National Institute of Technology Rourkela - 769008
Mid Semester Examination, 2023
Session : 2023-24 (Autumn)

Course: PH - 5001 | **Nuclear and Particle Physics** | **Dept. Code: PH**
No. of pages: 2 | **Full Marks: 30** | **Duration: 2 hours**

Figures at the right hand margin indicate marks
All questions are compulsory
Notations carry their usual meaning

1. In a scattering experiment, the incident free particle wave function can be expanded in terms of spherical waves as
$$\psi_0(r) = e^{ikr\cos\theta} = \sum_l i^l\ (2l+1)\ j_l(kr)\ P_l(\cos\theta).$$
The scattered wave function can be expressed as
$$\psi(r) = \sum_l\ (A_l\ j_l(kr) + B_l\ y_l(kr))\ \ P_l(\cos\theta).$$
The large-r or asymptotic behaviour of the spherical Bessel functions $j_l(kr)$ and $y_l(kr)$ are given by
$$j_l(kr) \sim \frac{\sin(kr - l\pi/2)}{kr},\ y_l(kr) \sim -\frac{\cos(kr - l\pi/2)}{kr}.$$
Using the above behaviour of spherical Bessel functions express, the scattered wave function can be written as
$$\psi(r) = \psi_0(r) + \frac{e^{ikr}}{r} f(\theta).$$
Find $f(\theta)$. Using $f(\theta)$ find the differential scattering cross section $d\sigma/d\Omega$ and total cross section σ using
$$\sigma = \frac{4\pi}{k}\text{Im}f(\theta = 0).$$
(Ω is the solid angle.) **[10]**

2. The semiempirical mass formula is given as
$$M(Z, A) = Zm(^1\text{H}) - Nm_n - B(Z, A)/c^2, \tag{1}$$
where
$$B(Z, A) = a_v A - a_s A^{2/3} - a_c Z(Z-1)A^{-1/3} - a_{\text{sym}}\frac{(A-2Z)^2}{A} + \delta \tag{2}$$

   (a) Show that for constant A equation(1) represents a parabola. Hence find the value of Z for which the parabola reaches the minimum. Using proper approximation show that for small A, $Z_{\text{min}} \simeq A/2$ but for large A, $Z_{\text{min}} < A/2$. ($a_v = 15.5$ MeV, $a_s = 16.8$ MeV, $a_c = 0.72$ MeV $a_p = 34$ MeV and $a_{\text{sym}} = 23$ MeV) **[5]**

   (b) Refer to figure(1) and explain why there is one parabola for $A = 125$ but two for $A = 128$. For parabola, $A = 128$, explain the transitions represented in arrows. **[2]**

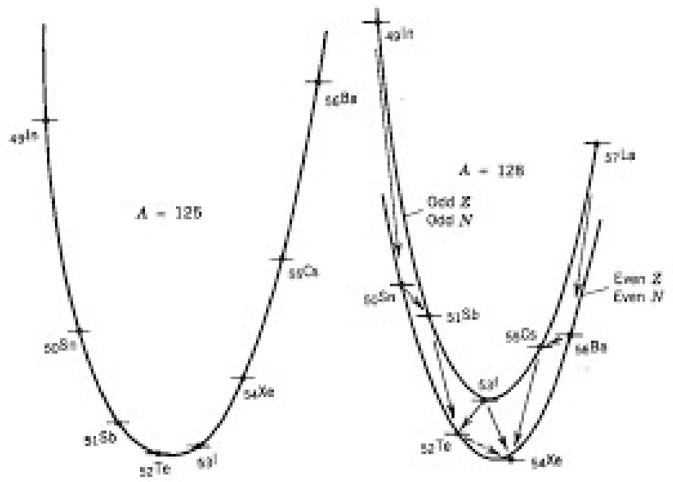

Figure 1: Mass parabola

3. One experimental result of differential scattering cross section as a function of scattering angle is given in figure (2). Write some of the facts that you can observe from the figure. (You may refer to question (1)). Using the results of diffraction through a circular disc,

$$\sin\theta = \frac{1.22\lambda}{D} \quad \text{(for the first minimum of the diffraction pattern),}$$

find out the size of ^{12}C. Justify and comment on the use of above formula for the problem under consideration. **[4]**

4. The magnetic dipole moment of Deuteron can be calculated as $\mu_D = \left(g_p \hat{S_P} + g_n \hat{S_n} + \frac{\hat{L}}{2}. \right) \mu_N$.

   (a) Identify each term in the expression of μ_D. **[1]**

   (b) Calculate μ_D in the ground state of the Deuteron by taking $g_p = 5.585691$ and $g_n = -3.826084$. **[4]**

   (c) Using the values $\mu_D(L = 0) = 0.8798\ \mu_N$ and $\mu_D(L = 2) = 0.3101\ \mu_N$ find the percentage admixture of the $(L = 2)$ state if the deuteron magnetic moment were given by $\mu_D = 0.8325\ \mu_N$. **[2]**

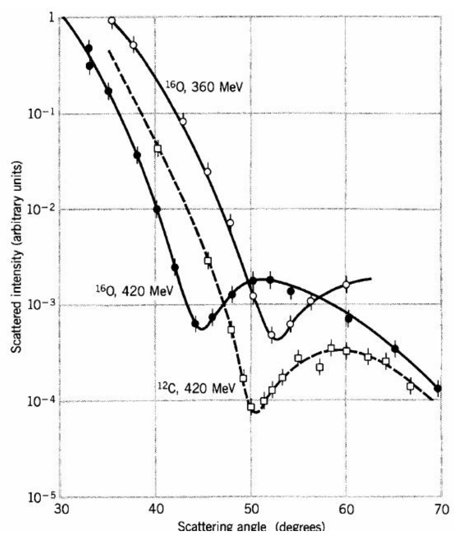

Figure 2: Scattering cross-section

5. What is the minimum photon energy necessary to dissociate ^{2}H? Take the binding energy to be 2.224589 MeV. **[2]**