Wave Behaviour

Diffraction

The spreading out of waves as they pass through openings or the edges of obstacles is called **diffraction.** All waves can be diffracted but the effects are more noticeable with long wavelength waves such as sound and radio waves than short wavelength waves.

The amount of spreading when the wave has passed through the gap depends on the relative size of the gap and the wavelength.

- For a gap that is many wavelengths wide, no detectable spreading takes place.
- Some spreading occurs when waves pass through a gap that is several wavelengths wide.
- The maximum amount of spreading corresponds to a gap that is the same size as the wavelength.

Diffraction explains why long wavelength radio broadcasts can be detected in the shadows of hills and buildings, but short wavelength broadcasts cannot.

Superposition

The **superposition** of a wave occurs when two or more waves cross. This is happening all the time, but the effects are so short-lived that we seldom notice them. One of the easiest effects of superposition to observe is **two-source interference**. This can be demonstrated with sound, light, surface water waves and 3cm electromagnetic waves. If an observer walks along a line parallel to two loudspeakers vibrating in phase, they notice that:

- There are regions where sound is much louder than from one loudspeaker alone
- There are regions where the sound is barely audible
- In between these, the intensity of the sound varies from loud to quiet.

This is explained using the principle of superposition, which describes how two waves can reinforce each other or cancel each other out.

When two or more waves cross, the resultant displacement is equal to the vector sum of the individual displacements.

Phase Difference

All waves have a **phase** or point on a repeating cycle. Two waves superposing will have a phase relationship to each other. They can either be in phase (in step), in **antiphase** (out of step) or any value in between. If two sources are in phase, then at any point equidistant from both sources the waves arrive in phase. At all other points, there is a **path difference**, i.e. the wave from one source has travelled further than the wave from another source.

- If the waves are in phase, then **constructive interference** takes place resulting in a loud sound.
    - Constructive interference takes place when the path difference is a **whole number of wavelengths** [$n\lambda$], where n is a whole number.
- If the waves are in antiphase, then **destructive interference** tales place, resulting in no sound.
    - Destructive interference takes place when the path difference is one and a half wavelengths, two and a half wavelengths etc. [$(2n+1)\lambda/2$].

The waves do not need to have the same amplitude for interference to take place. The effect of one wave having a greater amplitude than the other is that the destructive interference is not total.

Any value of phase difference between two sources gives an interference pattern that is stationary, provided that the phase difference is constant. Two sources with a **constant phase difference** are said to be **coherent**. Coherent sources must have the same wavelength and frequency.

Thin Film Superposition

Light can reflect from the top of the surface, or can pass through and reflect off the inner layer, of a thin layer (film) of oil, petrol, detergent, butterfly wings, peacock feathers etc. This results in a path difference which is twice the thickness of the film.

For a given wavelength of light e.g. blue, if the path difference is equal to an odd number of half wavelengths then the colour disappears (in antiphase), leaving the other colours more visible. The thickness of the thin film can change, resulting in moving patterns on the surface.

Standing Waves

A **standing**, or **stationary**, wave is a wave that remains in a constant position. Stationary waves are caused by the superposition of two waves of the same wavelength travelling in **opposite directions**. They often arise when a wave is **reflected** at a boundary, but the waves can come from two separate coherent sources.

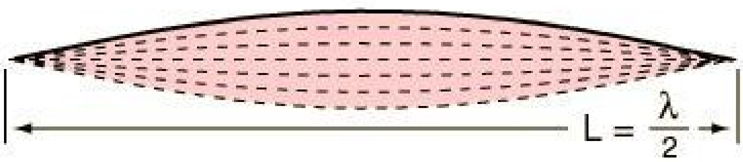
Stationary waves differ from progressive waves:

- There is no flow of energy along a stationary wave, although stationary waves often radiate energy.
- Within each loop of a stationary wave, all particles vibrate in phase and exactly out of phase (180° phase difference) with the particles in adjacent loops.
- The amplitude of vibration varies with position to the loops.
- There are **nodes** where the displacement is always zero (because when the amplitudes add up, it equals 0).
- There are **antinodes** which are positions varying **between** 0 and the maximum amplitude.

The wavelength of a stationary wave is twice the distance between two adjacent nodes or antinodes.

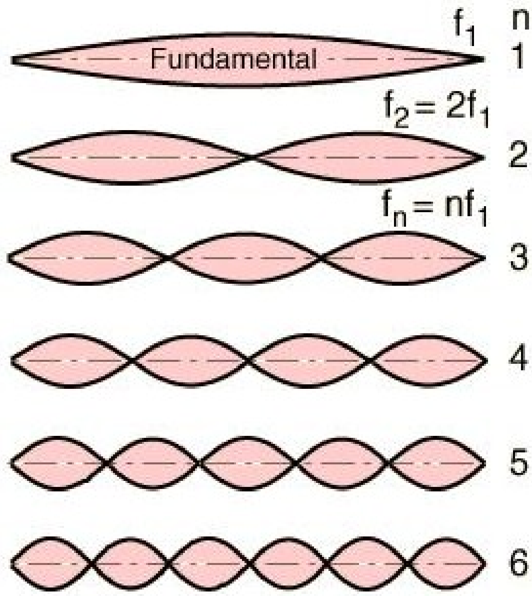
Standing Waves in Musical Instruments

Strings



This is the **fundamental frequency, and is half a wavelength.**

The following are called **harmonics, or overtones.** The first harmonic has a wavelength of 1, the next has a wavelength of 1.5 etc.

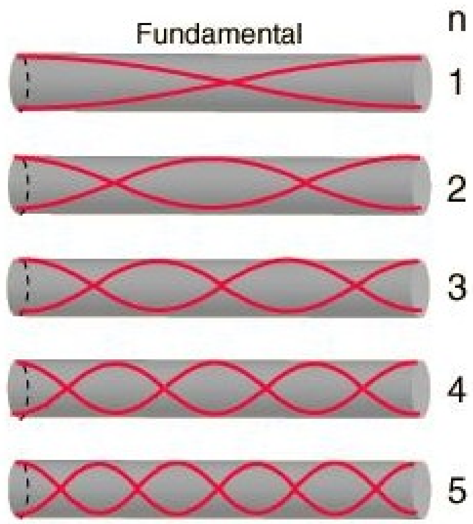


Pipes

The air particles vibrate backwards and forwards in a pipe. Sound can be reflected from an open end (due to change in pressure) as well as a closed end. **Antinodes** are present at the open ends of pipes, **nodes** are present at the closed ends.

The fundamental frequency at which the tube will **resonate** will set up standing waves. As the frequency is increased, standing waves occur at regular intervals, which we call harmonics.

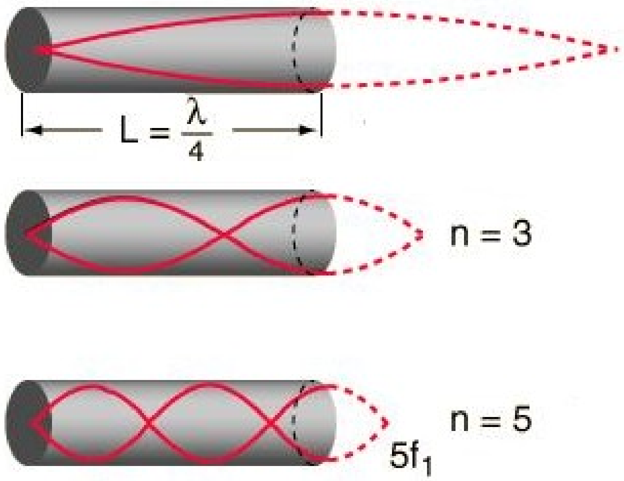
Open at both ends:



The fundamental frequency is **half** a wavelength.

Closed at one end:

The fundamental frequency is a **quarter** of a wavelength.



When a pipe is closed at **both ends**, the fundamental frequency is half a wavelength, and nodes are at both ends.