Chapter 10
Dynamics of Rotational Motion

\[ \tau = Fl = rF \sin(\theta) = F_{cm}r \]

\[ \bar{\tau} = \bar{r} \times \bar{F} \]

\[ \sum \tau_z = I\alpha_z \]

\[ K = \frac{1}{2} Mv_{cm}^2 + \frac{1}{2} I_{cm}\omega^2 \]

\[ v_{cm} = R\omega \]

\[ \sum \bar{F}_{ext} = M\bar{a}_{cm} \]

\[ \sum \tau_z = I_{cm}\alpha_z \]

\[ W = \int_{\theta_1}^{\theta_2} \tau_z d\theta \]

\[ W = \tau_z(\theta_2 - \theta_1) \]

\[ W = \int_{\omega_1}^{\omega_2} I\omega_z d\omega_z = \frac{1}{2} I\omega_z^2 - \frac{1}{2} I\omega_1^2 \]

\[ P = \tau_z\omega_z \]

\[ \bar{L} = \bar{r} \times \bar{p} = \bar{r} \times m\bar{v} \]

\[ \bar{L} = I\bar{\omega} \]

\[ \sum \bar{\tau} = \frac{d\bar{L}}{dt} \]

Chapter 11
Equilibrium and Elasticity

Conditions for equilibrium

\[ \sum \bar{F} = 0 \]

\[ \sum F_x = 0 \quad \sum F_y = 0 \quad \sum F_z = 0 \]

\[ \sum \bar{\tau} = 0 \]

\[ \bar{\tau}_{cm} = \frac{m_1\bar{r}_1 + m_2\bar{r}_2 + m_3\bar{r}_3 + \cdots}{m_1 + m_2 + m_3 + \cdots} = \frac{\sum m_i\bar{r}_i}{\sum m_i} \]

\[ \text{Stress} \quad \text{Strain} = \text{Elastic modulus} \]

\[ Y = \frac{\text{Tensile stress}}{\text{Tensile strain}} = \frac{F_{\perp}/A}{\Delta l/l_0} = \frac{F_{\perp}l_0}{A\Delta l} \]

\[ p = \frac{F_{\perp}}{A} \quad (\text{pressure in a fluid}) \]

\[ B = \frac{\text{Bulk stress}}{\text{Bulk strain}} = -\frac{\Delta p}{\Delta V/V_0} \]

\[ S = \frac{\text{Shear stress}}{\text{Shear strain}} = \frac{F_\parallel/A}{x/h} = \frac{F_\parallel h}{A x} \]
Chapter 12  Gravitation

\[ F_g = \frac{G m_1 m_2}{r^2} \]

Weight of a body of mass \( m \) at the earth’s surface

\[ w = F_g = \frac{G m_1 m}{R_E^2} \]

Acceleration due to gravity at the earth’s surface

\[ g = \frac{G m_1}{R_E^2} \]

\[ U = -\frac{G m_1 m}{r} \]

\[ v = \sqrt{\frac{G m_1}{r}} \] (circular orbit)

\[ T = \frac{2\pi r}{v} = 2\pi \sqrt{\frac{r}{G m_1}} \]

\[ R_s = \frac{2GM}{c^2} \] (Schwarzschild radius)

Chapter 13  Periodic motion

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

(relationships between frequency and period)

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

\[ F_s = -kx \]

(restoring force exerted by an ideal spring)

\[ a_s = \frac{d^2 x}{dt^2} = -\frac{k}{m} x \] (simple harmonic motion)

\[ \omega = \sqrt{\frac{k}{m}} \] (simple harmonic motion)

\[ f = \frac{\omega}{2\pi} = \frac{1}{2\pi} \sqrt{\frac{k}{m}} \]

(simple harmonic motion)

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

(simple harmonic motion)

\[ x = A \cos(\omega t + \phi) \] (harmonic displacement)

\[ E = \frac{1}{2} m v^2 + \frac{1}{2} kx^2 = \frac{1}{2} k A^2 \] = constant

(total mechanical energy)

Angular or rotational harmonic motion

\[ \omega = \sqrt{\frac{\kappa}{I}} \quad \text{and} \quad f = \frac{1}{2\pi} \sqrt{\frac{\kappa}{I}} \]
Simple pendulum
\[ \omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{mg}{L}} = \sqrt{\frac{g}{L}} \]
\[ f = \frac{\omega}{2\pi} = \frac{1}{2\pi} \sqrt{\frac{g}{L}} \]
\[ T = \frac{2\pi}{\omega} = \frac{1}{f} = 2\pi \sqrt{\frac{L}{g}} \]

Physical pendulum
\[ \omega = \sqrt{\frac{mgd}{I}} \]
\[ T = 2\pi \sqrt{\frac{I}{mgd}} \]

Damping - small
\[ x = Ae^{-\left(\frac{b}{2m}\right)t} \cos(\omega't + \phi) \]
\[ \omega' = \sqrt{\frac{k - b^2}{m - 4m^2}} \]

Driven oscillator
\[ A = \frac{F_{\text{max}}}{\sqrt{(k - m\omega_d^2)^2 + b^2\omega_d^2}} \]

Chapter 14  Fluid mechanics
\[ \rho = \frac{m}{V} \] (definition of density)
\[ p = \frac{dF}{dA} \] (definition of pressure)
\[ p_2 - p_1 = -\rho g (y_2 - y_1) \] (pressure in a fluid of uniform density)
\[ p = p_0 + \rho gh \] (pressure in a fluid of uniform density)
\[ A_1v_1 = A_2v_2 \] (continuity equation, incompressible fluid)
\[ \frac{dV}{dt} = Av \] (volume flow rate)
\[ p_1 + \rho g y_1 + \frac{1}{2} \rho v_1^2 = p_2 + \rho g y_2 + \frac{1}{2} \rho v_2^2 \]
Bernoulli’s equation

Chapter 17 Temperature and Heat
\[ T_F = \frac{9}{5}T_C + 32^\circ \]
\[ T_C = \frac{5}{9}(T_F - 32^\circ) \]
\[ T_K = T_C + 273.15 \]
\[ \frac{T_2}{T_1} = \frac{p_2}{p_1} \] (constant-volume gas thermometer, T in kelvins)
\[ \Delta L = \alpha L_0 \Delta T \]  
(linear thermal expansion)

\[ \Delta V = \beta V_0 \Delta T \]  
(volume thermal expansion)

\[ \frac{F}{A} = -Y \alpha \Delta T \]  
(thermal stress)

\[ Q = mc \Delta T \]  
(heat required for a temperature change \( \Delta T \) of mass \( m \))

\[ Q = nC \Delta T \]  
(heat required for temperature change of \( n \) moles)

\[ Q = \pm mL \]  
(heat transfer in a phase change)

\[ H = \frac{dQ}{dt} = kA \frac{T_H - T_C}{L} \]  
(heat current in conduction)

\[ H = A e \sigma T^4 \]  
(heat current in radiation)

\[ H_{net} = A e \sigma T^4 - A e \sigma T_v^4 = A e \sigma (T^4 - T_v^4) \]

\[ K_v = \frac{3}{2} nRT \]  
(average translational kinetic energy of \( n \) moles of ideal gas)

\[ \frac{1}{2} m \left( \frac{v^2}{\text{av}} \right) = \frac{3}{2} k_B T \]  
(average translational kinetic energy of a gas molecule)

\[ v_{rms} = \sqrt{\left( \frac{v^2}{\text{av}} \right)} = \sqrt{\frac{3k_B T}{m}} = \sqrt{\frac{3RT}{M}} \]  
(root-mean-square speed of a gas molecule)

\[ \Lambda = v_{\text{mean}} = \frac{V}{4\pi \sqrt{2r^2 N}} \]  
(mean free path of a gas molecule)

\[ C_v = \frac{3}{2} R \]  
(molar heat capacity of an ideal monoatomic gas, constant volume)

\[ C_v = \frac{5}{2} R \]  
(molar heat capacity of an ideal diatomic gas, constant volume)

\[ C_v = 3 \frac{N}{V} k_B T \]  
(high temperature limit, solid heat capacity, \( N/V \) - atom density)

\[ f(v) = 4\pi \left( \frac{m}{2\pi k_B T} \right)^{3/2} v^2 e^{-mv^2/2k_B T} \]  
(Maxwell-Boltzmann distribution)
Chap. 19 The First Law of Thermo
\[ W = \int_{V_i}^{V_f} p\,dV \]
(work done by the system in a volume change)

\[ W = p(V_f - V_i) \]
(work done by the system in a volume change at constant pressure)

\[ U_2 - U_1 = \Delta U = Q - W \]
(first law of thermo)

\[ dU = dQ - dW \]
(first law of thermo, infinitessimal process)

\[ C_p = C_v + R \]
(molar heat capacity of an ideal gas, constant pressure)

\[ \gamma = \frac{C_p}{C_v} \]
(ratio of heat capacities)

\[ W = nC_v(T_f - T_i) \]
(adiabatic process, ideal gas)

\[ W = \frac{C_v}{R}(p_iV_i - p_2V_2) = \frac{1}{\gamma - 1}(p_iV_i - p_2V_2) \]
(adiabatic process, ideal gas)

\[ pV^\gamma = \text{constant} \]
\[ TV^{\gamma-1} = \text{constant} \]
\[ \frac{T}{\gamma} = \text{constant} \]
\[ \frac{P}{\gamma} = \text{constant} \]
(adiabatic process, ideal gas)

Chap. 20. The Second Law of Thermo
\[ e = \frac{W}{Q_H} = 1 + \frac{Q_L}{Q_H} = 1 - \frac{|Q_C|}{|Q_H|} \]
(thermal efficiency of an engine)

\[ e = 1 - \frac{1}{\gamma - 1} \]
(thermal efficiency in Otto cycle)

\[ K = \frac{|Q_C|}{|W|} = \frac{|Q_C|}{|Q_H| - |Q_L|} \]
(coefficient of performance of a refrigerator)

\[ e_{Carnot} = 1 - \frac{T_C}{T_H} = \frac{T_H - T_C}{T_H} \]
(efficiency of a Carnot engine)

\[ K_{Carnot} = \frac{T_C}{T_H - T_C} \]
(coefficient of performance of a Carnot refrigerator)

\[ S = k_B \ln w \]
(microscopic expression for entropy)

\[ \Delta S = \int_i^f \frac{dQ}{T} \]
(entropy change in a reversible process)

\[ \Delta S = S_2 - S_1 = \frac{\Delta Q}{T} \]
(reversible isothermal process)

\[ \Delta S = S_2 - S_1 = Nk_B \ln \left( \frac{V_2}{V_1} \right) \]
(for an ideal gas in an isothermal process)