PH-105 - Quantum Physics and Applications
Tutorial Sheet - 2
(Black body radiation, Photoelectric effect, Compton Scattering)

29. (a) A source of photons of frequency ν is moving with a speed *V* in laboratory frame of reference. Show that in the limit *V* << c , the frequency of photon ν' , as observed in laboratory frame of reference is given by the following expression:

$$\nu' = \nu\left(1 - \frac{v}{c}\right)$$

(b) What is the value of the required speed in case the energy of photons of energy 14.4 KeV is to be increased by 10^{-6} eV? **[Ans: 2.1 cm/s]**

30. A small 10W source of ultraviolet light of wavelength 1000 Å is held at a distance of 0.1m from a metal surface. If the radius of an atom is approximately 0.5 Å, how many photons strike an atom per minute? If the efficiency(i.e. the fraction of photons that succeed in knocking out the electron is) 1%, how many electrons are ejected from a unit area of the metal per second? If the work function of the metal is 1.8 eV, how long would it take classically, to absorb this much energy from the given light source? Assume the light energy to be spread uniformly over the wavefront and efficiency of 1% for this part of the problem. **[Ans: 19; 4 x 10^{17}; 46 s]**

31. In a photoionization experiment, let ε be the binding energy and let the photon with frequency ν be incident. Assuming that the recoil energy of the atom is small, show that the electron comes out with a momentum approximately equal to $[2m(h\nu - \varepsilon)]^{1/2}$. Obtain an expression for the recoil energy of the atom when the electron comes out at an angle of ϕ with respect to the momentum of the photon.

[Ans. $[2mc^2(h\nu - \varepsilon) + h^2\nu^2 - 2h\nu\left(2mc^2(h\nu - \varepsilon)\right)^{1/2}\cos\phi]/2Mc^2$**]**

32. If the fireball of a nuclear weapon can be approximated at some instant to be a black body of radius 0.5 m with a surface temperature of 10^7 K, find (a) the total electromagnetic power radiated ; (b) the wavelength at which the maximum power is radiated.

[Ans: 1.8 x 10^{21} W; 2.9 Å]

33. A laser beam with an intensity of 120 W/m^2 is incident on a surface of sodium. It takes a minimum energy of 2.3 eV to release an electron from sodium (the work function ϕ of sodium). Assuming the electron to be confined to an area of radius equal to that of sodium atom (1Å), how long will it take for the surface to absorb enough energy to release an electron?

[Ans: 0.10s]

34. Light of wavelength 2000 Å falls on a metal surface. If the work function of the metal is 4.2 eV, find the kinetic energy of the fastest and the slowest emitted photoelectrons. Also find the stopping potential and cutoff wavelength for the metal.

[Ans: 2.0 eV, 0, 2V, 2960 Å]

35. An experiment on photoelectric effect of a metal gives the result that the stopping potential for $\lambda = 1850$Å and 5460Å are $4.62V$ and ٠.١٨V respectively. Find the value of Planck's constant, the threshold frequency and the work function.

[Ans: 6.64 x 10^{-34} Js, 0.5 x 10^{15} Hz, and 2.1 eV]

36. A 200 MeV photon strikes a stationary proton. If the photon is back scattered, what is the kinetic energy of the recoiling proton? **[Ans: 60 MeV]**

37. Consider an x-ray beam with $\lambda = 1\text{Å}$ and a γ ray beam with $\lambda = 1.88\times10^{-2}\,\text{Å}$. The radiation scattered from free electron is viewed at 90^o to the incident beam. In each case (a) What is the Compton shift? (b) What is the kinetic energy of the recoiling electron? (c) What percentage of initial energy is lost in collision?

[Ans:0.024Å, 0.295 KeV, 371 KeV, 2.4%, 57%]

38. Show that a free electron can not absorb a photon. Hence photoelectron requires bound electron. In Compton effect, however, the electron can be free.

39. Find the angle θ for which the energy of the Compton scattered photon would be $2m_oc^2$, if the energy of the incident photon is $4m_oc^2$. Show that if θ is greater than 60^o, the scattered photon will never have an energy greater than $2m_oc^2$, irrespective of the energy of the incident photon.

40. Find the energy of the incident x-ray if the maximum kinetic energy of the Compton electron is $m_oc^2/2.5$.

41. Find the smallest energy that a photon may have and still transfer one half of its energy to an electron intially at rest. **[Ans: 0.256 MeV]**

42. A 200 MeV photon strikes a stationary proton. If the photon is back scattered, what is the kinetic energy of the recoiling proton? **[Ans: 60 MeV]**

43. A photon strikes an electron at rest and the following process takes place: $\gamma + e^- \rightarrow e^+ + e^- + e^-$. The final state electrons and the positron move with identical momenta in the same direction as that of the incident photon. Find the energy of the photon and the energy of the three particles produced. **[Ans: 2 MeV, 0.83 MeV]**

44. In Compton scattering of radiation by an angle θ, by a scatterer of rest mass m if the scatterer gets excited (or de-excited) consequent to scattering so that its final rest mass becomes $M \neq m$, show that the change in the wavelength will become $\Delta\lambda = \lambda_c(1-\cos\theta) + (\lambda\lambda'/2hm)(M^2 - m^2)$. Show that the additional term is consistent with energy conservation.

45. A spacecraft is receding from the earth with a speed 0.97c. The spacecraft carries a light source that emits photons of electric field $\vec{E} = \vec{E}_0 \sin\left[1.0\times10^4\, m^{-1}(x - ct)\right]$. Find out the frequency of the photon observed by the observer on earth.

**** Problems 29, 31, 34, 35, 38, 39, and 44 will be solved during the tutorial session.**