Physics 2220 (Schroeder) Name ______________________________
fall 2009

Problem Set 11

(due Friday, November 6)

1. A lamp radiates 40 watts of energy at an average wavelength of 590 nm. (a) What is the average energy of a photon emitted by this lamp? (Please express your answer both in joules and in electron-volts.) (b) Roughly how many photons does the lamp emit in one second?
2. Consider a photoelectric effect experiment of the type described in class, in which sodium metal is illuminated with monochromatic light and the voltage that builds up between the electrodes is measured with a high-resistance voltmeter (which allows essentially no current to pass). When the wavelength of the light is 420 nm, the voltage reading is 0.65 V; when the wavelength is 310 nm, the voltage reading is 1.69 V. From this information, calculate Planck's constant and the work function for sodium.
3. Does the data described in the previous problem disprove the wave model of light? If so, why? If not, what additional information would be necessary?
4. When an electron and its antiparticle, a positron, annihilate each other, the reaction produces two gamma-ray photons, each with an energy of 511,000 eV. (a) What is the momentum of such a photon? (b) What is its wavelength? (c) What is its frequency?
5. A high-power pulsed laser emits a burst of light carrying a total energy of one joule. This light hits a mirror and bounces straight back. (a) By how much does the momentum of the light change as it bounces off the mirror? (b) If the mass of the mirror is one gram and it is free to move but initially at rest, what is its recoil velocity? (c) If the wavelength of the light is 500 nm, how many photons are in the burst?
6. A bullet of mass 40 g travels at a speed of 1000 m/s. (a) What is its de Broglie wavelength? (b) Why is the wave nature of the bullet not revealed by diffraction effects, say, when it passes through a doorway?
7. In an ordinary television set, electrons are accelerated through a voltage difference of 25 kV. What is the de Broglie wavelength of these electrons?
8. Calculate the wavelength of each of the following particles, assuming that its kinetic energy is 1.0 keV: (a) an electron; (b) a photon; (c) a neutron.
9. A modified oscilloscope is used to perform an electron interference experiment. Electrons are incident on a pair of slits 0.060 μm apart. The bright bands in the interference pattern are separated by 0.40 mm on the screen, 20 cm away from the slits. Find the voltage difference that the electrons were accelerated through to give this pattern.
10. Imagine playing baseball in a universe (not ours!) where Planck's constant is 0.60 J-s. What would be the minimum uncertainty in the position of a 0.50 kg baseball traveling at 20 m/s, if the uncertainty in its speed is 1 m/s?
11. Draw a wavefunction with a small Δx and a large Δp_x. Then draw a wavefunction with a small Δp_x and a large Δx. Finally, draw a wavefunction with a large Δx and a large Δp_x. (Hint: To have a small Δp_x, the wave must go through many cycles with a well-defined wavelength.)

Study Guide

The Einstein relation between energy and frequency (useful only for photons) is

$$E = hf,$$

where h is Planck's constant, 6.63×10^{-34} J-s. You should be able to apply this equation to explain the results of the photoelectric effect experiment.

The de Broglie relation between momentum and wavelength (useful for photons as well as electrons) is

$$|\vec{p}| = \frac{h}{\lambda}.$$

You should know enough about energy and momentum and voltage and wave physics to apply this equation to electrons and other particles in a variety of situations (as in the homework).

The momentum of a photon (or any electromagnetic wave) is related to its energy by

$$|\vec{p}_{\text{photon}}| = \frac{E}{c},$$

where c is the speed of light. This relation follows from Maxwell's equations, or from the Einstein and de Broglie relations. Note that photons do not obey the more familiar relation $K = p^2/2m$, which is accurate only for particles moving much slower than the speed of light.

You should understand the concept of a "wavefunction", and be able to draw wavefunctions with definite position and definite momentum. You should understand the interpretation of the square of the wavefunction as being proportional to the probability of finding the particle at a given location. You should be able to use the concept of a wavefunction to explain the results of interference experiments with photons and other particles.