

Waves and sound

Typed version of the handwritten O Level Physics class notes (21 to 28 September 2020). The original handwritten pages are on the same page of megalecture.com.

Waves

A wave is a disturbance produced in a medium, travelling in an outward direction away from the source, or the mechanism by which transfer of energy occurs (without transfer of matter). Examples:

1. Source: a hand; disturbance in a string.
2. Source: a vibrating tuning fork; disturbance caused in air.
3. Source: a stone or rock; disturbance caused in water.

Particles vibrate; waves travel (the movement of energy in the form of vibrations).

Types of waves

- **Mechanical wave:** a wave which requires a medium for its propagation.
- **Non-mechanical wave:** a wave which does not require a medium for its propagation, e.g. all electromagnetic waves.

(Sketch of a row of numbered particles on a string, frame by frame: particle 1 is lifted, then 2, then 3, and so on, while each particle only moves up and down about its own position.)

- The particle oscillates, or moves about, in its own position; the particle does not move from its place.
- The only thing physically moving is the disturbance. Energy transfers in the wave direction.
- **Transverse wave:** a wave in which the particles of the medium oscillate in a perpendicular direction with respect to the direction of motion of the wave, e.g. a string, a water wave.
- **Longitudinal wave:** a wave in which the particles of the medium oscillate in a parallel direction with respect to the direction of motion of the wave, e.g. a sound wave, a spring.

Wave terms

Wave pattern: the representation of a wave using a displacement–time graph or a displacement–distance graph. On a displacement–time graph the gap between two crests is the time period T ; on a displacement–distance graph it is the wavelength λ .

- **Crest:** the highest point of the wave; a point which lies at the top of the wave.
- **Trough:** the lowest point of the wave; a point which lies at the bottom of the wave.
- **Oscillation:** one complete cycle about a fixed point.
- **Amplitude:** the maximum displacement of the wave from the mean position; the displacement of a crest or trough from the mean position.
- **Wavelength (λ):** the shortest distance between two consecutive crests or troughs; the distance travelled by one complete wave in one time period (can only be shown on a displacement–distance graph).



- **Time period (T):** the shortest time between two consecutive crests or troughs; the time taken to form one complete wave, or to complete one oscillation (can only be shown on a displacement–time graph).
- **Frequency (f):** the number of waves produced in one second. $f = 1 / T$.
- **Wave speed (v):** the distance covered by the wave in unit time. In general $s = d/t$; for waves $v = \lambda/T = \lambda \times (1/T)$, so $v = f\lambda$.
- **Wave front:** a surface joining the position of all the crests, or all the troughs, that are in phase; all identical points in a wave. The distance between two consecutive wave fronts is equal to the wavelength of the wave. (Sketches: straight wave fronts one wavelength apart; circular wave fronts spreading from a point.)
- **In phase:** points on a wave are in phase if they are at the same displacement and moving in the same direction.

Ripple tank experiment

Apparatus: a shallow tank of water on legs, a paper sheet beneath it, a lamp above, and an oscillator (an electric motor with a metal sphere dipping into the water). Circular ripples spread from the sphere; a straight bar dipper gives straight ripples.

The ripple tank experiment is used to produce waves on the surface of water and to study the properties of waves produced on the surface of water. To find the speed use $v = f\lambda$; the frequency of the electric motor is used.

1. **To study that water waves are transverse.** Keep a piece of paper on the surface of the water in the tank. Produce water waves with the vibrator: the paper vibrates up and down in its fixed position, showing that the waves are transverse.
2. **To study reflection of water waves.** Place a straight barrier upright in the water and produce water waves with the vibrator. The water waves are reflected from the barrier obeying the laws of reflection, i.e. $i = r$ (measured from the normal). Only the direction changes; everything else remains the same.
3. **To study refraction of waves.** First make the water deep and shallow by keeping a glass block inside the tank. When water waves enter from deep to shallow water: the frequency remains the same (because the source is the same); the wavelength decreases; the speed decreases. Calculate the refractive index: $n = \lambda_1/\lambda_2 = v_1/v_2$ (v is the speed in deep and shallow water). The speed of the wave is higher in deep water and lower in shallow water; the wavelength is longer in deep water and shorter in shallow water; $v = f\lambda$ with f constant, so v and λ are directly proportional. Where the speed is greater, the angle from the normal is greater. When the waves enter at 90° , nothing happens to the direction, but the speed changes because of the change in medium.

Sound

- A disturbance produced in the medium in the form of compressions and rarefactions, travelling in an outward direction, is called a sound wave.
- It is an example of a longitudinal wave.
- It can be produced in solids, liquids and gases. (Sound is generally the motion of compressions and rarefactions.)

- All sound-generating sources have one part that vibrates. (Sketch: a tuning fork prong moving to and fro pushes the air layers together, then lets them spread, sending compressions C and rarefactions R outwards.)
- **Rarefaction:** a region of low pressure in which the particles of the medium are forced apart from each other.
- **Compression:** a region of high pressure in which the particles of the medium are close to each other.

Bell jar experiment

An electric bell hangs inside a glass jar closed with a cork; a vacuum pump is connected to the base.

When we close the switch, current passes through the hammer and it continuously hits the bell, producing a sound. If we switch on the vacuum pump, the air gradually leaves the glass jar and the intensity of sound starts to decrease. After a certain time, the intensity of sound will become zero. The hammer will be seen hitting the bell but no sound will be heard. Hence it is proved that sound needs a medium to travel (or: it cannot travel in a vacuum). If we switch off the vacuum pump, the air returns and the intensity of sound begins to increase from zero. After a certain time you will hear the sound at the same intensity as before.

- We can use the vacuum pump both ways: to suck air from the glass jar, or let air inside.
- The hitting of the hammer could not produce a sound because there were no particles to be disturbed or to oscillate about their mean position.

Determination of the speed of sound in air

Person A fires a starting pistol; person B, a measured distance d away, holds a stopwatch. (The distance must be one from which the flash is visible.)

- The starting pistol produces a sound and a flash of light.
- Light reaches person B before the sound, and they start the stopwatch.
- After a few seconds the sound reaches person B and they stop the stopwatch.
- We use the formula for speed to calculate the speed of sound in air (d = the distance between the two persons): $s = d/t = 800 \text{ m} / 2.4 \text{ s} = 333 \text{ m/s}$.
- Apparatus: a large open field (to avoid echoes), a measuring tape, a sound source, a stopwatch.
- The speed of sound is about 333 m/s; it varies from 300 to 330 m/s because of the temperature of the air (the density of the air affects the travel of sound: higher density, higher speed of sound).

Medium	Iron (all solids)	Water	Air
Speed of sound	5000 m/s	1500 m/s	300 m/s

Particles closer together pass the vibrations on faster: solid > liquid > gas. Speed of light = $3 \times 10^8 \text{ m/s}$.

Echo

Echo: hearing a reflected sound shortly after the actual sound is produced (e.g. a person claps facing

a wall or hard flat surface).

Uses of echo: determining the depth below sea level; the position of objects (echolocation). A ship sends a transmitted sound down to the sea bed and receives the reflected sound. $\text{speed} = \text{distance} / \text{time}$, and the sound travels there and back, so $v = 2d/t$ and $d = vt/2$.

Reverberation: the prolonging of a sound due to the overlapping of the echo with the actual sound.

Hearing and frequency

- To produce sound we need to place a vibrating object in a medium.
- The frequency of the vibrating object's vibration = the frequency of the sound.
- Humans can hear sounds that have a frequency of 20 Hz to 20 000 Hz.
- **Audible sound:** a sound which can be heard by the human ear (20 Hz to 20 kHz).
- **Range of audibility:** the range of frequency of sound which can be heard by humans: 20 Hz to 20 000 Hz.
- **Infrasound:** sound with a frequency less than 20 Hz, e.g. a steel ruler (when hit against a surface and vibrating).
- **Ultrasound:** sound with a frequency greater than 20 kHz, e.g. a dog whistle.

Uses of ultrasound

1. **Quality and thickness control:** to check if an object has uniform (desired) thickness or density. A transmitter of ultrasound sits above the object and a receiver below. Uniform density: the wave passes. Non-uniform density: it completely or partly deflects. The receiver records the intensity of the wave, helping us to check whether the density of the object is uniform or not.
2. **Cleaning of small objects**, e.g. jewellery: placed inside a cleaning liquid; ultrasound hits the jewellery, causing it to oscillate with the frequency of the ultrasound (which is very high); the dirt is dusted off.
3. **Prenatal scanning:** to form a two-dimensional image of an unborn baby inside a mother's womb using ultrasound (ultrasound pulses are sent into the body by means of a transmitter and the echoes are reflected; absorbed by soft surfaces and reflected by hard).
4. **Depth below sea level** (see the echo notes above).

Pitch, loudness and quality

- **Pitch of sound:** a property of sound which is affected by its frequency. Higher frequency = higher pitch (shrill = high pitch, grave = low pitch).
- **Loudness of sound:** a property of sound which is affected by its amplitude. Larger amplitude = louder.
- **Quality of sound (timbre):** a property of sound which is affected by the shape of the waveform: a uniform change in displacement gives a good-quality (pure) sound, a non-uniform change in displacement gives a poor-quality sound (the pitch and frequency are the same in both). (Sketches: a smooth sine wave for good quality; a jagged wave for bad quality.)

Factors affecting the speed of sound in air: temperature, density, humidity (all directly proportional).

Factors affecting the quality of sound: the waveform of the sound wave; the fundamental frequency of the sound; higher frequencies known as harmonics.

Checked by Mega Lecture

This typed version follows the handwritten notes. The Urdu side notes are given in English. The sketches (particle-by-particle wave, ripple tank, reflection at a barrier, bell jar, echo sounding, waveforms) are described in words. Spelling corrected: longitudinal, vacuum, two-dimensional. Spotted a mistake? Tell us on WhatsApp: +92 336 780 1123.