UNIVERSITY OF COLOMBO, SRI LANKA

FACULTY OF SCIENCE

LEVEL I EXAMINATION IN SCIENCE – SEMESTER I – 2013

PH 1001– MODERN PHYSICS

(Two Hours)

Answer ALL (FOUR) questions

Electronic calculators are allowed*.

(This question paper consists of 04 questions in 07 pages.)

Important Instructions to the Candidates

- If a page or a part of this question paper is not printed, please inform the supervisor immediately.
- Enter Your Index Number in all pages.
- Use the papers provided to answer questions 1, 2 and 3. Question 4 consists of 15 Multiple Choice Questions. In each of these multiple choice questions pick one of the alternatives (a), (b), (c), (d) and (e) which is correct or most appropriate and encircle your response on the question paper itself.
- At the end of the time allowed for this paper, attach question 4, both English and Sinhala versions with the marked responses to your written answers to questions 1, 2 and 3 (answer book) and hand them over to the supervisor or invigilator as one answer script.
- You are permitted to remove only questions 1, 2 and 3 of the question paper from the Examination Hall.

* No calculators and electronic devices capable of storing and retrieving text, including electronic dictionaries and mobile phones may be used.

Some useful constants, conversions and formulae are;

Planck constant $h = 6.63 \times 10^{-34}$ J s

Wien's Constant = 3000 μm K

Speed of light in free space $c = 3.00 \times 10^{8}$ m s^{-1} ; $hc = 12.4 \times 10^{3}$ eV Å = 1240 eV nm

Rest mass of the electron $m_e = 0.511$ MeV $= 9.11 \times 10^{-31}$ kg

Electronic charge $= 1.60 \times 10^{-19}$ C ; 1 eV $= 1.60 \times 10^{-19}$ J

Compton shift formula : $\lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\theta)$; $g = 10$ m s^{-2}

All the symbols have their usual meaning.

(1) Consider a simple pendulum of mass m and length l undergoing small oscillations. It is displaced through a maximum angle of θ.

(a) (i) Write down an expression for the frequency f of the pendulum in terms of l and g.

(ii) If $l = 2.5$ m calculate f.

(b) (i) Write down an expression for the total mechanical energy E of the pendulum in terms of m, g, l, and θ.

(ii) If $m = 0.01$ kg, and $\theta = 10^0$ calculate E.

(c) (i) Applying $E = nhf$ for the pendulum determine the value of n (quantum number) for the pendulum.

(ii) Determine the fractional change, $\frac{\Delta E}{E}$, in energy that could occur in the pendulum. Comment on the result.

(iii) 'Quantum numbers for macroscopic systems should be very large'. Justify this statement.

(2) In a photoelectric effect set-up a point source of light of power 3.2×10^{-3} W emits monochromatic photons of energy 5.0 eV. The source is located at a distance of 0.8 m from a small photosensitive disk of radius 8.0×10^{-3} m. The work function of the photosensitive material is 3.0 eV. The efficiency of photoelectric emission is one electron for every 10^6 incident photons. Assume that the disk is isolated and initially neutral. Determine the following

(i) The number of photoelectrons emitted per second from the disk.

(ii) The kinetic energy of the fastest photoelectron.

(iii) The potential acquired by the disk when the photoelectron emission stops.

(3) (a) An incident X-ray photon is scattered from a free electron that is initially at rest. The photon is scattered straight back at an angle of 180^0 from its initial direction. The wavelength of the scattered photon is 0.0830 nm.

(i) What is the wavelength of the incident photon?

(ii) What is the magnitude of the momentum of the electron after the collision?

(iii) What is the kinetic energy of the electron after the collision?

(b) Consider Compton scattering of a photon by a **moving electron**. Before the collision the photon has wavelength λ and it is moving in the $+x$-direction and the electron is moving in the $-x$-direction with a **total energy** E. The photon and the electron collide head-on. After the collision both are moving in the $-x$-direction. Write down the necessary equations in order to derive an expression for the wavelength λ' of the scattered photon. (No need to simply or derive; You could use any other appropriate symbols to represent required parameters)

- **Enter Your Index Number in all pages.**
- Question 4 consists of 15 Multiple Choice Questions. In each of these multiple choice questions pick one of the alternatives (a), (b), (c), (d) and (e) which is correct or most appropriate and encircle your response on the question paper itself.

(4)

Index No. :.......................

(i) Which of the following statements is true about a photon?

(a) A photon has zero mass and zero momentum.

(b) A photon has a finite mass and a finite momentum.

(c) A photon has zero mass but a finite momentum.

(d) A photon has a finite mass but zero momentum.

(e) A photon has an infinite mass and a finite momentum.

(ii) The temperature of the skin of a person is approximately $35\,^0\mathrm{C}$. The wavelength at which the peak occurs in the radiation emitted from the skin is

(a) 9740 nm (b) 9840 nm (c) 9940 nm (d) 10940 nm (e) 85714 nm

(iii) A cavity radiator has its maximum spectral radiancy at a wavelength of 30.0 μm. The absolute temperature of the radiator is increased so that the radiant intensity of the radiator is doubled. The new temperature of the radiator is

(a) $\sqrt[4]{100}$ K (b) $\sqrt[4]{200}$ K (c) $\sqrt[4]{2}\times 100$ K (d) $\sqrt[4]{4}\times 100$ K

(e) $\sqrt{1000}$ K

(iv) The work function of platinum is twice that of the work function of calcium. If the minimum photon energy required to emit photoelectrons from the surface of platinum is E, then the minimum photon energy required to emit photoelectrons from the surface of calcium would be

(a) $4E$ (b) $2E$ (c) E (d) $E/2$ (e) $E/4$

Index No. :.....................

(v) Photoelectric effect can take place when photons strike bound electrons or electrons embedded in a metal surface. This is in accordance with the

(a) Law of conservation of energy (b) Law of conservation of mass

(c) Law of conservation of momentum (d) Law of conservation of both mass and momentum. (e) Law of conservation of both energy and momentum.

(vi) Bremsstrahlung radiation

(a) is emitted when an incoming neutron interacts with a bound electron.

(b) is responsible for the line spectrum of X-rays emitted from a target.

(c) is responsible for the continuous spectrum of X-rays emitted from a target.

(d) is responsible for the characteristic spectrum of X-rays emitted from a target.

(e) is emitted when an incoming photon interacts with a bound electron.

(vii) Molybdenum's innermost (K-shell) electrons have an energy of -20000 eV. The M-shell electrons have an energy of -200 eV. The wavelength of the K_β X-ray line is

(a) 0.626 $\overset{0}{\mathrm{A}}$ (b) 0.614 $\overset{0}{\mathrm{A}}$ (c) 0.512 $\overset{0}{\mathrm{A}}$ (d) 0.412 $\overset{0}{\mathrm{A}}$ (e) 0.312 $\overset{0}{\mathrm{A}}$

(viii) Which of the following properties of a hydrogen atom was adequately explained for the first time by the wave-particle duality?

(a) An infinite number of orbits exist for the electron.

(b) More than one orbit exists for the electron.

(c) More than one energy state exists for the electron.

(d) More than one momentum exists for the electron.

(e) Only certain energy states are possible for the electron.

Index No. :.....................

(ix) Which of the following transitions emits the **shortest** wavelength photon in a hydrogen atom?

(a) $n = 2$ to $n = 1$ (b) $n = 3$ to $n = 2$ (c) $n = 3$ to $n = 1$ (d) $n = 4$ to $n = 3$

(e) $n = 4$ to $n = 2$

(x) A certain quantum state of a triply ionized beryllium (Be^{+++}) has the same orbital radius as the ground state of hydrogen. The corresponding quantum number n of Be^{+++} is

(a) $n = 1$ (b) $n = 2$ (c) $n = 3$ (d) $n = 4$ (e) $n = 5$

(xi) Hydrogen atoms in the ground state are excited by monochromatic radiation of photon energy 12.1 eV. According to the Bohr theory, the number of spectral lines emitted by hydrogen will be

(a) 2 (b) 3 (c) 4 (d) 5 (e) 6

(xii) The de Broglie wavelength of an electron moving with a velocity 1.5×10^8 m s^{-1} is equal to the wavelength of a photon. The ratio

$$\frac{\text{The kinetic energy (non relativistic) of the electron}}{\text{The energy of the photon}} \text{ is equal to}$$

(a) 2 (b) 4 (c) 1/2 (d) 1/4 (e) 1/8

(xiii) If the wave properties of a particle are difficult to observe, it is probably due to the particle's

(a) small size (b) low momentum (c) high charge (d) large mass

(e) small mass

Index No. :......................

(xiv) The ratio $\dfrac{\text{The Compton wavelength}(\lambda_C)}{\text{de Broglie wavelength}(\lambda_d)}$ for a relativistic electron of total energy E and rest mass m_0 is given by

(a) $\dfrac{\lambda_C}{\lambda_d} = \left[\left(\dfrac{m_0c^2}{E}\right) - 1\right]$ (b) $\dfrac{\lambda_C}{\lambda_d} = \left[\left(\dfrac{m_0c^2}{E}\right) - 1\right]^{1/2}$ (c) $\dfrac{\lambda_C}{\lambda_d} = \left[1 - \left(\dfrac{m_0c^2}{E}\right)\right]^{1/2}$

(d) $\dfrac{\lambda_C}{\lambda_d} = \left[\left(\dfrac{E}{m_0c^2}\right)^2 - 1\right]$ (e) $\dfrac{\lambda_C}{\lambda_d} = \left[\left(\dfrac{E}{m_0c^2}\right)^2 - 1\right]^{1/2}$

(xv) The Newton's second law in relativistic form can be expressed as (here m is the rest mass of an object and v is its speed)

(a) $F = m\left(1 - \dfrac{v^2}{c^2}\right)^{-3/2} \dfrac{dv}{dt}$ (b) $F = m\left(1 - \dfrac{v^2}{c^2}\right)^{3/2} \dfrac{dv}{dt}$

(c) $F = m\left(1 - \dfrac{v^2}{c^2}\right)^{-1/2} \dfrac{dv}{dt}$ (d) $F = m\left(1 - \dfrac{v^2}{c^2}\right)^{1/2} \dfrac{dv}{dt}$

(e) $F = m\left(\dfrac{v^2}{c^2} - 1\right)^{-3/2} \dfrac{dv}{dt}$

____________%%%%%%%%____________