PH-107 (2021): Tutorial Sheet 1

* marked problems will be solved in the Wednesday tutorial class

Photoelectric Effect:

1. *In a photoelectric effect experiment, excited hydrogen atoms are used as light source. The light emitted from this source is directed to a metal of work function Φ. In this experiment, the following data on stopping potentials (V_s), for various Balmer lines of hydrogen, is obtained.

$$n = 4 \rightarrow n = 2, \text{ transition line : } V_S = 0.43 \text{ V}$$
$$n = 5 \rightarrow n = 2, \text{ transition line : } V_S = 0.75 \text{ V}$$
$$n = 6 \rightarrow n = 2, \text{ transition line : } V_S = 0.94 \text{ V}$$

a) What is the work function Φ of the metal in eV?
b) What is the stopping potential (in Volts) for Balmer line of the shortest wavelength?
c) What will be the photocurrent corresponding to Paschen series (ending in $n = 3$) transitions?

2. In an experiment on photoelectric effect of a metal, the stopping potentials were found to be 4.62 V and 0.18 V for $\lambda_1 = 1850$ Å and $\lambda_2 = 5460$ Å, respectively. Find the value of Planck's constant, the threshold frequency and the work function of the metal.

3. A monochromatic light of intensity 1.0 μW/cm^2 falls on a metal surface of area 1 cm^2 and work function 4.5 eV. Assume that only 3% of the incident light is absorbed by the metal (rest is reflected back) and that the photoemission efficiency is 100 % (i.e. each absorbed photon produces one photo-electron). The measured saturation current is 2.4 nA.

   (a) Calculate the number of photons per second falling on the metal surface.
   (b) What is the energy of the incident photon in eV ?
   (c) What is the stopping potential ?

4. In a photoelectric experiment, a photocathode is illuminated separately by two light sources of same intensity but different wavelengths, 480 nm and 613 nm. The resulting photocurrent is measured as a function of the potential difference (V) between the cathode and the anode. Observed photocurrent for three values of V is given below

V	current (nA)	
	480 nm	613 nm
-0.1	76.3097	64.7039
-0.2	67.6194	44.4078
-0.3	58.9291	24.1118

   (a) Using this data, obtain the work function of the photocathode and the cut off wavelength.
   (b) What is the maximum kinetic energy of the electron for $\lambda = 480$ nm? What should be the wavelength of light to emit electrons half this kinetic energy?

(c) When the photocathode material is changed, it is found that the cut off frequency is 1.2 times the cut off frequency of the old material. What is the work function of the new material?

5. 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.

Black Body Radiation:

1. * According to Planck, the spectral energy density $u(\lambda)$ of a blackbody maintained at temperature T is given by

$$u(\lambda, T) = \frac{8\pi hc}{\lambda^5} \frac{1}{\exp\left(\frac{hc}{\lambda k_B T}\right) - 1}$$

where λ denotes the wavelength of radiation emitted by the blackbody.

(a) Find an expression for λ_{max} at which $u(\lambda, T)$ attains its maximum value (at a fixed temperature T). λ_{max} should be in terms of T and fundamental constants h, c and k_B.

(b) Expressing λ_{max} as $\frac{\alpha}{T}$, obtain an expression for $u_{\text{max}}(T)$ in terms of α, T and the fundamental constants.

2. The earth rotates in a circular orbit about the sun. The radius of the orbit is 140×10^6 km. The radius of the earth is 6000 km and the radius of the sun is 700,000 km. The surface temperature of the sun is 6000 K. Assuming that the sun and the earth are perfect black bodies, calculate the equilibrium temperature of the earth.

3. (a) Given Planck's formula for the energy density, obtain an expression for the Rayleigh Jeans formula for $U(\nu, T)$.

(b) For a black body at temperature T, $U(\nu, T)$ was measured at $\nu = \nu_0$. This value is found to be one tenth of the value estimated using Rayleigh Jeans formula. Obtain an implicit equation in terms of $h\nu/k_B T$

(c) Solve the above equation to obtain the value of $h\nu/k_B T$, up to the first decimal place.

4. Using appropriate approximations, derive Weins' displacement law from Planck's formula for energy density of black body radiation.

Compton Scattering:

1. A photon of energy $h\nu$ is scattered through 90° by an electron initially at rest. The scattered photon has a wavelength twice that of the incident photon. Find the frequency of the incident photon and the recoil angle of the electron.

2. Find the energy of the incident x-ray if the maximum kinetic energy of the Compton electron is $m_0 c^2/2.5$.

3. Show that a free electron cannot absorb a photon so that a photoelectron requires bound electron. However, the electron can be free in Compton Effect. Why?

4. Two Compton scattering experiments were performed using x-rays (incident energies E_1 and $E_2 = E_1/2$). In the first experiment, the increase in wavelength of the scattered x-ray, when measured at an angle $\theta = 45°$, is 7×10^{-14} m. In the second experiment, the wavelength of the scattered x-ray, when measured at an angle $\theta = 60°$, is 9.9×10^{-12} m.

   (a) Calculate the Compton wavelength and the mass (m) of the scatterer.

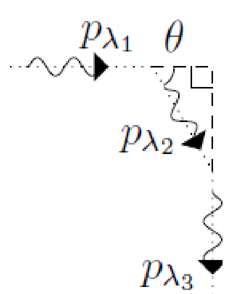
   (b) Find the wavelengths of the incident x-rays in the two experiments.

5. Find the smallest energy that a photon can have and still transfer 50% of its energy to an electron initially at rest.

6. *γ-rays are scattered from electrons initially at rest. Assume the it is back-scattered and its energy is much larger than the electron's rest-mass energy, $E \gg m_e c^2$.
   (a) Calculate the wavelength shift
   (b) Show that the energy of the scattered beam is half the rest mass energy of the electron, regardless of the energy of the incident beam
   (c) Calculate the electron's recoil kinetic energy if the energy of the incident radiation is 150MeV

7. In Compton Scattering, show that the maximum energy of the scattered photon will be $2m_0c^2$, irrespective of the energy of the incident photon. Find the value of θ_0, the angle at which the maximum energy occurs.

8. * In a Compton scattering experiment (see figure), X-rays scattered off a free electron initially at rest at an angle $\theta(> \pi/4)$), gets re-scattered by another free electron, also initially at rest.



   (a) If $\lambda_3 - \lambda_1 = 1.538 \times 10^{-12}$ m, find the value of θ.

   (b) If $\lambda_2 = 68 \times 10^{-12}$ m , find the angle at which the first electron recoils due to the collision.