Physics Standard X: Sound Waves Notes

Comprehensive Study Guide for Examinations

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1 Introduction to Oscillatory Motion

Oscillatory motion refers to the repetitive to-and-fro movement of an object about its equilibrium position at regular intervals. A classic example is a swing or a pendulum.

- **Type of Motion**: The motion of a swing is oscillatory, not circular.
- **Equilibrium Position**: When a swing starts from its free state, it begins at the equilibrium position (denoted as O in diagrams). From here, it moves to points A or B (extreme positions) and returns.
- **Amplitude**: The maximum displacement from the equilibrium position to one side (e.g., from O to A) is called amplitude, denoted by a, measured in meters (m).
- **One Oscillation**: A complete oscillation occurs when the pendulum starts from O, moves to A, then to B, and returns to O. Alternatively, if starting from A, it moves to B and back to A.

1.1 Key Definitions

- **Period (T)**: The time taken to complete one oscillation, measured in seconds (s).
- **Frequency (f)**: The number of oscillations per second, measured in Hertz (Hz). It is the reciprocal of the period: $f = \frac{1}{T}$.

1.2 Example Calculation

For a pendulum completing 30 oscillations in 1 minute (60 s):

$$\text{Time for 1 oscillation} = \frac{60\,\text{s}}{30} = 2\,\text{s}$$

$$\text{Frequency} = \frac{\text{Number of oscillations}}{\text{Time}} = \frac{30}{60} = 0.5\,\text{Hz}$$

2 Simple Pendulum Experiment

A simple pendulum consists of a bob tied to a string and hung from a stand. The frequency and period depend on the pendulum's length (ℓ).

Table 1: Simple Pendulum Experiment Data

Length (ℓ) (cm)	**Time for 10 Oscillations (s)**	**Period (T) (s)**	**Frequency (f) (Hz)**
25	Measure experimentally	$\frac{\text{Time}}{10}$	$\frac{10}{\text{Time}}$
60	Measure experimentally	$\frac{\text{Time}}{10}$	$\frac{10}{\text{Time}}$
100	Measure experimentally	$\frac{\text{Time}}{10}$	$\frac{10}{\text{Time}}$

- **Observation**: As the length of the pendulum increases, the frequency decreases, and the period increases.
- **Relation**: $f = \frac{1}{T}$. A longer pendulum takes more time per oscillation, reducing the frequency.

3 Frequency Units in Practical Applications

Frequency is often expressed in larger units for applications like radio and television:

$$1\,\text{kHz} = 10^3\,\text{Hz}, \quad 1\,\text{MHz} = 10^6\,\text{Hz}$$

4 Tuning Forks and Natural Frequency

Tuning forks vibrate at a specific frequency, known as their natural frequency, marked on them (e.g., 256 Hz). This indicates the number of vibrations per second.

- **Natural Frequency Factors**: Influenced by the object's length, size, elasticity, and material.
- **Observation**: Different tuning forks produce distinct sounds due to variations in frequency.

5 Forced Vibration and Resonance

Forced vibration occurs when an object vibrates due to an external vibrating source. Resonance occurs when the natural frequencies of the forcing and forced objects match, leading to maximum amplitude.

- **Example**: Pressing a vibrating tuning fork (e.g., 512 Hz) on a table causes the table to vibrate, amplifying the sound.
- **Hacksaw Blade Experiment**: When blade A is excited, blades C and E (with the same natural frequency) vibrate with maximum amplitude due to resonance.
- **PVC Pipe Experiment**: Adjusting the air column length in a PVC pipe near a 512 Hz tuning fork produces a louder sound at resonance, when the air column's natural frequency matches the tuning fork's frequency.

5.1 Applications of Forced Vibration and Resonance

- MRI scanning
- Radio tuning
- Musical instruments (e.g., guitar, violin, mridangam)
- Stethoscopes (amplifying faint heartbeats)
- Megaphones and horns

6 Wave Motion

Wave motion involves the transfer of energy through a medium via oscillations without displacing the medium's particles permanently.

- **Example**: In a slinky, compressing and releasing coils creates a disturbance that travels without moving the coils permanently.

- **Definition**: Wave motion is the continuous propagation of energy through oscillations from one part of a medium to another.

6.1 Types of Waves

Table 2: Waves and Their Medium Requirements

Waves Requiring a Medium	Waves Not Requiring a Medium
Seismic waves	Radio waves
Sound waves	Light waves
Ripples on water	Microwaves, UV rays, X-rays, Gamma rays

- **Electromagnetic Waves**: Travel without a medium (e.g., radio waves, light).
- **Mechanical Waves**: Require a medium and are classified as:
  - **Longitudinal Waves**: Particles vibrate parallel to the wave's direction (e.g., sound waves).
  - **Transverse Waves**: Particles vibrate perpendicular to the wave's direction (e.g., waves on a string).

6.2 Longitudinal Waves: Sound

Sound travels as longitudinal waves, creating compressions (high-pressure regions, denoted C) and rarefactions (low-pressure regions, denoted R) in the medium.

- **Example**: A tuning fork's prong moving to side A increases air pressure (compression), and to side B decreases it (rarefaction).

6.3 Transverse Waves

In transverse waves, particles move perpendicular to the wave's direction, forming crests (elevated portions) and troughs (lowest portions).

- **Example**: Oscillating a spring vertically creates crests and troughs, as seen in a slinky or string experiment.

Table 3: Comparison of Longitudinal and Transverse Waves

Longitudinal Waves	Transverse Waves
Particles vibrate parallel to wave direction	Particles vibrate perpendicular to wave direction
Form compressions and rarefactions	Form crests and troughs
Pressure variations occur in the medium	No pressure variations occur
Example: Sound waves	Example: Light waves, waves on a string

7 Characteristics of Waves

- **Amplitude**: Maximum displacement from the equilibrium position (e.g., points A, B in a displacement-time graph).

- **Period**: Time for one complete vibration.
- **Frequency**: Number of cycles per second ($f = \frac{1}{T}$).
- **Wavelength (λ)**: Distance between two consecutive particles in the same phase (e.g., two crests or two compressions), measured in meters.
- **Speed (v)**: Distance traveled by the wave per second, related by:

$$v = f\lambda$$

7.1 Relation Between Frequency and Wavelength

When wave speed is constant, frequency is inversely proportional to wavelength:

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

7.2 Example Calculations

- **Speed**: If a wave travels 700 m in 2 s:

$$v = \frac{700}{2} = 350\,\text{m/s}$$

- **Longitudinal Wave**: For a wave with $f = 35\,\text{Hz}$, $v = 350\,\text{m/s}$:

$$\lambda = \frac{v}{f} = \frac{350}{35} = 10\,\text{m}$$

  (Distance between consecutive compressions or rarefactions is 10 m.)

- **Sound Wave**: For $f = 175\,\text{Hz}$, $\lambda = 2\,\text{m}$:

$$v = f\lambda = 175 \times 2 = 350\,\text{m/s}$$

8 Reflection of Sound

Sound waves reflect off surfaces, similar to light. Smooth surfaces reflect sound more effectively than rough ones.

- **Experiment**: Using PVC pipes and a glass plate, sound from an alarm clock reflects to be heard through another pipe. Rough surfaces reduce the loudness of reflected sound.

8.1 Echo

An echo is the distinct reflection of the initial sound after a delay, heard if the reflecting surface is at least 17.5 m away (based on the speed of sound in air, 350 m/s, and persistence of hearing, 0.1 s).

- **Calculation**: For sound traveling 350 m/s:

$$\text{Distance} = 350 \times 0.1 = 35\,\text{m}, \quad \text{Minimum distance} = \frac{35}{2} = 17.5\,\text{m}$$

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- **Example**: If an echo is heard after 1 s:

$$\text{Distance} = \frac{350 \times 1}{2} = 175\,\text{m}$$

- **In Water**: Speed of sound = 1480 m/s:

$$\text{Distance} = 1480 \times 0.1 = 148\,\text{m}, \quad \text{Minimum distance} = \frac{148}{2} = 74\,\text{m}$$

8.2 Reverberation

Reverberation is the lingering of sound due to multiple reflections, creating a booming effect (e.g., in Gol Gumbaz's whispering gallery). Rough walls in auditoriums reduce reverberation for clearer sound.

9 Limits of Audibility

Humans can hear sounds between 20 Hz and 20 kHz. Below 20 Hz (infrasonic) and above 20 kHz (ultrasonic) are inaudible.

- **Example**: A galton whistle (30 kHz) is ultrasonic and inaudible to humans.

10 Uses of Ultrasonic Waves

- Medical: Ultrasonography, kidney stone crushing, physiotherapy.
- Industrial: Cleaning spiral tubes, electronic components.
- Navigation: SONAR for measuring underwater distances.

10.1 SONAR Example

For an ultrasonic wave in seawater ($v = 1522\,\text{m/s}$) returning after 0.2 s:

$$\text{Distance} = \frac{1522 \times 0.2}{2} = 152.2\,\text{m}$$

11 Seismic Waves and Tsunami

Seismic waves travel through the Earth's crust due to earthquakes or explosions. Tsunamis are gigantic ocean waves triggered by underwater seismic activity.

- **Safeguards**: Follow tsunami warning center instructions, evacuate to higher ground, and avoid coastal areas during alerts.

12 Assessment Questions and Solutions

1. **Which statement is correct?**
   - Answer: c) Sound is a longitudinal wave, and light is a transverse wave.

2. **Maximum wavelength for a bat (120 kHz, 350 m/s)**:

$$\lambda = \frac{v}{f} = \frac{350}{120 \times 10^3} = 0.00292\,\text{m} = 2.92\,\text{mm}$$

3. **Wave with frequency 2000 Hz**:
   - Answer: b) 2000 Hz is audible (within 20 Hz to 20 kHz).

4. **Distance traveled by wave (2 kHz, 35 cm, 0.5 s)**:

$$v = f\lambda = 2000 \times 0.35 = 700\,\text{m/s}, \quad \text{Distance} = 700 \times 0.5 = 350\,\text{m}$$

5. **Frequency of wave (50 crests, 50 troughs in 0.5 s)**:

$$f = \frac{50}{0.5} = 100\,\text{Hz}$$

6. **Frequency of transverse wave (distance between troughs = 2 m, speed = 20 m/s)**:

$$f = \frac{v}{\lambda} = \frac{20}{2} = 10\,\text{Hz}$$

7. **Sound transmission**:
   - Answer: The wave travels, not the particles, medium, or source.

8. **Pith balls near tuning fork**:
   - a) Forced vibration causes slight movement.
   - b) Resonance causes maximum movement when piano notes match the tuning fork's frequency.

13 Extended Activities

- **Resonance Activity**: Set up two tuning forks of the same frequency. Excite one and place it near the other to observe resonance (increased amplitude in the second fork).
- **Seminar on Ultrasonic Waves**: Discuss applications in medicine (ultrasonography, kidney stone treatment), industry (cleaning), and navigation (SONAR).