Unit 2

- Principle of Einsteinian Relativity

- Lorentz transformations

$$x' = \gamma (x - vt)$$

$$t' = \gamma t (1 - v x/c)$$

$$\gamma = 1/\sqrt{1-\beta^2}$$

- time dilation: $\Delta t = \gamma \Delta t_p$

- Lorentz contraction:

$$L = L_p/\gamma$$

- Exponential Decay Law

$$N(t) = N_0 \exp\left(-\frac{\ln 2\, t}{t_{1/2}}\right)$$

- Relativistic Doppler Shift

$$f = f_0 \frac{\sqrt{1+\beta}}{\sqrt{1-\beta}}$$

- Rel. Momentum: $p = \gamma m v$

- Rel. Energy: $KE = mc^2(\gamma - 1)$

- Binding Energy:

$$E_b = \sum_i m_i c^2 - M_{Bound} c^2$$

Unit 3

Wien's Law: $\lambda_{max} T = 2.9 \times 10^{-3}\, m \cdot K$

Stefan-Boltzmann Law:

$$\frac{Power}{Area} = \epsilon \sigma T^4$$

Quantum: $E = h\nu$

Photoelectric Effect:

$$h\nu - \phi = \frac{1}{2} m v_{max}^2 = eV_0$$

Compton Effect: $\Delta \lambda = \frac{h}{mc}(1 - \cos\theta)$

Unit 4:

Angular momentum: $L = n\hbar$

Uncertainty Principles:

$$\Delta p \Delta x \geq \hbar/2$$

$$\Delta E \Delta t \geq \hbar/2$$

Hydrogen Atom Radius: $r_n = \frac{n^2 \hbar^2 4\pi\epsilon_0}{me^2}$

$$= n^2 a_0 = 0.53 Å$$

-ground state Energy:

$$E_1 = \frac{-me^4}{2\hbar^2 (4\pi\epsilon_0)^2} = -13.6 eV = (-E_0)$$

Rydberg Equation:

$$\frac{1}{\lambda} = \frac{E_0}{hc}\left[\frac{1}{n_B^2} - \frac{1}{n_A^2}\right]$$

Balmer: $n_B = 1$

Lyman: $n_B = 2$

Paschen: $n_B = 3$

Unit 5:

Time Independent Schrödinger Eq.:

$$-\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2} + U(x)\psi(x) = E\psi(x)$$

Normalization of wave-function:

$$P = \int_{-\infty}^{\infty} \psi^*(x)\psi(x)\,dx = 1$$

Solution when $V(x) = 0$

$$\psi(x) = A\sin kx + B\cos kx \quad \left(k = \frac{\sqrt{2mE}}{\hbar}\right)$$

- when $E > V(x) \neq 0$

$$\rightarrow k = \frac{\sqrt{2m(E-V_0)}}{\hbar}$$

Infinite Square Well Energy levels:

$$E_n = \frac{n^2\pi^2\hbar^2}{L^2 2m}$$

Expectation Values:

$$\langle f(x)\rangle = \int_{-\infty}^{\infty} \psi^* f(x)\psi\,dx$$

Operators: $\hat{p} = -i\hbar\frac{\partial}{\partial x}$ $\quad \hat{x} = x$

$\hat{E} = i\hbar\frac{\partial}{\partial t}$ $\quad \hat{t} = t$

Finite Square Well: $E < V_0$

- wave function in walls

$$\psi(x) = Ce^{+\alpha x} + De^{-\alpha x}$$

$$\alpha = \sqrt{\frac{2m}{\hbar^2}(V_0 - E)}$$

- penetration distance

$$\delta x = \frac{1}{\alpha} = \hbar/\sqrt{2m(V_0-E)}$$

Simple Harmonic Oscillator:

Wave function: $\psi_n(x) = H_n(x)e^{-\alpha x^2/2}$

$n = 0 \qquad H_0(x) = \left(\frac{\alpha}{\pi}\right)^{1/4}$

$n = 1 \qquad H_1(x) = \left(\frac{\alpha}{\pi}\right)^{1/4}\sqrt{2\alpha}\;x$

$n = 2 \qquad H_2(x) = \left(\frac{\alpha}{\pi}\right)^{1/4}\frac{1}{\sqrt{2}}(2\alpha x^2 - 1)$

Energy levels: $E_n = (n+\frac{1}{2})\hbar\omega$

Unit 6:

Potential step:

Reflection: $R = \dfrac{(\sqrt{E} - \sqrt{E-V_0})^2}{(\sqrt{E} + \sqrt{E-V_0})^2}$

Transmission: $T = \dfrac{4\sqrt{E(E-V_0)}}{(\sqrt{E} + \sqrt{E-V_0})^2}$

Potential Barrier: $(E > V_0)$

Reflection:

$$R = \frac{\sin^2[\sqrt{2m(E-V_0)}\, L/\hbar]}{\sin^2[\ldots] + 4\left(\frac{E}{V_0}\right)\left[\frac{E}{V_0} - 1\right]}$$

Complete transmission:

$$E = V_0 + \frac{n^2\pi^2\hbar^2}{2mL^2}$$

Transmission:

$$T = \left[1 + \frac{V_0^2 \sin^2[\ldots]}{4E(E-V_0)}\right]$$

$E < V_0$ case: Tunneling

Reflection:

$$R = \frac{\sinh^2[\sqrt{2m(V_0-E)}\, L/\hbar]}{\sinh^2[\ldots] + 4\left(\frac{E}{V_0}\right)\left[1 - \frac{E}{V_0}\right]}$$

Transmission:

$$T = \left[1 + \frac{V_0^2 \sinh^2[\ldots]}{4E(V_0-E)}\right]^{-1}$$

Wide Barrier:

$$T = 16\frac{E}{V_0}\left(1 - \frac{E}{V_0}\right)e^{-2\alpha x}$$

Unit 7:

3D Normalization condition:

$$P = \int_{-\infty}^{\infty} \psi^*(\vec{r}) \psi(\vec{r}) \, dV = 1$$

3D Infinite Potential Well:

$$E_n = \frac{\pi^2 \hbar^2}{2m} \left(\frac{n_1^2}{L_1^2} + \frac{n_2^2}{L_2^2} + \frac{n_3^2}{L_3^2} \right)$$

Orbital Angular Momentum:

$$L_z = m_l \hbar \qquad m_l = 0, \pm 1, \pm 2 \ldots \pm l$$

$$|L| = \sqrt{l(l+1)} \, \hbar \qquad l = 0, 1, 2 \ldots n-1$$

Energy levels: $E = \frac{-me^4}{2(4\pi\epsilon_0)^2 \hbar^2} \frac{1}{n^2}$

Radial Equation: $R(r) = Ae^{-r/a_0}$

Ground State Energy: $E = \frac{-\hbar^2}{2ma_0^2} = -E_0$

Spectroscopic notation:

$l =$	0	1	2	3	4	5
	s	p	d	f	g	h

Unit 8

Angular Magnetic Dipole Moment:

$$\vec{\mu}_L = \frac{-e}{2m_e}\vec{L}$$

Larmor frequency: $\frac{d\phi}{dt} = \frac{eB}{2m_e}$

Spin angular momentum:

$$|S| = \sqrt{s(s+1)}\,\hbar$$

$$S_z = m_s \hbar \qquad m_s = -s, \ldots +s$$

- spin magnetic dipole moment

$$\vec{\mu}_s = \gamma \frac{q}{2m}\vec{S}$$

Potential from Spin-Orbit coupling:

$$V_{SL} = -\vec{\mu}_s \cdot \vec{B}$$

$$\propto SL\cos\alpha \qquad (\alpha \text{ angle of } \vec{S} \text{ to } \vec{L})$$

Unit 10:

p-n Junction Diode:

$$|I_r| >> |I_t|$$

Reverse Bias: $I_{n\to p} \propto N e^{-eV_0/kT} = I_0$

Forward Bias: $I_{p\to n} \propto N e^{-e(V-V_0)/kT}$

$$= I_0 e^{eV/kT}$$

Total current:

$$I_{total} = I_0 \left(e^{eV/kT} - 1\right)$$