General Physics Formulae

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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):

$$I = I_0 + Mh^2 \tag{1}$$

Euler-Lagrange equations (for each generalized coordinate q_j):

$$\frac{\partial L}{\partial q_j} - \frac{d}{dt}\frac{\partial L}{\partial \dot{q}_j} = 0 \tag{2}$$

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

$$\dot{q}_k = \frac{\partial H}{\partial p_k} \tag{3}$$

$$-\dot{p}_k = \frac{\partial H}{\partial q_k} \tag{4}$$

2 Thermodynamics and Statistical Mechanics

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

Thermodynamic identity:

$$dE = T\,ds - p\,dV \tag{5}$$

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:

$$S = k \ln \Omega \tag{6}$$

3 Electricity and Magnetism

Here we will use SI units.

Maxwell's equations:

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0} \tag{7}$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \tag{8}$$

$$\nabla \cdot \mathbf{B} = 0 \tag{9}$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \epsilon_0 \frac{\partial \mathbf{J}}{\partial t} \tag{10}$$

Electric field in a homogeneous linear dielectric filling all space:

$$\mathbf{E} = \frac{1}{\epsilon_r} \mathbf{E}_{\text{vac}} \tag{11}$$

where the dielectric constant $\epsilon_r = \epsilon/\epsilon_0$.

Biot-Savart Law:

$$d\mathbf{B} = \frac{\mu_0}{4\pi} \frac{I \, d\mathbf{l} \times \hat{\mathbf{r}}}{r^2} \tag{12}$$

Larmor formula for power radiated by a point charge:

$$P = \frac{\mu_0 q^2 a^2}{6\pi c} \tag{13}$$

Current amplitude in driven LRC circuit:

$$I = \frac{\mathcal{E}_0}{\sqrt{R^2 + \left(\omega L - \frac{1}{wC}\right)^2}} \tag{14}$$

Resonance frequency:

$$\omega_{\text{res}} = \frac{1}{\sqrt{LC}} \tag{15}$$

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)

$$\nu' = \nu \frac{v \pm v_D}{v \pm v_S} \tag{16}$$

First-order spherical lens equation (holds for mirrors too):

$$\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f} \tag{17}$$

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):

$$\frac{1}{f} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \tag{18}$$

Diffraction equation for bright fringes (holds for double-slit as well as diffraction grating, although physics is different)

$$d \sin\theta = m\lambda \tag{19}$$

Thin film interference (bright fringes, film in air, requires film to be above a material w/higher refractive index)

$$2L = (m + 1/2)\frac{\lambda}{n_2} \tag{20}$$

Rayleigh criterion:

$$\sin\theta = 1.22\frac{\lambda}{d} \tag{21}$$

5 Special Relativity

Lorentz transformation (primed frame moving wrt to first frame with speed v):

$$t' = \gamma\left(t - \frac{v}{c^2}x\right) \tag{22}$$
$$x' = \gamma(x - vt) \tag{23}$$
$$y' = y \tag{24}$$
$$z' = z \tag{25}$$

Einstein velocity addition:

$$v_{AC} = \frac{v_{AB} + v_{BC}}{1 + (v_{AB}v_{BC}/c^2)} \tag{26}$$

Relativistic energy:

$$E = \frac{mc^2}{\sqrt{1-\beta^2}} = \gamma mc^2 \tag{27}$$

Relativistic momentum:

$$\mathbf{p}_{\text{rel}} = \gamma m\mathbf{v} \tag{28}$$

Momentum-energy relation:

$$E^2 = m^2c^4 + p^2c^2 \tag{29}$$

Doppler effect for light:

$$\nu = \nu_0\frac{\sqrt{1\pm\beta}}{\sqrt{1\mp\beta}} \tag{30}$$

6 Atomic, Nuclear, and Particle Physics

Wien's displacement law (for blackbody spectrum):

$$\lambda_{\text{max}}T = 2.898\times10^{-3}\ \text{m}\cdot\text{K} \tag{31}$$

Stefan-Boltzmann law for power radiated per unit area:

$$\frac{P}{A} = \epsilon\sigma T^4 \tag{32}$$

where σ=5.67×10^{-8} W/(m^2K^4).

Energy levels of hydrogen atom:

$$E_n = -\frac{mZ^2e^4}{2\hbar^2(4\pi\epsilon_0)^2}\frac{1}{n^2} = -\frac{13.6\ \text{eV}}{n^2} \tag{33}$$

7 Quantum Mechanics

Commutator product rules:

$$[\hat{A}\hat{B},\hat{C}] = \hat{A}[\hat{B},\hat{C}] + [\hat{A},\hat{C}]\hat{B} \tag{34}$$
$$[\hat{A},\hat{B}\hat{C}] = \hat{B}[\hat{A},\hat{C}] + [\hat{A},\hat{B}]\hat{C} \tag{35}$$

Angular momentum operator commutation relations:

$$[L_x, L_y] = i\hbar L_z \tag{36}$$

and likewise for cyclic permutations. Angular momentum eigenstates $|lm\rangle$:

$$\mathbf{L}^2|lm\rangle = l(l+1)\hbar^2|lm\rangle \tag{37}$$

$$L_z|lm\rangle = m\hbar|lm\rangle \tag{38}$$

Position representation of angular momentum eigenstates:

$$Y_l^m(\theta, \phi) = \left[\frac{(2l+1)(l-m)!}{4\pi(l+m)!}\right]^{1/2} (-1)^m e^{im\phi} P_l^m(\cos\theta) \tag{39}$$

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

Dipole selection rules:

$$\Delta n = \text{anything} \tag{40}$$

$$\Delta l = \pm 1 \tag{41}$$

$$\Delta m_l = 0, \pm 1 \tag{42}$$

Time-independent, nondegenerate perturbations:

$$E^1 = \langle\psi|H_p|\psi\rangle \tag{43}$$

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

8 Miscellaneous

Poisson distribution: $\sigma = \sqrt{\mu}$