2022

PHYSICS

Paper : PHY-513

(Nuclear and Particle Physics)

Full Marks : 50

The figures in the margin indicate full marks.

Candidates are required to give their answers in their own words as far as practicable.

Answer ***any five*** questions.

1. (a) Using the extreme single particle model, find the ground state spin parity of the nuclei ${}^{41}_{20}\mathrm{Ca}$ and ${}^{39}_{20}\mathrm{Ca}$. Using Nordheim rules, comment on the possible spin parity of ground state ${}^{40}_{19}\mathrm{K}$.

   (b) What is the observed ground state spin parity of deuteron? Explain the possible admixture of orbital angular momentum states in deuteron in view of the fact that it has a non-zero quadrupole moment.

   (c) For neutron-proton scattering, define scattering length. Explain the significance of its sign for two-body systems.

   (2+2)+(1+2)+(2+1)

2. (a) Assume that the proton-neutron potential in deuteron can be represented by a square well potential. Write down the Schrödinger equation and obtain a relation between the depth and the range of the potential and the deuteron binding energy.

   (b) Explain why coherent neutron-proton scattering is possible only at low energies. Obtain an expression for cross-section of neutron scattering by ortho-hydrogen in terms of singlet and triplet scattering lengths.

   4+(2+4)

3. (a) What is Gamow peak? Obtain an expression for Gamow peak energy.

   (b) Explain the Bohr-Wheeler model of nuclear fission.

   (c) Using the Boltzmann entropy relation, and assuming the relation between the excitation energy of the nucleus E and its temperature T given by $E = aT^2$, find an expression for the level density.

   (2+2)+3+3

4. (a) For a three-dimensional harmonic oscillator potential for the nuclear shell model, obtain the magic numbers. Explain the importance of including a spin-orbit interaction.

   (b) What is the deuterium bottleneck in big bang nucleosynthesis (BBN)? Why couldn't the BBN have started when the average photon energy just fell below the binding energy of deuterium?

   (c) Explain how Ghosal's experiment verified compound nucleus hypothesis.

   (3+2)+(1+2)+2

Please Turn Over

5. (a) Show that the nuclei which undergo β^+ decay can also decay by electron capture, but the reverse is not true.

(b) Explain why, in Fermi's theory of beta decay, we can neglect (as a first approximation) the momentum dependence of the leptonic wave functions.

(c) Check the nature of the following β-transitions (allowed/forbidden, Fermi/Gamow-Teller/mixed):

(i) $0^- \to 0^-$

(ii) $1^- \to 2^-$

(d) Show that $\overline{\Psi}\gamma_\mu \Psi_L = \overline{\Psi}_L \gamma_\mu \Psi_L$, where Ψ_L is the left-chiral spinor. 3+2+2+3

6. (a) Estimate the range of weak interaction if the mass of W is about 80 GeV. You may use that $\hbar c$ = 200 MeV fm.

(b) Write down the four-fermion point-interaction Lagrangian for the muon decay process $\mu^- \to e^- \nu_\mu \bar{\nu}_e$. Write down the corresponding amplitude in terms of the particle and antiparticle spinors $u(p)$ and $v(p)$. How is this amplitude modified when one considers W-boson exchange in the place of point interaction? Hence relate the Fermi constant G_F to the weak coupling constant g and the W-boson mass (you may neglect numerical factors).

(c) Consider the bound states of two nucleons with $L = 0$ and $S = 0$. Why such states must occur in an isotriplet?

(d) Write down the spin-triplet and spin-singlet states obtained by combining the S_z- eigenstates $\uparrow$ and $\downarrow$ of two spin-$\frac{1}{2}$ particles. Hence write down the isotriplet and isosinglet meson states, given the two isospin doublets $q = (u\ d)^T$ and $\tilde{q} = \left(\bar{d}\ \ -\bar{u}\right)^T$. 1+(1+1+1+1)+2+(1+2)

7. (a) Write down the values of Q, T_3, S and Y for the omega baryon with the quark content sss.

(b) Write down the Gell-Mann matrices corresponding to the three components of isospin and to hypercharge.

(c) Represent the equations **3** × **3** = **6** + **3*** and **3*** × **3** = **8** + **1** in terms of $SU(3)$ Young tableaux. (You do not have to find the dimensionality of the representations.)

(d) Explain why the existence of the Δ^{++} baryon with spin-$\frac{3}{2}$ leads to the color degree of freedom.

(e) (i) Why cannot a free proton decay?

(ii) Why cannot Λ^0 decay into p and π^- by strong or electromagnetic interaction?

2+2+2+2+(1+1)