2019

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 out the ground state spin parity of the unclei $^{41}_{20}Ca$ and $^{39}_{20}Ca$. Using Nordheim rules, comment on the possible spin parity of ground state $^{40}_{19}K$.

   (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) Using the effective range theory for bound n-p system, find a relation between phase shift (δ) with the scattering length (a) and effective range $\left(r_{eff}\right)$.

   (b) Explain why we need an imaginary term in the optical potential.

   (c) Describe briefly how the liquid drop model explains fission. 6+2+2

3. (a) Write down the reactions that produce helium in Big Bang nucleosynthesis. Explain qualitatively why elements heavier than Lithium are not produced in Big Bang.

   (b) Find an expression for Gamow peak in astrophysical reactions at a temperature T.

   (c) Find the most probable nature and multipolarity for the following γ-transitions :

   (i) $1^- \rightarrow 2^+$

   (ii) $3/2^- \rightarrow 1/2^-$. 2+1+3+4

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 potential.

   (b) Sketch the nuclear binding energy per nucleon as a function of mass number. Explain why the binding energy per nucleon falls off at higher masses.

   (c) Write the Hamiltonian for an axially symmetric rotor and write down its eigenvalues. (3+2)+(2+1)+(1+1)

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

(b) Write down whether the following transitions are allowed or first forbidden, and Fermi, Gamow-Teller or mixed : (i) $0^+ \to 0^+$ (ii) $1^+ \to 1^+$.

(c) In Wu's experiment $\left({}^{60}\text{Co} \to {}^{60}\text{Ni} + e^- + \bar{\nu}_e\right)$, ^{60}Co has $J_z = 5$ and ^{60}Ni has $J_z = 4$. Assuming the initial nucleus to be at rest, in which direction will the electrons be preferentially emitted? Explain why.

(d) Put the u, d and s quarks in an I_3-Y diagram. 3+2+(1+2)+2

6. (a) Consider $\psi(x) \to e^{i\theta(x)}\psi(x)$. If $D_\mu\psi \equiv \left(\partial_\mu + ieA_\mu\right)\psi$ transforms in the same way as ψ, find the transformation of A_μ. Write down the Lagrangian of QED using D_μ. Why cannot one put a photon mass term in this Lagrangian?

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

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

7. (a) Write down the isotriplet and isosinglet two-nucleon states. Hence show that

$\sigma\left(pn \to \pi^0 d\right) : \sigma\left(pp \to \pi^+ d\right) = 1 : 2$. (Here σ denotes cross-section.)

(b) If Φ is an $SU(2)$ doublet, show that $\tilde{\Phi} \equiv i\tau_2\Phi^*$ is also an $SU(2)$ doublet. Hence construct an $SU(2)$ doublet from the antiquarks $\bar{u}$ and $\bar{d}$.

(c) Represent the equation $\mathbf{3} \times \mathbf{3} = \mathbf{6} + \mathbf{3}^*$ in terms of $SU(3)$ Young tableaux. Use this equation to explain why there cannot be a two-quark hadron. (2+2)+(3+1)+(1+1)