1. Special Relativity

Lorentz Transformations:

$$x' = \gamma(x - vt), \quad t' = \gamma(t - \frac{vx}{c^2})$$

where the Lorentz factor is:

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

Relativistic Dynamics:

- Time Dilation: $\Delta t = \gamma \Delta t_0$
- Length Contraction: $L = L_0/\gamma$
- Relativistic Momentum: $p = \gamma m_0 v$
- Total Energy: $E = \gamma m_0 c^2 = K + m_0 c^2$
- Energy-Momentum Relation: $E^2 = (pc)^2 + (m_0 c^2)^2$

2. Quantum Nature of Light

Photon Energy & Momentum:

$$E = hf = \frac{hc}{\lambda}, \quad p = \frac{E}{c} = \frac{h}{\lambda}$$

Photoelectric Effect:

$$K_{\max} = eV_s = hf - \Phi = h(f - f_0)$$

Where Φ is the work function, V_s is stopping potential.

Compton Scattering:

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\theta)$$

Compton wavelength $\lambda_C = \frac{h}{m_e c} \approx 2.43$ pm.

3. Matter Waves & Uncertainty

de Broglie Wavelength:

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mK}}$$

For accelerated electrons: $\lambda = \frac{1.227}{\sqrt{V}}$ nm.

Heisenberg Uncertainty Principle:

$$\Delta x \Delta p_x \geq \frac{\hbar}{2}, \quad \Delta E \Delta t \geq \frac{\hbar}{2}$$

where $\hbar = \frac{h}{2\pi} \approx 1.054 \times 10^{-34}$ J · s.

4. Atomic Models

Bohr Model (Hydrogen-like):

- Angular Momentum: $L = mvr = n\hbar$
- Radius: $r_n = \frac{n^2 a_0}{Z}$, where $a_0 \approx 0.529$ Å
- Energy Levels: $E_n = -13.6\frac{Z^2}{n^2}$ eV

Rydberg Formula:

$$\frac{1}{\lambda} = RZ^2(\frac{1}{n_1^2} - \frac{1}{n_2^2})$$

where $R \approx 1.097 \times 10^7$ m^{-1}.

5. Quantum Mechanics

1D Time-Dependent Schrödinger Eq:

$$-\frac{\hbar^2}{2m}\frac{\partial^2\Psi}{\partial x^2} + V(x)\Psi = i\hbar\frac{\partial\Psi}{\partial t}$$

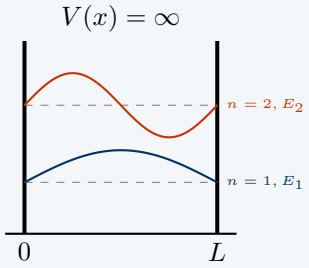
Infinite Potential Well (Box of width L):

$$\psi_n(x) = \sqrt{\frac{2}{L}}\sin(\frac{n\pi x}{L}), \quad E_n = \frac{n^2\pi^2\hbar^2}{2mL^2}$$

Quantum Harmonic Oscillator:

$$E_n = (n + \frac{1}{2})\hbar\omega, \quad n = 0, 1, 2, \ldots$$

6. Visual: Particle in a Box



7. Nuclear Physics

Mass Defect & Binding Energy:

$$\Delta m = [Zm_p + (A - Z)m_n] - M_{\text{nucleus}}$$

$$E_b = \Delta m \cdot c^2 = \Delta m \text{ (in u)} \times 931.5 \text{ MeV}$$

Radioactive Decay Law:

$$N(t) = N_0 e^{-\lambda t}, \quad A(t) = \lambda N(t)$$

- Half-Life: $T_{1/2} = \frac{\ln 2}{\lambda} \approx \frac{0.693}{\lambda}$
- Mean Life: $\tau = \frac{1}{\lambda} = \frac{T_{1/2}}{\ln 2}$

8. Solid State & Semiconductors

Intrinsic Carrier Concentration:

$$n_i^2 = n \cdot p = N_c N_v e^{-E_g/k_B T}$$

Mass Action Law:

$$n \cdot p = n_i^2 \quad \text{(Doped Semiconductors)}$$

Conductivity:

$$\sigma = e(n\mu_n + p\mu_p)$$

Band Gap Energy (E_g):

- Silicon (Si): ≈ 1.1 eV
- Germanium (Ge): ≈ 0.67 eV

9. Fundamental Constants

Speed of light (c)	3.00×10^8 m/s
Planck's constant (h)	6.626×10^{-34} J $\cdot$ s
Electron Volt (1 eV)	1.602×10^{-19} J
Electron mass (m_e)	9.109×10^{-31} kg
Proton mass (m_p)	1.673×10^{-27} kg
Atomic mass unit (1 u)	1.6605×10^{-27} kg
Rydberg constant (R)	1.097×10^7 m^{-1}

10. Key Relations Quick-Ref

- Photon Momentum: $p = h/\lambda$
- Bragg's Law: $2d \sin\theta = n\lambda$
- Stefan-Boltzmann: $P = \sigma A T^4$
- Wien's Law: $\lambda_{\max} T = 2.898 \times 10^{-3}$ m $\cdot$ K