6.1 Understanding Waves

6.1.1 Types of waves

<table>
<thead>
<tr>
<th>Transverse waves</th>
<th>Longitudinal waves</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Transverse wave diagram" /></td>
<td><img src="image" alt="Longitudinal wave diagram" /></td>
</tr>
</tbody>
</table>

- **Transverse waves** are waves in which the particles of the medium oscillate perpendicular to the direction of propagation.
- **Examples:** Water waves, light waves

- **Longitudinal waves** are waves in which the particles of the medium oscillate parallel to the direction of propagation.
- **Examples:** Sound waves

6.1.2 Phase

When two particles in a wave are in the same phase, they are at the same displacement from their position of rest and are moving in the same direction.

6.1.3 Wave Fronts

A wave front is an imaginary line that connects all the points on the crest of a wave. Wave fronts are always perpendicular to the direction of propagation.

<table>
<thead>
<tr>
<th>Plane wave</th>
<th>Circular wave</th>
</tr>
</thead>
</table>

Direction of propagation
Amplitude, Period, Frequency, and Wavelength

- **Amplitude, *A***: Maximum displacement of a wave particle from its position of equilibrium [m]
- **Period, *T***: Time taken for one complete oscillation of a wave [s]
- **Frequency, *f***: Number of complete oscillations of a wave in one second [Hz]
- **Wavelength, *λ***: Perpendicular distance between two successive points of the same phase in a wave [m]

**Extra Note:**
- **Amplitude** represents the *energy of the particle* of the wave. The higher the energy possessed by the wave particle, the higher the amplitude of the wave.
- **Frequency** represents the *overall energy* of the wave. The higher the frequency, the higher the overall energy possessed by the wave.

Relationship between frequency and period:

\[ f = \frac{1}{T} \]

The wavelength of a longitudinal wave is measured between two consecutive compression or rarefaction points.

**6.1.4 Wave Equation**

\[ v = f \lambda \]

*where*

- \( v \) = velocity \([\text{m s}^{-1}]\)
- \( f \) = frequency \([\text{Hz}]\)
- \( \lambda \) = Wavelength \([\text{m}]\)
An oscillating system which has reducing amplitude over time is said to be undergoing **damping**. Damping is due to *lost energy through friction and heat*.

![Graph showing displacement and amplitude over time](image)

### 6.1.6 Resonance

<table>
<thead>
<tr>
<th>Natural frequency:</th>
<th>The frequency of a system that is left to oscillate freely without an external force / energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forced frequency:</td>
<td>The frequency of a system that is forced to oscillate continuously due to external force / energy</td>
</tr>
<tr>
<td>Resonance:</td>
<td>The phenomenon when a system is forced to oscillate at a frequency equal to its natural frequency</td>
</tr>
</tbody>
</table>

An object that vibrates with resonance has the **highest** amplitude because it is receiving maximum energy from the external system.

The following shows the setup of Barton’s pendulum that is used to study the phenomenon of resonance.

![Diagram of Barton’s pendulum](image)

- When the control pendulum $X$ is oscillated, its energy is transferred to the other pendulums through the string.
- The other pendulums are forced to oscillate at the same frequency as pendulum $X$.
- Because pendulum $D$ has the same natural frequency as $X$ (same length), pendulum $D$ will oscillate at resonance and will have the maximum amplitude.
6.2  Water Waves

6.2.1  Ripple tank

[Diagram of a ripple tank showing the motor to produce vibrations, lamp, tank, water, ripples, wave shadows on screen, and a strobeoscope (spinning disc) to "freeze" the wave motion. Below the diagram, a schematic showing light from the lamp hitting the water and creating bright and dark regions on a white paper (screen).]
6.3 Reflection of Waves

All waves obey the law of reflection which states the angle of reflection is equal to the angle of incidence.

The physical quantities of a wave which changes when it undergoes reflection:

- X Wavelength
- X Frequency
- ✔ Speed
- Amplitude (decreases due to loss of energy which was absorbed by the reflector)

6.3.1 Light Waves

6.3.2 Water Waves

6.3.3 Sound Waves
6.4 Refraction of Waves

Refraction of waves is the phenomenon of waves caused by the change in the speed of the waves.

The physical quantities of a wave which changes when it undergoes refraction:

- ✓ Wavelength
- ✓ Speed
- ✓ Frequency
- ✓ Amplitude
- ✓ Amplitude

6.4.1 Refraction of light waves

Light refraction is a phenomenon where the direction of light is changed when it crosses the boundary between two materials of different optical densities. It occurs as a result of a change in the velocity of light as it passes from one medium to another.

When a light ray travels from medium A to medium B which is optically denser than A:

- The ray of light will refract towards normal; $r < i$

When a light ray travels from medium C to medium D which is optically denser than C:

- The ray of light will refract away from normal; $r > i$

When a light ray crosses the boundary between two different mediums at a right angle:

$i = 0^\circ$, $r = 0^\circ$

6.4.2 Refraction of water waves

1. Water waves travel faster in deeper waters and slower in shallower waters.
2. When traveling from deep to shallow, the water waves refract towards normal.
3. When traveling from shallow to deep, the water waves refract away from normal.
4. To study the phenomenon of water wave refraction, a piece of glass or Perspex block is placed at the base of the ripple tank to make a shallow region.
The diagram on the right shows the plan view of water waves approaching the shoreline from the sea.

- In the middle of the sea, the wave fronts are almost in a straight line, as per $A_1B_1C_1D_1$ due to the same water depths.
- As the waves approach the beachline, the wave fronts begin to curve to follow the shape of the beachline, as per $A_2B_2C_2D_2$ and $A_3B_3C_3D_3$
- Energy from $A_1B_1$ is focused on the cape at $A_3B_3$ causing the cape to be hit by strong waves.
- Energy from $B_1C_1$ is spread out through the bay at $B_3C_3$ causing the water at the bay to be calmer.
- This is why the bay is always selected as a location for recreational activities and construction of seaside structures.

6.4.3 Refraction of sound waves

The following diagram shows the setup of an experiment to study the refraction of sound waves.

1. The experiment is first setup without the balloon, and the amplitude of the sound wave generated by the loudspeaker that is detected by the microphone is observed.
2. The experiment is then conducted with a balloon filled with carbon dioxide. Carbon dioxide is used because it is a denser gas therefore the balloon acts as a convex lens which focuses the sound waves towards the microphone, and hence, the amplitude of the sound waves detected by the microphone will be larger.
3. To further study refraction of sound waves, the carbon dioxide in the balloon can be replaced by helium which is a less dense gas, therefore the balloon will then act as a concave lens which diverges the sound waves. The amplitude of the sound waves detected by the microphone will be smaller.

**Sound refraction in the daytime**

In the day, the air above the ground is hotter than the air higher in the atmosphere. As sound travels from hot air to cold air, its speed decreases and refracts towards normal; hence the sound wave curves upwards.

**Sound refraction at night**

At night, the air above the ground is colder than the air higher in the atmosphere. As sound travels from cold air to hot air, its speed increases until a point where the angle of incidence is greater than the critical angle and total internal reflection occurs; hence the sound wave curves downwards.
6.5 Diffraction of Waves

Diffraction is the wave phenomenon where waves bend around an obstacle and spread out.

The physical quantities of a wave which changes when it undergoes diffraction:

<table>
<thead>
<tr>
<th>X</th>
<th>Wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>Frequency</td>
</tr>
<tr>
<td></td>
<td>Speed</td>
</tr>
<tr>
<td>✓</td>
<td>Amplitude (decreases due to the spreading of energy with the increasing length of the wavefronts)</td>
</tr>
</tbody>
</table>

Diffraction of water waves is more visible when:
- the wavelength of the wave is larger
- the obstacle is smaller than the wavelength.
- the aperture is smaller than the wavelength.

6.5.1 Diffraction of water waves

Larger wavelength
Diffraction is more obvious

Smaller wavelength
Diffraction is less obvious

Smaller aperture
Diffraction is more obvious

Bigger aperture
Diffraction is less obvious

Smaller obstacle
Diffraction is more obvious

Bigger obstacle
Diffraction is less obvious
6.5.3 Diffraction of light waves

The following diagram shows the setup of experiment to study the diffraction of light waves.

A monochromatic light source must be used in this experiment. Monochromatic light waves are light waves with one wavelength or one colour only.

Results that will be observed in the screen:
6.6 Interference of Waves

6.6.1 Principle of superposition

1. The principle of superposition states that when two waves propagate through the same point at the same time, the displacement at that point is the vector sum of the displacement of each individual wave.
2. Coherent wave sources have the same frequency and constant phase difference.
3. The superposition effect creates interference.

![Constructive interference (antinode):](image)

![Destructive interference (node):](image)

6.6.2 Wave Interference

The interference equation is given as:

\[ \lambda = \frac{ax}{D} \]

where \( \lambda \) = wavelength \([\text{m}]\)
\( a \) = distance between sources \([\text{m}]\)
\( x \) = distance between two successive antinodal/nodal lines \([\text{m}]\)
\( D \) = distance between \( a \) and \( x \) \([\text{m}]\)

<table>
<thead>
<tr>
<th>Different frequencies</th>
<th>Different distance between sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low frequency (large wavelength)</td>
<td>Larger distance between the sources</td>
</tr>
<tr>
<td>Value of ( x ) is larger</td>
<td>Value of ( x ) is smaller</td>
</tr>
<tr>
<td>High frequency (small wavelength)</td>
<td>Smaller distance between the sources</td>
</tr>
<tr>
<td>Value of ( x ) is smaller</td>
<td>Value of ( x ) is larger</td>
</tr>
</tbody>
</table>
6.6.3 Interference of Sound Waves

The following diagram shows the setup of the experiment to study the interference of sound waves.

When walking along a straight line in front of the loudspeakers, the observer will hear alternating loud and soft sounds. The loud sounds are due to constructive interference whereas the soft sounds are due to destructive interference.

6.6.4 Interference of Light Waves

The following diagram shows the setup of experiment to study the interference of light waves. In this experiment, a monochromatic light source must be used.

Results that will be observed in the screen:
### 6.7 Sound Waves

1. Sound waves are transverse waves.
2. They are *mechanical* waves, which means that they need a medium to propagate.
3. Speed of sound in mediums: Solid > Liquid > Gas
4. Speed of sound *increases* with temperature.

#### 6.7.1 Amplitude and Loudness

The higher the amplitude, the *louder* the sound.

#### 6.7.2 Frequency and Pitch

The higher the frequency, the *higher* the pitch.

#### 6.7.3 Quality of Sound

Different musical instruments can produce notes of the same loudness and pitch, yet they are easily discernible from one another. This is due to the *quality* or *timbre* of the note produced by the musical instruments.

Each note consists of a *fundamental frequency* that is mixed with weaker frequencies called *overtones*.

#### 6.7.4 Ranges of sound waves

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Infrasonic / Subsonic</strong></td>
<td>Frequency too low for human ears</td>
<td>Less than 20 Hz</td>
</tr>
<tr>
<td><strong>Audible frequency</strong></td>
<td>Frequency audible to human ears</td>
<td>20 - 20 000 Hz</td>
</tr>
<tr>
<td><strong>Ultrasonic / Supersonic</strong></td>
<td>Frequency too high for human ears</td>
<td>More than 20 000 Hz</td>
</tr>
</tbody>
</table>

#### 6.7.5 Depth detection and Echo-Sounding

Sound waves can be used to:
- Determine the depth of the sea
- Create an image of a baby or an internal organ
- Detect flaws in metal structure

\[
 d = \frac{vt}{2}
\]

where \( d \) = distance / depth \([\text{m}]\), \( v \) = speed of the wave \([\text{m s}^{-1}]\), \( t \) = time \([\text{s}]\)

This is derived from the formula:

\[
 v = \frac{2d}{t}
\]

Where the distance is doubled because the wave travels back and forth. If the wave only travels in one direction, remove the number “2”.

*Note: This formula can also be used for RADAR and any other wave reflection measurement methods.*
6.8 Electromagnetic Waves

Electromagnetic waves are electrical and magnetic waves oscillating perpendicular to each other around a single axis.

Characteristics:
- Transverse waves
- Fulfills the wave equation $v = f\lambda$
- Travels at the same speed (speed through vacuum: $c = 3 \times 10^8$ m s$^{-1}$)
- Does not need a medium to propagate

Polaroid is a type of material which allows waves to penetrate through in one plane only.

Wave types and their uses:
- Long waves: radio waves
- Medium waves: microwave, satellite TV, microwave oven
- Short waves: visible light, X-ray, gamma ray

Dangers:
- Mercury lamp
- Sun
- Detector of forgery notes

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<table>
<thead>
<tr>
<th>Electromagnetic wave</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma ray</td>
<td>- Kill cancer cells</td>
</tr>
<tr>
<td></td>
<td>- Sterilization</td>
</tr>
<tr>
<td></td>
<td>- Food preservation</td>
</tr>
<tr>
<td></td>
<td>- Kill agricultural pests</td>
</tr>
<tr>
<td></td>
<td>- Detect flaws or worn parts in car engines</td>
</tr>
<tr>
<td>X-ray</td>
<td>- Detect bone flaws or fractures</td>
</tr>
<tr>
<td></td>
<td>- Detect structural or machine flaws</td>
</tr>
<tr>
<td></td>
<td>- Investigate crystal structures and elements in a material</td>
</tr>
<tr>
<td></td>
<td>- Examine bags at the airport</td>
</tr>
<tr>
<td>Ultraviolet ray</td>
<td>- Treats the skin with the right exposure (for Vitamin D)</td>
</tr>
<tr>
<td></td>
<td>- Detects counterfeit money</td>
</tr>
<tr>
<td>Visible light</td>
<td>- Enables vision</td>
</tr>
<tr>
<td></td>
<td>- Enables photography</td>
</tr>
<tr>
<td></td>
<td>- Photosynthesis</td>
</tr>
<tr>
<td></td>
<td>- Optic fibre to see inside tissues and organs</td>
</tr>
<tr>
<td></td>
<td>- Laser light in optic fibre for communication</td>
</tr>
<tr>
<td>Infrared ray</td>
<td>- Physiotherapy</td>
</tr>
<tr>
<td></td>
<td>- Pictures of internal organs</td>
</tr>
<tr>
<td></td>
<td>- Satellite pictures</td>
</tr>
<tr>
<td>Microwave</td>
<td>- Communication - satellite, radar</td>
</tr>
<tr>
<td></td>
<td>- Cooking</td>
</tr>
<tr>
<td>Radiowave</td>
<td>- VHF &amp; UHF</td>
</tr>
<tr>
<td></td>
<td>- Radio and television</td>
</tr>
<tr>
<td></td>
<td>- SW, MW &amp; LW</td>
</tr>
<tr>
<td></td>
<td>- Radio broadcast</td>
</tr>
</tbody>
</table>

END OF CHAPTER