- 1. Problem 13.1, Schwabl [*perturbation theory of helium atom*] Add parts (c): Compute J_{20} and K_{20} defined in (13.28), and compare them in size to each other, and to (13.25). (d) A student asked in class, how do we know that the $(1s)^2$ configuration of He actually has lower energy than the 1s2s configuration? The idea behind the question was (I think) that in the latter configuration there would be less Coulomb repulsion energy of the two electrons, which conceivably could offset the fact that the second electron is not as tightly bound. In fact, the electron repulsion pushes the ground state energy fairly close to that of the unperturbed 1s2s level. Use your results of part (b) and (c) to compare (in this approximation) the energy of the $(1s)^2$ configuration to the lowest energy in the 1s2s configuration.
- 2. Problem 13.3, Schwabl [term symbols of transition metals]
- 3. Problem 15.7, Schwabl [rotational and vibrational levels of ¹H³⁵Cl]
- 4. The "dissociation energy" required to separate a D₂ molecule into two deuterium atoms (4.54 eV) is not the same as that of an H₂ molecule (4.46 eV), although the proton and deuteron are practically indistinguishable to the electrons. (a) Explain why the dissociation energies are different. (b) Use the above information to compute the zero-point energy of vibration in the H₂ and D₂ molecules. (c) Compute the rms nuclear vibration amplitude in the ground state of H₂, and compare it numerically to the nuclear separation, and to the formula on the right hand side of (15.6). (Neglect the small nuclear motion within in the atoms, and tiny finite nuclear size and hyperfine effects.)
- 5. The van der Waals interaction of two hydrogen atoms arises at second order in perturbation theory, and is thus necessarily attractive in the ground state. It decreases as $1/R^6$, since it involves the square of the leading order, $1/R^3$ term in the 1/R expansion of the interatomic potential (15.47b). But let's look more closely at *first* order in perturbation theory, to determine whether there could be a $1/R^4$ term or $1/R^5$ term. (a) Show that inversion symmetry of the unperturbed atomic ground states implies vanishing of the $1/R^4$ term, and that (b) spherical symmetry implies the $1/R^5$ term vanishes in d = 3 dimensions, but is nonzero and positive (repulsive) in d = 2 or d > 5 dimensions. [*Hint* for (b): Using spherical symmetry, express all the non-vanishing terms as multiples of $\langle 0|x_1^2x_2^2|0\rangle$.]