Chapters 5 & 6: Forces & Friction

\[ \vec{F} = m \vec{a} \] Newton's 2nd Law

\[ \vec{F}_g = F_N = N = mg = W \text{ (weight)} \]

\[ f_{s, \text{max}} = \mu_s F_N \] force due to static friction

\[ f_{k, \text{max}} = \mu_k F_N \] force due to kinetic (or sliding) friction

\[ a_c = \frac{v^2}{r} \] centripetal acceleration (circular motion)

\[ F = \frac{mv^2}{r} \] centripetal force (circular motion)

Chapters 7 & 8: Energy

\[ K = \frac{1}{2} mv^2 \] Kinetic energy

\[ W = \vec{F} \cdot \vec{d} \] Work

\[ \Delta K = K_f - K_i = W \] Work - Kinetic Energy Theorem

\[ W_g = m \vec{d} \cos(\phi) \] Work done by gravity

\[ \vec{F}_s = -k \vec{d} \] Hooke's Law (force of a spring)

\[ W_s = \frac{1}{2} k x_i^2 - \frac{1}{2} k x_f^2 \] Work done by a spring

\[ \Delta U = -W \] Change in potential energy is minus the work

\[ \Delta U = mg (y_f - y_i) = mg (\Delta y) = mgh \] Potential energy

\[ U(x) = \frac{1}{2} k x^2 \] Potential energy of a spring

\[ E_{\text{mech}} = K + U \] Total mechanical energy = kinetic + potential

\[ K_f + U_f = K_i + U_i \] Conservation of Mechanical Energy

\[ P_{\text{avg}} = \frac{W}{\Delta t} = \frac{\Delta E}{\Delta t} \] average Power
Chapter 9: Center of Mass & Linear Momentum

\[ r_{\text{com}} = \frac{1}{M} \sum_{i=1}^{n} m_i r_i \]  
center of mass in general (M is total mass of all particles)

\[ \vec{p} = m \vec{\dot{v}} \quad \text{linear momentum} \]

\[ \vec{J} = \Delta \vec{p} = \vec{p}_f - \vec{p}_i, \quad \text{Impulse} \]

\[ J = \vec{F} \Delta t \]

\[ \vec{p}_f = \vec{p}_i \quad \text{Conservation of Linear Momentum} \]

Chapter 10: Rotation

\[ \theta = \frac{s}{r} \quad \text{angular position} \]

\[ \omega_{\text{avg}} = \frac{\Delta \theta}{\Delta t} \quad \text{angular velocity} \]

\[ \alpha_{\text{avg}} = \frac{\Delta \omega}{\Delta t} \quad \text{angular acceleration} \]

\[ s = \theta r \quad \text{linear position} \]

\[ v = \omega r \quad \text{linear velocity} \]

\[ a_r = \alpha r \quad \text{linear tangential acceleration} \]

\[ a_r = \frac{v^2}{r} = \omega^2 r \quad \text{linear radial acceleration} \]

\[ T = \frac{2 \pi r}{v} = \frac{2 \pi}{\omega} \quad \text{Period of an object undergoing uniform circular motion} \]

\[ \tau = \vec{r} \times \vec{F} = r F \sin(\phi) \quad \text{Torque} \]

Chapter 11: Rolling, Torque, and Angular Momentum

\[ K = \frac{1}{2} I_{\text{com}} \omega^2 + \frac{1}{2} M v_{\text{com}}^2 \quad \text{Kinetic energy of a rolling wheel} \]

\[ v_{\text{com}} = \omega R \quad \text{linear velocity of wheel's center of mass} \]

\[ a_{\text{com}} = \alpha R \quad \text{linear acceleration of wheel's center of mass} \]

\[ \vec{I} = \vec{r} \times \vec{p} = m(\vec{r} \times \vec{\dot{v}}) \quad \text{angular momentum} \]
\[ l = rm \sin(\phi) \]

\[ \vec{L}_f = \vec{L}_i \] Conservation of Angular Momentum

Chapter 12: Statics

For a system in static equilibrium:

\[ F_{net} = 0 \quad \text{(sum of all the forces must be zero.)} \]

\[ \tau_{net} = 0 \quad \text{(sum of all the torques must be zero.)} \]

Chapter 15: Oscillations

Simple Harmonic Motion

\[ x(t) = x_m \cos(\omega t + \phi) \quad \text{(displacement)} \]

\[ x_m \] is the amplitude

\[ \omega = \frac{2\pi}{T} = 2\pi f \quad \text{(angular frequency)} \]

\[ v(t) = -\omega x_m \sin(\omega t + \phi) \quad \text{(velocity)} \]

\[ v_m = \omega x_m \quad \text{(velocity amplitude)} \]

\[ a(t) = -\omega^2 x_m \cos(\omega t + \phi) \quad \text{(acceleration)} \]

\[ a_m = \omega^2 x_m \quad \text{(acceleration amplitude)} \]

\[ a(t) = -\omega^2 x(t) \]

For linear simple harmonic oscillator (S.H.O.)

\[ \omega = \sqrt{k/m} \quad \text{(angular frequency)} \]

\[ T = 2\pi \sqrt{m/k} \quad \text{(period of a spring)} \]

\[ T = 2\pi \sqrt{L/g} \quad \text{(period of simple pendulum)} \]

Energy

\[ U(t) = \frac{1}{2} kx^2 = \frac{1}{2} kx_m^2 \cos^2(\omega t + \phi) \quad \text{(potential energy)} \]

\[ K(t) = \frac{1}{2} mv^2 = \frac{1}{2} kx_m^2 \sin^2(\omega t + \phi) \quad \text{(kinetic energy)} \]

\[ E = U + K = \frac{1}{2} kx_m^2 \quad \text{(total energy)} \]
Chapter 16: Waves

Types of waves:
- Mechanical (must have a medium through which to propagate)
- Electromagnetic (does not need a medium through which to propagate)

Transverse waves: Displacement of every oscillating element is perpendicular to direction of travel.
Examples: waves in water, waves on a string

Longitudinal waves: Displacement of every oscillating element is parallel to direction of travel.
Examples: sound waves

\[ y(t) = y_m \sin(kx - \omega t) \] (general expression for a wave)

- \( y_m \) is the amplitude
- \( k \) is angular wave number
- \( x \) is position
- \( \omega \) is angular frequency
- \( t \) is time

\[ \omega = \frac{2 \pi}{T} \]

\[ f = \frac{1}{T} = \frac{\omega}{2\pi} \]

Speed of traveling wave (assume \( kx - \omega t \) is constant)

\[ v = \frac{\omega}{k} = \frac{\lambda}{T} = \lambda f \]

\[ y(x, t) = \sin(kx \pm \omega t) \] (- means wave travels in +x direction)
(+ means wave travels in – x direction)

\[ v = \sqrt{\frac{T}{\mu}} \] (for a stretched string)

Constructive & destructive interference

Chapter 17: Sound

sound is longitudinal, mechanical wave

\[ f = f_v \frac{v \pm v_p}{v \pm v_s} \] Doppler effect
Chapter 14: Fluids

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

\[ p = \frac{F}{A} \]  pressure (if force is uniform over a flat area)

\[ A_1 v_1 = A_2 v_2 \]  Continuity Equation

\[ p + \frac{1}{2} \rho v^2 + \rho g y = \text{constant} \]  Bernoulli’s equation based on Conservation of Mechanical Energy

\[ p + \rho g y = \text{constant} \quad \text{or} \quad p_2 = p_1 + \rho g (y_1 - y_2) \]  for fluid at rest, \( v = 0 \)

\[ p + \frac{1}{2} \rho v^2 = \text{constant} \]  for \( y = \) constant; if \( v \) increases, then \( p \) decreases

Chapter 18: Temperature, Heat, and the 1\textsuperscript{st} Law of Thermodynamics

\[ \Delta L = L \alpha \Delta T \]  Linear thermal expansion

\[ Q = cm(T_f - T_i) \]  Heat; \( c \) is specific heat of material

\[ Q = Lm \]  Heat of Transformation

\[ \Delta E_{\text{internal}} = E_{\text{internal}, f} + E_{\text{internal}, i} = Q - W \]  1\textsuperscript{st} Law of Thermodynamics

Special cases of the 1\textsuperscript{st} Law of Thermodynamics

adiabatic process:  \( Q = 0, \Delta E_{\text{internal}} = -W \)

constant-volume process:  \( W = 0, \Delta E_{\text{internal}} = Q \)

cyclical process:  \( \Delta E_{\text{internal}} = 0, Q = W \)

free expansions:  \( Q = W = \Delta E_{\text{internal}} = 0 \)

\[ P_{\text{cond}} = \frac{Q}{t} = kA \frac{T_H - T_C}{L} \]  Heat Conduction Rate