PHYSICS DEPARTMENT; BITS-PILANI, PILANI

2ND SEMESTER 2021 - 2022

NUCLEAR & PARTICLE PHYSICS (PHY F343); Mid-Term Examination (Closed Book)

Date & Time - 12/03/2022 ; 9:00 AM - 10:30 AM; Max. Marks - 60

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

1. Answer the following questions briefly and precisely.

   (a) If Li_3^6 with spin-parity $J^p = 0^+$ is one of the members of isospin multiplet $I = 1$ family, write down the other members of this multiplet having the same spin-parity.

   (b) You are perhaps aware that the elements Co_{27}^{65} and Ga_{31}^{65} are unstable against β decay. Write down the appropriate $\beta^{\pm}$ decay chains through which these elements transform into a stable element.

   (c) From the perspective of Q-values, prove/disprove that Cu_{29}^{64} is a $\beta^{\pm}$ emitter. Take neutrino mass to be zero.

   [3 + 3 + 6]

2. Answer the following questions supplemented with a few mathematical steps.

   (a) The neutron and proton separation energies of O_8^{16} nucleus are denoted by S_n & S_p, respectively. Using SEMF, determine the numerical value (in MeV) of $(S_n - S_p)$.

   (b) Using SEMF determine the Q value (in MeV) for the β^+ decay of C_6^{11} nucleus. Take neutrino mass $m_\nu = 0$.

   (c) In the context of α-decay through quantum tunneling (Gamow's theory), determine the maximum barrier height V_m (in MeV) and barrier width b (in fm) encountered by the α particle for Fr_{87}^{212} nucleus. Take $Q_\alpha \simeq T_\alpha =$ 6.5 MeV.

   [3 × 8]

3. Assume a hypothetical n-n bound state of spin-parity, $J^P = 2^+$ with the effective potential, $V_{eff}(r) = -V_0 + \frac{\hbar^2 l(l+1)}{2\mu r^2}$. Here, $V_0 = 38$ MeV is the minimum depth of the potential well to make n-n barely bound.

   (a) For this hypothetical state, estimate the numerical value of $V_{eff}(r)$ (in MeV) at r = 2 fm.

   (b) For the operator $S_{12} = [3(\vec{\sigma}_1.\hat{r})(\vec{\sigma}_2.\hat{r}) - \vec{\sigma}_1.\vec{\sigma}_2]$, obtain the expectation value $< S_{12} >$ for the above hypothetical state. Here, $\sigma_{1,2}$ are the Pauli matrices of two neutrons, and $\hat{r}$ is the unit vector along their separation vector.

   [5 + 5]

4. Consider the n-p scattering with energy E and wave vector $k = \sqrt{\frac{2\mu E}{\hbar^2}}$. The scattering amplitude is given as, $f(\theta) = \frac{1}{k}\,\Sigma_l\,(2l+1)\; e^{i\delta_l}\;\sin\delta_l\;\; P_l(\cos\theta)$.

   (a) Using the above expression of $f(\theta)$, obtain the *total* n-p scattering cross section σ (express as sum over all partial waves l). Obtain the relation between σ and the imaginary part of the forward scattering amplitude $f(\theta = 0)$, i.e., relate σ with Im $f(0)$.

   (b) Now consider $E \to 0$ limit with the phase shift $\sin^2\delta_0 = E/(E + |E_B|)$. Suppose you (wrongly) believe that the measured value of n-p cross section of magnitude 21 barn results from the triplet state scattering only. What do you then conclude about the numerical value of deuteron's binding energy $|E_B|$? Find the corresponding scattering length (in fm). (1 barn = 100 fm^2).

   [(5 + 2)+(5 + 2)]

Symbols/Formulae/Data :

Standard/lecture class symbols have been used. For example, total angular momentum (J), Spin (S), Isospin (I), proton spin (s_p), neutron spin (s_n), Pauli matrices (σ), etc.

You can use : $\hbar c \simeq$ 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; $\mu_p = 2.793\ \mu_N$; $\mu_n = -1.913\ \mu_N$; radius parameter $r_0 =$ 1.2 fm.

Semi-empirical formula for 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 : $M(64, 27) = 63.9358\ u, M(64, 28) = 63.9280\ u, M(64, 29) = 63.9298\ u, M(64, 30) = 63.9291\ u, 1\ u \equiv 931.5$ MeV .

Algebra involving Pauli matrices : $(\vec{\sigma}.\vec{a})(\vec{\sigma}.\vec{a}) = (\vec{a}.\vec{b})I + i(\vec{a} \times \vec{b}).\vec{\sigma}$

ALL THE BEST