Serial No: 5195

Your Roll No.....

a) Name of Course: B.Sc. Hons.–(Physics)_NEP: UGCF-2022

b) Semester: VIII- Semester (GE Paper)

c) Name of the Paper: **Modern Physics**

d) Unique Paper Code: 2224001203

Duration: **3 hours** Maximum marks: **90**

Instructions for Candidates

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

All Questions carry equal marks. Q. No. 1 is compulsory.

Answer any four of the remaining five questions.

Use of non-programmable scientific calculators are allowed

1. Attempt any six questions out of seven. $(6 \times 3 = 18)$

(a) Calculate the binding energy per nucleon of an alpha particle ($^4_2$He) if its total binding energy is found to be 28.3 MeV.

(b) In a Compton scattering experiment, a photon is scattered at an angle of $\theta = 90^\circ$. Find the scattered wavelength change $\Delta\lambda$ in terms of the Compton wavelength λ_C.

(c) State the de Broglie hypothesis and explain how it reconciles the dual nature of matter.

(d) Why is a macroscopic object like a moving tennis ball unable to show observable wave properties or uncertainty limitations?

(e) Define the terms "Metastable state" and "Population Inversion" in the context of laser operation.

(f) X-rays of wavelength 0.154 nm undergo first-order Bragg reflection from a crystal plane at a glancing angle of 30°. Compute the interplanar spacing d.

(g) Briefly explain why very heavy nuclei tend to undergo nuclear fission from the standpoint of the binding energy curve.

Q2. (a) Describe the photoelectric effect experiment. Discuss why classical wave theory failed to explain the existence of a threshold frequency and instantaneous emission, and how Einstein's photon hypothesis resolved these issues. **(10 Marks)**

(b) A wave packet is governed by the relation $\omega = ck^2$. Derive the explicit expressions for its:

1. Phase velocity (v_p)
2. Group velocity (v_g)
   Show the functional relationship between v_g and v_p for this specific medium. **(8 Marks)**

3. (a) Outline the single slit diffraction thought experiment (Heisenberg's slit) to show that attempting to measure a particle's spatial position precisely introduces a corresponding minimum uncertainty in its transverse momentum. **(10 Marks)**

(b) An unstable elementary particle has a lifetime of 2.0×10^{-8} s. Compute the minimum inherent uncertainty in its rest energy measurement (in eV). **(8 Marks)**

4. (a) Formulate the time-independent Schrödinger Equation for a free particle. Apply appropriate boundary conditions to solve for the normalization constant and the wave functions of an electron trapped inside a 1D rigid box of length L. **(10 Marks)**

(b) A particle is in the ground state of a one-dimensional infinite square well of width $a = 0.1$ nm. Compute the expectation value of its position $\langle x \rangle$ and momentum $\langle p \rangle$. **(8 Marks)**

5. (a) Establish the relationship between the Einstein coefficients A_{21} and B_{21} for spontaneous and stimulated emissions. Discuss the physical significance of these coefficients regarding the thermal equilibrium of a system. **(10 Marks)**

(b) A three-level laser medium emits light at a wavelength of $\lambda = 694.3$ nm. Find the ratio of the population of the upper laser level to the lower laser level at a room temperature of $T = 300$ K. **(8 Marks)**

6. (a) Detail the physical meaning behind the Volume energy, Surface energy, and Asymmetry energy terms in the Bethe-Weizsäcker semi-empirical mass formula. Explain how the asymmetry term acts as a correction for the proton-to-neutron ratio. **(10 Marks)**

(b) Using the liquid drop model parameters ($a_v = 15.8, a_s = 18.3, a_c = 0.714, a_a = 23.2, a_p = 12$ all in MeV), calculate the electrostatic Coulomb energy penalty and the surface energy loss for a $^{16}_{8}O$ nucleus. **(8 Marks)**