Wave Equation
\( v \) – wave velocity
\( A \) – amplitude
\( k \) – wave number
\( \omega \) – angular frequency
\( T \) – period
\( f \) – frequency

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

\( v = \frac{\lambda}{T} \)
\( k = \frac{2\pi}{\lambda} \)

\( v \) is positive if sign of \( \omega \) is negative

Harmonic Motion
\( \omega \) – angular frequency
\( A \) – amplitude
\( k \) – stiffness
\( m \) – mass
\( \delta \) – phase angle
\( x_0 \) – initial displacement
\( v_0 \) – initial velocity
\( T \) – period
\( f \) – frequency

\[ x(t) = A \sin(\omega t + \delta) \]
\[ v(t) = A \omega \cos(\omega t + \delta) \]
\[ a(t) = -A \omega^2 \sin(\omega t + \delta) \]

\( \omega = \sqrt{\frac{k}{m}} \)
\( A = \sqrt{a_1^2 + a_2^2} \)
\( \delta = \tan^{-1}\left(\frac{a_2}{a_1}\right) \)

\( a_1 = \frac{v_0}{\omega} \quad a_2 = x_0 \)
\( T = \frac{2\pi}{\omega} \quad f \equiv \frac{1}{T} \)
\( \omega = 2\pi f \)

Parallel Axis Theorem
\( I = I_{cm} + Md^2 \)

Pendulums
Simple: \( \omega = \sqrt{\frac{g}{l}} \)
Physical: \( \omega = \sqrt{\frac{Mgr}{I}} \)

Speed of Sound in Air
\( v \approx (331 + 0.60T) \text{ m/s} \)
\( T \) in °C

Beat Frequency: \( |f_2 - f_1| \)

Natural Frequencies:
\( \lambda \) – wavelength
\( L \) – Length
\( n \) – harmonic
\( T \) – tension
\( \mu \) – mass per unit length
\( f \) – frequency
\( v \) – wave velocity in medium

String
\( \lambda_n = \frac{2L}{n} \)

\( f_n = \frac{v}{\lambda_n} = \frac{n}{2L} \sqrt{\frac{T}{\mu}} \)

Air Columns
\( \lambda = \frac{4L}{n} \) closed (n odd)
\( \lambda = \frac{2L}{n} \) open

Wave Speed
Cables, Ropes, etc.
\( T \) – tension
\( \mu \) – mass per unit length
\( E \) – modulus of elasticity
\( \rho \) – mass density

Transverse: \( v = \sqrt{\frac{T}{\mu}} \)

Longitudinal: \( v = \sqrt{\frac{E}{\rho}} \)

Light Waves
Law of Reflection \( \theta_i = \theta_a \)

Index of Refraction \( n = \frac{c}{v} \)

Law of Refraction
\( n_a \sin \theta_a = n_b \sin \theta_b \)

Light Wavelength \( \lambda = \frac{\lambda_0}{n} \)

Total Internal Reflection
\( \sin \theta_{crit} = \frac{n_b}{n_a} \)
1. (14 pts) After an earthquake shock the houses in Elm street vibrated in simple harmonic motion. Their initial displacement and velocity were 0.95 inches and 25 inch/sec respectively. If the natural frequency was 5.1 Hz, what was the phase angle ($\delta$)? (Answer should be in radians).

2. (14 pts) After landing on an unfamiliar planet ($g=10.7 \text{ m/s}^2$), a space explorer constructs a physical pendulum of length 50 cm and a mass of 6 kg (string + weight). She finds that the pendulum makes 100 complete swings in 136 seconds. What is the mass moment of inertia of the pendulum as it pivots about the top?
3. (14 pts) With what tension must a rope with a length of 2.5 meters and a mass of 120 grams be stretched for a transverse wave of frequency 40 Hz to have a wavelength of 75 cm? (Note: this wave is NOT a standing wave).

4. (14 pts) A stretched cord of length 0.65 meters and a mass of 1.5 kg produces a wave with a speed of 92 m/s. By how many Hz is the third harmonic greater than the first harmonic? \((f_3 - f_1)\)
5. (14 pts) A single person singing the Tennessee Waltz produces a sound level of 72 dB. Some people join in so that the new sound level is 85 dB. Assuming all people sing with the same intensity, how many people are now singing the Tennessee Waltz?

6. (14 pts) You are driving west on Northshore Drive at a speed of 28 m/s. A police car whose siren emits a sound at a frequency of 4000 Hz is traveling east on Northshore Drive. After the police car goes past you, you hear a frequency of 3300 Hz. How fast is the police car going? Assume the speed of sound is 343 m/s.
7. (14 pts) A laser shines through an unknown material as shown. Determine the index of refraction of the material. Assume the index of refraction of air is 1.0.

8. (2 pts) A boat is moored in a fixed location, and waves make it move up and down. If the spacing between wave crests is 10 m and the speed of the waves is 5 m/s, how long does it take the boat to go from crest to crest?
   a. 1 second
   b. 2 seconds
   c. 4 seconds
   d. 8 seconds
   e. 16 seconds