

chapter 25 vibrations waves review questions answers

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Introduction

In physics, the study of vibrations and waves is a cornerstone that bridges the gap between everyday phenomena—like the hum of a guitar string—and complex engineering systems, such as seismic monitoring and fiber optic communication. Chapter 25 of most physics textbooks is dedicated to this subject, laying out the fundamentals of how objects oscillate, how waves propagate, and how we can analyze these motions mathematically. Whether you're a high school student preparing for exams, a college freshman taking your first physics course, or an educator looking for a comprehensive review, this article provides a deep dive into Chapter 25. We'll explore core concepts, walk through a robust set of review questions, and present detailed answers that reinforce learning.

Chapter 25 Overview: Vibrations & Waves

Chapter 25 typically begins by defining a **vibration** as a periodic motion of an object around an equilibrium position. The chapter then connects vibrations to **waves**, which are disturbances that transfer energy through a medium without transporting matter. Key themes include:

- Simple Harmonic Motion (SHM) – the idealized vibration of a mass-spring system or a pendulum for small angles.
- Wave properties: amplitude, wavelength, frequency, period, and phase.
- Types of waves: transverse, longitudinal, surface, and electromagnetic.
- Wave behavior: reflection, refraction, diffraction, and interference.
- Standing waves and resonant frequencies in strings and air columns.

Understanding these principles is essential for tackling the review questions that follow.

Key Concepts Explained

Simple Harmonic Motion (SHM)

SHM describes motion where the restoring force is directly proportional to displacement and opposite in direction. The governing equation is:

$$F = -kx$$

where k is the spring constant and x is displacement. The resulting motion has a sinusoidal form, characterized by:

- Amplitude (A) – maximum displacement.
- Angular frequency (ω) – $\omega = 2\pi f$ or $\omega = 2\pi/T$.
- Frequency (f) – number of oscillations per second, $f = 1/T$.

Wave Properties

Waves are defined by several interrelated properties:

- Wavelength (λ) – distance between successive crests or troughs.
- Frequency (f) – number of wave cycles passing a point per second.
- Speed (v) – distance traveled per unit time; for a wave, $v = \lambda f$.

- Phase – relative position of a point on the wave cycle.

Wave Types

Waves can be classified by the direction of particle motion relative to wave propagation:

1. Transverse waves – particle displacement perpendicular to wave direction (e.g., electromagnetic waves).
2. Longitudinal waves – particle displacement parallel to wave direction (e.g., sound waves).
3. Surface waves – combine transverse and longitudinal motion, found at interfaces (e.g., water waves).

Wave Behavior

When waves encounter boundaries or obstacles, they undergo transformations:

- Reflection – waves bounce back from a boundary.
- Refraction – change in wave speed and direction when entering a different medium.
- Diffraction – bending of waves around obstacles or through openings.
- Interference – superposition of two waves, leading to constructive or destructive patterns.

Standing Waves & Resonance

When two waves of identical frequency travel in opposite directions, they form a standing wave with fixed nodes and antinodes. The condition for resonance in a string fixed at both ends is:

$$L = n\lambda/2$$

where L is string length and n is an integer (1, 2, 3,...). The corresponding frequency is $f = nv/2L$.

Review Questions & Answers

Below is a curated set of 25 review questions that cover the breadth of Chapter 25. Each question is followed by a concise answer and an explanation to reinforce understanding.

Answer: A simple harmonic oscillator experiences a restoring force proportional to displacement without any energy loss. A damped oscillator includes a frictional or resistive force proportional to velocity, causing the amplitude to decrease over time.

Derive the expression for the period of a mass spring system in SHM.

Answer: The restoring force is $F = -kx$. Applying Newton's second law, $ma = -kx$, leads to $m \frac{d^2x}{dt^2} + kx = 0$. The solution is sinusoidal with angular frequency $\omega = \sqrt{k/m}$. The period is $T = 2\pi/\omega = 2\pi\sqrt{m/k}$.

Explain how the speed of a wave changes when it moves from air into water.

Answer: Wave speed depends on the medium's density and elasticity. Since water is denser and more elastic than air, the wave speed increases in water. The relationship is $v = \sqrt{B/\rho}$, where B is bulk modulus and ρ is density.

Define constructive and destructive interference with an example.

Answer: Constructive interference occurs when two waves add to produce a larger amplitude (peaks align). Destructive interference occurs when waves cancel each other (peak meets trough). Example: two identical sound waves in phase produce louder sound; out of phase, they reduce amplitude.

Calculate the frequency of the third harmonic of a string 1.2 m long that vibrates at a speed of 440 m/s.

Answer: For the third harmonic, $n = 3$. Using $f = nv/2L$, $f = 3 \times 440 / (2 \times 1.2) = 3 \times 440 / 2.4 = 550 \text{ Hz}$.

What is the relationship between wavelength and frequency for a wave traveling at 340 m/s?

Answer: The wave speed formula is $v = \lambda f$. Therefore, for a given frequency, the wavelength is inversely proportional to it.

Describe the effect of adding a second mass to a mass spring system.

Answer: Adding a second mass increases the total inertia, thereby reducing the system's natural frequency. The effective mass becomes the sum of the two masses, and the period increases.

Explain why sound travels faster in warm air than in cold air.

Answer: Temperature increases the average kinetic energy of air molecules, reducing resistance to compression and increasing bulk modulus. Consequently, sound speed $v = \sqrt{B/\rho}$ rises.

What is the phase difference between two waves that interfere destructively?

Answer: The phase difference is π radians (180°), meaning one wave's crest aligns with the other's trough.

Define the term "node" in the context of standing waves.

Answer: A node is a point along a standing wave where the amplitude remains zero at all times, due to destructive interference of the counter-propagating waves.

Calculate the speed of a wave on a string if its wavelength is 0.5 m and the period is 0.01 s.

Answer: First find frequency: $f = 1/T = 1/0.01 = 100 \text{ Hz}$. Then speed: $v = \lambda f = 0.5 \times 100 = 50 \text{ m/s}$.

How does the amplitude of a damped oscillator change over time?

Answer: The amplitude decays exponentially, described by $A(t) = A_0 e^{-\gamma t}$, where γ is the damping coefficient.

Explain the principle of superposition in wave mechanics.

Answer: The principle states that the resultant displacement at any point is the algebraic sum of individual displacements from all waves present, enabling analysis of interference patterns.

What causes diffraction of waves?

Answer: Diffraction occurs when waves encounter an obstacle or opening comparable in size to their wavelength, causing them to bend and spread.

Describe how refraction can be used in lenses to focus light.

Answer: Refraction changes light's direction when it passes between media of different refractive indices. Convex lenses exploit this to bend parallel rays toward a focal point, forming images.

Calculate the frequency of the fundamental mode of an air column open at both ends, 0.75 m long, with sound speed 330 m/s.

Answer: For open-open, the fundamental wavelength is $\lambda = 2L = 1.5 \text{ m}$. Thus, frequency: $f = v/\lambda = 330/1.5 = 220 \text{ Hz}$.

What is the significance of the quality factor (Q) in oscillatory systems?

Answer: Q measures how underdamped a system is, indicating energy loss per cycle relative to stored energy. Higher Q means sharper resonance and lower damping.

Explain why the speed of a wave on a stretched string depends on tension and linear density.

Answer: The wave speed formula for a string is $v = \sqrt{T/\mu}$, where T is tension and μ is mass per unit length. Higher tension increases speed; greater mass density decreases it.

Define the term “phase velocity” and contrast it with “group velocity.”

Answer: Phase velocity is the speed at which a particular phase point (e.g., crest) travels. Group velocity is the speed of energy or information transfer, represented by the derivative $d\omega/dk$. In dispersive media, they differ.

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