[This question paper contains 2 printed pages.]

Sr. No. of Question Paper : 1815

Your Roll No...............

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Unique Paper Code : 2222012401

Name of the Paper : Modern Physics (DSC)

Name of the Course : B.Sc. (Hons.) Physics – NEP UGCF-2022

Semester : IV

Duration: 3 Hours

Maximum Marks : 90

Instructions for Candidates

Write your Roll No. on the top immediately on receipt of this question paper.

Question No. 1 is compulsory. Attempt any four from the remaining five questions.

All questions carry equal marks.

Use of non-programmable calculators is allowed.

1. Attempt any **six** of the following questions: (6×3=18)

(i) Explain the term "Ultraviolet Catastrophe" and mention which classical law led to this discrepancy.

(ii) Prove that the complete absorption of a photon by a free electron at rest is not permitted by conservation laws of momentum and energy.

(iii) Consider an electron in an infinitely deep well of width 0.6 Å. Calculate the energy of the electron in the third excited state (n = 4). (Mass of electron = 9.1×10^{-31} kg)

(iv) Using Moseley's relation, calculate the wavelength of the K_α line for iron ($Z = 26$).

(v) Discuss the production mechanism of continuous X-rays and characteristic X-rays.

(vi) Determine the binding energy per nucleon for ^{235}U. ($Z = 92$, $M_U = 230.033087$ u, $m_p = 1.007825$ u, $m_n = 1.008665$ u)

(vii) What is the activity of 1 g of ^{226}Ra, whose half-life is 5.05×10^{10} s?

2. (a) Define the Compton effect. Derive the formula for the kinetic energy of the recoil electron as a function of the incident photon energy $h\nu$ and the scattering angle θ. Explain why Compton scattering is predominantly observed with X-rays or Gamma-rays rather than ultra-violet radiation. (10)

(b) Use the Heisenberg uncertainty principle ***($\Delta x \,.\, \Delta p) \geq \hbar/2$)*** to estimate the minimum kinetic energy (in MeV) of a proton confined within a nucleus of radius **$R \approx 10^{-15}$ m.** Contrast this value with the typical binding energy per nucleon **(≈ 8 MeV).** (8)

3. (a) Show that for a plane wave state given by $\psi(x) = A\,e^{i(kx-\omega t)}$, the probability current density is $J = |A|^2 v$, where v is the classical velocity of the particle. Explain the physical meaning of a negative value for the probability current density J(x,t). (10)

   (b) The wavefunction of a particle is represented by $\psi(x) = Ae^{-ax^2}$, $-\infty < x < \infty$, where a is a constant ($a > 0$). Normalize the wave function. (8)

4. (a) A stream of particles of mass m and energy E moves from right to left, strikes a potential step $V(x) = V_o$ for $x \leq 0$ and $V(x) = 0$ for $x > 0$. Taking $E > V_o$, obtain expressions for the reflection coefficient and transmission coefficients. Discuss the differences between the classical and quantum behaviour of the particle. (10)

   (b) Using Heisenberg uncertainty principle, explain the quantum mechanical possibility of a particle penetrating the classically forbidden region ($x > 0$) for $V_o > E$. (8)

5. (a) Discuss Einstein's A and B coefficients. State the principle of detailed balancing and derive the general thermodynamic relationships between them when the upper and lower electronic states possess explicit degeneracies (g_2 *and* g_1). (10)

   (b) In 2p → 1s transition in a hydrogen atom, the lifetime of 2p state for spontaneous emission is given by 1.6×10^{-9} sec. The energy of this transition is 10.2 eV. Calculate Einstein's A and B coefficients. (8)

6. (a) What is a synchrotron? Discuss the principle, construction, working, advantages and disadvantages of a synchrotron. (10)

   (b) In a cyclotron, magnetic field of 1.6 Tesla is used to accelerate protons. Calculate the (i) frequency to accelerate the protons, (ii) maximum energy of protons in Mev. The radius of cyclotron is given, $r = 0.5$ m. (Mass of proton = 1.67×10^{-27} kg). (4)

   (c) Why does the number of neutrons tend to exceed the number of protons in stable nuclei? Why are even-even nuclei most stable? (4)

Show that for a plane wave state given by $\psi(x) = A\,e^{i(kx-\omega t)}$, the probability current density is $J = |A|^2 v$, where v is the classical velocity of the particle. Explain the physical meaning of a negative value for the probability current density J(x,t).