Portland State University
General Physics Workshop
Problem Set 9

Quantum Physics

Equations and Relations:

Wien's displacement law
$$f_{peak} = \left(5.88\times10^{10}\, s^{-1}\cdot K^{-1}\right)T$$

$$E_n = n\,h\,f \qquad n = 0,1,2,3,\ldots$$

Photon energy
$$E = h\,f$$

Cutoff frequency
$$f_0 = \frac{W_0}{h}$$
$$K_{\max} = h\,f - W_0$$

Momentum of a photon
$$p = \frac{h\,f}{c} = \frac{h}{\lambda}$$

Compton effect
$$\Delta\lambda = \lambda' - \lambda = \frac{h}{m_e c}\left(1-\cos\theta\right)$$

de Broglie wavelength
$$\lambda = \frac{h}{p}$$

Energy
$$E = \frac{p^2}{2m}$$

Crystal diffraction
$$2d\sin\theta = m\lambda \qquad m = 1,2,3,\ldots$$

Heisenberg
$$\Delta p_y \Delta y \ge \frac{\hbar}{2}$$
$$\Delta E\,\Delta t \ge \frac{\hbar}{2}$$

1. A photon of wavelength 2.0×10^{-11} m strikes a free electron of mass m_e that is initially at rest. After the collision, the photon is shifted in wavelength by an amount $\Delta\lambda = 2h/m_e c$, and reversed in direction.
   (a) Determine the kinetic energy of the electron after the collision(in joules and eV).
   (b) Determine the momentum of the incident photon.
   (c) Is the photon wavelength increased or decreased by the interaction? Explain.
   (d) Determine the magnitude of the momentum acquired by the electron.

2. A photon of energy 240 keV is scattered by a free electron. If the recoil electron has a kinetic energy of 190 keV, what is the wavelength of the scattered photon?

3. An incident photon of wavelength 0.0100 nm is Compton scattered; the scattered photon has a wavelength of 0.0124 nm. What is the change in kinetic energy of the electron that scattered the photon?

- ➢ *The Compton shift is the same for x-rays and for visible light. Why is it that the Compton shift for x-rays can be measure readily but that for visible light cannot?*

4. Two different monochromatic light sources, one yellow (580 nm) and one violet (425 nm), are used in a photoelectric effect experiment. The metal surface has a photoelectric threshold frequency of 6.20×10^{14} Hz.
   (a) Are both sources able to eject photoelectrons from the metal? Explain.
   (b) How much energy is required to eject an electron from the metal?

- ➢ *In a photoelectric effect experiment, how is the stopping potential determined? What does the stopping potential tell us about the electrons emitted from the metal surface?*

- ➢ *Of the following statements about the photoelectric effect, which are true and which are false?*
  1. *The greater the frequency of the incident light, the greater the stopping potential.*
  2. *The greater the intensity of the incident light, the greater the cutoff frequency.*
  3. *The greater the work function of the target material, the greater the stopping potential.*
  4. *The greater the work function of the target material, the greater the frequency.*
  5. *The greater the frequency of the incident light, the greater the maximum kinetic energy of the ejected electrons.*
  6. *The greater the energy of the photons, the smaller the stopping potential.*

- ➢ *A darkroom used for developing black-and-white film can be dimly lit by a red lightbulb without ruining the film. Why is a red lightbulb used rather than white or blue or some other color?*

5. What are the de Broglie wavelengths of electrons with the following values of kinetic energy?
   (a) 1.0 eV
   (b) 1.0 keV

6. What is the ratio of the wavelength of a 0.100-keV photon to the wavelength of a 0.100-keV electron?

7. What is the de Broglie wavelength of a basketball of mass 0.50 kg when it is moving at 10 m/s? Why don't we see diffraction effects when a basketball passes through the circular aperture of the hoop?

8. An electron passes through a slit of width 1.0×10^{-8} m. What is the uncertainty in the electron's momentum component in the direction parallel to the slit?

9. If the momentum of the basketball (see problem above) has a fractional uncertainty of $\Delta p/p = 10^{-6}$, what is the uncertainty in its position?

   - *The uncertainty principle does not allow us to think of the electron in an atom as following a well-defined trajectory. Why, then, are we able to define trajectories for golf balls, comets, and the like? [Hint: How are the uncertainties in momentum and velocity related?]*

   - *An electron and a proton have the same kinetic energy. Which has the greater de Broglie wavelength?*

10. Halogen light bulbs can have higher filament temperatures than regular incandescent bulbs. A standard light bulb operates at about 2900 K while halogen bulbs might be 3500 K hot.
    (a) What is the peak frequency for both bulbs?
    (b) The human eye is most sensitive in the green (~550 nm) part of the visible spectrum. Which bulb produces a peak frequency closer to the frequency of green light?
    (c) At what temperature would a light bulb need to be to have peak frequency that corresponds to the frequency were the eye is most sensitive?

    - *An incandescent light bulb is connected to a dimmer switch. When the bulb operates at full power, it appears white, but as it is dimmed it looks more and more red. Explain.*

    - *Some stars are reddish in color, others bluish, and others yellowish-white (like the Sun). How is the color related to the surface temperature of the star? What color are the hottest stars? What color are the coolest?*

Additional Questions

1. How can we demonstrate the existence of matter waves?

2. Of the electromagnetic waves generated in a microwave oven, and in your dentist's x-ray machine, which has (a) the greater wavelength, (b) the greater frequency, and (c) the greater photon energy?