PH-107 (2014)
Tutorial Sheet 1 (Revision)

***** Problems to be done in tutorial.

A: Introduction:

P1: Using equipartition law, find specific heat of a has containing triatomic (a) linear molecules. Will the result be different if the molecule was non- linear? In what way?

P2*: Show that the Einstein's expression of specific heat gives a value of 3R at high temperatures and tends to zero as temperature tends to zero.

B: Bohr Model:

P3*: Show that if the nucleus in the Bohr atom is assumed to be of finite mass, the angular momentum of the system, the allowed radii and energies are all given by identical expressions except for replacement of m by the reduced mass μ.

P4*: Two similar particles of mass *m* are connected to each other by a spring of negligible natural length and mass and spring constant *k*. The particles are made to rotate in a circle about their common centre of mass, such that the distance between them is *R*. Assume that the only force between the particles is the one provided by the spring. Apply Bohr's quantization rule to this system and find the allowed value of *r* and the energies in terms of fundamental constants if any, the mass and the spring constant.

P5: Assume that the wavelengths λ of the hydrogen atom spectra are given by the following expression instead of the usual one.

$$\frac{1}{\lambda} = R\left(\frac{1}{m^3} - \frac{1}{n^3}\right)$$

Here *R* is a constant and *m* and *n* are integers with *n*>*m*. If we write the angular momentum (*L*) quantization condition as $L = a\,\hbar$, what values *a* should take so as to explain the above spectra. Construct a theory similar to Bohr's using this quantization condition and find out an expression of the energy and the Bohr's radius.

P6: A μ^- meson is an elementary particle of charge –*e* and mass that is 207 times the mass of the electron. A muonic atom consists of a nucleus of charge *Ze* with μ^- meson circulating about it.

(a) Calculate the radius of the first Bohr orbit of a muonic atom with *Z=1*.
(b) Calculate the binding energy of a muonic atom with Z=1.
(c) Find the wavelength of the first line in the Lymann series for such an atom.

[**Ans.:** 2.85×10^{-3} Å, 2.53 keV, 6.55 Å]

P7*: One of the lines in the Hydrogen atom has a wavelength 4861.320 Å. It was later discovered this line has a faint companion located at 4859.975 Å. The explanation for this line was the presence of a small amount of heavier isotope deuterium in hydrogen. Use this data to compute the deuterium mass to the proton mass.

P8: A positronium atom (consisting of an electron and a positron revolving about common centre of mass; positron being a particle with mass equal to the mass of electron but charge plus *e*) is excited from a state with n=1 to n=4. Apply Bohr's theory with suitable modifications. (a) Calculate the energy that would have been absorbed by the atom. (b) Calculate minimum possible wavelength emitted when such an electron de-excites. (c) Calculate the recoil speed and recoil energy of the positronium atom, assumed initially at rest, after the excitation takes place.

P9*: (a) Calculate the recoil speed of hydrogen atom assumed initially at rest, when it makes a transition from n=4 to n=1.

(b) What is the kinetic energy given to the hydrogen atom.

(c) At what temperature would the hydrogen atoms have this as the average speed assuming the gas to be classical?

(d) What would you expect if the hydrogen atoms were in motion approaching the photon?

(e) Can you think of a simple experiment that can be used to cool a gas?

[**Ans.:** 4.1 m/s, 8.65×10^{-8} eV, 0.7 mK]

C: Photoelectric Effect:

P10: 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 slopping potential and cutoff wavelength for the metal.

[**Ans.:** 2.0 eV, 0, 2V, 2960 Å]

P11*: An experiment on photoelectric effect of a metal gives the result that the stopping potential for λ = 1850 Å and 5460 Å are 4.62 and 0.18 V respectively. Find the value of Planck's constant, the threshold frequency and the work function.

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

P.12*: Show that a free electron cannot absorb a photon. Hence photoelectron requires bound electron. In Compton effect, however, the electron can be free.

D: Compton Effect:

P.13: X-ray of wavelength λ = 0.1 Å is scattered by an electron. At what angle will the scattered photon have a wavelength of 0.11 Å?

[**Ans.:** 54.3^{o}]

P.14: 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]

P.15*: Consider an x-ray beam with λ = 1 Å and a γ ray beam with $\lambda = 1.88\times10^{-2}$ 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.:** 0.024 Å, 0.295 keV, 2.4% and 57%]

P.16: Find the smallest energy that a photon may have and still transfer one half of its energy to an electron initially at rest.

[**Ans.:** 0.256MeV]

P.17: A photon of energy $h\nu$ is scattered through 90^o by an electron initially at rest. The scattered photon has a wavelength twice that of incident photon. Find the frequency of the incident photon and the recoil angle of the electron.

[**Ans.:** 1.23×10^{20} Hz, $\theta= 26.6^o$]

P.18: Find the energy of the incident x-ray if the maximum kinetic energy of the Compton electron is $m_oc^2/2.5$.

[**Ans.:** 0.69 m_oc^2]

P.19: Compare the momentum of an electron with that of a photon whose energy is same as the kinetic energy of the electron.

P.20: A beam of mono-energetic x-ray gets scattering from a particle of mass m_o. It is found that the wavelength of the x-ray scattered at 60^o is half that scattered at 120^o. Find the incident energy of the photon.

[**Ans.:** 2 m_oc^2]

P21*: Consider Compton Scattering. Show that if the angle of scattering θ increases beyond a certain value θ_o, the scattered photon will never have energy larger than $2m_oc^2$, irrespective of the energy of the incident photon. Find the value of θ_o.

[**Ans.:** $\theta_o= 60^o$]