# THE OPEN UNIVERSITY OF SRI LANKA

**DEPARTMENT OF PHYSICS**

**BACHELOR OF SCIENCE DEGREE PROGRAMME -2017/2018**

**LEVEL 04**

**PHU4300 /PYU 2160 – MODERN PHYSICS**

**FINAL EXAMINATION.**

**TIME: -TWO HOURS (2 hrs.)** **ANSWER FOUR QUESTIONS ONLY.**

**Date: 20.04.2019** **Time: 9.30 am – 11.30 am**

$c$=3x10$^{8}$ ms$^{-1}$, $h$= 6.63x10$^{-34}$ Js, 1eV=1.6x10$^{-19}$J, $\pi$=3.14, mass of the electron=9.1x10$^{-31}$ kg, mass of the proton=1.67x10$^{-27}$ kg, $R_H$= 1.097x10$^{7}$ m$^{-1}$, e=1.6x10$^{-19}$ C

1. (a) What is the photoelectric effect? **(3 marks)**
   (b) How does the kinetic energy of the photoelectrons depend on the intensity and frequency of the incident radiation? **(3 marks)**
   (c) Define the terms (i) photoelectric work function (ii) stopping potential and (iii) Threshold frequency **(6 marks)**
   (d) Write down the Einstein's photoelectric equation. **(2 marks)**
   (e) The work function for tungsten metal is 4.52 eV.
   (i) What is the cutoff wavelength for tungsten?
   (ii) What is the maximum kinetic energy of the electrons when radiation of wavelength 198 nm used?
   (iii) What is the stopping potential in this case?
   **(6 marks)**
   (f) The electromagnetic radiation itself is quantized and consists of photons. What are the energy and momentum of a photon of red light of wavelength 650nm?
   **(5 marks)**

2. In the Bohr model of the hydrogen atom, an electron is orbiting around a proton such that its angular momentum $mvr_n = n\hbar$ (where $n$ is an integer 1,2,3……) and its radius of an orbit is $r_n = \frac{n^2\hbar^2}{mk_e e^2}$ (where $k_e = \frac{1}{4\pi\epsilon_0}$ =8.9x10$^{9}$ Nm$^2$C$^{-2}$)
   (a) Derive the expressions for, the kinetic energy of the electron in the $r_n$ th orbit of the hydrogen atom. **(3 marks)**
   (b) What is meant by Bohr radius of the hydrogen atom? Show that Bohr radius is given as $a_0 = \frac{\hbar^2}{mk_e e^2}$ .
   **(5 marks)**

(c) If the total energy of the atom E is given by $E = -k_e \frac{e^2}{2r}$, show that the energy of the electron in the hydrogen atom is given by $E_n = \frac{-1}{n^2}\frac{k_e e^2}{2a_0}$ **(4 marks)**

(d) Calculate the binding energy for the hydrogen atom in eV. Hence show that the energy values of the electron in a hydrogen atom can be expressed as $E_n = \frac{-13.6}{n^2}\ eV$ ($n$=1, 2, 3...) **(6 marks)**

(e) Using the result obtained in part (d), find the wavelength of the photon that is emitted when the electron in a hydrogen atom make a transition from $n_i$=4 to $n_f$=2. **(7 marks)**

3. A quantum particle of mass $m$ moves in a potential well of length $a$. Its potential energy is infinite for x<0 and for x>$a$ . Inside the region 0≤x≤ $a$, its potential energy is zero.

(a) Show that proper solution of the time-independent Schrodinger equation can be written as $\psi(x) = \sqrt{\frac{2}{a}}\sin\frac{n\pi x}{a}$ $n = 1,2,3 \ldots\ldots$ **(7marks)**

(b) Show that the allowed energies are given by $E_n = \frac{n^2\pi^2\hbar^2}{2ma^2}$ $n = 1,2,3,..$ **(6 marks)**

(c) If the particle, confined to a two-dimensional, potential rectangle of length $a$ and width $b$, which is defined as the potential energy $V(x,y)$=0 in the region $0 \le x \le a$ and $0 \le y \le b$ ,and $V(x,y)$=∞ elsewhere.

Write down the normalized wave function and the corresponding energy values for the particle using the results obtained in part (a) and part (b). **(6 marks)**

(d) When the given potential rectangle becomes a potential square of side $a$ (i.e. when $a$=$b$), describe the degeneracies of the ground and the first excited levels of the particle. **(6 marks)**

4. (a) State the Einstein's postulates of special relativity. **(4 marks)**

(b) What is meant by the "Time dilation"? **(2 marks)**

(c) Write down the Lorentz transformations with usual notation. **(4 marks)**

(d) Using the Lorentz transformations show that the simultaneity is not possible between

two reference frames. **(4 marks)**

(e) A beam of muons travels through the laboratory with speed $v = \frac{4c}{5}$ ($c$ is the velocity of light). The lifetime of a muon in its rest frame is $2.2\text{x}10^{-6}$ s. Find the mean distance travelled by the muons in the lab frame. **(5 marks)**

(f) According to observer $O$, a blue flash occurs at $x_b$=10.4m when $t_b$=0.124 μs, and a red flash occurs at $x_r$=23.6 m when $t_r$=0.138 μs. According to the observer $O'$, who is in motion relative to $O$ at velocity $u$, the two flashes appear to be simultaneous. Find the velocity $u$. **(6 marks)**

5. (a) Briefly describe the red shift related to the Doppler effect in light. **(5 marks)**

(b) If an observer directly moving away from a light source of wavelength $\lambda_0$ with a relative velocity, $v$, write an expression for the wavelength $\lambda$ measured by the observer. **(5 marks)**

(c) The wavelength of the Balmer series of spectral lines of hydrogen atom can be described by using the Rydberg formula.

$$\frac{1}{\lambda} = R_H\left[\frac{1}{n_{lower}^2} - \frac{1}{n_{upper}^2}\right]$$

The longest wavelength of light emitted by hydrogen in the Balmer series is measured as λ=1458 nm in light from a distant galaxy. Find the speed at which the galaxy is receding from earth. **(15 marks)**

6. (a) Without deriving any equation state the relativistic expression of mass-velocity relation for a particle of mass $m_0$, write down the relativistic expressions for its momentum, $p$ and its total energy, $E$. Hence or otherwise, prove that $E^2 = p^2c^2 + m_o^2c^4$ **(10 marks)**

(b) A neural K meson (rest energy 497.7 MeV) is moving with a kinetic energy of 77.0 MeV. It decays into a pi meson (rest energy 139.6 MeV) and another particle of unknown mass. The pi meson is moving in the direction of the original K meson with momentum of $127.2\text{x}10^{-8}$ MeV.

(i) Find the momentum and total relativistic energy of the unknown particle.

(ii) Find the rest energy of the unknown particle.

**(15 marks)**