M. Sc. (Physics) 3rd Semester Examination 2018
PHY 513 (Nuclear and Particle Physics)

Answer in your own words as far as practicable. The marks on the right-hand side denote the full marks for the respective questions.

Full Marks : 50

Time: 2 Hours

Answer **Question no. 1** and **any three** from the rest, taking **at least one** from **each** of the groups A and B

1. Answer any five:

4×5

(a) Explain how the nuclear radius can be estimated from the binding energies of mirror nuclei. The binding energy of ${}^{7}_{3}$Li and ${}^{7}_{4}$Be are 5.60 MeV and 5.37 MeV. Estimate the value of r_0 in the expression for the nuclear radius $R = r_0 A^{1/3}$.

(b) Obtain an expression of $n-p$ scattering cross-section in terms of the scattering length and the effective range.

(c) Establish a formula for level density from thermodynamic arguments and assuming the Fermi gas model.

(d) Comment on the most probable multipolarity and nature of the following γ-transitions: (i) $2^- \longrightarrow 0^+$, (ii) $5/2^+ \longrightarrow 3/2^+$.

(e) What is the helicity of a massless anti-neutrino? Use this fact, momentum conservation and angular momentum conservation to deduce the helicity of the e^- emitted in the decay $\pi^- \to e^- \bar{\nu}_e$ in the rest frame of the π^-. Why is this decay suppressed?

(f) An $SU(3)$ Young tableau has two boxes in a column. Find the dimensionality of the corresponding representation by filling up the boxes with different labels. Repeat the exercise for an $SU(3)$ Young tableau with three boxes in a row.

Group A

2. Predict the spin-parity of the ground state of the nuclei ${}^{17}_{9}$F and ${}^{17}_{8}$O. Deduce an expression for the magnetic moment in the extreme single particle model. Calculate the magnetic moment of the ground states of the above two nuclei.

For a three dimensional square well potential of depth V_0 and radius r_0 for deuteron, show that for negligibly small binding energy of deuteron,

$$V_0 r_0^2 \approx \frac{\hbar^2 \pi^2}{4M}$$

where M is the nucleon mass. [(2+2+2)+4]

3. For the Fermi gas model of the nucleus, show that the average kinetic energy of the nucleons is three-fifth of the Fermi energy. Explain how the concept of surface energy arises in this model.

Mention the importance of the spin-orbit term in the shell model.

Explain the nature of the excitations for the excited levels of nuclei given below. The energies are given in keV in the parentheses.

Zr-90: 0+(1761), 2+(2186), 5-(2319), 4-(2739), 3-(2747), 4+(3077), 2+(3309)
Pd-106: $0^+(0)$, 2+(511), 2+(1128), 0+(1134), 4+(1229), 3+(1558), 2+(1562)
U-234: $0^+(0)$, 2+(43), 4+(143), 6+(296), 8+(497), 10+(741) [(3+2)+2+3]

4. The neutron-proton interconversion stopped at $t \approx 1$ sec when $n_n/n_p = 0.2$, and the big bang nucleosynthesis stopped at $t \approx 400$ sec, when all the remaining neutrons are absorbed in ^{4}He. If $m_n - m_p = 1.3$ MeV and the half-life of neutron is 614 sec, calculate the Helium fraction, i.e. the mass fraction in ^{4}He compared to the total baryonic mass.

What would have happened to the abundance of elements heavier than helium if

i) Be-8 was stable?

ii) the Hoyle resonance in C-12 was absent?

Discuss the Bohr-Wheeler theory of nuclear fission. Using the liquid drop mass formula, show that for symmetric fission of a nucleus of mass number A and atomic number Z, the Q-value is approximately given by

$$Q = a_s A^{2/3}(1 - 2^{1/3}) + a_c \frac{Z^2}{A^{1/3}}(1 - 2^{-2/3})$$

where a_s and a_c are the coefficients of the surface term and the volume term, respectively. [2+2+(3+3)]

Group B

5. (a) Explain, deducing the expressions you have to use, why $_4Be^7$ changes to $_3Li^7$ by electron capture, but not by positron emission, given that the atomic mass difference is 0.86 MeV.

(b) Explain whether $\frac{1}{2}^+ \to \frac{1}{2}^+$ transition is allowed or first forbidden, and Fermi, Gamow-Teller or mixed.

(c) Write down the Fermi Lagrangian in its $V - A$ form, responsible for the decay $\mu^- \to e^- \nu_\mu \bar{\nu}_e$.

(d) Represent the equations $\mathbf{3} \times \mathbf{3} = \mathbf{6} + \mathbf{3}^*$ and $\mathbf{3}^* \times \mathbf{3} = \mathbf{8} + \mathbf{1}$ in terms of $SU(3)$ Young tableaux. (You do not have to find the dimensionality of the representations.)

(e) Write down the three-quark color singlet state made of the three color states R, G and B.

[3+2+1+2+2]

6. (a) Show that $\bar{\psi}\gamma_\mu\psi_L = \bar{\psi}_L\gamma_\mu\psi_L$ where ψ_L is the left-chiral spinor.

(b) Deduce the mass dimensions of ψ and ϕ from the massless Dirac and the massless Klein-Gordon Lagrangians respectively. If there is a term $\lambda\bar{\psi}\psi\phi$ in the Lagrangian, find the mass dimension of the coupling constant λ.

(c) 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 $q = (u \quad d)^T$ and $\tilde{q} = (\bar{d} \quad -\bar{u})^T$.

[3+3+(2+2)]