

## HELIUM ATOM: PARAHELIUM AND ORTHOHELIUM

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Reference: Griffiths, David J. (2005), Introduction to Quantum Mechanics, 2nd Edition; Pearson Education - Problem 5.10.

We looked at a very crude model of the helium atom, in which we ignored the interaction between the two electrons. In that model, the spatial wave function for helium is just the product of two hydrogen-like functions. In all but the ground state, we can construct totally symmetric and totally antisymmetric combinations of the wave functions. Since a system composed of two fermions (which the electrons are) must have an overall antisymmetric wave function, we need to combine symmetric spatial functions with antisymmetric spin functions, and vice versa.

States with an antisymmetric spin function are known as *parahelium*, and states with a symmetric spin function are known as *orthohelium*. Since the ground state always has a symmetric spatial function, it is always parahelium, but the excited states all come in both forms.

Because of the exchange force, the average distance between two identical particles in a symmetric spatial state is less than for an antisymmetric spatial state. Since two electrons have a higher interaction energy if they are closer together, we'd expect parahelium (symmetric spatial and antisymmetric spin) energies to be higher than the corresponding orthohelium (antisymmetric spatial and symmetric spin) states, and this is, in fact, observed experimentally.

If electrons were bosons, the situation would be reversed and the ground state would be orthohelium, since now must combine a symmetric spatial state with a symmetric spin state. When we add the two spins, the possible states are the symmetric triplet state (with total spin 1) and the antisymmetric singlet state (with total spin 0). Thus the ground state contains the triplet state. The excited states must pair a symmetric spatial state with a symmetric spin state, so all such states are triplets. All other states are singlets. The orthohelium states would now have higher energy, since they contain the symmetric spatial states.

If electrons were distinguishable, then there are no constraints on combinations of spatial and spin functions, so every energy level is four-fold degenerate, and there should be, on average, no difference in energy levels between ortho and parahelium. (I say 'on average', because atoms with a symmetric spatial function will still have higher energy, but in a large

collection of atoms, there would be roughly equal numbers of ortho and parahelium atoms with any given spatial function, so the average energy of each group would be the same.)

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