

Section A. Quantum Mechanics

1. Hydrogen Molecule

Consider a hydrogen molecule, H_2 , the bound state of two protons and two electrons.

a) Write down the Hamiltonian, keeping only the kinetic energy terms and the Coulomb interactions of all the constituents, and omitting any terms which cause fine and hyperfine structure.

In what follows, neglect all fine and hyperfine structure effects, and neglect the overall center of mass motion, but do include the spins and the relative motion of all the constituents:

b) What is the degeneracy of the ground state(s)? Give all quantum numbers and symmetries of the ground state(s), including of the electron and proton spin degrees of freedom. Explain.

c) What is the degeneracy, and what are all the quantum numbers of the first excited state(s) of this molecule? Explain.

d) What is the energy difference between ground and first excited states? Estimate it first through a formula in terms of properties of the molecule's ground state, and then give an order of magnitude estimate in electron-Volts (eV). Explain.