E&M II - Project 2 outline

For the project we plan to calculate the hyperfine structure (Zeeman effect) for Hydrogen and another atom. Since these calculations become exponentially more involved with the difficulty of the atomic nuclei structure, we will perhaps try to look at simple atoms such as deuterium. We will then find how different magnetic fields affect the structure and determine if any anomalies occur for different magnetic fields. It will be up to both of us together to complete these calculation (since they are involved).

The largest part of the project will be creating methods of calculating the Hamiltoniann. This will probably take the most time, which we could hopefully expect to have completed in a couple weeks (since ¡Eric¿ may be gone multiple times to visit grad schools). Once that is complete we should take another week to compute the effect that different magnetic fields have on the structure. We will numerically or graphically represent the results for a range of cases with different magnetic field strengths. We will start with the simple hydrogen atom calculations and determine the correction terms due to a magnetic field. From this, we can determine the Hamiltonian and use perturbation theory to solve for energy and wave function corrections. This may prove different for higher energy states of Hydrogen due to degeneracies which is where a computer system will be applied to help solve for the corrections. We may only be able to achieve results for a couple low level n states but we will see.

If we have time at the end, we can look at how a linearly changing magnetic field can induce an electric field. Since a time dependent magnetic field will cause an induced changing electric field, this will cause the stark effect to play a role in the corrections to the Hamiltonian. This would be very complicated on its own so we can perhaps look at a specific case for the hydrogen atom, such as the ground state and choose a simple magnetic field changing in time to explore how this affects the perturbations. This is where we can involve much more E&M into our project, but I suspect it will be far too much work to try and generalize the effects of a changing magnetic field any.

explanation of the models and theoretical calculations

The energy levels of a Hydrogen atom are somewhat fixed when it is not interacting with outside matter. The wave function describing the atom as well as the energy levels for each state can be determined to an approximation using the radial wave functions and spherical harmonics and then the energy levels can be determined using the Schrödinger's equation. These values are generally expressed in terms of something known as a Hamiltonian, which is essentially the total energies contained within a system. Naturally, there can exist degeneracies within the equations for energies of a system in which more than one condition produce the same energy.

When matter interacts with either an electric or a magnetic field, there are changes in the conditions in which the wave functions and energies are changed (changes in the hamiltonian). These changes in the Hamiltonian affect the solutions to Schrödinger's equation and thus the energies. The degeneracies can be removed and instead there will be slight shifts in the energies from the previously found solutions. These shifts are often referred to as perturbations. Perturbation theory is the process of changing the Hamiltonian by a small factor (or perturbation) and calculating the corrections to the energy levels and wave functions using quantum mechanics.

When a uniform electric field interacts with a hydrogen atom, we see effects/corrections that are referred to as the Stark effect. Similarly, when a uniform magnetic field is introduced and acts upon a hydrogen atom, the Zeeman effect takes affect which is just shifts in the energy levels. If there is a varying magnetic or electric field, there will be an induced electric or magnetic field respectively and this would cause an effect from both of these effects. For the purpose of our

project, we will primarily focus solely on the Zeeman effect (that is a uniform magnetic field). Using perturbation theory, we can see the energy corrections to the hydrogen model and see that it depends on the strength of the magnetic field (see calculations in calculations folder).

Updated Project Timeline

(by week)

1. Finish researching and finding articles on the zeeman effect.
   (a) Explore through research other atoms such as deuterium as well.
2. Finish calculations of energy corrections from zeeman effect.
   (a) Attempt calculations for another atomic nuclei.
   (b) Explore changing magnetic field in time. (oooh scary!)
3. Explore variable magnetic field strengths and states of hydrogen atom and model data using a computer.
   (a) Also any other atoms we have calculations for.
   (b) Make conclusions.
4. Finish compiling information into poster