	Origin	Order (of α)	Consequences
Fine structure	1. Replacing the electron kinematic energy term in Hamiltonian with the full relativistic form 2. Spin-orbit couplings between the electron's orbital angular momentum and its spin, of the form **L·S**	α^2	• The hydrogen energy levels acquire a dependence on the ***total*** spin j • Since **J** commutes with **L·S**, m_j is conserved. • The energies are degenerate in m_j • The degeneracy in l is broken
Lamb shift	1. Quantum electrodynamics correction	α^3	• Split the 2s and 2p levels with j=1/2 (which are degenerate even including fine structure since they both have the same j)
Hyperfine structure	1. Magnetic dipole interaction between the spins of the electron and the proton, known as spin-spin coupling	α^2 (but suppressed by the ratio m_e/m_p)	• The ground state of hydrogen is split depending on whether the two spins are in the singlet of triplet state. • The triplet has the higher energy, roughly because the spins are aligned, and magnetic dipoles want to be anti-aligned • The wavelength of the emitted photon in a transition between these two states is about 21cm, with energy about 5×10^{-6} ev
Stark effect	1. Placing an atom in external electric field, $\underline{\Delta H = e\mathbf{E}\cdot\mathbf{r}}$	—	• There is not change in the ground state energy of hydrogen or any hydrogen atom, to first order in $\lvert\mathbf{E}\rvert$ • The lowest-energy states to show a 1st-order shift are the n=2 state. The states with m=±1 are unperturbed, but the 2s state and the 2p state with m=0 are split. • The magnitude of the splitting: from the dimensional analysis, $\Delta E = ke\lvert\mathbf{E}\rvert d$, where d is some length and k is a constant (which is not determined by this reasoning). The only length scale of the hydrogen atom is the Bohr radius, so $d \approx a_0$

Zeeman effect	1. Placing an atom in external magnetic field,
	$\underline{\Delta H = (e/2m)(\mathbf{L}+2\mathbf{S})\cdot\mathbf{B}}$
	(e/2m: gyromagnetic ratio; the extra factor of 2 in front of the spin operator is because the quantum gyromagnetic ratio is twice the classical value)
		—	• In play are three operators, **L**, **S**, **J=L+S**. Depending on the magnitude of **B**, different combinations of these operators may be conserved, and hence different combinations of eigenvalues may label the energies.
			
			If $\lvert\mathbf{B}\rvert$ is small:
			• The Zeeman Hamiltonian is a perturbation on top of fine structure, for which the energies are labeled by j, l, m_j.
			• The weak-field Zeeman effect splits the j-states according to m_j, with the lower energy for the most negative mj.
			  ‣ The electron spin wants to be anti-aligned with the magnetic field, since it is energetically favorable
			• The splitting of energy levels according to spin can be seen in the ***Stern-Gerlach experiment***, where an inhomogeneous magnetic field splits a beam of atoms into two, effective performing a measurement of m_j.
			
			If $\lvert\mathbf{B}\rvert$ is large:
			• The fine structure as a perturbation on top of the Zeeman Hamiltonian
			• In convention, we align **B** to point in the $\hat{\mathbf{z}}$-direction ⇒ L_z and S_z both commute with the Zeeman Hamiltonian.
			  ‣ l, m_l, m_s are now conserved before fine structure comes into the picture
			  ‣ Total spin j and m_j are *not* conserved, because the magnetic field provides an external torque
			• The energy of the Zeeman states depends on m_l and m_s in the same way as for the weak-field effect, and fine structure causes these states to develop a dependence on l.