Problem Set 3

Instructions:

1. Answer all questions below. Show your work for full credit.
2. The first problem is due at the start of class on 18 Sept 2013
3. The second problem is due at the start of class on 20 Sept 2013
4. The remaining problems are due by the end of the day on 23 Sept 2013
5. You may collaborate, but everyone must turn in their own work.

Daily problem due 18 Sept 2013: Determine the maximum scattering angle in a Compton experiment for which the scattered photon can produce a positron-electron pair. *Hint:* twice the electron's rest energy $m_e c^2$ is required of the incident photon for pair production.

Daily problem due 20 Sept 2013: If we wish to observe an object which is 0.25 nm in size, what is the minimum-energy photon which can be used?

The problems below are due by the end of the day on 23 Sept 2013.

1. In Compton scattering, what is the kinetic energy of the electron scattered at an angle φ to the incident photon? Your answer should involve only φ, the incident photon frequency (or energy), and fundamental constants.

2. Potassium is illuminated with UV light of wavelength 250 nm. **(a)** If the work function of potassium is 2.21 eV, what is the maximum kinetic energy of the emitted electron? **(b)** If the UV light has an intensity of $2\,\mathrm{W/m^2}$, calculate the rate of electron emission per unit area.

3. The resolving power of a microscope is proportional to the wavelength used. We desire a 10^{-11} m (0.01 nm) resolution in order to "see" an atom. **(a)** If electrons are used, what minimum kinetic energy is required to reach this resolution? Do not assume that the electron can be treated without relativity.

4. By doing a nuclear diffraction experiment, you measure the de Broglie wavelength of a proton to be 9.16 fm. **(a)** What is the speed of the proton? **(b)** Through what potential difference must it be accelerated to achieve that speed?

5. The Compton shift in wavelength $\Delta\lambda$ is independent of the incident photon energy $E_i = hf_i$. However, the Compton shift in *energy*, $\Delta E = E_f - E_i$ is strongly dependent on E_i. Find the expression for ΔE. Compute the fractional shift in energy for a 10 keV photon and a 10 MeV photon, assuming a scattering angle of 90°.

6. A hydrogen atom is moving at a speed of 125.0 m/s. It absorbs a photon of wavelength 97 nm that is moving in the opposite direction. By how much does the speed of the atom change as a result of absorbing the photon?

7. Suppose an atom of iron at rest emits an X-ray photon of energy 6.4 keV. Calculate the "recoil" momentum and kinetic energy of the atom *Hint: do you expect to need classical or relativistic kinetic energy for the atom? Is the kinetic energy likely to be much smaller than the atom's rest energy?*

8. *Time delay in the photoelectric effect.* A beam of ultraviolet light of intensity 1.6×10^{-12} W is suddenly turned on and falls on a metal surface, ejecting electrons through the photoelectric effect. The beam has a cross-sectional area of $1\,\text{cm}^2$, and the wavelength corresponds to a photon energy of 10 eV. The work function of the metal is 5 eV. How soon might one expect photoelectric emission to occur? *Note:* $1\,\text{eV} = 1.6 \times 10^{-19}$ J.

(a) One classical model suggests an estimate based on the time needed for the work function energy (5 eV) to be accumulated over the area of one atom (radius ~0.1 nm). Calculate how long this would be, assuming the energy of the light beam to be uniformly distributed over its cross section.

(b) Actually, as Lord Rayleigh showed in 1916, the estimate from (a) is too pessimistic. An atom can present an effective area of about λ^2 to light of wavelength λ corresponding to its resonance frequency. Calculate a time delay on this basis.

(c) On the quantum picture of the process, it is possible for photoelectron emission to begin immediately – as soon as the first photon strikes the emitting surface. But to obtain a time that may be compared to the classical estimates, calculate the *average* time interval between arrival of successive 10 eV photons. This would also be the average time delay between switching on the source and getting the first photoelectron. *Hint:* think of the power as photons per unit time.