Please answer 5 of 6 questions, showing all calculations - 35 points each, 175 total.

1. Briefly explain why the hydrogen atom wavefunction solutions are not exact for a helium atom.

2. Given the term symbol $^2P$ for a sodium atom in an excited state (1s$^2$2s$^2$2p$^6$4p$^1$), explain the meaning of the superscript 2 and the P. How many distinct types of wavefunctions would the $^2P$ term symbol allow in this case? Calculate the orbital angular momentum for this term symbol.

3. When doing a numerical calculation of the wavefunctions for a given atom, a common approach is called the Hartree-Fock (HF) self-consistent field (SCF) method. Describe how this approach is used to generate ground state wavefunctions and energies for a given atom.

4. Write the Slater determinant for the ground state wavefunction of a boron atom (B, 5 electrons). Use the notation 1s$_A^\alpha_A$, 2s$_B^\beta_B$, 3p$_C^\alpha_C$, etc. for the electrons labeled A through E, where $\alpha$ and $\beta$ are the spin portion of the wavefunction for each electron. Explain how this determinant relates to the Pauli principle and anti-symmetry of the wavefunction.

5. For a hydrogen atom, calculate the radius ($r_{2s}$) at which the probability of finding the electron in the 2s subshell is 90%. For hydrogen, $Z = 1$ and $a = 0.5295 \times 10^{-8}$ cm. For a spherical integral, $d\tau = r^2 \sin \theta \, dr \, d\theta \, d\phi$.

$$
\Psi_{2s} = \left( \frac{1}{4} \right) (2 \pi)^{1/2} (Z/a)^{3/2} (2 - Z \cdot r/a) e^{-Z \cdot r^2 a}
$$

6. Recall that when adding spin and orbital angular momenta to arrive at a total electronic angular momentum $J$, we use the sum $J = |L + S|$, $|L + S - 1|$, ..., $|L - S|$. What are possible $J$ values for each of the following term symbols: $^4P$, $^3D$ and $^2S$. 