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 of Fluid Pressure**

$$P_2 = P_1 + \rho g d$$

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 and 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**

$$P_1 + \rho g y_1 + \tfrac{1}{2}\rho {v_1}^2 = P_2 + \rho g y_2 + \tfrac{1}{2}\rho {v_2}^2$$

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

- **Viscosity**
Real fluids have viscosity. Poiseuille's law is

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

The unit of viscosity (η) are Pa-s.

- **Viscous Drag**
- **Surface 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 is called **Young's** modulus

$$\frac{F}{A} = Y\frac{\Delta L}{L}$$

- **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

$$E_{total} = \tfrac{1}{2}kA^2$$

- **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

$$v_m = \omega A \text{ and } a_m = \omega^2 A$$

- **Graphical Analysis of SHM**
  If a particle's position is given by

  $$x(t) = A\cos\omega t$$

  It's speed and acceleration are

  $$v(t) = -A\omega\sin\omega t \quad \text{and} \quad a(t) = -A\omega^2\cos\omega t$$

  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.

Chapter11: 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

$$I = \frac{P}{A} = \frac{P}{4\pi r^2}$$

  The latter relation holds for spherical waves.

- **Transverse and Longitudinal Waves**
  The particles oscillate perpendicular to the motion of the wave in **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 μ,

$$v = \sqrt{\frac{F}{\mu}}$$

  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 (λ)– 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 from equilibrium for the wave.

  Harmonic waves are sinusoidal periodic waves

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

$$y(x,t) = A\cos[\omega(t - x/v)] \quad \text{or} \quad y(x,t) = A\cos(\omega t - kx)$$

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, 2π, 4π, etc.
  - **Destructive** interference occurs when the phase relation between the coherent waves is π, 3π, 5π, 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 a 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

$$\lambda_n = \frac{2L}{n} \quad n = 1, 2, 3, \dots$$

The frequencies are

$$f_n = \frac{nv}{2L} \quad n = 1, 2, 3, \dots$$

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 antinodes.
  - All harmonics are heard.
  - The frequencies are

$$f_n = n\frac{v}{2L} = nf_1 \quad n = 1, 2, 3, \dots$$

  For a pipe with one end open,

- The open end is an antinode, the closed end is a node.
- Only odd harmonics are heard.
- The frequencies are

$$f_n = n\frac{v}{4L} = nf_1 \quad n = 1,3,5,\ldots$$

- **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

$$f_{beat} = \left| f_1 - f_2 \right|$$

- **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.
  - Moving source

$$f_O = \left(\frac{1}{1 - v_S / v}\right) f_S \qquad v_S > 0 \text{ if source moves in the direction of the wave}$$

  - Moving observer

$$f_O = (1 - v_O / v)\, f_S \qquad v_O > 0 \text{ if observer moves in the direction of the wave}$$

  - 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.