Midterm Quiz: Atomic and Molecular Physics 475
February 22, 2007

2-sided formula sheet only plus the text book. Total 40 points. Individual values follow each question. Try and resist the temptation to look up all of the answers or you will run out of time.

1. (a) Who was the first philosopher to suggest an atomic theory of matter? When? (2)
   (b) What is electrolysis? Who was the pioneer of this technique? What does it suggest about the nature of "chemical" forces? (3)
   (c) What is the ultraviolet catastrophe? How was this problem resolved by Planck and what result of classical statistical mechanics had to be discarded? Give an example of where a similar problem is encountered in the kinetic theory of gases. (4)
   (d) What is Compton scattering? How does it demonstrate the particle nature of EM radiation? What is the final wavelength in a Compton experiment if the initial wavelength is 0.100 Åand the scattering angle is 80 degrees. (4)
   (e) What experiment was used to demonstrate the quantization of the z-component of angular momentum? Was the angular momentum measured in this experiment of an orbital or spin nature? What is the difference between orbital and spin angular momentum? (4)

2. (a) What is the relationship between operators and observables in quantum mechanics (or at least the expectation value of the observable)? If you are using an equation name in your answer clearly identify the different elements. What kind of operator must it be if it corresponds to a physical observable? (4)
   (b) If two quantum mechanical operators commute what does it mean for their eigenstates? (1)
   (c) In the special case of commuting operators when one of the operators is the Hamiltonian can we say anything further? (2)
   (d) What is the name of the simultaneous eigenfunctions for operators L_z and L^2? (1)
   (e) Give Y_{10} and show that it is a simulataneous eigenfunction of L_z and L^2 and demonstrate that it gives the conventional eigenvalues. (4)
   (f) Show that Y_{10} is orthogonal to Y_{00}. The appropriate solid angle integral is

$$\int d\Omega\, Y_{00}^*(\theta,\phi) Y_{10}(\theta,\phi) = \int_0^{2\pi} d\phi \int_0^{\pi} d\theta\, \sin\theta\, Y_{00}^*(\theta,\phi) Y_{10}(\theta,\phi) \tag{1}$$

   (3 points)

3. Consider an eigenstate of J_z and J^2 that is acted upon by J_+, the raising operator.
   (a) Show that the resulting state is not "Hilbert space vomit" but is still a simultaneous eigenstate of J_z and J^2. You may find the following commutation rules useful

$$[J_z, J_+] = \hbar J_+ \tag{2}$$

$$[J^2, J_+] = 0 \tag{3}$$

   (4 points)

(b) Considering the result from the first part of the question established as

$$J_+\psi_{jm} = N\psi_{j,m+1} \tag{4}$$

calculate the value of the normalisation factor N if we take N to be positive and real. You may find

$$J_-J_+ = J^2 - J_z^2 - \hbar J_z \tag{5}$$

$$J_+^\dagger = J_- \tag{6}$$

useful. Please state any assumptions clearly. (4)