Name
Section
Rec TA

Ch 1a, Problem Set Two
Due Friday, Oct. 6, 2006
at 4 PM in the Drop Box

*Problems 1, 3 and 7 are designated (✋) as "**no collaboration**" problems. From this point on, each set will have a select number of problems designated as such. For these problems you must complete them yourself! You may not work with others, consult upperclassman, or compare final answers. Failure to abide by this policy will be considered a violation of the honor code!*

As with Problem Set One, be sure to watch the significant figures and answer problems in the units specified! Please report uncertainties to one significant figure only.

✋ 1. (15 Points, 5 Each) Electromagnetic (EM) radiation figures heavily not only into what we see, but also in what we hear.

   a. An excited sodium atom emits light as it undergoes a transition from one energy level to another that is 3.61×10^{-19} J lower in energy. Determine the wavelength, in nm, and the color of the light you would expect upon heating a compound like NaCl in a flame.

   b. The coating on the walls of a mercury vapor light tube primarily converts 254.0 nm ultraviolet light to 585.0 nm visible light (among other frequencies that we will conveniently ignore), by absorbing and then emitting again. However, the principle of conservation of energy means something has to be done with the remainder of the energy it absorbed from the UV photon. How many eV's (electron volts) of energy are left over (as heat) after one absorption and emission event?

   c. "101.1 KRTH" (the FCC approved call signal out of Los Angeles carrying oldies to the entire southland) broadcasts at 101.1 MHz as its name suggests. What is the wavelength of this radio signal? What is its energy?

2. (15 Points) Using the Bohr model, determine the wavelength of light ***emitted*** for all possible electronic transitions from $n_i = 5,4,3,2$ in a hydrogen atom. For each transition specify the initial and final values of n, the principle quantum number; the wavelength of light generated by the transition in nm; and the approximate color of light produced by the emission (see table for colors). This is not as hard as it seems; a systematic approach will quickly lead you to all answers. Please present your final answers in a table format for clarity.

Wavelength (nm)	Color	Wavelength (nm)	Color
< 400	UV	530 - 580	Yellow
400 - 430	Violet	580 - 620	Orange
430 - 480	Blue	620 - 700	Red
480 - 530	Green	> 700	IR

3. (5 Points) Based on your work in the previous problem, classify the ***general*** colors (be it UV, visible, or IR) produced by emissions in the He^+ analogs of the Lyman ($n_f = 1$), Balmer ($n_f = 2$), and Paschen ($n_f = 3$) series.

4. (15 Points, 5 Each) The development of the Bohr theory of the hydrogen atom depended on both the recognition that Coulombic attraction and centripetal force could be used to model the opposing forces between a proton and an electron in an atom, and the realization that the orbiting electron's angular momentum was quantized. We'll apply this model to the case of a satellite in orbit around the Earth. Consider a satellite that completes its orbit in 24.0 hr. Its mass is 2315 kg, and orbits at an altitude of 35786 km, and $r_{Earth} = 6480$ km.

    a. Substituting gravitational attraction for Coulombic attraction and assuming that Bohr's angular momentum postulate applies to satellites, find the quantum number of the satellite's orbit. (*Hint: significant figures are very important!*)

    b. Find the distance (in meters) between its orbit and the next higher "allowed" orbit as specified by the Bohr model.

    c. Comment on the separation between these two adjacent orbits. Would you expect orbit quantization to be observable with this satellite?

5. (20 Points, 5 Each) Although the theory of "cold-fusion" was debunked in the 1980's, talk persists in some circles that low-temperature fusion power is possible. The major obstacle is the strong electron-electron repulsion that develops in conventional matter at the small internuclear distances required to initiate fusion. To counter this obstacle, muon-catalyzed fusion has been proposed. Muons carry the same charge as the electron, but are 207 times as massive. As a result of this extra mass, a muon will have a smaller orbit than an electron. Consider the muon analog of Be^{+3} consisting of a Be nucleus (+4 charges) and a muon (-1 charge).

    a. What is the radius, in Å, of the first ($n = 1$) Bohr orbit?

    b. What is the ground state energy (in eV) for this system?

    c. What wavelength and type of radiation is emitted when the muon changes orbit from $n = 2$ to 1? microwave, infrared, visible, etc…? (*Hint: See Gray, p. 138*)

    d. How many Bohr orbits in this muon Be^{+3} fit into a standard $n = 1$ orbit of an electron in Be^{+3}?

6. (15 Points, 5 Each) de Broglie's postulate suggests that every particle possesses wavelike properties related to its momentum.

   a. Despite occasional daydreams about being able to "bring the heat", Professor Lewis would probably be lucky to throw a baseball 68 mph. If the baseball weighs 145 g what is the de Broglie wavelength of a baseball thrown with this "high heat"?

   b. During nuclear fission, ^{235}U decays by emitting a neutron, which has the similar mass as a proton but is not charged. What is the de Broglie wavelength (in nm) of one of these neutron particles if it has an energy of 3.27 MeV? (*Hint: you are dealing with a relativistic atom, so p does not equal mv. Instead use the more general form $E = p^2/2m$ in your calculation*)

   c. Diffraction of a wave through an opening may be observed when its wavelength is comparable (to within a factor of 100) to the dimensions of the opening. Consider directing beams of baseballs and neutrons onto a crystal, where the 1-2 Å distance between planes of atoms is akin to a diffraction slit. Comment on the possibility of seeing wavelike effects from either the baseball or the neutron.

7. (15 Points, 5 Each) In the lectures on atomic spectra, we did not discuss how narrow spectral lines really are. The Heisenberg Uncertainty Principle, which chemists often write in terms of momentum and position (see Oxtoby, Gillis, & Nachtrieb, p.529-530), may also be derived in terms of energy, E, and time, t, to yield another form:

$$\Delta E \Delta t \geq \frac{h}{4\pi} \qquad (1)$$

   a. Equation (1) is often used to determine the wavelength broadening of a laser beam in chemistry. Derive a relationship between the uncertainty in energy and the uncertainty in wavelength using basic wavelength/energy relationships. (*Hint: Express your answer such that only ΔE, E, Δλ, and λ are employed. You can change derivatives to deltas. Ignore negatives.*)

   b. From your answer to part (a.) and Equation (1), calculate the uncertainty in the wavelength of laser pulse at 415 nm which lasts for 0.1 femtoseconds. Consider the uncertainty in time to be the duration of the laser pulse itself.

   Equation 1 may also be used to determine the uncertainty associated with lifetimes of atomic transitions. For instance, an electron excited in Rubidium remains so for 1.9×10^{-8} s before relaxing down to the ground state. This emits a 780.2 nm photon. The timescale for emission is known to within 1.5×10^{-9} s, consider this the uncertainty in time.

   c. Estimate the uncertainty in both the wavelength and energy of the emitted photon.