UNIVERSITY OF ALABAMA
Department of Physics and Astronomy

PH 253 / LeClair　　　　Fall 2010

Problem Set 3: Photons

Instructions:

1. Answer all questions below. Show your work for full credit.
2. All problems are due Fri 10 September 2010 by the end of the day.
3. You may collaborate, but everyone must turn in their own work.

1. The emitter in a photoelectric tube has a threshold wavelength of 600 nm. Determine the wavelength of the light incident on the tube if the stopping potential for this light is 2.5 V.

2. Find the strength of the transverse magnetic field required to bend all the photoelectrons within a circle of 20 cm when light of wavelength 400 nm is incident on a barium emitter. The work function of barium is 2.5 eV.

3. Show that the relation between the directions of motion of the scattered photon and the recoiling electron in Compton scattering is

$$\frac{1}{\tan\left(\theta/2\right)} = \left(1 + \frac{hf_i}{m_e c^2}\right)\tan\varphi \tag{1}$$

4. If the maximum energy imparted to an electron in Compton scattering is 45 keV, what is the wavelength of the incident photon?

5. Show that a free electron at rest cannot absorb a photon, and hence Compton scattering *must* occur with free electrons. *Hint:* try to conserve energy and momentum.

6. 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 is required of the incident photon, see `http://en.wikipedia.org/wiki/Pair_production`.

7. In Compton scattering what is the kinetic energy of the electron scattered at an angle φ with respect to the incident photon?

8. A radio station broadcasts at a frequency of 1 MHz with a total radiated power of 5 kW. **(a)** What is the wavelength of this radiation? **(b)** What is the energy (in electron volts) of the individual quanta that compose the radiation? How many photons are emitted per second? Per cycle of oscillation? **(c)** A certain radio receiver must have 2 μW of radiation power incident on its antenna in order to provide an intelligible reception. How many 1 MHz photons does this require per second? Per cycle of oscillation? **(d)** Do your answers for parts (b) and (c) indicate that the granularity of electromagnetic radiation can be neglected in these circumstances?

9. *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 $1\,\mathrm{cm}^2$, 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:* $1\,\mathrm{eV} = 1.6 \times 10^{-19}$ 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.