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

Course: PH - 5001	**Nuclear and Particle Physics**	**Dept. Code: PH**
No. of pages: 3	**Full Marks: 50**	**Duration: 3 hours**

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

1. In extreme single particle Shell model the spin-parity (I^π) and magnetic dipole moments of nuclei are determined by the single unpaired nucleon. Using this concept, answer the following.

   (a) Derive the general formula for calculating the magnetic dipole moment of nuclei having odd number of neutrons or protons. [**6**]

   (b) Match your results with figure (2) for nuclei having odd number of neutrons and protons separately, with proper justification. All important aspects in the figure must be explained. [**3**]

   (c) The observed nuclear magnetic dipole moment of $^{209}_{83}\mathrm{Bi}$ is; $\mu = +4.1\mu_N$ ($I = 9/2$). Determine the expected values for these moments according to the simple Shell model. [**3**]

   (d) Find the configuration of the protons and neutrons in the incomplete shells and hence the ground state spin and parity assignments for the following nuclei
   (a) $^{7}_{3}\mathrm{Li}$ (b) $^{23}_{11}\mathrm{Na}$ (c) $^{33}_{16}\mathrm{S}$ (d) $^{41}_{21}\mathrm{Sc}$:
   under the assumption that the ordering of the lowest single particle nuclear energy levels is: $^{1}\mathrm{S}_{1/2}$, $^{1}\mathrm{P}_{3/2}$, $^{1}\mathrm{P}_{1/2}$, $^{1}\mathrm{d}_{5/2}$, $^{2}\mathrm{S}_{1/2}$, $^{1}\mathrm{d}_{3/2}$ $^{1}\mathrm{f}_{7/2}$, $^{2}\mathrm{P}_{3/2}$. [**4**]

2. Figure (1) represents a schematic diagram of mass spectrograph. Suppose a sample of Krypton is given to you.

   (a) Explain how it operates to find the masses of different isotopes and their relative abundances step wise. [**2**]

   (b) Why does one use mass doublet method? [**1**]

   (c) In a spectrograph, singly charged Argon ions enter a velocity filter, where the electric field is 5×10^4V/m and magnetic field is 0.4 Tesla. What is the velocity of the ion emerging the velocity filter? If the ions enter the magnetic field of 0.8 Tesla, what will be the distance between the ions focused on the photographic plate for the three isotopes: $^{36}_{18}\mathrm{Ar}$, $^{38}_{18}\mathrm{Ar}$ and $^{40}_{18}\mathrm{Ar}$? [**3**]

3. The semiempirical mass formula is given as

$$M(Z,A) = Zm(^1\mathrm{H}) - Nm_n - B(Z,A)/c^2,$$

   where

$$B(Z,A) = a_v A - a_s A^{2/3} - a_c Z(Z-1)A^{-1/3} - a_{\mathrm{sym}}\frac{(A-2Z)^2}{A} + \delta$$

   The mass difference between the pair of nuclei $^{11}_{6}\mathrm{C}$ and $^{11}_{5}\mathrm{B}$ is given as $\Delta\frac{\mathrm{MeV}}{C^2}$. According to the Semi-empirical mass formula, what will be the mass difference between the pair of mirror nuclei $^{17}_{9}\mathrm{F}$ and $^{17}_{8}\mathrm{O}$? ($m_p \sim 938\frac{\mathrm{MeV}}{c^2}$ and $m_n = 938\frac{\mathrm{MeV}}{c^2}$) ($a_v = 15.5$ MeV, $a_s = 16.8$ MeV, $a_c = 0.72$ MeV $a_p = 34$ MeV and $a_{\mathrm{sym}} = 23$ MeV) [**4**]

4. Using a square well potential for np interaction that can give duteron binding energy, the calculated low energy np scattering cross-section comes out to be 4.2 barns. The observed value is however 20 barns. Explain this discrepancy and obtain the scattering cross-section for $S = 0$ state. [**3**]

5. The first excited state of $^{120}_{50}$Ti appears at about 600 keV and has $I^\pi = 2^+$. The next three excited states occur at around 1.2 MeV and have $I^\pi = 0^+, 2^+, 4^+$. Explain the origin of these excited states. [**3**]

6. In many of the even-even nuclei with $A < 150$, the first exited state occurs at about 0.5 - 1 MeV with spin-parity 2^+. What kind of motion of the nucleus gives this state and why it is 2^+. Give proper explanation. [**2**]

7. A deformed nucleus $150 < A < 190$ has the first excited state at 90 keV with parity 2^+. What is the expected energy for the next excited state? [**3**]

8. In α-decay process, show that the energy carried by the α particle is 98 ٪ of the Q-value of the process. [**2**]

9. The highest energy α particle emitted in the decay of $^{238}_{92}$U to $^{234}_{90}$Th is 4196 ± 4 keV. From this information and the known mass of $^{238}_{92}$U, compute the mass of $^{234}_{90}$Th. [**2**]

10. Figure (3) represents a result from two nucleon scattering experiment. Interpret the relevant result and point out one important feature of force between two nucleons. [**2**]

11. Write some of the decay channels of Higgs boson. Which channel did lead to the discovery of Higgs boson at LHC, CERN ? [**2**]

12. Make one table each for three generations of leptons and quarks showing their charges (electric) and quantum numbers like $L_{e,\mu,\tau}$ and baryon numbers. Which are the heaviest lepton and quark? [**3**]

13. State any five facts that you know about Large Hadron Collider (LHC). [**2**]

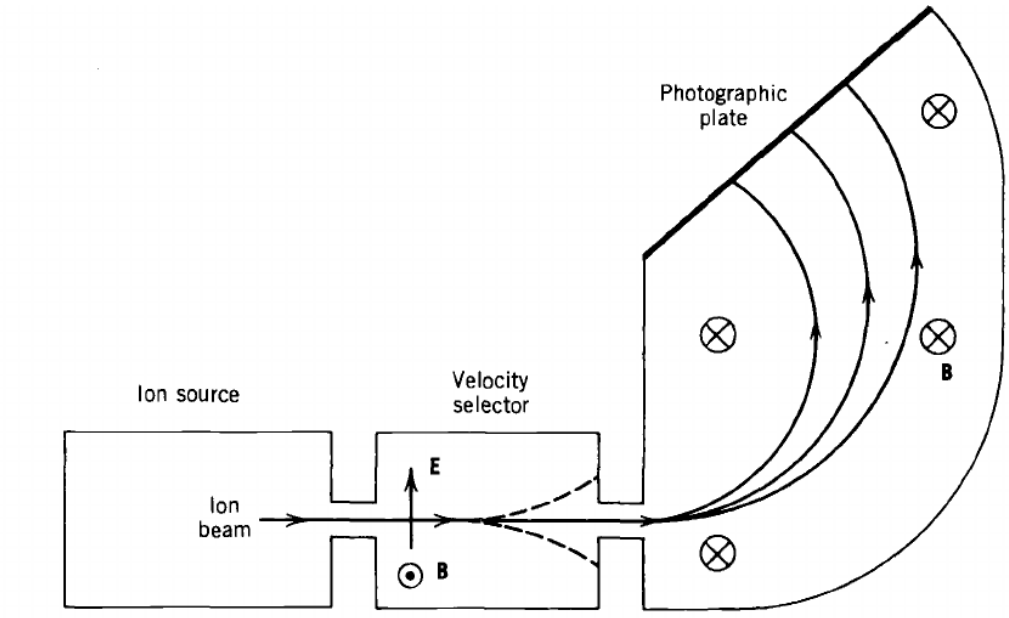

Figure 1

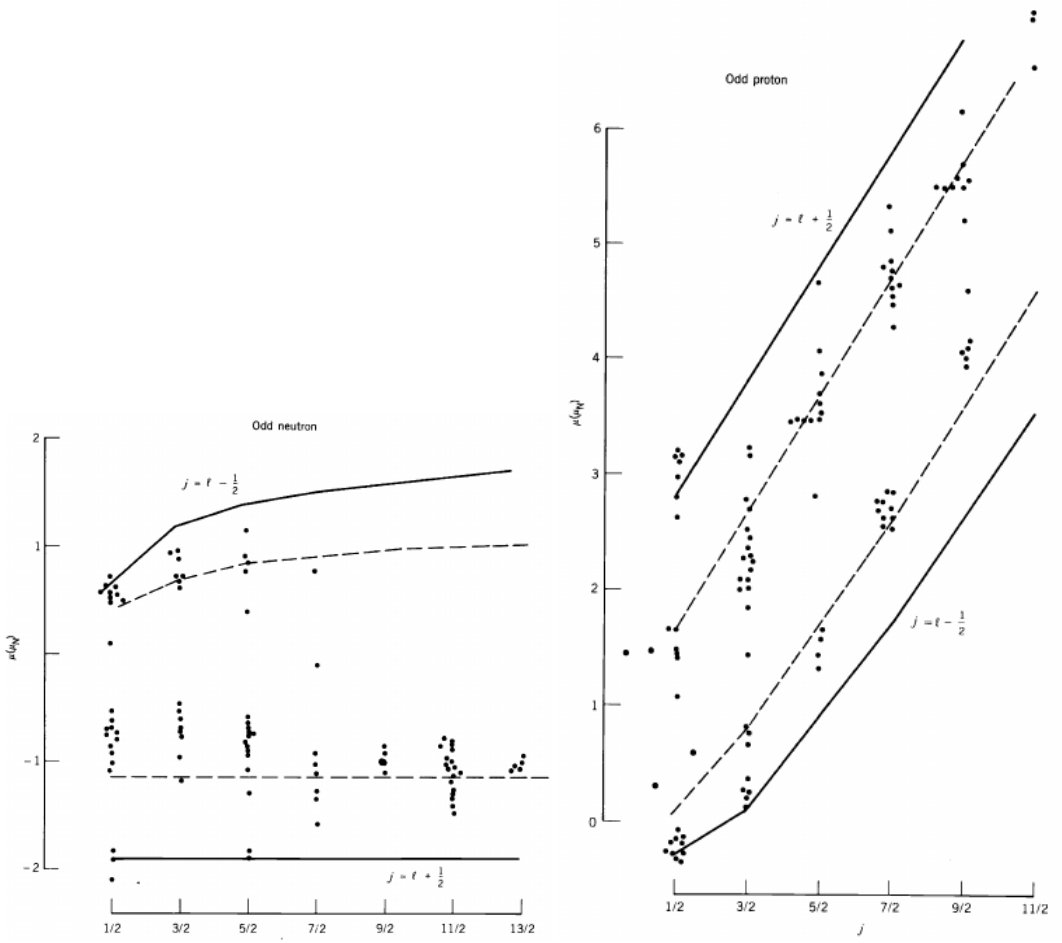

Figure 2

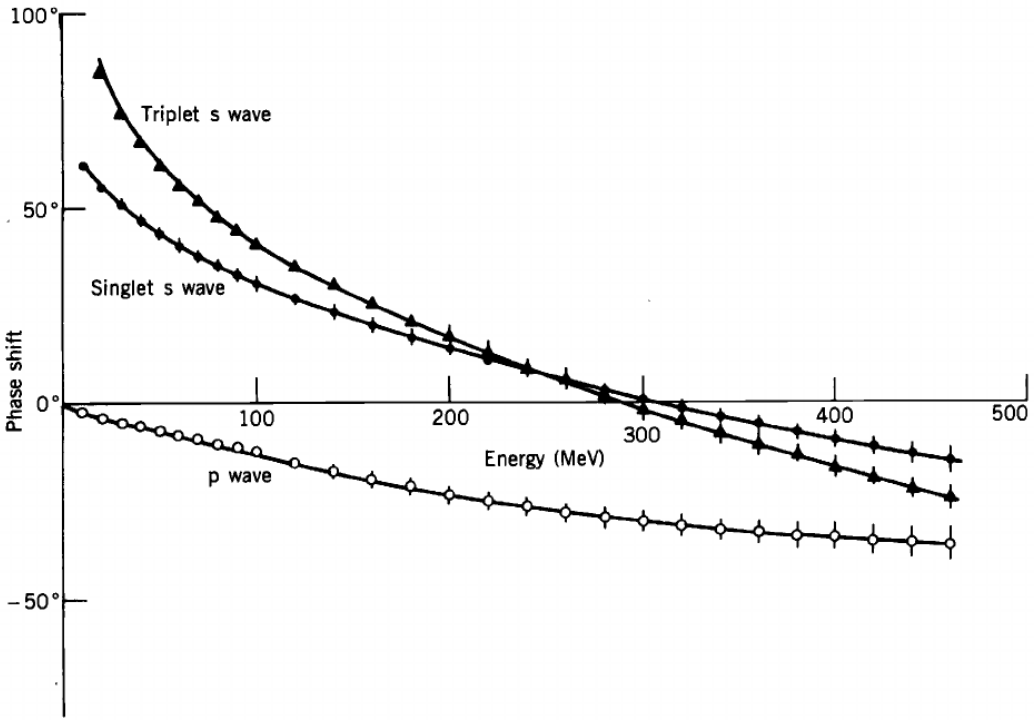

Figure 3