ASTR 545
Homework 3 (60 points)
Due: Tuesday September 27

1. **Schrödinger Hydrogenic Atoms (20 points):** Consider the energy structure for the Schrödinger Model (shown in left panel of Figure 1 provided with this homework).

   (a) What are the quantum numbers for the states of a Schrödinger atom? From a geometric stand point, what does each quantum number represent with regard to a given wavefunction (state) of the atom? That is, what is being quantized into integers?

   (b) What is the expression for the multiplicity of states, g_{nl}? What physically is g_{nl} quantifying?

   (c) What is the multiplicity of states, g_n, for $n = 1$, $n = 2$, and $n = 3$. What physically is g_n quantifying?

   (d) Write down the dipole selection rules for bound-bound transition in the Schrödinger atom.

   (e) Using the dipole selection rules, on the left panel of Figure 1 draw the transitions corresponding to Hβ on the Schrödinger level energy diagram. Label each transition using <u>spectroscopic notation</u>. List which transitions are energy degenerate?

2. **Dirac Hydrogenic Atoms (25 points):** Consider the energy structure for the Dirac Model.

   (a) What three physical phenomena (i.e., what physics) are included in the Hamiltonian yielding the Dirac model that were not included in the Hamiltonian of the Schrödinger model? What are the quantum numbers for the Dirac model states?

   (b) State which physics is/are responsible for the shifts in the energy levels (as compared to the Schrödinger model)? To what power of α are these shifts?

   (c) State which physics is/are responsible for the splitting of the energy levels? To what power of α are these splits?

   (d) How (quantitatively and physically) are the multiplicity of states, g_{nl} and g_n, different for the Dirac model as compared to the Schrödinger model, and why?

   (e) Write down the dipole selection rules for the Dirac atom.

   (f) In the right panel of Figure 1, clearly draw the energy level diagram for the Dirac model. Clearly align the energy levels relative to the Schrödinger model and the l states. Clearly label each state by its quantum numbers. [Accuracy counts; no scratched out work- reprint the figure of you need a "do over".].

   (g) Using the dipole selection rules for the Dirac atom, draw the transitions corresponding to Hβ on your Dirac energy level diagram. Label each transition using <u>spectroscopic notation</u> for single electron atoms. [You can use the space to the right of Figure 1 if you want to label them that way- it will be cleaner]. List any transitions that are energy degenerate with each other?

3. **Feynman's Hydrogenic Atoms (15 points):** Consider the energy structure for the Quantum Electrodynamics (Feynman) Model.

   (a) Using one to three Feynmann diagrams (in which all particles are labeled), explain the physics giving rise to the energy level shifts as compared to the Dirac atom? To what power of α are these shifts?

   (b) Which transition (use spectroscopic notation) was measured to verify that these energy shifts exist in nature? Draw the energy diagram and transition for just this transition in Feynman model and graphically compare it to the Driac energy diagram (draw your own energy diagram, don't use Figure 1 from the previous problems; label the quantum states of your energy states).

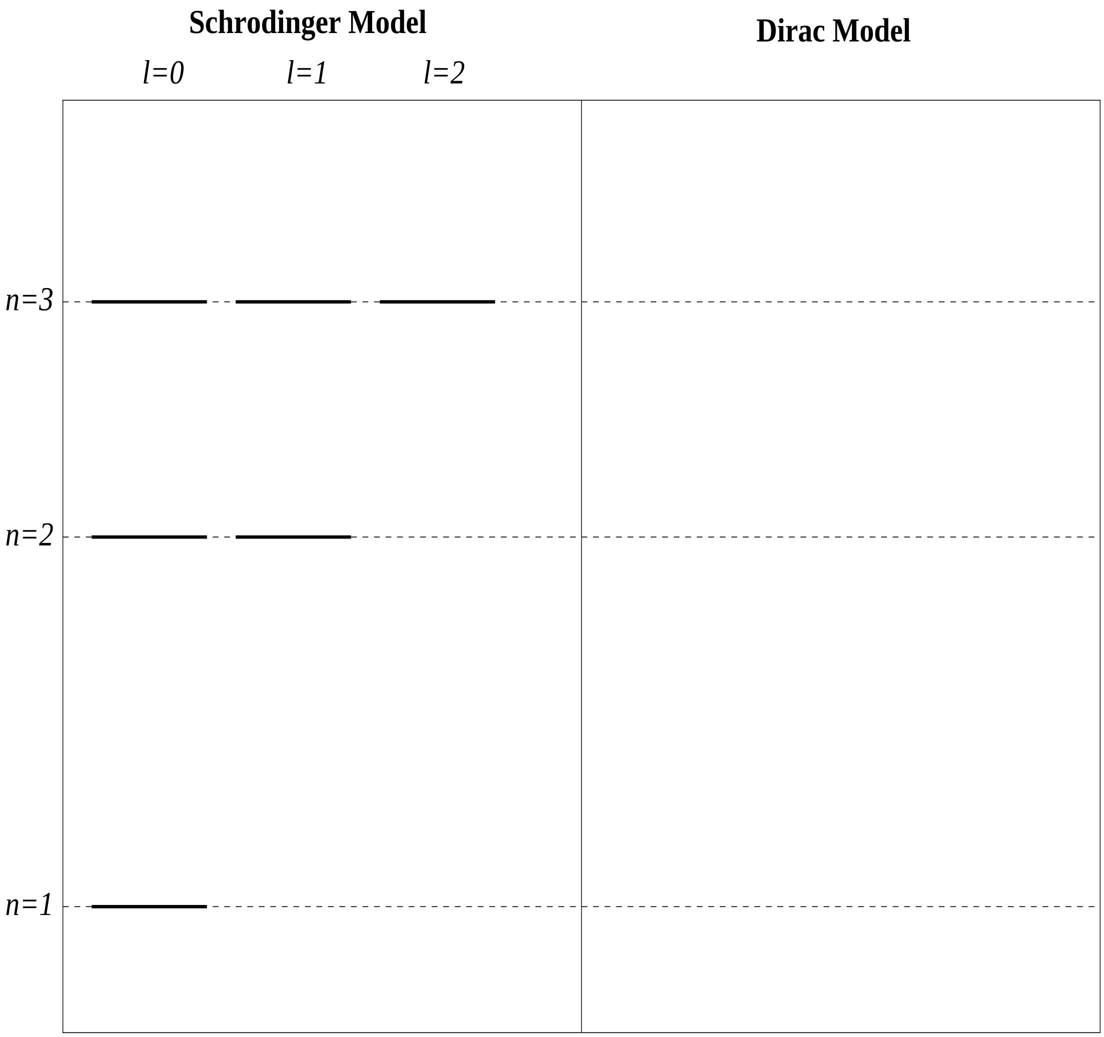

Figure 1: (left) Energy structure of Schrödinger Model. — (right) Energy structure of Dirac Model.