Physics 2710 (Schroeder) Name ______________________________
fall 2012

Problem Set 4

(due Wednesday, October 3, 5:00 p.m.)

1. Photon fundamentals.

   (a) Show that $hc = 1240$ eV·nm.

   (b) Calculate the energy of a photon with each of the following wavelengths: 650 nm (red light); 450 nm (blue light); 0.1 nm (x-ray); 1 mm (typical for the cosmic background radiation).

   (c) Calculate the number of photons emitted in one second by a 1-milliwatt red He-Ne laser ($\lambda = 633$ nm).

2. Suppose that, in a photoelectric effect experiment of the type described in class, light with a wavelength of 400 nm results in a voltage reading of 0.8 V.

   (a) What is the work function for this photocathode?

   (b) What voltage reading would you expect to obtain if the wavelength were changed to 300 nm? What if the wavelength were changed to 500 nm? 600 nm?

3. Summarize in your own words why the photoelectric effect experiment (as described in class) provides evidence that light behaves like a particle.

4. The electrons in a television picture tube are typically accelerated to an energy of 10,000 eV. Calculate the momentum of such an electron, and then use the de Broglie relation to calculate its wavelength.

5. In the electron diffraction experiment discussed in class, the effective slit spacing was 6 μm and the distance from the "slits" to the detection screen was 16 cm. The spacing between the center of one bright line and the next (before magnification) was typically 100 nm. From these parameters, determine the wavelength of the electron beam. What voltage was used to accelerate the electrons?

6. The de Broglie relation applies to all "particles," not just electrons and photons.

   (a) Calculate the wavelength of a neutron whose kinetic energy is 1 eV.

   (b) Estimate the wavelength of a pitched baseball. (Use any reasonable values for the mass and speed.) Explain why you don't see baseballs diffracting around bats.

7. On page 91, Taylor and Zafiratos assert that the radius of a typical atom is approximately 0.1 nm (a unit also known as 1 Ångstrom). But they offer no evidence for this assertion. Think about how you might measure the approximate size of an atom, and write a paragraph or two describing an experiment (or series of experiments) to make such a measurement. Please include in your paragraph whatever formulas would be needed to connect the raw data to the ultimate results. (There are several possible experimental procedures, but none of them are easy. Feel free to consult other sections of your textbook, other textbooks, etc.)

8. Suppose that a hydrogen atom makes a transition from a high-n state to a low-n state, emitting a photon in the process. Calculate the energy and wavelength of the photon for each of the following transitions: $2 \to 1$, $3 \to 2$, $4 \to 2$, $5 \to 2$. Describe the approximate color (or "infrared" or "ultraviolet" for invisible colors) of each photon.

9. Use the Bohr model of the atom to estimate the quantum number n at which the size of a hydrogen atom would be 3 nm, the approximate average distance between molecules in a gas at normal temperature and pressure. (Under these conditions, higher n values are suppressed and rarely observed. To observe hydrogen atoms in higher-n states, you would want to reduce the pressure of the gas.)

10. (T+Z, Problem 5.13.) The negative muon is a subatomic particle with the same charge as the electron but a mass that is about 207 times greater. A muon can be captured by a proton to form a "muonic hydrogen atom." (a) Use the Bohr model to estimate the size and energy of the $n = 1$ state of muonic hydrogen. (b) Find the energy and wavelength of the photon emitted when muonic hydrogen makes a transition from the $n = 2$ state to the $n = 1$ state. In what part of the electromagnetic spectrum does this photon lie (visible? IR? . . .).

11. A certain particle in a one-dimensional universe has the wavefunction

$$\psi(x) = \begin{cases} Ax\sin kx & \text{for } 0 < x < 2\pi/k, \\ 0 & \text{elsewhere,} \end{cases}$$

where k and A are constants.

(a) Sketch a reasonably accurate graph of this wavefunction, or use a computer to plot it.

(b) Sketch a graph of the square of this wavefunction (or plot it with a computer).

(c) If you were to measure the position of this particle, approximately what value would you be most likely to obtain (in terms of k)? Explain briefly.

(d) Assuming that the probability of finding the particle *somewhere* must equal 1, find an expression for A in terms of k. (Use Mathematica to evaluate the integral, or look it up in a table. Either way, be sure to document exactly how you got the answer.)

(e) What is the probability of finding this particle somewhere between $x = 0$ and $x = \pi/k$? (Express your answer as a numerical percentage.)