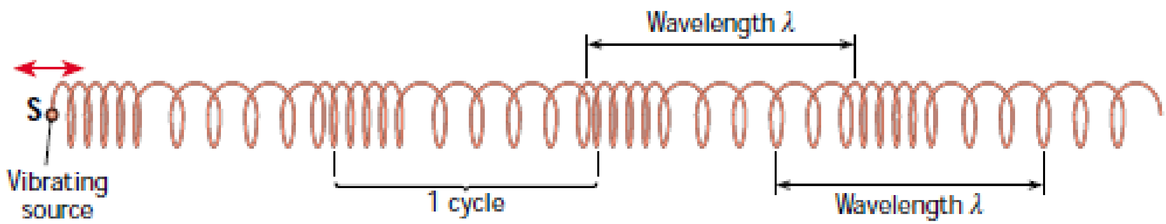
Chapter 17: Vibrations and Sound.

Def: Sound is a form of energy that travels by longitudinal mechanical waves



Sound is given off by something vibrating. E.g. String of a guitar or tuning fork.

We also know sound is a wave because it acts like one.

- **Reflection** in the form of an echo
- **Refraction** because sound is clearer on a cold night.
- **Diffraction** because sound travels through gaps and spreads out to be heard.
- **Interference**: If you rotate a vibrating tuning fork, there will be positions of low noise and high noise. This is caused by compressions and rarefactions interfering with each other.

- Reduction of Noise by Destructive Interference

Loud noises from machinery can be reduced using destructive interference. A sample of the noise is recorded and recreated electronically. The crest of the real and the trough of the created will overlap, reducing the sound level.

How a Vibrating Object Produces a Sound

When a tuning fork vibrates, it emits a sound. When the fork moves to the right, it moves the molecules of air closer together. (**compression**). This compression moves on to the other molecules of air.
When it moves to the left, it pulls the molecules apart again. (**rarefaction**) This also gets passes onto the other molecules of air.

This back and forth movement causes the compressions and rarefactions to vibrate the molecules until they reach the ear drum. The molecule next to your eardrum cause it to vibrate with the same frequency, forming a sound.

Speed of Sound

Firstly, sound needs a medium to travel in.

The speed at which sound travels in depends on the medium itself. Sound travels faster in dense, warm mediums.

However in a gas, sound travels faster in warm air but is heard clearer in cold air. This is because on a warm day, the air nearer the ground is warmer than higher up, so the sound gets refracted upwards.

(See fig 17.9 pg 194)

Material	Approx Speed (m/s)
Air (0^oC)	331
Air (100^oC)	384
Water	1500
Copper	3400
Steel	4800

Overtones

Def: Frequencies which are multiples of a certain frequency are called overtones of that frequency.

f = frequency
2f = first overtone
3f = second overtone

Notes.

Notes have 3 main characteristics.

1. Loudness

The loudness of a sound wave depends on the amplitude of the wave. If 2 waves have the same amplitude, sounds of a certain frequency will be heard louder then.

2. Pitch

The pitch of a note depends on the frequency.

The higher the frequency, the higher the pitch.

3. Quality

The quality of the note depends on the shape of the sound wave. It also depends on the number and amplitude of the harmonics (overtones) present.

Different instruments emit different numbers of overtones. This is why the same note sounds different from different instruments.

Frequency Limit of Audibility

Humans hear sound from 20 Hz to 20000 Hz. However, the upper limit decreases with age. Animals, such as dogs and bats hear sounds above 20000 Hz. These are **ultrasonic** sounds.

Natural Frequency

The natural frequency of an object that vibrated freely, is the frequency that predominates.

Fundamental frequency

This is the lowest natural frequency of a vibrating object.

Resonance

Def: Resonance is the rapid amplification of oscillation when a periodic force is applied at the same frequency as the natural frequency of the body.

An example would be pushing a child on a swing. If you apply a gentle push on the highest point on the way back, the height would increase in the forward movement.

STS of Resonance.

- Water molecules in a microwave.
- A singer shattering a wine glass
- Sound produced by our vocal chords which resonates in our larynx, nose, mouth.
- Collapse of the Tacoma Bridge in Washington State

Threshold of Hearing

Def: The threshold of hearing is the smallest sound intensity detectable by the average human ear at a frequency of 1KHz.

Intensity of Sound

Sound is a mechanical wave transferring energy from one place to another. The further you move away from a noise source, the quieter it gets. This is because the energy being passed through an area of $1m^2$ is less than if you were close to it. See fig 17.14 pg 197.

Def: The sound intensity (I) at a point is the rate at which sound energy is passing through unit area at right angles to the direction in which the sound is travelling.

$$Sound = \frac{Power}{Area} \qquad \text{or} \qquad I = \frac{P}{A}$$

The Frequency Response of the Ear

• The ear is most sensitive between 2000 Hz and 4000 Hz, and the ear hears sound loudly because the sound causes the ear to resonate.

• Frequencies above or below this are not heard as loud by the ear, causing less damage to the ear.

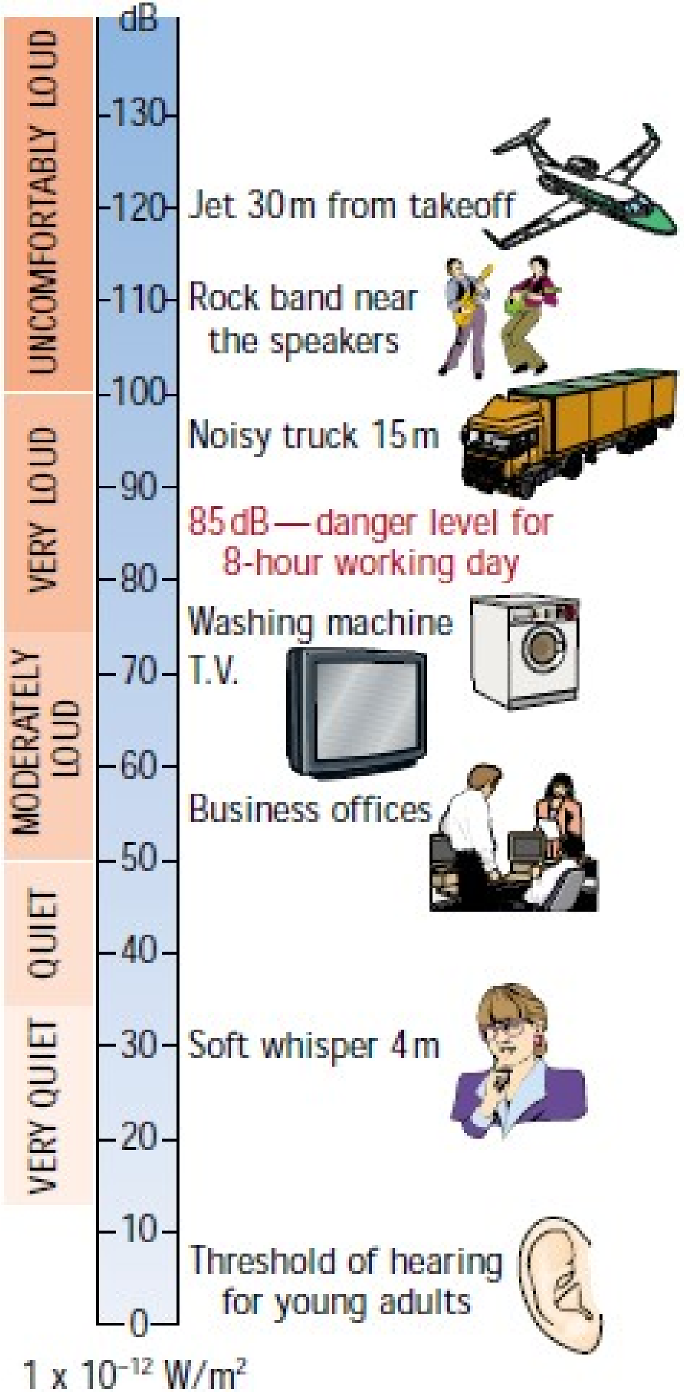
• Two sounds carrying the same energy will not have equal loudness if their frequencies are different.

Sound Intensity Level

Sound is measured in decibels (dB), going from 0 dB up to around 130 dB.
The scale is much easier to use than the W m^{-2}

Decibel Adjusted dB(A) Scale

The decibel adjusted scale is used because it is adapted to the ear's frequency response.
The ear is most sensitive to frequencies between 2000 Hz and 4000 Hz and the Decibel Adjusted scale takes this into account.
The sound-level meter used by environmental engineers has a decibel adjusted scale.


dB
130
120
110
100
90
80
70
60
50
40
30
20
10
0
UNCOMFORTABLY LOUD
VERY LOUD
MODERATELY LOUD
QUIET
VERY QUIET
Jet 30m from takeoff
Rock band near the speakers
Noisy truck 15m
85dB—danger level for 8-hour working day
Washing machine
T.V.
Business offices
Soft whisper 4m
Threshold of hearing for young adults
1 x 10⁻¹² W/m²

Fundamental Frequency of a String

Def: A string vibrating with an antinode at its centre and a node at each end, is vibrating at its fundamental frequency.

If a string is fixed at its 2 ends (nodes) and is plucked, a standing wave is produced. The string will vibrate at its fundamental frequency and cause the air around it to vibrate at the same frequency.

The longer the string, the lower the fundamental frequency will be.

$$f \propto \frac{1}{l}$$

So doubling the length will cause the frequency to halve.

Harmonics in a String

Def: Frequencies which are multiples of a certain frequency f are called harmonics.

f = first harmonic

2f = second harmonic

And so on.

See diagram pg 201

Factors affecting the fundamental frequency:

- Length, greater the length, lower the f. $f \propto \frac{1}{l}$
- Tension, higher the tension, higher the f. $f \propto \sqrt{T}$
- Mass per unit length, greater the mass per unit length, lower the f. $f \propto \frac{1}{\sqrt{\mu}}$

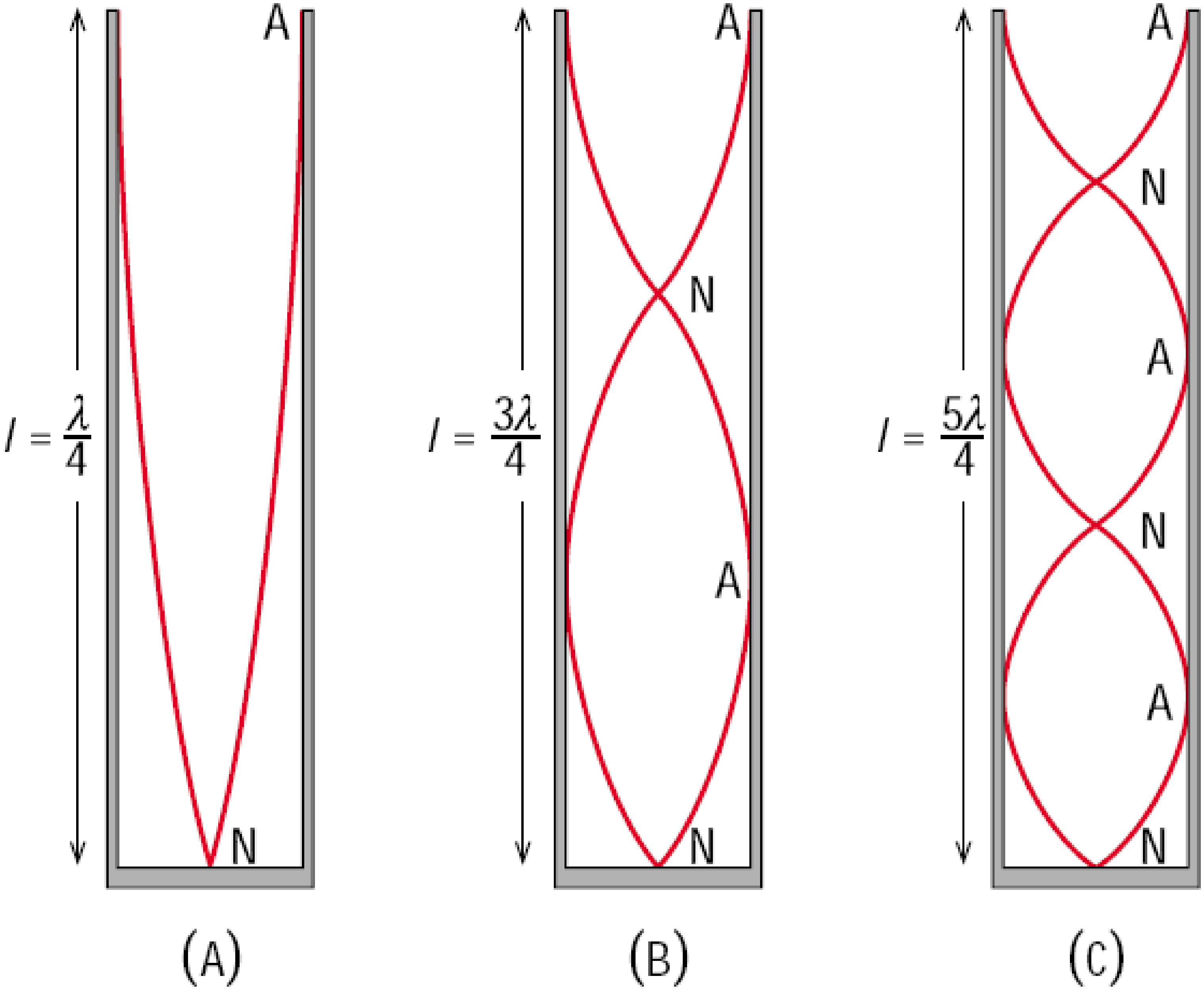
Stationary Waves in a Closed Pipe.

This is a pipe closed at one end. If a tuning fork is emitting a sound at the open end, the sound will travel down the pipe.

However, interference occurs because of the incident waves and the reflected waves overlap. But if the pipe length is adjusted, resonance will occur and a longitudinal wave will be set up in the pipe.

The node is at the closed end of the pipe. As you move along the pipe, the amplitude of the sound molecules increases and the maximum is at the end, or the antinode (load sound heard).

Note, this length is $\frac{\lambda}{4}$



A
N
$l = \frac{\lambda}{4}$
(A)
A
N
A
N
$l = \frac{3\lambda}{4}$
(B)
A
N
A
N
A
N
$l = \frac{5\lambda}{4}$
(C)

Harmonics in a Closed Pipe.

$$f_1 = \frac{c}{\lambda} = \frac{c}{4l}$$

But if $l = \frac{3\lambda}{4}$

$$f_2 = \frac{c}{\lambda} = \frac{c}{\frac{4l}{3}} \Rightarrow 3\left(\frac{c}{4l}\right)$$

$$f_2 = 3f_1$$

Similarly, $$f_3 = 5f_1$$

STS: The clarinet, trombone and saxophone are examples of instruments where air resonates in a closed pipe. Longer the pipe, the lower the note.

Measuring the Speed of Sound in Air

This is done using a resonance tube, tuning forks and a large cylinder of water. The tuning fork is held above the tube and the loudest sound is listened for as the tube is moved down the cylinder. The length (L) is recorded.

However, the distance from the tuning fork to the top of the tube cannot be ignored. This is called the end correction and is approximately 0.3d, (where d = internal diameter of the tube)

$$\frac{\lambda}{4} = l$$

So now....

$$\frac{\lambda}{4} = l + 0.3d$$

$$\lambda = 4(l + 0.3d)$$

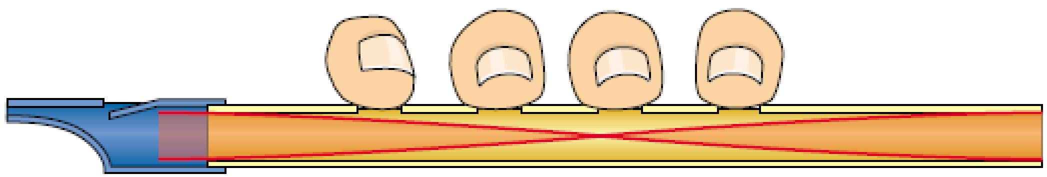
But: $c = f\lambda$

$$c = 4f(l + 0.3d)$$

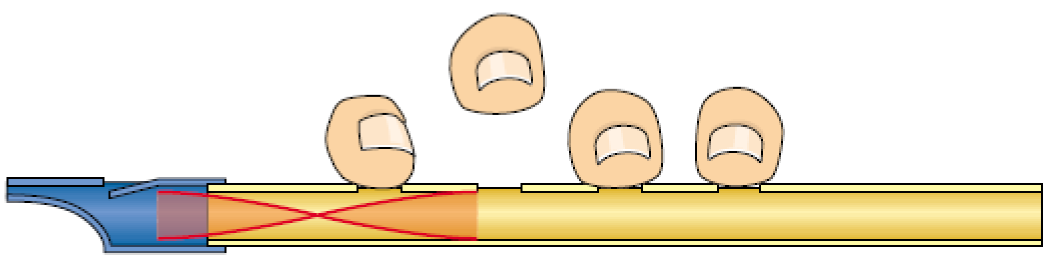
Stationary Waves in a Open Pipe.

Examples of such pipes are the tin whistle and flute.

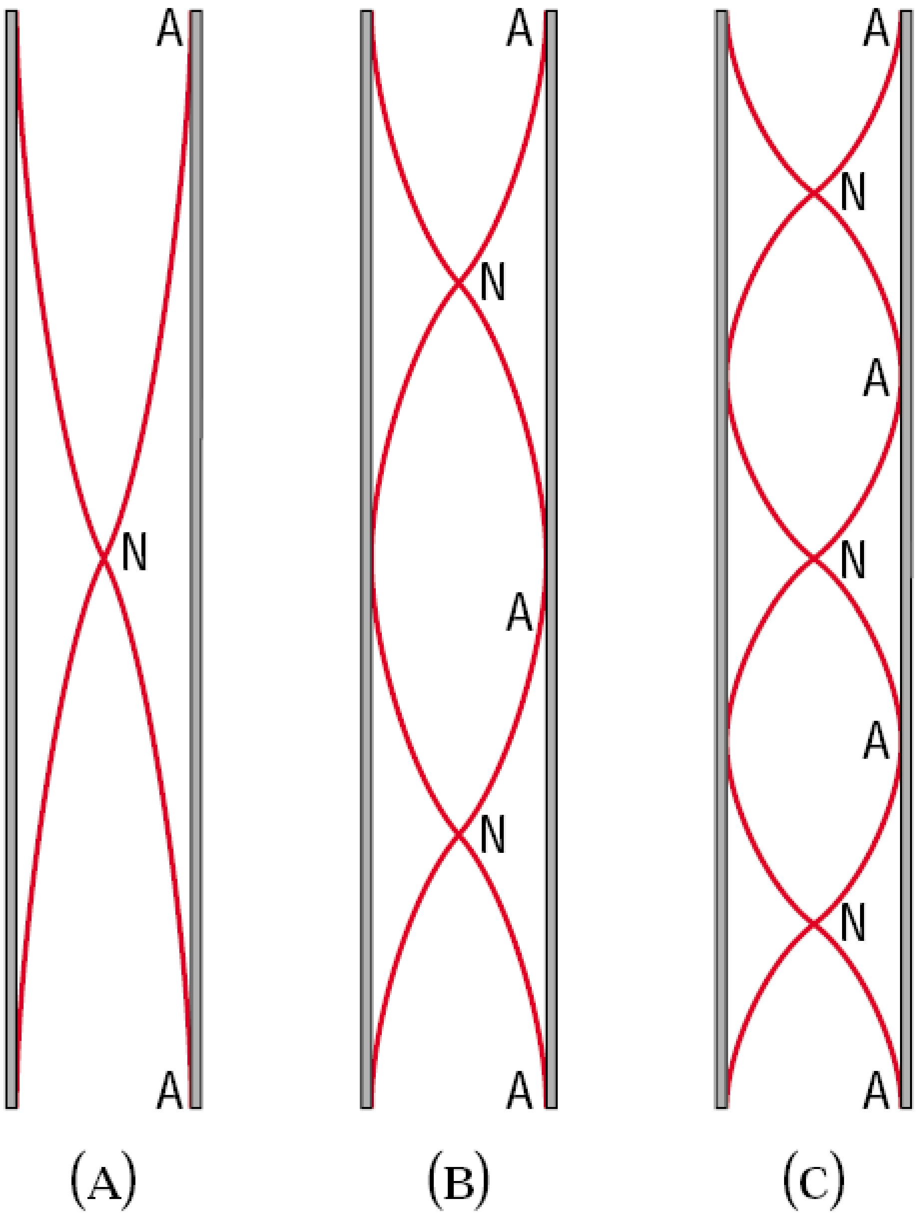
Here, an antinode is produced at each end and note produced is varied by blocking holes in the pipe.



Low note



High note



If we strike a tuning fork and place it at one end of an open pipe, (and adjust the length by sliding another pipe out of it), at certain lengths resonance will be heard.

The wavelength in B is half the wavelength in A.
Also, the wavelength in C is a third the wavelength in A.
So the frequencies are f, 2f and 3f.