University of Alabama
Department of Physics and Astronomy

PH 253 / LeClair Fall 2010

Problem Set 8: Various & Sundry

Instructions:

1. Answer all questions below. Show your work for full credit.
2. All problems are due Monday 2 November 2010 by the end of the day.
3. You may collaborate, but everyone must turn in their own work.

1. Transitions occur in an atom between an $l = 3$ and an $l = 2$ state in a field of $B = 0.2\,\text{T}$. If the wavelength before the field was turned on was 400 nm, determine the final wavelengths observed.

2. Calculate the frequency at which an electron's orbital magnetic moment μ precesses in a magnetic field B. Hint: open your PH106 book and look at the torque on a magnetic moment. This phenomenon is known as *Larmor precession.*

3. For $l = 3$, calculate the possible angles $\vec{L}$ makes with the z axis.

4. **(a)** What is the energy difference (in eV) between two electron spin orientations when the electrons are in a magnetic field of 0.5 T? **(b)** What wavelength of radiation could cause the electrons to "flip" their spins?

5. Estimate the strength of the magnetic field produced by the electron's orbital motion which results in the two sodium D lines (588.995 nm and 589.592 nm).

6. Neglecting spin, in a strong external magnetic field of 5 T, determine the lines resulting from the $2p \rightarrow 1s$ transition ($\lambda_o = 121.0\,\text{nm}$) in hydrogen. Provide a sketch of the energy levels and their m_l values.

7. *Multiplicity of atomic magnetic moments.* Calculate the magnetic moments that are possible for the $n = 3$ level of Hydrogen, making use of the quantization of angular momentum. You may neglect the existence of spin. Compare this with the Bohr prediction for $n = 3$.

8. *Transitions in a magnetic field.* Transitions occur in an atom between $l = 2$ and $l = 1$ states in a magnetic field of 0.6 T, obeying the selection rules $\Delta m_l = 0, \pm 1$. If the wavelength before the field was turned on was 500.0 nm, determine the wavelengths that are observed. You may find the following relationship useful:

$$|\Delta\lambda| = \frac{\lambda^2 \Delta E}{hc} \tag{1}$$

Recall that the Zeeman effect changes the energy of a single-electron atom in a magnetic field by

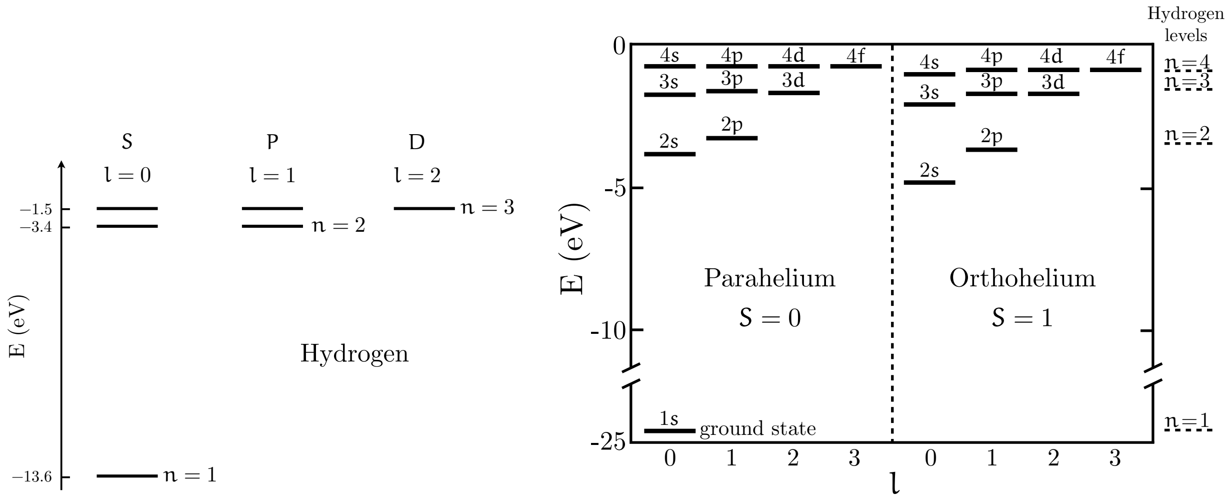
$$\Delta E = m_l \left(\frac{e\hbar}{2m_e}\right) B \qquad \text{with} \qquad m_l = -l, -(l-1), \ldots, 0, \ldots, l-1, l \tag{2}$$

For convenience, note that $e\hbar/2m_e = \mu_B \approx 57.9\,\mu\text{eV/T}$, and neglect the existence of spin.

9. *Dipole selection rules.*

(a) For hydrogen, the energy levels through $n=3$ are shown below. What are the possible electric dipole transitions for these states? It may be convenient to simply draw arrows in the diagram. Recall the "selection rules" for electric dipole transitions, $\Delta l = \pm 1$. Spin may be ignored.

(b) Repeat for para- and ortho-helium, also shown below, treating both as distinct atoms.[i]



Problem 9. **(left)** *Energy levels of H through* $n=3$*, neglecting spin.* **(right)** *Energy levels of para- and ortho- He through* $n=4$.

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[i] Two types of helium: para-helium, with the two electron spins parallel ($S=0$), and ortho-helium, with the two electron spins antiparallel ($S=1$). According to the dipole selection rules, helium atoms cannot change by a radiative process from one to the other, as this would not conserve angular momentum, so ortho- and para-helium behave largely as distinct atoms. (Forbidden transitions are not strictly forbidden, but violating the selection rules incurs a cost of $\sim 10^5$ in transition probability).

As the energy level diagram shows, the lowest state corresponds to para-helium, and the next highest excited state ortho-helium. The ortho-helium excited state can be reached by electrical discharge excitation, a non-radiative process (i.e., not obeying the same selection rules.) This excited state is very long lived ($\sim$10 ms) because returning to the ground state would violate selection rules.