Physics 322 Problem Set #11
(Its the End of the Problem Sets as We Know Them ... And I Feel Fine)

Due Thursday, May 7 at 4:00 pm

ASSUMED READING: Before starting this homework, you should have read Sections 1 through 4 of Chapter 8 of Harris' *Modern Physics*.

SCORING: There are 60 points possible on this Problem Set. Scoring per problem is indicated.

1. **[Harris 8.5 tweaked] (5 points)** The neutron comprises multiple charged quarks. Can a particle that is electrically neutral but really composed of charged constituents have a magnetic dipole moment? **Clearly** explain your answer. **HINT:** What combination of electric charges would be neutral? What sort of magnetic dipole moment exists when you have positive and negative charges countercirculating (by which I mean the positive charges are circulating in the opposite direction as the negative ones)?

2. **[Harris 8.25 tweaked] (10 points)** Just to convince you of the non-classical situation we have with the electron's intrinsic spin, consider the following question. The electron is known to have a radius no larger than 10^{-18} m. If actually produced by circulating mass, its intrinsic angular momentum of roughly $\hbar$ would imply a very high speed, even if all the mass were as far from the axis as possible.
    - **a.** Using simply rp (from $|\vec{r} \times \vec{p}|$) for the angular momentum of a mass at radius r, obtain a rough value of p and show that it would imply highly relativistic speed.
    - **b.** At such speeds, $E = \gamma mc^2$ and $p = \gamma mu$ combine to give $E \approx pc$ (just as for the speedy photon or the LHC-produced protons from the first midterm). How does this energy compare with the known internal energy of the electron? What does that imply about how "classical" the electron's intrinsic angular momentum is?

3. **[Harris 8.32 tweaked] (10 points)** Is intrinsic angular momentum "real" angular momentum? The famous **Einstein-de Haas effect** demonstrates it is! Suppose you have a cylinder 2 cm in diameter hanging motionless from a threat connected at the very center of its circular top. A representative atom in the cylinder has atomic mass 60 and one electron free to respond to an external field. Initially, spin orientations are as likely to be up as down, but a strong magnetic field in the upward direction is suddenly applied, causing the magnetic moments of all free electrons to align with the field.
   - **a.** Viewed from above, which way would the cylinder rotate?
   - **b.** What would be the initial rotation rate?
   - **c.** While the actual experiment is constructed a bit differently, the equivalent rotation has been seen. Should you be impressed the physicists made the measurement? What does this mean about the nature of electron spin?

4. **[Harris 8.35] (10 points)** Two particles in a box occupy the n=1 and n'=2 individual particle states. Given that the normalization constant is the same as in Example 8.2, calculate for both the symmetric and antisymmetric state the probability that both particles would be found in the left side of the box (*i.e.* between 0 and $\frac{1}{2}L$). Do the results make sense given what you know about symmetric versus antisymmetric states.

5. **[Harris 8.7] (5 points)** A friend asks: "Why is there an exclusion principle?" Explain in the simplest terms.

6. **[Harris 8.41 tweaked] (10 points)** What is the minimum possible energy for five (non-interacting) spin-$\frac{1}{2}$ particles of mass m in a one-dimensional box of length L? What if the particles were spin-1 or spin-$\frac{3}{2}$? Clearly provide your explanation in words as well as mathematics.

7. **[Harris 8.13 tweaked] (10 points)** Concisely state why the Periodic Table of the Elements is, in fact, periodic.