1 Classical Mechanics

Parallel axis theorem (moment of inertia $I$ about a parallel axis $h$ from axis where moment of inertia $I_0$ is known):

\[ I = I_0 + Mh^2 \]  

(1)

Euler-Lagrange equations (for each generalized co-ordinate $q_j$):

\[ \frac{\partial L}{\partial q_j} - \frac{d}{dt} \frac{\partial L}{\partial \dot{q}_j} = 0 \]  

(2)

Hamilton’s equations (where $p_j = \frac{\partial L}{\partial \dot{q}_j}$)

\[ \dot{q}_k = \frac{\partial H}{\partial p_k} \]  

(3)

\[ -\dot{p}_k = \frac{\partial H}{\partial q_k} \]  

(4)

2 Thermodynamics and Statistical Mechanics

In an adiabatic process, $pV^\gamma = \text{constant}$, where $\gamma = C_p/C_V = 1 + R/C_V$.

Thermodynamic identity:

\[ dE = T ds - p dV \]  

(5)

Equipartition theorem: in classical stat mech, a system has a mean energy of $\frac{1}{2}kT$ per independent quadratic term in the Hamiltonian.

Entropy in terms of microstates:

\[ S = k \ln \Omega \]  

(6)

3 Electricity and Magnetism

Here we will use SI units.
Maxwell’s equations:
\[
\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0} \\
\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \\
\nabla \cdot \mathbf{B} = 0 \\
\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \varepsilon_0 \frac{\partial \mathbf{J}}{\partial t}
\]

Electric field in a homogeneous linear dielectric filling all space:
\[
\mathbf{E} = \frac{1}{\varepsilon_r} \mathbf{E}_{\text{vac}}
\]
where the dielectric constant \( \varepsilon_r = \varepsilon / \varepsilon_0 \).

Biot-Savart Law:
\[
d\mathbf{B} = \frac{\mu_0}{4\pi} \frac{I \, d\mathbf{l} \times \hat{\mathbf{r}}}{r^2}
\]

Larmor formula for power radiated by a point charge:
\[
P = \frac{\mu_0 q^2 a^2}{6\pi c}
\]

Current amplitude in driven LRC circuit:
\[
I = \frac{\mathcal{E}_0}{\sqrt{R^2 + (\omega L - \frac{1}{wC})^2}}
\]

Resonance frequency:
\[
\omega_{\text{res}} = \frac{1}{\sqrt{LC}}
\]

Time constant for RC circuit: \( \tau_{RC} = RC \)

Time constant for LR circuit: \( \tau_{LR} = L/R \)

4 Waves and Optics

Doppler effect for sound (detector speed \( v_D \), source speed \( v_S \))
\[
\nu' = \nu \frac{v \pm v_D}{v \pm v_S}
\]

First-order spherical lens equation (holds for mirrors too):
\[
\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f}
\]
Here negative image distances \( s_o \) correspond to virtual images.

Lens-maker’s equation (thin lens in air, radius of curvature positive for light incident on a convex refracting surface):
\[
\frac{1}{f} = (n - 1) \left( \frac{1}{r_1} - \frac{1}{r_2} \right)
\]

Diffraction equation for bright fringes (holds for double-slit as well as diffraction grating, although physics is different)
\[
d \sin \theta = m \lambda
\]

Thin film interference (bright fringes, film in air, requires film to be above a material w/higher refractive
\[ 2L = (m + 1/2) \frac{\lambda}{n_2} \]  
Rayleigh criterion:
\[ \sin \theta = 1.22 \frac{\lambda}{d} \]  

5 Special Relativity

Lorentz transformation (primed frame moving wrt to first frame with speed \( v \)): 
\[ t' = \gamma \left( t - \frac{v}{c^2} x \right) \] 
\[ x' = \gamma(x - vt) \] 
\[ y' = y \] 
\[ z' = z \]

Einstein velocity addition:
\[ v_{AC} = \frac{v_{AB} + v_{BC}}{1 + (v_{AB}v_{BC}/c^2)} \]

Relativistic energy:
\[ E = \frac{mc^2}{\sqrt{1 - \beta^2}} = \gamma mc^2 \]  
Relativistic momentum:
\[ \mathbf{p}_{\text{rel}} = \gamma m \mathbf{v} \]  

6 Atomic, Nuclear, and Particle Physics

Wien’s displacement law (for blackbody spectrum):
\[ \lambda_{\text{max}} T = 2.898 \times 10^{-3} \text{ m} \cdot \text{K} \]  
Stefan-Boltzmann law for power radiated per unit area:
\[ \frac{P}{A} = \epsilon \sigma T^4 \]
where \( \sigma = 5.67 \times 10^{-8} \text{ W/(m}^2\text{K}^4) \).

Energy levels of hydrogen atom:
\[ E_n = -\frac{mZ^2e^4}{2\hbar^2(4\pi\epsilon_0)^2 n^2} = -\frac{13.6 \text{ eV}}{n^2} \]

7 Quantum Mechanics

Commutator product rules:
\[ [\hat{A}\hat{B}, \hat{C}] = \hat{A}[\hat{B}, \hat{C}] + [\hat{A}, \hat{C}]\hat{B} \]  
\[ [\hat{A}, \hat{B}\hat{C}] = \hat{B}[\hat{A}, \hat{C}] + [\hat{A}, \hat{B}]\hat{C} \]
Angular momentum operator commutation relations:
\[ [L_x, L_y] = i\hbar L_z \]  \hspace{1cm} (36)
and likewise for cyclic permutations. Angular momentum eigenstates \(|lm\rangle\):
\[ L^2|lm\rangle = l(l + 1)\hbar^2|lm\rangle \quad \text{(37)} \]
\[ L_z|lm\rangle = m\hbar|lm\rangle \quad \text{(38)} \]

Position representation of angular momentum eigenstates:
\[ Y^m_l(\theta, \phi) = \left[ \frac{(2l + 1)(l - m)!}{4\pi(l + m)!} \right]^{1/2} (-1)^m e^{im\phi} P^m_l(\cos \theta) \]  \hspace{1cm} (39)

In the associated Legendre polynomials \(P^m_l(\cos \theta)\), the highest power of \(\cos \) or \(\sin \) \(\theta\) is \(l\).

Dipole selection rules:
\[ \Delta n = \text{anything} \quad \text{(40)} \]
\[ \Delta l = \pm 1 \quad \text{(41)} \]
\[ \Delta m_l = 0, \pm 1 \quad \text{(42)} \]

Time-independent, nondegenerate perturbations:
\[ E^1 = \langle \psi | H_p | \psi \rangle \quad \text{(43)} \]

First-order energy correction given by expectation value of perturbing Hamiltonian on unperturbed eigenstates.

8 Miscellaneous

Poisson distribution: \(\sigma = \sqrt{\mu}\)