

**Formulas and constants:**

$hc = 12,400 \text{ eV}\cdot\text{Å}$  ;  $k_B = 1/11,600 \text{ eV/K}$  ;  $ke^2 = 14.4 \text{ eV}\cdot\text{Å}$  ;  $m_e c^2 = 0.511 \times 10^6 \text{ eV}$  ;  $m_p / m_e = 1836$

Relativistic energy - momentum relation  $E = \sqrt{m^2 c^4 + p^2 c^2}$  ;  $c = 3 \times 10^8 \text{ m/s}$

Photons:  $E = hf$  ;  $p = E/c$  ;  $f = c/\lambda$  Lorentz force:  $\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$

Planck's law :  $u(\lambda) = n(\lambda)\bar{E}(\lambda)$  ;  $n(\lambda) = \frac{8\pi}{\lambda^4}$  ;  $\bar{E}(\lambda) = \frac{hc}{\lambda} \frac{1}{e^{hc/\lambda k_B T} - 1}$

Energy in a mode/oscillator :  $E_f = nhf$  ; probability  $P(E) \propto e^{-E/k_B T}$

Stefan's law :  $R = \sigma T^4$  ;  $\sigma = 5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4$  ;  $R = cU/4$  ,  $U = \int_0^\infty u(\lambda)d\lambda$

Planck :  $u(\lambda) = n(\lambda)\bar{E}(\lambda)$  ;  $n(\lambda) = \frac{8\pi}{\lambda^4}$  ;  $\bar{E}(\lambda) = \frac{hc}{\lambda} \frac{1}{e^{hc/\lambda k_B T} - 1}$  ; Wien :  $\lambda_m T = hc/4.96k_B$

Photoelectric effect :  $eV_0 = (\frac{1}{2}mv^2)_{\text{max}} = hf - \phi$  ,  $\phi \equiv$  work function

Compton :  $\lambda_2 - \lambda_1 = \frac{h}{m_e c}(1 - \cos\theta)$  ;  $\lambda_c \equiv \frac{h}{m_e c} = 0.0243 \text{ Å}$  ; Rutherford :  $b = \frac{kq_1 q_2}{m_e v^2} \cot(\theta/2)$  ;  $\Delta N \propto \frac{1}{\sin^4(\theta/2)}$

Electrostatics :  $F = \frac{kq_1 q_2}{r^2}$  (force) ;  $V = \frac{kq}{r}$  (potential) ;  $U = q_0 V$  (potential energy)

Hydrogen spectrum :  $\frac{1}{\lambda} = R(\frac{1}{m^2} - \frac{1}{n^2})$  ;  $R = 1.097 \times 10^7 \text{ m}^{-1} = \frac{1}{911.3 \text{ Å}}$

Bohr atom :  $r_n = r_0 n^2$  ;  $r_0 = \frac{a_0}{Z}$  ;  $E_n = -E_0 \frac{Z^2}{n^2}$  ;  $a_0 = \frac{\hbar^2}{mke^2} = 0.529 \text{ Å}$  ;  $E_0 = \frac{ke^2}{2a_0} = 13.6 \text{ eV}$  ;  $L = mvr = n\hbar$

$E_k = \frac{1}{2}mv^2$  ;  $E_p = -\frac{ke^2 Z}{r}$  ;  $E = E_k + E_p$  ;  $F = \frac{ke^2 Z}{r^2} = m\frac{v^2}{r}$  ;  $hf = hc/\lambda = E_n - E_m$

Reduced mass :  $\mu = \frac{mM}{m+M}$  ; X-ray spectra :  $f^{1/2} = A_n(Z-b)$  ; K :  $b=1$ , L :  $b=7.4$

de Broglie :  $\lambda = \frac{h}{p}$  ;  $f = \frac{E}{h}$  ;  $\omega = 2\pi f$  ;  $k = \frac{2\pi}{\lambda}$  ;  $E = \hbar\omega$  ;  $p = \hbar k$  ;  $E = \frac{p^2}{2m}$  ;  $\hbar c = 1973 \text{ eV}\cdot\text{Å}$

Wave packets :  $y(x,t) = \sum_j a_j \cos(k_j x - \omega_j t)$ , or  $y(x,t) = \int dk a(k) e^{i(kx - \omega(k)t)}$  ;  $\Delta k \Delta x \sim 1$  ;  $\Delta \omega \Delta t \sim 1$

group and phase velocity :  $v_g = \frac{d\omega}{dk}$  ;  $v_p = \frac{\omega}{k}$  ; Heisenberg :  $\Delta x \Delta p \sim \hbar$  ;  $\Delta t \Delta E \sim \hbar$

Wave function  $\Psi(x,t) = |\Psi(x,t)| e^{i\theta(x,t)}$  ;  $P(x,t) dx = |\Psi(x,t)|^2 dx =$  probability

Schrodinger equation :  $-\frac{\hbar^2}{2m} \frac{\partial^2 \Psi}{\partial x^2} + V(x)\Psi(x,t) = i\hbar \frac{\partial \Psi}{\partial t}$  ;  $\Psi(x,t) = \psi(x)e^{-i\frac{E}{\hbar}t}$

Time-independent Schrodinger equation :  $-\frac{\hbar^2}{2m} \frac{\partial^2 \psi}{\partial x^2} + V(x)\psi(x) = E\psi(x)$  ;  $\int_{-\infty}^{\infty} dx \psi^* \psi = 1$

$\infty$  square well :  $\psi_n(x) = \sqrt{\frac{2}{L}} \sin(\frac{n\pi x}{L})$  ;  $E_n = \frac{\pi^2 \hbar^2 n^2}{2mL^2}$  ;  $x_{op} = x$  ,  $p_{op} = \frac{\hbar}{i} \frac{\partial}{\partial x}$  ;  $\langle A \rangle = \int_{-\infty}^{\infty} dx \psi^* A_{op} \psi$

Eigenvalues and eigenfunctions :  $A_{op} \Psi = a \Psi$  ( $a$  is a constant) ; uncertainty :  $\Delta A = \sqrt{\langle A^2 \rangle - \langle A \rangle^2}$

Harmonic oscillator :  $\Psi_n(x) = C_n H_n(x) e^{-\frac{m\omega}{2\hbar} x^2}$  ;  $E_n = (n + \frac{1}{2})\hbar\omega$  ;  $E = \frac{p^2}{2m} + \frac{1}{2}m\omega^2 x^2 = \frac{1}{2}m\omega^2 A^2$  ;  $\Delta n = \pm 1$

Step potential :  $R = \frac{(k_1 - k_2)^2}{(k_1 + k_2)^2}$  ,  $T = 1 - R$  ;  $k = \sqrt{\frac{2m}{\hbar^2}(E - V)}$

Tunneling:  $\psi(x) \sim e^{-\alpha x}$  ;  $T \sim e^{-2\alpha \Delta x}$  ;  $T \sim e^{-2 \int_a^b \alpha(x) dx}$  ;  $\alpha(x) = \sqrt{\frac{2m[V(x) - E]}{\hbar^2}}$