Name of the Department:	Physics
Name of Course:	B.Sc. Hons Physics (CBCS)
Semester:	V (DSE)
Name of the Paper:	Nuclear and Particle Physics
Unique Paper Code :	32227504
Question Paper Set Number :	1
Duration:	3 Hours
Maximum Marks:	75

All questions carry equal marks. Attempt any four of the following questions.

1. (a) What is 'nuclear saturation density'? Obtain expressions for the nuclear saturation (i) mass density, and (ii) nucleon number density. What does the saturation of nuclear density tell us about the nature of force between nucleons in a nucleus? (Marks = 1.5 + 3 + 1.75 = 6.25)
(b) What physical information regarding a nucleus can be inferred from its quadrupole moment? If a given nucleus A has exactly zero quadrupole moment, what inference can we draw regarding this nucleus? (Marks = 2 + 1 = 3)
(c) The nucleus $^{176}Lu_{71}$ is observed to possess a quadrupole moment of 8e barn. Assuming that the nuclear deformation is of the form of an ellipsoid of rotation, with equal extensions along two of the coordinate axes (x and y), and a longer extension along a third axis (z), determine the values of the semi-major and semi-minor axes for this nucleus. (Marks = 6.5)
(d) What is 'nuclear magneton'? Write the expression for the same, and its value. How does a 'nuclear magneton' differ from the 'Bohr magneton'? (Marks = 3)

2. (a) Explain the origin of the Pairing Energy term/ "Odd-Even Effect" in the Liquid Drop Model. (Marks = 4)
(b) Write the expression for Nuclear Binding Energy from the Liquid Drop Model, and the Semi-Empirical Mass Formula, while identifying each term from the Model. (Marks = 3)
(c) On the basis of the above expressions for the Nuclear Binding energy/ Semi Empirical Mass Formula, obtain the expression for the most stable nuclide for a given mass number A. Accordingly, calculate the value expected for the atomic number for the most stable nuclide if
(i) A = 238, and (ii) A = 4, and identify these nuclei. (Marks = 6.75 + 2 = 8.75)
(d) Consider a nucleus with a larger number of neutrons than protons. As per the Fermi Gas Model, is the depth of the nuclear potential well for the neutrons expected to be the same as that for the protons? If not, should it be larger or smaller than for the protons? Justify. (Marks = 3)

3. (a) What are the basic assumptions of Gamow's theory of alpha decay? Sketch the potential experienced by an alpha particle both within and outside the nucleus. What is the Coulomb barrier to alpha particle emission, and how is its value determined? (Marks = 4.75)
(b) What is Geiger-Nuttall law? Obtain an expression for the tunneling probability for alpha particle from a general $^{A}X_{Z}$ nucleus. Estimate the decay constant λ for this process, hence recovering Geiger-Nuttall law. (Marks = 1.5+8+3 = 12.5)
(c) What is β^{+} decay? Give an example of a nucleus undergoing this form of beta decay. (Marks = 1.5)

4. (a) What are direct and compound reactions? Mention three major differences between a direct reaction and a compound reaction. (Marks = 1.75 + 3 = 4.75)
(b) Explain what are Stripping Reactions and Pick-up Reactions. Give an example for each.
. (Marks = 2 + 2 = 4)
(c) The Cadmium-113 isotope ($^{113}Cd_{48}$) has strongly absorbs room-temperature (thermal) neutrons, the cross-section for this neutron-capture reaction being 2×10^{4} barn. Compare this cross section for the thermal neutron absorption, with the actual geometrical cross section of this nucleus. Estimate the mean free path of thermal neutrons in a $^{113}Cd_{48}$ target. What fraction of an incident beam of thermal neutrons is absorbed by a cadmium sheet 0.1 mm thick? What thickness of cadmium is needed to absorb 99 percent of an incident beam of thermal neutrons?
(Given: The $^{113}Cd_{48}$ isotope constitutes only 12% of natural cadmium. You may regard natural Cadmium as being comprised of $^{112}Cd_{48}$ isotope only, with atomic mass approximately 112 u, and a density of 8.64 g/cm^{3}.)
(Marks = 2 + 3 + 2.5 + 2.5 = 10)

5. (a) What is a scintillation detector? With the aid of a labelled diagram, explain the construction and working of a photomultiplier tube. (Marks = 10)
(b) Consider a (sufficiently energetic) cosmic gamma ray photon in deep space, away from all matter. Can this gamma ray photon produce an electron-positron pair? Substantiate your answer by checking the mutual compatibility of energy and momentum conservation laws, for this process. (Marks = 4)
(c) Prove that the maximum kinetic energy transferred by a photon to an electron in Compton scattering can be written in terms of the incident photon energy E as:

$$KE_{max} = \frac{E^2}{E + (m_0c^2)/2}.$$

For very high energy photons, with $E \gg m_0c^2$, what can be inferred? (Marks = 4.75)

6. (a) Which of the following are conserved in (i) a strong reaction? (ii) a weak reaction? Strangeness, Isospin, z-component of Isospin, Baryon Number, Electric Charge
(Marks = 2)

(b) Given that the following reactions are all strong interactions, use the relevant conservation laws to identify the attributes/quantum numbers of the unknown particle X. Hence, identify X.

(i) $K^- + p \to K^+ + X$

(ii) $\pi^- + p \to K^0 + X$

(iii) $p + p \to n + \pi^+ + \Delta^0 + X$

(Marks = 4×3=12)

(c) Compute the ratio of, as well as the magnitudes of the maximum energy of protons, deuterons, and alpha particles, that can be obtained from a cyclotron of 75 cm radius, with a magnetic field strength of 1.4 T. (Marks = 4.75)