Exam 3 Review

Chapter 9: Fluids
Learn the physics of liquids and gases.

- **States of Matter**
  Solids, liquids, and gases.

- **Pressure**

  \[ P_{av} = \frac{F}{A} \]

- **Pascal’s Principle**
  A change in pressure at any point in a confined fluid is transmitted everywhere throughout the fluid.

- **The Effect of Gravity on Fluid Pressure**

  \[ P_2 = P_1 + \rho gd \]

  The density is defined as

  \[ \rho = \frac{m}{V} \]

- **Measuring Pressure**
  Use a U-tube manometer. There are many units for pressure. Gauge pressure is the pressure above an atmosphere.

  \[ P_{gauge} = P_{abs} - P_{atm} \]

- **Buoyant Force**
  Archimedes’ principle - A fluid exerts an upward buoyant force on a submerged object equal in magnitude to the weight of the volume of fluid displaced by the object.

  \[ F_B = \rho g V \]

- **Fluid Flow**
  Continuity equation comes from the conservation of mass

  \[ A_1 v_1 = A_2 v_2 \]
• Bernoulli’s Equation

\[ P_1 + \rho g y_1 + \frac{1}{2} \rho v_1^2 = P_2 + \rho g y_2 + \frac{1}{2} \rho v_2^2 \]

You need a lot of information to use Bernoulli’s equation.

• Viscosity

Real fluids have viscosity (fluid friction). Poiseuille’s law is

\[ \frac{\Delta V}{\Delta t} = \frac{\pi}{8} \frac{\Delta P / L}{\eta} r^4 \]

The unit of viscosity (\( \eta \)) are Pa-s.

Turbulent flow involves the formation of swirling vortices of fluid. Compare it to laminar flow.

• Viscous Drag

According to Stokes’ law, for viscous drag on a sphere is proportional the sphere’s velocity through the fluid:

\[ F_D = 6\pi\eta rv \]

• Surface Tension

The surface of a fluid behaves like a stretched membrane under tension.

Chapter 10: Elasticity and Oscillations

A stress will deform a body and that body can be set into periodic oscillations.

• Elastic Deformations of Solids

Elastic objects return to their original shape after the stress is removed.

• Hooke’s Law for Tensile and Compressive Forces

Stress is defined as

\[ \text{stress} = \frac{F}{A} \]

Strain is defined as the fractional change of length

\[ \text{strain} = \frac{\Delta L}{L} \]

Hooke’s law asserts that the stress is proportional to the stain. The proportionality constant is called Young’s modulus
Beyond Hooke’s Law
If the stress takes the material out of the elastic regime, permanent changes can occur.

- Elastic limit is the stress where the elastic behavior ends.
- Further stress can fracture the solid at its breaking point.
- The maximum stress that can be reached without breaking is called the ultimate strength.

Ductile and brittle materials have different behavior.
- Ductile materials can stretch before they fracture.
- Brittle materials fracture abruptly.

Shear and Volume Deformations
The shear modulus

\[ \frac{F}{A} = S \frac{\Delta x}{L} \]

The bulk modulus

\[ \Delta P = -B \frac{\Delta V}{V} \]

The negative sign is needed since the volume decreases with the stress.

Simple Harmonic Motion (SHM)
In the vicinity of stable equilibrium, small excursions lead to a restoring force proportional to the displacement from equilibrium.

The maximum displacement from equilibrium is called the amplitude.

If dissipative forces are small, conservation of mechanical energy can be used to show that the mechanical energy is

\[ E_{total} = \frac{1}{2} kA^2 \]

The Period and Frequency for SHM
The period and frequency of periodic motion are related

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

Not all periodic motion is simple harmonic.
The kinematic equations for simple harmonic motion can be found from the equations for uniform circular motion. The angular frequency for a spring-mass system

\[ \omega = \sqrt{\frac{k}{m}} \]

Expressions for the period and linear frequency can be found. The maximum speeds and accelerations are

\[ v_m = \omega A \quad \text{and} \quad a_m = \omega^2 A \]

- **Graphical Analysis of SHM**
  If a particle’s position is given by
  
  \[ x(t) = A \cos \omega t \]
  
  Its speed and acceleration are
  
  \[ v(t) = -A \omega \sin \omega t \quad \text{and} \quad a(t) = -A \omega^2 \cos \omega t \]
  
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  \[ v(t) = A \omega \cos \omega t \quad \text{and} \quad a(t) = -A \omega^2 \sin \omega t \]
  
  The position, velocity, and acceleration are sinusoidal (sine or cosine functions).

- **The Pendulum**
  For small oscillations, the simple pendulum can be treated as a harmonic oscillator.
  
  \[ \omega = \sqrt{\frac{g}{L}} \]
  
  The period of a physical pendulum is
  
  \[ T = 2\pi \sqrt{\frac{I}{mgd}} \]
Here \( d \) is the distance from the center of mass of the pendulum to the point of support.

- **Damped Oscillations**
  Eventually dissipative forces take energy out of the oscillating system. The amplitude of oscillations will decrease.

- **Forced Oscillations and Resonance**
  When the driving frequency is equal to the natural frequency of the system, the amplitude of the motion is a maximum. **Resonance** can be destructive in mechanical systems.

**Chapter 11: Waves**
A wave transports energy without transporting mass. A wave can be thought of a large number of coupled harmonic oscillators.

- **Waves and Energy Transport**
  Waves transport energy. The **intensity** of a wave is

  \[
  I = \frac{P}{A} = \frac{P}{4\pi^2}
  \]

  The latter relation holds for spherical waves.

- **Transverse and Longitudinal Waves**
  The particles oscillate perpendicular to the motion of the wave in a **transverse** wave.
  The particles oscillate along the line of motion of the wave in a **longitudinal** wave.
  Some wave have both transverse and longitudinal properties.

- **Speed of Transverse Waves on a String**
  For a string under tension \( F \) and with mass per unit length \( \mu \),

  \[
  v = \sqrt{\frac{F}{\mu}}
  \]

  In general, “more restoring force makes faster waves; more inertia makes slower waves.”

- **Periodic Waves**
  Periodic wave repeat over some time \( T \).
A very important relationship for waves is

\[ v = f \lambda \]

**Period** \((T)\) – While staring at a point in the wave, how long does it take for the wave to repeat itself.

**Frequency** \((f)\) – The number of times the wave repeats per unit time. The inverse of the period.

**Wavelength** \((\lambda)\) – While looking at a photograph of the wave, it is the distance along the wave where the pattern will repeat itself.

**Amplitude** \((A)\) – The furthest displacement from equilibrium for the wave.

Harmonic waves are sinusoidal periodic waves

- **Mathematical Description of a Wave**
  For a traveling wave

  \[ y(x, t) = A \cos(\omega(t - x/v)) \]

  or \[ y(x, t) = A \cos(\omega t - kx) \]

  The wavenumber, \(k\) is

  \[ k = \frac{2\pi}{\lambda} \]

- **Graphing Waves**
  A very handy way to understand the motion of the wave.

- **Principle of Superposition**
  “When two or more waves overlap, the net disturbance at any point is the sum of the individual disturbances due to each wave.”

  The waves pass through each other undisturbed.

- **Reflection and Refraction**
  **Reflection** of a wave can occur at a boundary between one medium and another. A rope tied to wall is a good example.

  - The reflected wave will return inverted if the boundary is a fixed point.
  - The reflected wave will return upright if the boundary is free to move.

  The speed of the wave can change when traveling from one medium into another.

  - The wavelength changes. The frequency does not.

  When the wave travels from one medium into another, **refraction** can occur and its direction can change.

- **Interference and Diffraction**
  Because of the principle of superposition, the interaction of **coherent** wave can have dramatic effects.

  Coherent waves have the same wavelength and a constant phase relation.
Constructive interference occurs when the phase relation between the coherent waves is 0, 2\(\pi\), 4\(\pi\), etc.

Destructive interference occurs when the phase relation between the coherent waves is \(\pi\), 3\(\pi\), 5\(\pi\), etc.

Otherwise, the effect is between constructive and destructive.

**Diffraction** is the spreading of a wave around an obstacle.

- **Standing Waves**
  The constructive interference of an incident and reflected wave forms a standing wave.

\[
y(x,t) = 2A\cos \omega t \sin kx
\]

For a standing wave on a string, the stationary ends are **nodes**. Points of maximum vibration are called **antinodes**.

The possible wavelengths for the standing waves are

\[
\lambda_n = \frac{2L}{n} \quad n = 1, 2, 3, \ldots
\]

The frequencies are

\[
f_n = \frac{n\nu}{2L} \quad n = 1, 2, 3, \ldots
\]

The lowest frequency is called the **fundamental**.

These are the natural frequencies of the string.

**Chapter 12: Sound**

Apply our understanding of waves to a very important example.

- **Sound Waves**
  Longitudinal waves with an alternating series of compressions and rarefactions. Pressure nodes are displacement antinodes and *vice versa*.

  The average human can hear frequencies between 20 Hz and 20,000 Hz.

- **The Speed of Sound Waves**
  In general

\[
v = \sqrt{\frac{\text{a measure of the restoring force}}{\text{a measure of the inertia}}} \]

- **Amplitude and Intensity of Sound Waves**
  Intensity is measured on the decibel scale
\[ \beta = (10 \text{ dB}) \log_{10} \frac{I}{I_0} \]

The decibel scale more closely approximates the response of human hearing.

- **Standing Sound Waves**
  For a pipe with both ends open,
  - The ends are displacement antinodes.
  - All harmonics are heard.
  - The frequencies are
    \[ f_n = n \frac{v}{2L} = nf_1 \quad n = 1,2,3,… \]
  For a pipe with one end open,
  - The open end is a displacement antinode, the closed end is a displacement node.
  - Only odd harmonics are heard.
  - The frequencies are
    \[ f_n = n \frac{v}{4L} = nf_1 \quad n = 1,3,5,… \]

- **Timbre**
  The different mixture of fundamental frequencies and harmonics give instruments and voices their unique quality and color.

- **The Human Ear**
  The ear is remarkable device.
  **Loudness** is related to intensity. The decibel scale approximates the response of the ear to loudness
  **Pitch** is the ear’s response to frequency.

- **Beats**
  Two sound waves with similar frequencies interfere. The interfering waves combine and the envelope of the combining waves can be heard. The beat frequency for two sound waves with frequencies \( f_1 \) and \( f_2 \) is
    \[ f_{\text{beat}} = |f_1 - f_2| \]

- **The Doppler Effect**
  The frequency experience by an observer is influenced by the motion of the source and the observer. Used in many applications to measure velocity.
o Moving source

\[ f_o = \left( \frac{1}{1-v_s/v} \right) f_s \]

\( v_s > 0 \) if source moves in the same direction as the wave.

o Moving observer

\[ f_o = (1-v_o/v) f_s \]

\( v_o > 0 \) if source moves in the same direction as the wave.

o Source and observer moving

\[ f_o = \left( \frac{1-v_o/v}{1-v_s/v} \right) f_s \]

If the source moves faster than the speed of the wave in the medium, **shock waves** result.

- **Echolocation and Medical Imaging**
  - **Sonar** is used to image objects underwater.
  - **Ultrasound** is used to safely image inside the body.