PHYSICS DEPARTMENT; BITS-PILANI, PILANI

2ND SEMESTER 2022 - 2023

NUCLEAR & PARTICLE PHYSICS (PHY F343); Mid-Term Examination (Closed Book)
**Date & Time - 18/03/2023 ; 2:00 PM - 3:30 PM; Max. Marks - 60**

*Please attempt all parts of a question sequentially. Use the data appended below, if required.*

1. Answer the following questions supplemented with clean and precise logical/mathematical steps. **You will miss marks if you miss the important steps.**

   (a) n-n bound state may exist in superfluid neutron systems as n-n Cooper pairs. Prove/disprove that the symmetrization of the n-n state allows (i) $L = 1, S = 1$ and (ii) $L = 2, S = 1$.

   (b) Calculate the approximate mass density of nuclear matter in g/cm$^3$ in a nucleus.

   (c) Using atomic mass data, calculate the Q-value (in MeV) for $\beta^+$ decay of $Cu^{64}_{29}$ nuclide. Take $m_\nu = 0$.

   (d) The wave function describing n-p scattering can be written as, $\psi(r,\theta) = \psi_{inc} + \psi_{sc} = e^{ikz} + f(\theta)\frac{e^{ikr}}{r}$. If $f(\theta) = A\cos\theta$, ($A$ is a constant factor), obtain the total cross-section $\sigma$.

   (e) For s-wave (i.e., $l = 0$) n-p scattering, the total cross-section $\sigma$ can be expressed as, $\sigma = \frac{4\pi\hbar^2}{m_p}\frac{1}{E+|E_B|}$. Where $E$ and $|E_B|$ are the scattering energy and the binding energy of the n-p system, respectively. At zero scattering energy limit, the observed cross-section is 21 barn. If you believe the observed cross section can be explained only from the triplet state scattering, what value of binding energy $E_B$ do you expect for the n-p triplet state?

   (f) Consider the alpha decay chain, $A \to B \to C$ with decay constants of $A$ and $B$ are $\lambda_1$ and $\lambda_2$, respectively. At any time $t$, the number of $A$ and $B$ are given by $N_1(t) = N_1(0)e^{-\lambda_1 t}$ and $N_2(t) = \frac{\lambda_1 N_1(0)}{\lambda_2-\lambda_1}\left[e^{-\lambda_1 t} - e^{-\lambda_2 t}\right]$. Obtain the expression of $t = t_m$ when $N_2$ becomes maximum. If the mean-life time of $A$ and $B$ are 4 hr and 8 hr, respectively, determine the numerical value of $t_m$.

**[4 + 4 + 4 + 4 + 4 + 8 ]**

2. Answer the following questions supplemented with the required mathematical steps.

   (a) Assume the set of isobars with the mass number $A = 51$. Do the necessary algebra and determine the atomic number $Z_0$ of the most stable element (stable against $\beta^\pm$ decay) among the isobars.

   (b) The magnetic moment of deuteron ($J = 1; S = 1$) can be written as $\mu_d = (\mu_p+\mu_n)-(\mu_p+\mu_n-1/2) < L_z >$. Where, $L_z = \frac{\vec{L}.\vec{J}}{J^2}$. If $P_0$ and $P_2$ are the respective probabilities for the deuteron being in $L = 0$ and $L = 2$, obtain the expression of $P_0$ and $P_2$ in terms of $\mu_d, \mu_p$ and $\mu_n$. Show the algebra clearly. No need to put the numerical values of the magnetic moments.

   (c) In $\alpha$-decay, the decay probability is given as $T = e^{-G}$, with the Gamow Factor $G = a(\frac{8m_\alpha E_\alpha}{\hbar^2})^{1/2}\left[\frac{\pi}{2} - 2(\frac{R}{a})^{1/2}\right]$. Where $R$ is the radius of the daughter nucleus, and $a$ is the distance corresponding to the classical turning point. Now, do a suitable modification of various parameters that appears in the Gamow factor and calculate (numerically) the decay probability $T = e^{-G}$ for the (hypothetical) decay $Fr^{200}_{87} \to Tl^{188}_{81} + C^{12}_6$. The Q-value of the decay is 28 MeV.

**[8 + 12 + 12 ]**

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*Symbols/Formulae/Data :*
Standard/lecture class symbols have been used.
Example : Total angular momentum ($J$), spin ($S$), isospin ($I$), Pauli matrices ($\sigma$), etc.

You can use : 1 u $\equiv 931.5$ MeV ; $\hbar c \simeq$ 200 MeV-fm, $e^2/(4\pi\epsilon_0\hbar c) = 1/137$ ; $m_n c^2 = 939.565$ MeV,
$m_p c^2 = 938.272$ MeV, $m_e c^2 = 0.51$ 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-efficients (in MeV) : $a_v = 16$, $a_s = 17$, $a_c = 0.69$, $a_a = 25$, $a_p = 35$.
Atomic masses of few elements :
M(64, 27) = 63.9358 u, M(64, 28) = 63.9280 u, M(64,29) = 63.9298 u, M(64,30) = 63.9291 u

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*ALL THE BEST*