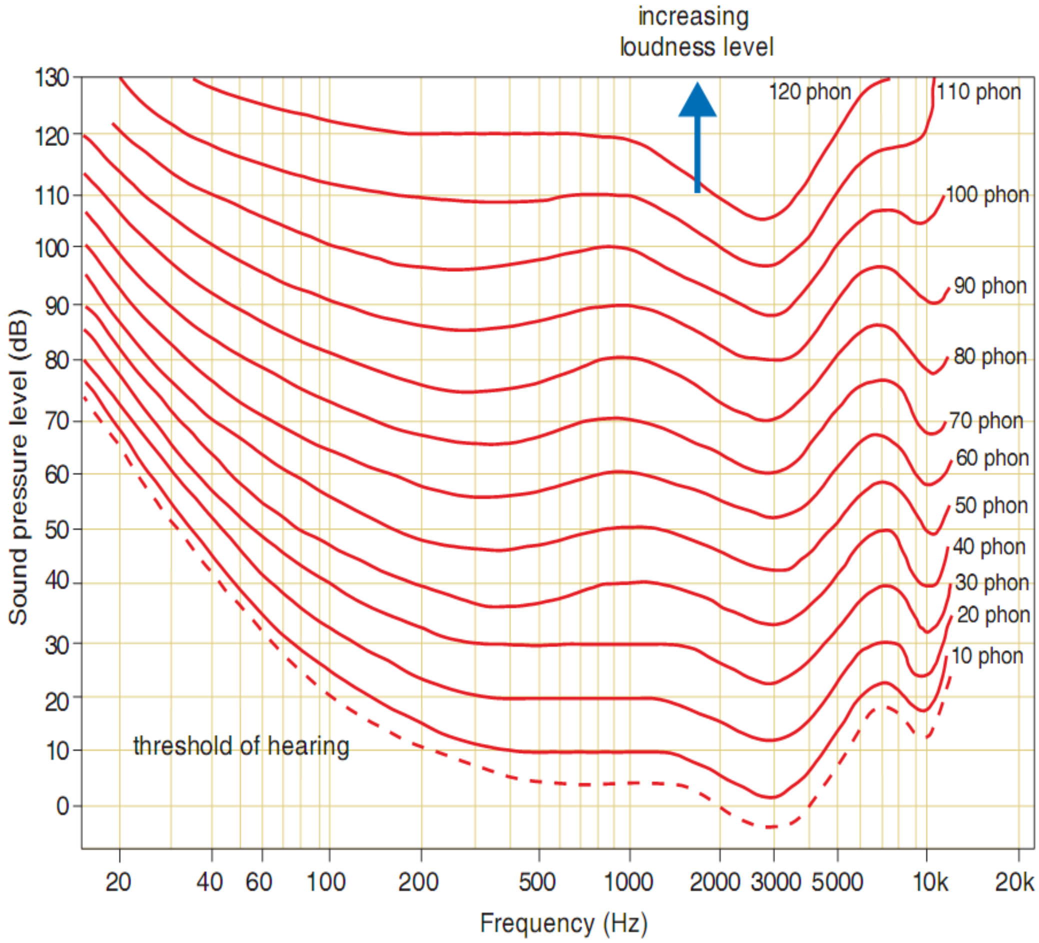
</table>

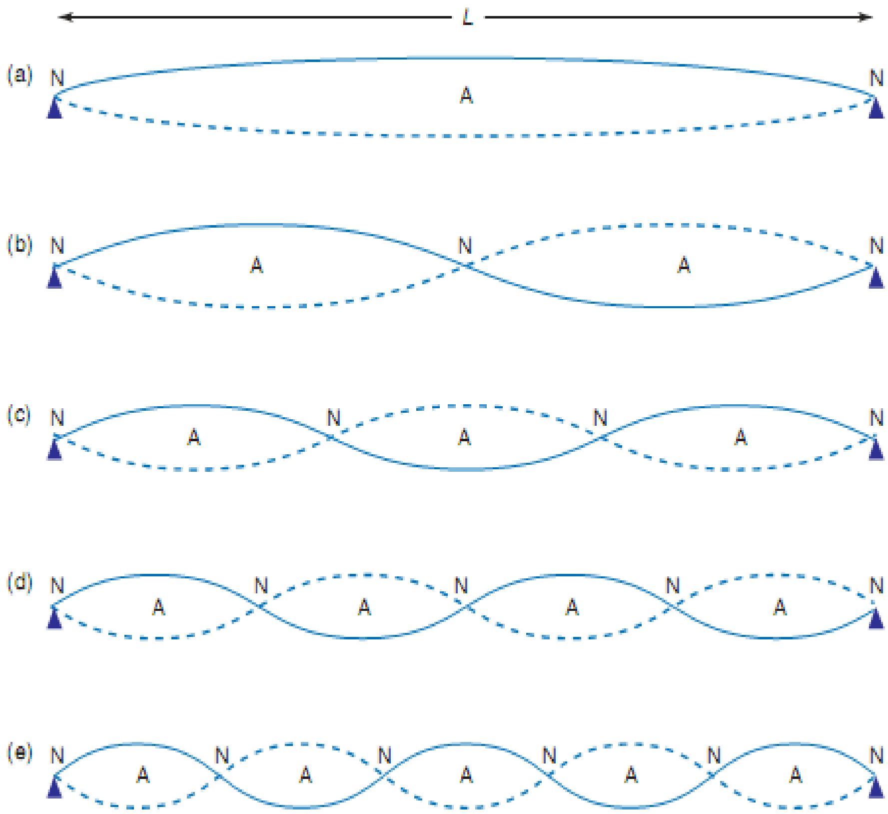
	Answer- Doubling the frequency halves the period so the trace would look like  Question 3- Sketch the trace produced by a sound with the original frequency but twice the pressure variation? Answer Doubling the pressure variation will double the amplitude of the trace 
Using the equation	*Example* *What is the speed of a sound wave if it has a wavelength of 54cm and a period of 1.6 ms?* $\lambda = 54\ cm = \mathbf{0.54\ m}$ $\quad$ $T = 1.6\ ms = \mathbf{1.6 \times 10^{-3}\ s}$ $f = 1/T$ $f = 1 / 1.6 \times 10^{-3}\ s = \mathbf{625\ Hz}$ $v = \lambda/T$ $v = 0.54\ m / 1.6 \times 10^{-3}\ s$ $v = \mathbf{337.5\ m\ s^{-1}}$ $v = f\lambda$ $v = 625\ Hz \times 0.54\ m$ $v = \mathbf{337.5\ m\ s^{-1}}$
Power	• Sound waves transfer energy. • The <u>RATE</u> at which energy is produced is called the **acoustical power** of the sound source. • Energy is measured in Joules (**J**) • Power (**P**) is measured in Watts (**W**) which is energy per unit time (Joules per second) **Power = Energy / Time** **Energy = Power x time = Pt**

Intensity	As sound propagates in all directions, the energy of the wave is spread out over a larger area, making the wave less **intense**. • **Intensity** (**I**) is the amount of **power** passing through a unit of **area** (area is perpendicular to the propagation of the sound wave) **I = P / AP = IA** For a spherical projection, • **Intensity** is measured in Watts per square meter (**W m^{-2}**) Spherical projection of sound Double the distance, quarter the intensity – I is proportional to $1/r^2$
Example	What is the intensity of a sound if 6.0×10^{-3} W of acoustical power passes through an open window that has an area of 0.30 m^2? $I = \frac{P}{A}$ $= \frac{6.0 \times 10^{-3}\ \text{W}}{0.30\ \text{m}^2}$ $= 2.0 \times 10^{-2}\ \text{W m}^{-2}$ How much energy is transferred to a human eardrum which has an area of 5.0×10^{-5} m^2 by a sound of intensity 2.0×10^{-2} W m^{-2} in 20 s? First we have to find the power of the sound. $P = IA$ $= 2.0 \times 10^{-2}\ \text{W m}^{-2} \times 5.0 \times 10^{-5}\ \text{m}^2$ $= 1.0 \times 10^{-6}\ \text{W}$ $\text{Energy} = Pt$ $= 1.0 \times 10^{-6}\ \text{W} \times 20\ \text{s}$ $= 2.0 \times 10^{-5}\ \text{J}$
Sound Intensity levels	Sound Intensity Levels Threshold of hearing = 1×10^{-12} W m^{-2} Threshold of pain = 1.0 W m^{-2} The Sound Intensity Level (**L**) is a mathematical comparison of the relative intensity of sound in relation to reference intensity (**I$_0$**) and is measured in decibels (**dB**). **I$_0$** = Threshold of hearing = 1.0×10^{-12} W m^{-2} $L(in\ \text{dB}) = 10\log\left(\frac{I}{I_0}\right)$ $\Delta L = 10\log\left(\frac{I_2}{I_1}\right)$ Human hearing response – logarithmic – discernible difference of 1dB $I = 10^{\left(\frac{L}{10} - 12\right)}$
What is the change in	Also, every approx 3dB represent doubling of intensity

Sound Intensity Level when the intensity changes from 6.0 $\times 10^{-9}$ W m^{-2} to 1.2 $\times$ 10^{-8} W m^{-2} ?	$=10\log_{10}\left(\frac{I_2}{I_1}\right)$ $=10\log_{10}\left(\frac{1.2\ \times 10\text{-}8\ W\ m\text{-}2}{6.0\ \times 10\text{-}9\ W\ m\text{-}2}\right)$ $=10\log_{10}(2)$ $=3.0dB$
Example	What is the change in Sound Intensity Level when the intensity changes from 9.0 $\times 10^{-8}$ W m^{-2} to 9.0 $\times 10^{-7}$ W m^{-2} ? $=10\log_{10}\left(\frac{I_2}{I_1}\right)$ $=10\log_{10}\left(\frac{9.0\ \times 10\text{-}7\ W\ m\text{-}2}{9.0\ \times 10\text{-}8\ W\ m\text{-}2}\right)$ $=10\log_{10}(10)$ $=10dB$ Increase in 10db represents 10 times the intensity
Qualities of sound	**Loudness** is the subjective perception of the energy of the wave. **Pitch** is the subjective perception of the frequency of the wave **Timbre** is the subjective quality of sound that allows us to determine different sources of the same frequency (i.e guitar vs piano)
Response of the human ear	The human ear has a non-linear perception of sound. The loudness of a sound is dependant on both its intensity and frequency. Loudness Level Curves are graphs showing sounds of differing frequencies and intensities that are perceived by human ears as being of the same loudness. The **phon** is the unit for equivalent loudness of a sound, relative to a reference sound (usually the threshold of hearing (1×10^{-12} W m^{-2}) at 1000Hz).

	
Standing waves	• A standing wave is the superposition of two wave trains at the same frequency travelling in opposite directions. • Sequence of soft and loud sound at fixed positions a quarter of a wavelength apart are formed • Pressure antinodes – maximum fluctuation – loud sound • Pressure nodes – minimum fluctuation – soft sound • Every object has resonant frequencies at which standing waves are established – **resonance** • **Fundamental frequency** (f_0) is the lowest resonant frequency of an object • **Overtones** are resonant frequencies above the fundamental frequency • **Harmonics** are whole number multiples of the fundamental frequency • Wavelength is twice the distance between adjacent nodes

Stringed instrument or open resonant tube



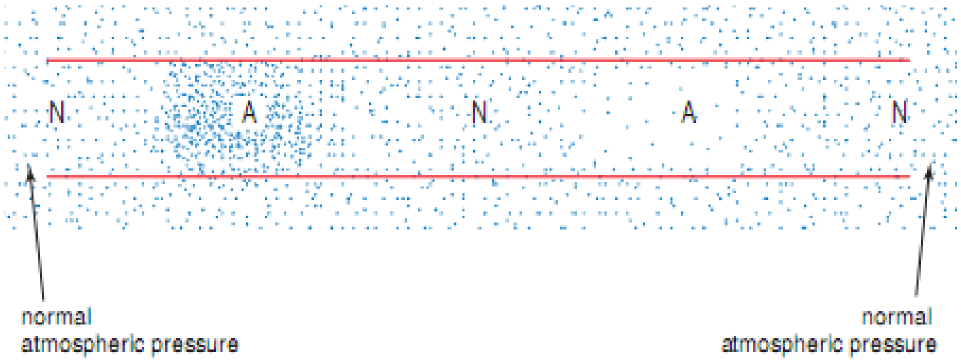
Stringed instrument, or OPEN RESONANT TUBE
Displacement nodes at ends for string
Pressure nodes at ends for open tube

Stringed instrument or open resonant tube

Overtones	Harmonics	λ	f = v/λ
Fundamental	1st	2L/1 = 2L	1(v/2L)
First	2nd	2L/2 = L	2(v/2L)
Second	3rd	2L/3	3(v/2L)
Third	4th	2L/4 = L/2	4(v/2L)

v is either the speed of the travelling wave in the string or the speed of the travelling sound wave in the resonant tube

open resonant tube



Resonant tube closed at one end

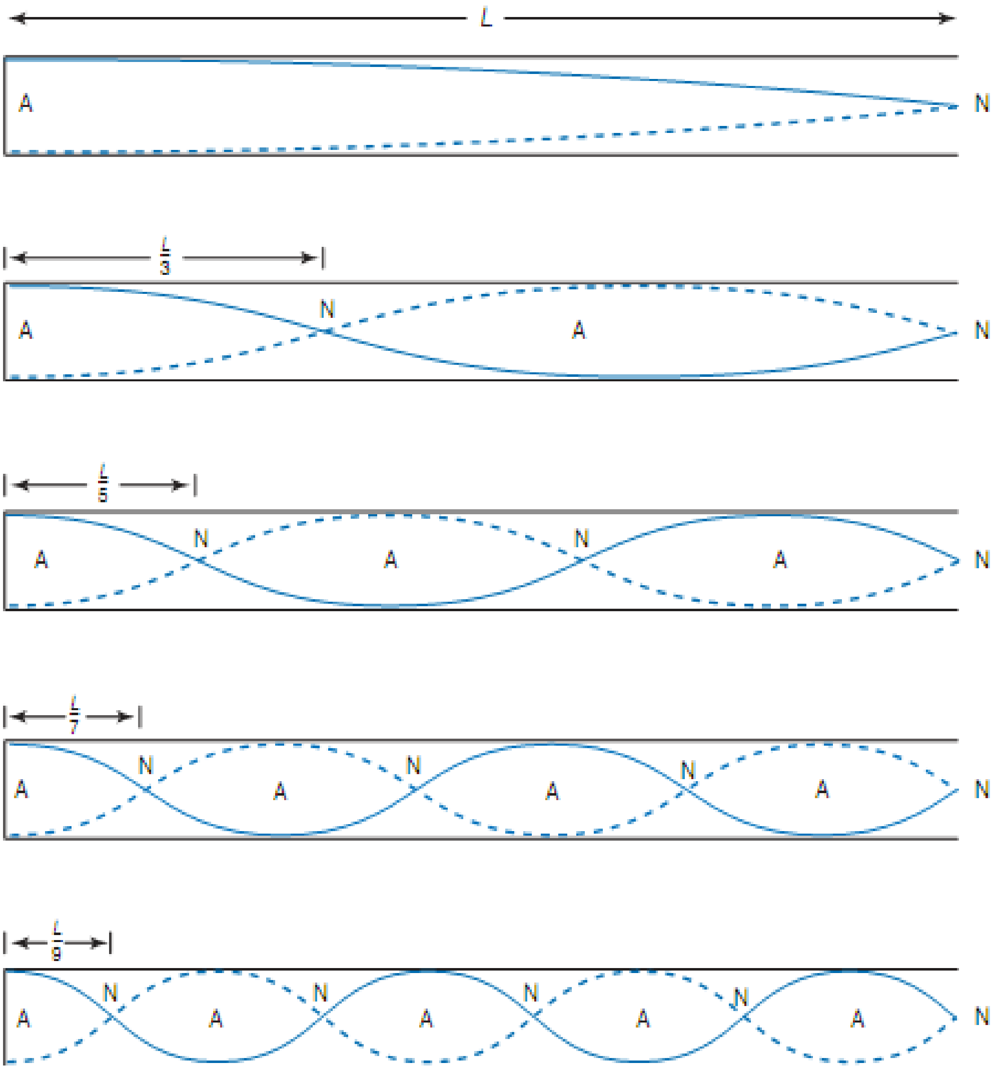
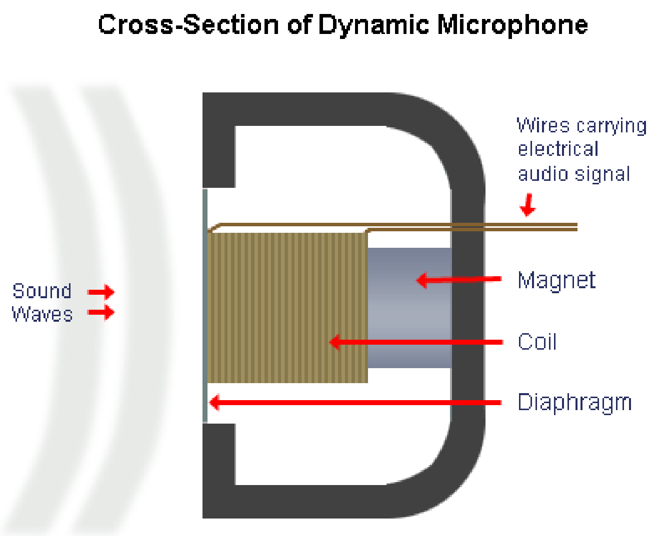
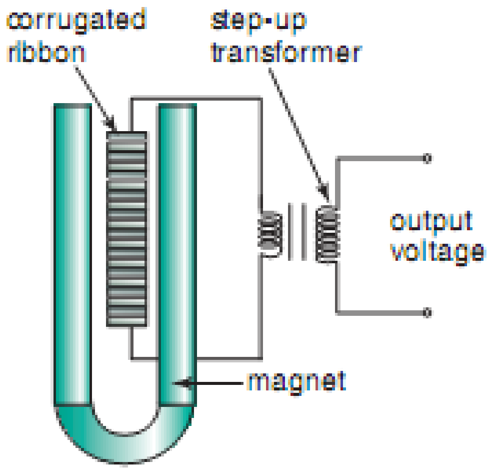
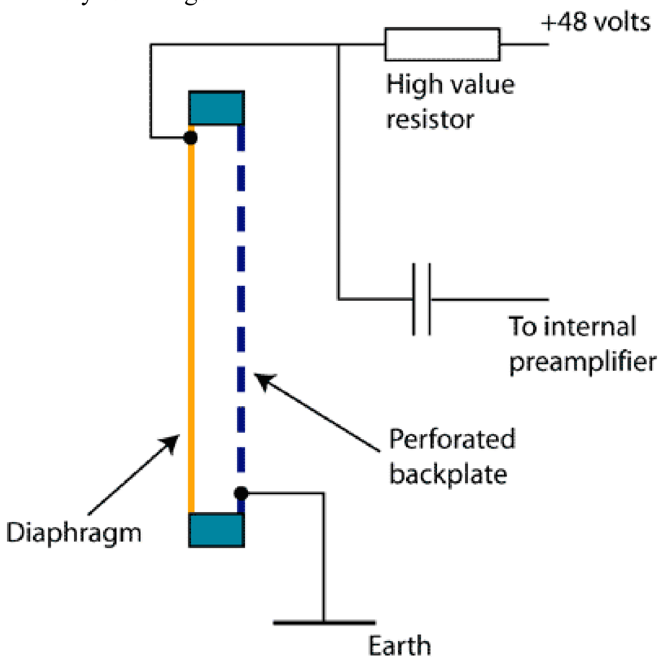
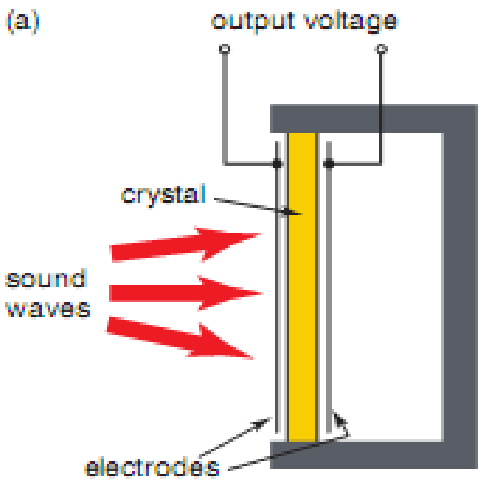


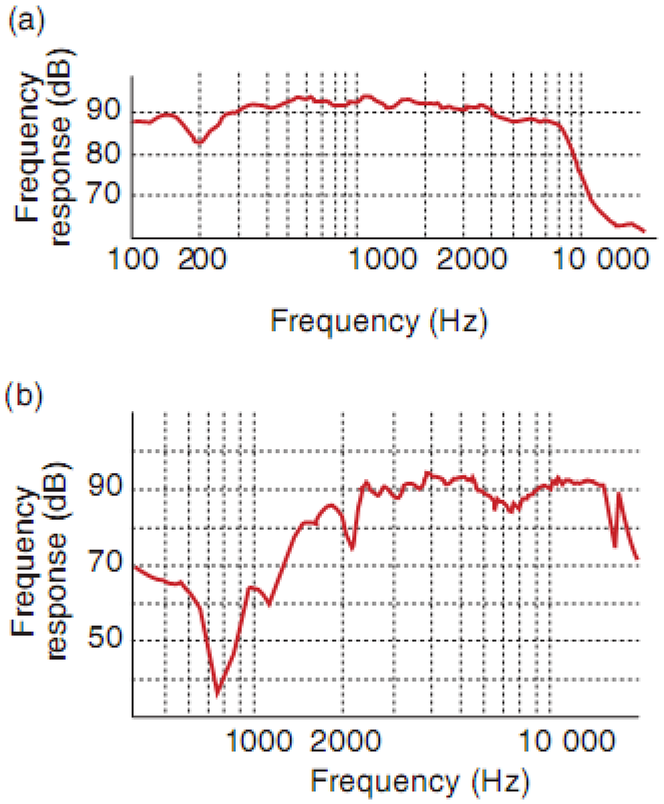
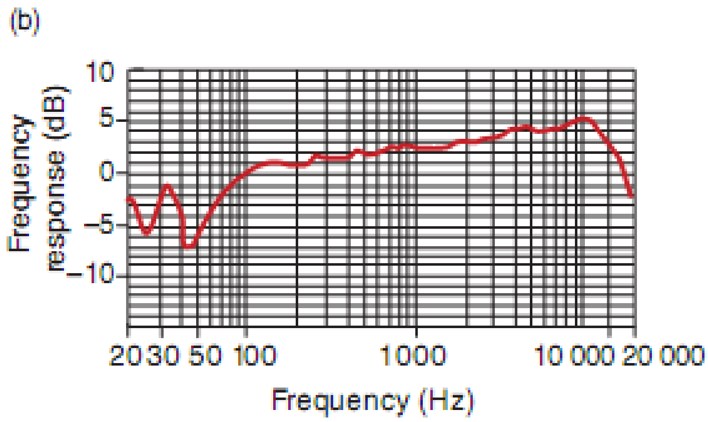
Figure 18.26 Standing waves for a pipe closed at one end

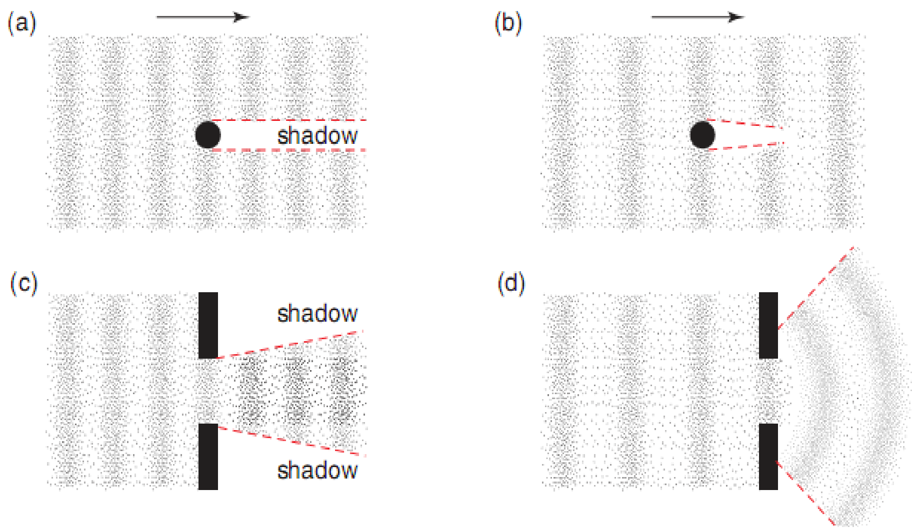
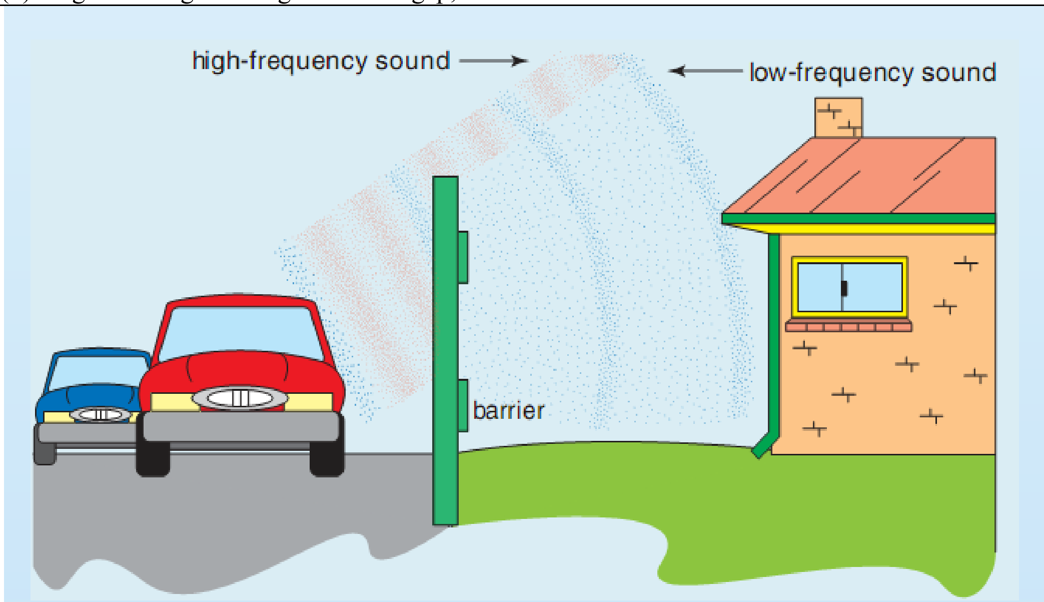
	Resonant tube closed at one end **Overtones** | **Harmonics** | **λ** | **f = v/λ** Fundamental | 1^{st} | 4L/1 | 1(v/4L) First | 3^{rd} | 4L/3 | 3(v/4L) Second | 5^{th} | 4L/5 | 5(v/4L) Third | 7^{th} | 4L/7 | 7(v/4L) Only odd harmonics occur in resonant tubes closed at one end
Microphones	Microphones Convert sound energy into electrical energy of the same frequency **Dynamic Microphone** The sound vibrates the cone, and in turn the coil of wire (in the magnetic field). This induces an EMF (signal) via electromagnetic induction  http://www.mediacollege.com/audio/microphones/dynamic.html
	Ribbon Microphone The vibrating air from the sound wave vibrates the metallic ribbon inside the magnetic field, inducing an EMF via electromagnetic induction

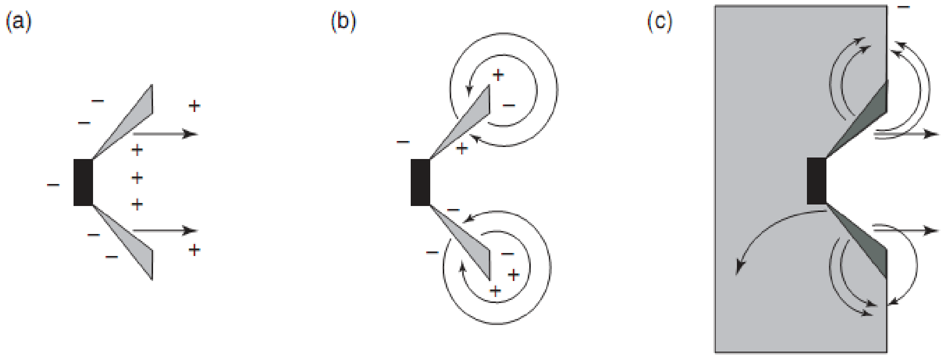
The table inside the first row, as a separate table:

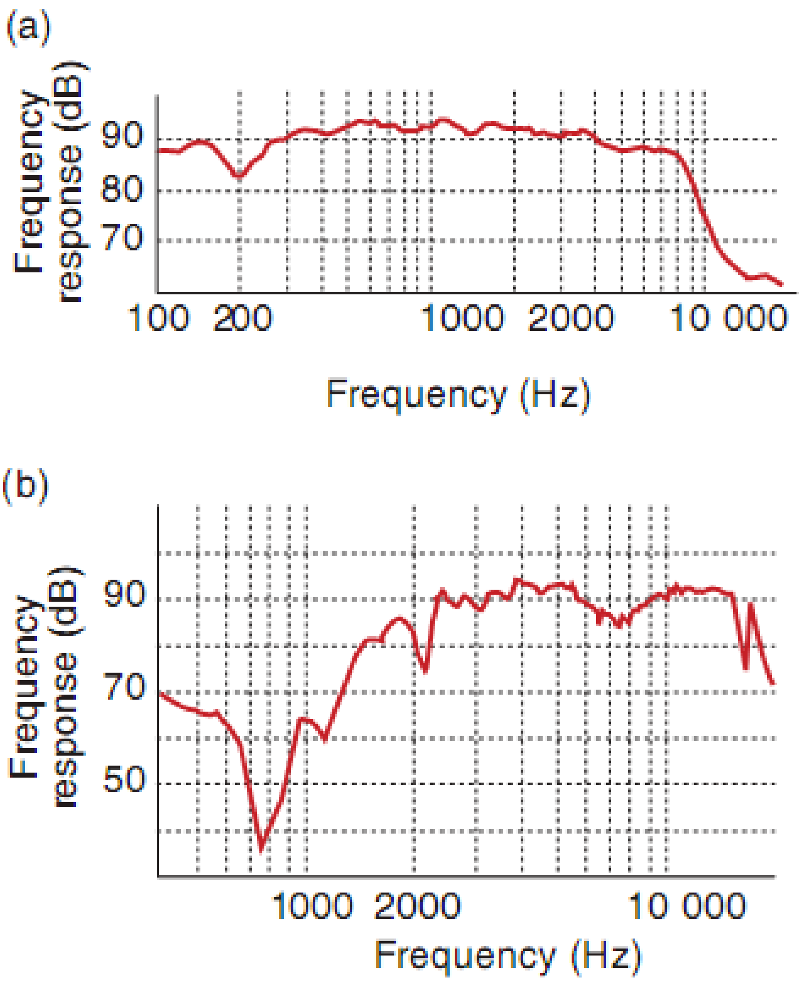
Overtones	Harmonics	λ	f = v/λ
Fundamental	1^{st}	4L/1	1(v/4L)
First	3^{rd}	4L/3	3(v/4L)
Second	5^{th}	4L/5	5(v/4L)
Third	7^{th}	4L/7	7(v/4L)

	
	Condenser Microphone The back plate and front plate (diaphragm) form a capacitor (charged by the battery). As the membrane vibrates, the change in distance between the two plates causes the output voltage to vary. In a **electret-condenser** microphone, a permanently charged material is used, thus it does not require a battery for charge. 
	Crystal Microphone Consists of a piezoelectric crystal, which produces a current in response to changes in pressure. When the sound waves vibrate the crystal, they cause changes in pressure, producing a signal. 

Frequency responses	 **Figure 19.10** Frequency response curves for (a) a woofer and (b) a tweeter 
	• Sound bends/diffracts as it travels past the edge of a barrier • Level of diffraction • High frequency diffracts less than low frequency • Significant diffraction occurs when $\propto \frac{\lambda}{w}$ $\frac{\lambda}{w} \geq 1$

	 Diffraction of water waves: (a) short wavelength around an object, (b) (b) long wavelength around the same object, (c) (c) short wavelength through a gap, (d) long wavelength through the same gap,
	

	Loudspeaker • Operates on the same principles as a dynamic microphone, in reverse • F = Bil Baffles Multi Speaker Systems
	 Initial cone movement Interaction of sound without baffle Loudspeaker enclosed in airtight cabinet (infinite baffle)

	 **Figure 19.10** Frequency response curves for (a) a woofer and (b) a tweeter