Quantum Theory

1. Is it correct to say that the maximum photoelectron energy KE_{max} is proportional to the frequency *n* of the incident light? If not, what would a correct statement of the relationship between KE_{max} and *n* be?

2. Find the energy of a 700-nm photon.

3. A 1.00-kW radio transmitter operates at a frequency of 880 kHz. How many photons per second does it emit?

4. Light from the sun arrives at the earth, an average of 1.5×10^{11} m away, at the rate of 1.4×10^{3} W/m^2 of area perpendicular to the direction of the light. Assume that sunlight is monochromatic with a frequency of 5.0×10^{14} Hz. (a) How many photons fall per second on each square meter of the earth's surface directly facing the sun? (b) What is the power output of the sun, and how many photons per second does it emit? (c) How many photons per cubic meter are there near the earth?

5. An iron surface is irradiated by ultra-violet light and no photoelectrons are ejected until the wavelength of the incident light falls below 288 nm.

(i) What will be the work function of the metal?
(ii) What will be the maximum kinetic energy of the emitted electron when the iron is illuminated with light of wavelength 140 nm?

6. An orbiting satellite can become charged by the photoelectric effect when sunlight ejects electrons from the vehicle's outer surface and satellites have to be designed to minimize such charging. If a satellite is coated with platinum, a metal with a particularly large work function of 5.32 eV, what will be the longest wavelength of incident sunlight that can eject an electron?

7. The maximum wavelength for photoelectric emission in tungsten is 230 nm. What wavelength of light must be used in order for electrons with a maximum energy of 1.5 eV to be ejected?

8. What is the maximum wavelength of light that will cause photoelectrons to be emitted from sodium? What will the maximum kinetic energy of the photoelectrons be if 200-nm light falls on a sodium surface?

9. 1.5 mW of 400-nm light is directed at a photoelectric cell. If 0.10 percent of the incident photons produce photoelectrons, find the current in the cell.

10. At what scattering angle will incident 100-keV x-rays leave a target with energy of 90 keV?

11. Show that, regardless of its initial energy, a photon cannot undergo Compton scattering through an angle of more than 60° and still be able to produce an electron-positron pair. (Hint: Start by expressing the Compton wavelength of the electron in terms of the maximum photon wavelength needed for pair production.)

12. Ultraviolet light of wavelength 350 nm and intensity 1.00 W/m^2 is directed at a potassium surface (work function 2.2 eV). a) Find the maximum kinetic energy of the photoelectrons. b) If 0.5 percent of the incident photons produce photoelectrons, how many photoelectrons are emitted per second if the potassium surface has an area of 1.00 cm^2?

13. Find the de Broglie wavelength of (a) 46-g golf ball with a velocity of 30m/s, and electron with a velocity of 10^7 m/s.

✓ The wavelength of the golf ball is so small compared with its dimensions that we would not expect to find any wave aspects in its behavior.

✓ The dimension of atoms is comparable with this figure the radius of the hydrogen atom for instance, is 5.3×10^{-11}m. It is therefore not surprising that the wave character of moving electrons is the key to understanding atomic structure and behavior.

14. Find the shortest wavelength present in the radiation from an x-ray machine where electrons were accelerated by a 50,000 V potential.

✓ **Explanation of λ_{min} in the light of photon**

In order to explain the existence of λ_{min} we must resort to the photon nature of light: The shortest wavelength of the emitted photon gains its energy, $E = hc/\lambda_{min}$, from the maximal loss of the *KE*. of an electron in a single collision. Hence the smallest wavelength of the emitted photon is given by which $K' = 0$ (loss all of its *KE*):

$$\frac{hc}{\lambda_{min}} = K = eV, \text{ or } \lambda_{min} = \frac{hc}{eV} = \frac{6.626\times10^{-34}\times3\times10^{8}}{1.6\times10^{-19}\times5\times10^{4}} = 2.48\times10^{-11}m = 0.0248\,nm$$

(Work function, W_0, is ignored as $W_0 << K$)

Plugging in some typical values, one finds that x-rays lie in the range of 0.01 to 10 nm. Note that the work function W_0 is ignored due to the fact that they are only a few electronvolts, whereas the accelerating potentials that is used to produce x-ray in an x-ray vacuum tube, V, is in the range of 10,000 V. This explains why λ_{min} is the same for different target materials. It is also important to note that the above picture is possible only if we view the x-ray to behave like a particle (i.e. photon). If it were 'wave' the wavelength of the emitted x-ray, according to classical Bremstraahlung, would have been continuous instead of a 'sharp' value, λ_{min}.

15. X-rays of wavelength 10.0 pm are scattered from a target. a) Find the wavelength of the x-rays scattered through 45 degrees. b) Find the maximum wavelength present in the scattered x-rays. c) Find the maximum kinetic energy of the recoil electrons.

16. An X-ray photon of wavelength 0.150 nm collides with an electron at rest and the scattered photon moves off at an angle of 80° from the direction of the incident photon.

(a) What will be the Compton shift in wavelength?

(b) What will be the wavelength of the scattered photon?

17. X-rays with a wavelength of 0.12 nm undergo Compton scattering.

(a) What will be the wavelengths of the photons scattered at angles of 30°, 90° and 150°?

(b) What will be the energy of the scattered electron for each of these events?

18. What would be the kinetic energy of an electron with a de Broglie wavelength of 5 nm? Through what potential difference should the electron be accelerated to achieve this kinetic energy?

Nuclear Physics

19. Find the number of alpha-decays that occur in a one gram sample of thorium [$^{232}_{90}Th$] in one year if the disintegration constant λ of $^{232}_{90}Th$ is 1.58x10^{-18} sec^{-1}. Also calculate the activity of one gram of $^{232}_{90}Th$. What would be the volume of helium gas produced by 1 gm of $^{232}_{90}Th$ in one year?

20. A 1.00 g sample of samarium emits alpha particles at a rate of 120 particle/sec. The responsible isotope is $^{147}_{62}Sm$, whose natural abundance in bulk samarium is 15%. Calculate the half life for the decay process. Molar mass of samarium = 150.35 g.

21. Calculate the activity of ^{40}K in 100 kg man assuming that 0.35% of the body weight is potassium. The abundance of ^{40}K is 0.012%; its half-life is 1.31×10^{9} years.

22. An old wooden piece has 25.6% of radioactive carbon as compared to ordinary wood. Find its age, if its half life is 5760 years.

23. The ratio of $^{235}_{92}U$ to $^{238}_{92}U$ in natural uranium deposits today is 7.2×10^{-3}. What was this ratio two billion years ago? Given, half-life of $^{235}_{92}U$ = 0.704x10^{9} y and half-life of $^{238}_{92}U$ = 4.47x10^{9} y.

24. A neutron breaks into a proton, electron and neutrino. Calculate the energy released in the process in MeV.

25. A city requires on the average 100 megawatts of electrical power per day and this is to be supplied by a nuclear reactor of efficiency 20%. Using U-235 as a nuclear fuel, calculate the amount of fuel required for one day's operation. Energy released per fission of U-235 nuclide is 200 MeV.

26. A deuterium nucleus fuses with tritium nucleus to produce ^{4}He and a secondary neutron in the following reaction $^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + \Delta E$. Suppose through this reaction, you want to produce 100 MW of power. Calculate the mass of $^{4}_{2}$He that will be produced per unit time.

27. What is the power output of a reactor fueled by uranium-235 if it takes 30 days to use up 10 Kg of fuel and if each fission gives 200 MeV of energy.

28. A fusion reactor uses deuterium as fuel to give 200 MW power output. Find the fuel consumption per day if the reactor works with 25% efficiency. Given the masses of $^{2}_{1}$H =2.0141 amu and $^{4}_{2}$He=4.002603 amu.

29. In the interior of the sun a continuous process of 4 protons fusing into a helium nucleus and a pair of positrons is going on. Calculate [a] the release of energy per reaction and [b] the rate of consumption of hydrogen to produce 1 MW of power. Given mass of $^{1}_{1}$H=1.007825 amu, $m_{\beta^+} = 5.5x10^{-4}\, amu$.