Spring Semester Examination - 2023

Course Code: PHYUGDS03
Course Title: Nuclear and Particle Physics-I
Department of Appearing Students: Physics, B. Sc. (Honours) (3rd Yr), SEM-VI
Full Marks: 60 **Time:** 2.30 hrs

[All notations bear conventional meaning]
Use separate answer sheet for Group-A and Group-B

Group-A [40 Marks]

Attempt question No. 1 and any two from the remaining

1. (a) Define the mean life of a radioactive specimen and obtain an expression for it. [1+3=4]
   (b) What will be the smallest distance between an alpha (α) particle and a Uranium-238 isotope (^{238}U) when the α-particle approaches towards the center of the stationary uranium target with energy E_α. Hence determine the distance of the closest approach if $E_\alpha = 10$ MeV [4]
   (c) If the binding energy of α-particle, B_α=28.3 MeV, the binding energy of deuteron, B_d = 2.226 MeV, then find the Q-value of the nuclear process: ^{2}H+^{2}H $\rightarrow$ ^{4}He [4]
   (d) Show that nuclear density is independent of the mass number of a nucleus. A spherical nucleus X is twice as large as another spherical nucleus Y. Which one is more dense? Give arguments in support of your answer. [4]
   (e) The maximum kinetic energy of a proton coming out of a cyclotron is 10 MeV. What can be the maximum energy of an α-partcle (^{4}He) coming out of the same cyclotron? [4]

2. State the general properties of nuclear forces. Graphically show the nature of an effective nucleon-nucleon interaction potential. State the significance of each region of the effective nuclear potential as indicated in your plot. [5+2+3=10]

3. Define nuclear binding energy. Show graphically how the binding energy per nucleon (f_B=B/A) varies with the mass number (A). With reference to the above f_B versus A graph, explain why light nuclei undergo nuclear fusion reactions and heavy nuclei undergo nuclear fission reactions. What are the mirror nuclei? Give example. [2+2 +4 +2=10]

4. (a) Write down the Bethe-Weizäcker semi-empirical mass formula and indicate the physical significance of each term.
   (b) Calculate the average binding energy per nucleon of ^{56}Fe and ^{235}U. Given: M(^{56}Fe)=55.93494u, M(^{235}U)=235.03278u, M_n = 1.008665u, M_p = 1.007276u. 1U =931.5 MeV. Comment on your result.

(c) Between the isobars ^{3}H and ^{3}He which is more stable and why? [(2+2)+4+2=10]

5. (a) Write down Schrödinger's equation assuming a 3D harmonic oscillator potential. Hence write down the energy general formula for the energy eigenvalues. Draw a few low-lying energy levels. Now redraw those levels if a spin-orbit coupling term is added to the 3D harmonic oscillator potential.

   (b) Determine the ground state spin-parity (J^P) of the following nuclei: ^{40}Ca, ^{15}O, ^{14}N and ^{19}F. [(2+2+ 3 +1)+2=10]

Group-B [20 Marks]

Answer **any two** questions. $10 \times 2 = 20$

1. Mention the types of symmetries broadly in nuclear and particle physics. Show the behaviour of the angular momentum under the parity (P) operation. Name the type of interaction in which the parity is violated. Discuss which quantum numbers are conserved or violated in the following reactions and also mention the type of interaction in each case.

   (a) $p + n \to d + \pi^0$,

   (b) $\Lambda^0 \to p + \pi^-$,

   (c) $\pi^+ \to \pi^0 + e^+ + \nu_e$. [1+2+1+2+2+2=10]

2. What is the group associated with isospin? How many generators are there in this group? Write down 2×2 matrices that form the group. What are the properties of those matrices? Name the type of interaction that satisfies the isospin conservation. Find the third components of isospin (I_3) for the proton and neutron using

$$p = \begin{pmatrix} 1 \\ 0 \end{pmatrix} ,$$

and

$$n = \begin{pmatrix} 0 \\ 1 \end{pmatrix} .$$

[1+1+3+2+1+2=10]

3. Draw the baryon and pseudoscalar meson octets in the plane of strangeness number (S) versus the third component of isospin (I_3). What are the quark compositions of Ξ^- and K^+? [4+4+2=10]