Physics Department; BITS-Pilani, Pilani
Compre-Exam.; 2nd Semester 2022 - 2023

Nuclear & Particle Physics (PHY F343)
Part - A (CB) ; Marks - 40
22 May 2023 ; (9:30 - 11:00) AM

Answer the following questions supplemented with a few **mathematical/logical steps**. *Each question carries* **four marks**. *Don't expect step marking for PART - A. However, you must show the steps; otherwise, no marks will be awarded, even if the final answer is correct. Take suitable approximation if it's a must.*

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1. Using the semi-empirical mass formula calculate the numerical value of Q_β for β^+-decay of N_7^{13} nucleus. Assume $m_\nu = 0$.

2. The Q-value in the decay $Po^{214} \longrightarrow U^{210} + \alpha$ is 5.27 MeV. Determine the numerical value of recoil energy T_U (in MeV) of the daughter nucleus.

3. Specify all allowed states of a two-neutron system with total angular momentum (i) $J = 0$ and (ii) $J = 2$. To specify the states, use the notation $^{2S+1}X_J$. Here X is the notation for the orbital angular momentum states, i.e., for $l = 0, X = S$; for $l = 1, X = P$ and so on.

4. For n-p bound state, consider an operator $\hat{O} = \frac{(\vec{\sigma_n}.\vec{r})(\vec{\sigma_p}.\vec{r})}{r^2}$; r is neutron-proton separation distance. Determine the quantity $\int \hat{O}\ d\Omega$. Where $d\Omega = \sin\theta\ d\theta\ d\phi$.

5. Mention all possible types (Allowed/Forbidden, Fermi/GT etc.) of the following nuclear transitions. The spin-parity of the nucleus is given in the bracket. (i) $K^{40}(4^-) \to Ca^{40}(0^+)$ (ii) $He^6(0^+) \to Li^6(1^+)$.

6. In a shell model, assume the single particle energy level (without l-s coupling) as $E_{nl} = \hbar\omega(\Lambda + 3/2)$. Where $\Lambda = 2n + l - 2$ is a non-negative integer with $n = 1, 2, 3, ...$ and $l = 0, 1, 2, ...$ If N_Λ denotes the maximum no of neutrons or protons that can be accommodated in the state "Λ", obtain the expression of N_Λ in terms of Λ, and hence determine the value of N_5.

7. Consider the reaction $p + p \longrightarrow p + p + p + \bar{p}$, where one of the initial protons is stationary (target), while the other (projectile) approaches the target. Find the *threshold energy* E_{th} (in MeV) of the projectile.

8. Starting from the flavor state $|\phi_f>$ of Δ^{++} baryon, obtain the flavor state of Δ^+ baryon. Write down the color state (derivation is not required) of Λ^0 baryon.

9. Using quark model, obtain the expression for the magnetic moment μ of Δ^+ baryon for the spin state $|\chi(3/2, 3/2)>$. The magnetic moment should be expressed in terms of magnetic moment of the constituent quarks μ_u, μ_d, etc.

10. In view of conservation principles, prove/disprove the following statements. Each question carries **one mark**.
    (a) $n \to p + \pi^-$ is an *allowed* decay process.
    (b) $\rho^0 \to \pi^0 + \pi^0$ is a *strong* decay process.
    (c) $\Lambda^0 \to K^0 + \pi^0$ is an *allowed weak* decay process.
    (d) $p + \bar{p} \to \pi^+ + \pi^-$ is a *forbidden* reaction.

Symbols/Formulae/Data :

Standard/lecture class symbols have been used.
Example : Total angular momentum (J), Total spin (S), isospin (I), Pauli matrices (σ), etc.
You can use : 1 u $\equiv 931.5$ MeV ; $\hbar c \simeq$ 200 MeV-fm, $e^2/(4\pi\epsilon_0\hbar c) = 1/137$; $m_nc^2 = 939.6$ MeV, $m_pc^2 = 938.3$ MeV, $m_ec^2 = 0.5$ MeV; radius parameter $r_0 = 1.2$ fm; 1 barn $= 10^{-28}$ m^2
Binding energy : $B = a_v\ A - a_s\ A^{2/3} - a_c\ \frac{z^2}{A^{1/3}} - a_a\ \frac{(A-2z)^2}{A} + \delta\ a_p\ A^{-3/4}$.
The values of various co-efficient (in MeV) : $a_v = 16$, $a_s = 17$, $a_c = 0.69$, $a_a = 25$, $a_p = 35$.
Angular Momentum Algebra (in unit of $\hbar$) : $J_\pm\ |J, M> \ = \sqrt{J(J+1) - M(M \pm 1)}\ |J, M \pm 1>$

ALL THE BEST