Formulas:

Time dilation; Length contraction : $\Delta t = \gamma \Delta t' \equiv \gamma \Delta t_p$; $\quad L = L_p / \gamma \quad$; $c = 3 \times 10^8 m/s$

Lorentz transformation : $x' = \gamma(x - vt)$; $y' = y$; $z' = z$; $t' = \gamma(t - vx/c^2)$; inverse : $v \rightarrow -v$

Spacetime interval : $(\Delta s)^2 = (c\Delta t)^2 - [\Delta x^2 + \Delta y^2 + \Delta z^2]$

Velocity transformation : $u_x' = \dfrac{u_x - v}{1 - u_x v/c^2}$; $u_y' = \dfrac{u_y}{\gamma(1 - u_x v/c^2)}$; inverse : $v \rightarrow -v$

Relativistic Doppler shift : $f_{obs} = f_{source} \sqrt{1 + v/c} \ / \ \sqrt{1 - v/c}$ (approaching)

Momentum : $\vec{p} = \gamma m\vec{u}$; Energy : $E = \gamma mc^2$; Kinetic energy : $K = (\gamma - 1)mc^2$

Rest energy : $E_0 = mc^2$; $E = \sqrt{p^2 c^2 + m^2 c^4}$

Electron : $m_e = 0.511 \ MeV/c^2$ Proton : $m_p = 938.26 \ MeV/c^2$ Neutron : $m_n = 939.55 \ MeV/c^2$

Atomic mass unit : $1 \ u = 931.5 \ MeV/c^2$; electron volt : $1eV = 1.6 \times 10^{-19} \ J$

Stefan's law : $e_{tot} = \sigma T^4$, $e_{tot} =$ power/unit area ; $\sigma = 5.67 \times 10^{-8} W/m^2 K^4$

$e_{tot} = cU/4$, $U =$ energy density $= \displaystyle\int_0^\infty u(\lambda, T) d\lambda$; Wien's law : $\lambda_m T = \dfrac{hc}{4.96 k_B}$

Boltzmann distribution : $P(E) = Ce^{-E/(k_B T)}$

Planck's law : $u_\lambda(\lambda, T) = N_\lambda(\lambda) \times \overline{E}(\lambda, T) = \dfrac{8\pi}{\lambda^4} \times \dfrac{hc/\lambda}{e^{hc/\lambda k_B T} - 1}$; $N(f) = \dfrac{8\pi f^2}{c^3}$

Photons : $E = hf = pc$; $f = c/\lambda$; $hc = 12,400 \ eV A$; $k_B = (1/11,600)eV/K$

Photoelectric effect : $eV_s = K_{max} = hf - \phi$, $\phi \equiv$ work function; Bragg equation : $n\lambda = 2d \sin\vartheta$

Compton scattering : $\lambda' - \lambda = \dfrac{h}{m_e c}(1 - \cos\theta)$; $\dfrac{h}{m_e c} = 0.0243A$; Coulomb constant : $ke^2 = 14.4 \ eV A$

Coulomb force : $F = \dfrac{kq_1 q_2}{r^2}$; Coulomb potential : $V = \dfrac{kq}{r}$; Coulomb energy : $U = \dfrac{kq_1 q_2}{r}$

Force in electric and magnetic fields (Lorentz force) : $\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$

Rutherford scattering : $\Delta n = C \dfrac{Z^2}{K_\alpha^2} \dfrac{1}{\sin^4(\phi/2)}$; $\hbar c = 1,973 \ eV A$

Hydrogen spectrum : $\dfrac{1}{\lambda_{mn}} = R\left(\dfrac{1}{m^2} - \dfrac{1}{n^2}\right)$; $R = 1.097 \times 10^7 \ m^{-1} = \dfrac{1}{911.3A}$

Bohr atom : $E_n = -\dfrac{ke^2 Z}{2r_n} = -E_0 \dfrac{Z^2}{n^2}$; $E_0 = \dfrac{ke^2}{2a_0} = \dfrac{m_e(ke^2)}{2\hbar^2} = 13.6eV$; $K = \dfrac{m_e v^2}{2}$; $U = -\dfrac{ke^2 Z}{r}$

$hf = E_i - E_f$; $r_n = r_0 n^2$; $r_0 = \dfrac{a_0}{Z}$; $a_0 = \dfrac{\hbar^2}{m_e ke^2} = 0.529A$; $L = m_e vr = n\hbar$ angular momentum

de Broglie : $\lambda = \dfrac{h}{p}$; $f = \dfrac{E}{h}$; $\omega = 2\pi f$; $k = \dfrac{2\pi}{\lambda}$; $E = \hbar\omega$; $p = \hbar k$; $E = \dfrac{p^2}{2m}$

Wave packets : $y(x,t) = \displaystyle\sum_j a_j \cos(k_j x - \omega_j t)$, 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 : $v_g = \dfrac{d\omega}{dk}$; $v_p = \dfrac{\omega}{k}$; Heisenberg : $\Delta x \Delta p \sim \hbar$; $\Delta t \Delta E \sim \hbar$

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

Time − independent Schrodinger equation: $-\dfrac{\hbar^2}{2m}\dfrac{\partial^2 \psi}{\partial x^2} + U(x)\psi(x) = E\psi(x)$; $\displaystyle\int_{-\infty}^{\infty} dx \; |\psi(x)|^2 = 1$

∞ square well: $\psi_n(x) = \sqrt{\dfrac{2}{L}}\sin(\dfrac{n\pi x}{L})$; $E_n = \dfrac{\pi^2\hbar^2 n^2}{2mL^2}$; $\dfrac{\hbar^2}{2m_e} = 3.81 eVA^2$ (electron)

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

Expectation value of [Q]: $<Q> = \int \psi^*(x)[Q]\psi(x)\,dx$; Momentum operator: $p = \dfrac{\hbar}{i}\dfrac{\partial}{\partial x}$

Eigenvalues and eigenfunctions: $[Q]\Psi = q\Psi$ (q is a constant) ; uncertainty: $\Delta Q = \sqrt{<Q^2> - <Q>^2}$

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

Tunneling: $\psi(x) \sim e^{-\alpha x}$; $T = e^{-2\alpha\Delta x}$; $T = e^{-2\int_{x_1}^{x_2}\alpha(x)dx}$; $\alpha(x) = \sqrt{\dfrac{2m[U(x)-E]}{\hbar^2}}$

Schrodinger equation in 3D: $-\dfrac{\hbar^2}{2m}\nabla^2\Psi + U(\vec{r})\Psi(\vec{r},t) = i\hbar\dfrac{\partial\Psi}{\partial t}$; $\Psi(\vec{r},t) = \psi(\vec{r})e^{-i\frac{E}{\hbar}t}$

3D square well: $\Psi(x,y,z) = \Psi_1(x)\Psi_2(y)\Psi_3(z)$; $E = \dfrac{\pi^2\hbar^2}{2m}(\dfrac{n_1^2}{L_1^2} + \dfrac{n_2^2}{L_2^2} + \dfrac{n_3^2}{L_3^2})$

Spherically symmetric potential: $\Psi_{n,\ell,m_\ell}(r,\theta,\phi) = R_{n\ell}(r)Y_\ell^{m_\ell}(\theta,\phi)$; $Y_\ell^{m_\ell}(\theta,\phi) = P_\ell^{m_\ell}(\theta)e^{im_\ell\phi}$

Angular momentum: $\vec{L} = \vec{r}\times\vec{p}$; $[L_z] = \dfrac{\hbar}{i}\dfrac{\partial}{\partial\phi}$; $[L^2]Y_\ell^{m_\ell} = \ell(\ell+1)\hbar^2 Y_\ell^{m_\ell}$; $[L_z] = m\hbar$

Radial probability density: $P(r) = r^2 |R_{n\ell}(r)|^2$; Energy: $E_n = -\dfrac{ke^2}{2a_0}\dfrac{Z^2}{n^2}$

Ground state of hydrogen and hydrogen - like ions: $\Psi_{1,0,0} = \dfrac{1}{\pi^{1/2}}(\dfrac{Z}{a_0})^{3/2}e^{-Zr/a_0}$

Orbital magnetic moment: $\vec{\mu} = \dfrac{-e}{2m_e}\vec{L}$; $\mu_z = -\mu_B m_l$; $\mu_B = \dfrac{e\hbar}{2m_e} = 5.79\times10^{-5}eV/T$

Spin 1/2: $s = \dfrac{1}{2}$, $|S| = \sqrt{s(s+1)}\hbar$; $S_z = m_s\hbar$; $m_s = \pm1/2$; $\vec{\mu}_s = \dfrac{-e}{2m_e}g\vec{S}$

Orbital + spin mag moment: $\vec{\mu} = \dfrac{-e}{2m}(\vec{L}+g\vec{S})$; Energy in mag. field: $U = -\vec{\mu}\cdot\vec{B}$

Two particles : $\Psi(\vec{r_1},\vec{r_2}) = +/- \Psi(\vec{r_2},\vec{r_1})$; symmetric/antisymmetric

Screening in multielectron atoms: $Z \to Z_{eff}$, $1 < Z_{eff} < Z$

Orbital ordering:
1s < 2s < 2p < 3s < 3p < 4s < 3d < 4p < 5s < 4d < 5p < 6s < 4f < 5d < 6p < 7s < 6d ~ 5f

Justify all your answers to all problems. Write clearly.