University of Alabama
Department of Physics and Astronomy

PH 102-2 / LeClair Spring 2008

Problem Set 11: Quantum and Atomic Physics

Instructions:

- Answer all questions below. Show your work for full credit.
- Due before 5pm, 21 Apr 2008 *i.e.,* right after spring break
- Problem sets may turned in *via* email or hard copy
- Hard copies may be left in Dr. LeClair's mailbox (Gallalee 206) or office (Bevill 228)
- You may collaborate, but everyone must turn in their own work

1. 15 points. The typical operating voltage for an electron microscope is $\Delta V = 50\,\text{kV}$. **(a)** What is the smallest feature one could hope to resolve? **(b)** What is the equivalent resolution if neutrons are used? **(c)** Explain in words why electrons are used, and not protons or neutrons.

2. 15 points. An accelerating charge loses electromagnetic energy at a rate of

$$\mathscr{P} = \frac{\Delta E}{\Delta t} = -\frac{2k_e q^2 a^2}{3c^3}$$

where k_e is Coulomb's constant, q is the charge of the particle, c is the speed of light, and a is the acceleration of the charge. Assume that an electron is one Bohr radius ($a_0 = 0.053\,\text{nm}$) from the center of a Hydrogen atom. **(a)** Find the acceleration of the electron (hint: circular path). **(b)** Calculate the kinetic energy of the electron and determine within an order of magnitude how long it will take the electron to loose all of its energy, assuming a constant acceleration as found in part (a).

3. 15 points. A hydrogen atom has a radius of $\sim 0.05\,\text{nm}$. **(a)** Assuming we know the position of an electron in a hydrogen atom to an accuracy of 1% of this radius, estimate the uncertainty in the velocity of the electron. How does this value compare to c? **(b)** Compare this value to the uncertainty in the velocity of a ball of mass 0.2 kg and radius 0.05 m whose position is known within 1% of its radius.

4. 10 points. A molecule is known to exist in an unstable higher energy configuration for $\Delta t = 10\,\text{nsec}$, after which it relaxes to its lower energy stable state by emitting a photon. **(a)** What uncertainty in the frequency Δf of the emitted photon is implied? **(b)** If this state is being probed with Nuclear Magnetic Resonance (NMR) at a frequency of $f \approx 500\,\text{MHz}$, what is the relative uncertainty in the measurement, $\Delta f / f$?

5. 10 points. In a coordination compound, the so-called "crystal field" gives rise to a difference in energy levels for some of the electrons in a transition metal ion. That is, electrons can occupy one of two states, separated by the crystal field splitting energy Δ.

The octahedral complex $[Cr(NH_3)_6]^{3+}$ has a crystal field splitting of $\Delta_o \sim 2.16\,\text{eV}$, while $[Co(NH_3)_6]^{3+}$ has $\Delta_o \sim 2.84\,\text{eV}$. What color are these compounds? Make use of the table below. If a compound absorbs a certain color of light, it exhibits the color *complementary* to the color of absorbed light.

6. 10 points. The energy required to break one O=O bond in ozone (O_3, O=O=O) is about 500 kJ/mol. What is the maximum wavelength of the photon that has enough energy to photodissociate ozone by breaking one of the O=O bonds?

$$O_3 \xrightarrow{hf} O + O_2$$

Note Avagadro's number is $N_A = 6.02 \times 10^{23}$ things/mol.

Table 1: *Absorbed wavelength λ and observed color*

λ (nm)	absorbed color	observed color
400	violet	greenish-yellow
450	blue	yellow
490	blue-green	red
570	yellow-green	violet
580	yellow	dark blue
600	orange	blue
650	red	green

7. 10 points. An FM radio transmitter has a power output of 130 kW and operates at a frequency of 98.3 MHz. How many photons per second does the transmitter emit?

8. 10 points. A pulsed ruby laser emits light at 694.3 nm. For a 13.6 ps pulse containing 3.40 J of energy, how many photons are in the pulse? 1 ps is 10^{-12}s.

9. 5 points. A light-emitting diode (LED) emits blue photons of wavelength 480 nm. What would be the minimum voltage you would expect to apply to the LED before it emits light? (Hint: we assume all of the potential energy of one electron is converted into light.)