CHAPTER 38
PHOTONS: LIGHT WAVES BEHAVING AS PARTICLES

Discussion Questions

Q38.1 They are similar in that they have energy and momentum. Photons are different in that they have zero rest mass and travel at the speed of light. Photons have neither mass nor charge. The speed of photons depends on the material in which they travel but within any given material they always have the same speed and can't be accelerated.

Q38.2 The energy the electron receives from the light would be $2hf$ rather than hf. $2hf$ would replace hf in Eq.(38.4). The threshold frequency f_0 would be $f_0 = eV_0/(2h)$, half what it is when only one photon is absorbed.

Q38.3 The number of photons emitted each second by ordinary light sources is very, very large. (See, for example Exercise 38.3.) There is no noticeable time interval between arrival of photons.

Q38.4 We would expect that the photon (particle) nature of light would be more important at the high-frequency end of the electromagnetic spectrum. High-frequency photons each have more energy and momentum so the quantized photon nature of light would be more apparent at high frequency.

Q38.5 A photon with wavelength 400 nm, at the short-wavelength edge of the visible spectrum, has an energy of 3.1 eV. Table 38.1 shows that the work function for most common metals is larger than this. And, surface impurities, such as oxide layers, increases the work function considerably. And any electrons lost from the surface are quickly replaced from the surrounding air. Photoelectric effect experiments must be done with very clean surfaces in high vacuum.

Q38.6 A certain threshold energy is needed to alter a molecule of the emulsion of the film such that the spot is "exposed". Therefore, there is a threshold frequency below which a photon doesn't have enough energy to expose the film. Longer wavelength light has lower frequency. The threshold need not be sharp; the lower the energy of the photon the less efficiently it can expose the film.

Q38.7 Yes. The higher frequency ultraviolet photons individually have enough energy to damage molecules in the skin.

Q38.8 Only electrons initially at the surface of the metal leave the surface with kinetic energy $hf - \phi$. For electrons that start within the metal some of the energy delivered by the photons is used to bring the electron to the surface of the metal, so less energy is left as kinetic energy of the released electron. More photoelectrons come from within the metal than from its surface; the photons usually penetrate beneath the surface of the metal before they are absorbed.

Q38.9 Above the threshold frequency the number of photoelectrons is independent of the frequency of the light. One photon absorbed produces one photoelectron. Changing the frequency changes the energy of each photon but doesn't change the number of photons.

Q38.10 A photoelectron receives energy from a single photon and the energy of a photon depends on its frequency or wavelength. Therefore, the maximum speed and kinetic energy of a photoelectron depends on the frequency of the light and is independent of the intensity of the light. And there is no time delay. The only statement that is true is (a).

Q38.11 No. A molecule of the phosphor that converts ultraviolet radiation to visible light absorbs an ultraviolet photon and emits only part of the energy as a photon, so the emitted photon has less energy and larger wavelength than the absorbed photon. The molecule can't emit a photon of more energy than the energy of the photon that was absorbed.

Q38.12 $K_{\max} = hf - \phi$. (a) No. Light of greater intensity produces more photoelectrons but doesn't change their maximum kinetic energy. (b) Yes. Increasing f increases $K_{\max}$. (c) No. Increasing λ decreases f and decreases $K_{\max}$. (d) No. Increasing ϕ decreases $K_{\max}$.

Q38.13 The photon transfers some of its energy to the electron so the scattered photon has less energy than the incident photon. This means that $f' < f$. Eq.(38.10) shows that the energy $P_{\mathbf{e}}^2 / 2m$ transferred to the electron depends on the angle ϕ. But for all values of ϕ the electron gains energy and the photon loses energy and $f' < f$. The only exception to this is $\phi = 0$; for this ϕ no energy is transferred to the electron and $f' = f$.

Q38.14 Yes, photons can scatter from protons and Eq.(38.7) still applies. But now m is the proton mass rather than the electron mass. The shift in wavelength will be much less.

Q38.15 Energetic electrons that have been accelerated through high voltages can produce x rays when they are stopped in solid pieces of metal.

Q38.16 Photons travel in straight lines in the direction of propagation of the light. What is oscillating in an electromagnetic wave are electric and magnetic fields. Photons have no charge and therefore an oscillating electric or magnetic field wouldn't exert a force on a photon to cause it to move along with the oscillation of the fields.

Q38.17 No. To get a wave function for the light that is localized in space a spread of frequencies (or wavelengths) must be combined. If the wave packet is spread out in space, as in a steady, continuous beam, it can be of more precise wavelength.