[This question paper contains 3 printed pages.]

Your Roll No. ....

UNIVERSITY OF DELHI

Department of Physics & Astrophysics

M. Sc. (Physics), Nov, 2016

PHYS-404 (Nuclear & Particle Physics)

Maximum Marks: 70 **Time: 3 hrs.**

(Write your Roll No. on the top immediately on receipt of this question paper)

This paper has three sections, A, B and C. The instructions and distribution of marks for each section are specified.

SECTION A

All questions in this section are compulsory.

1) **Answer all questions**

   a) Which of the following quantities are conserved for a particle moving with a velocity $\boldsymbol{v}$: energy (E), parity (π), components of the angular momentum (L_x, L_y, L_z) and L^2 in a (i) static central field and (ii) static uniform field along the z – direction? Justify your answer.

   b) The ground state spin parity of $^{30}_{15}P$ is 1^+. Justify its spin and parity based on the single particle shell model. What will be the ground state spin parity of it isobaric analog state (T=1) partners? Identify them.

   c) In a beta decay, if a ($3/2^+$) nuclear state decays by a 3rd forbidden transition, calculate the possible spin parity states for the final nuclei. Why is the transition called forbidden though beta decay is feasible?

   d) Proton - proton (p-p) scattering can be observed in the singlet spin state. Find out the p-p scattering cross-section when the scattering angle (θ) is $\pi/2$. Consider the nuclear potential to be negligible.

   e) What are the implications of charge symmetry and charge independence hypotheses on the nucleon-nucleon (NN) interaction? (Write in no more than ten sentences.)

   f) What information of the nuclear structure do the magnetic and electric moments of a nucleus provide?

(3+3+3+2+3+2)

2) **Answer all questions**

   a) If the mass of an electron in units of HEP is 511 keV/c^2, what is its mass in SI units?

   b) If an incident particle transfers a momentum of 20 GeV/c, what is the spatial resolution that it can attain?

   c) Will a free proton convert into a neutron, a positron, and an electron neutrino? If yes, why? If not, why not?

   d) What are the fundamental differences between strong and weak forces?

(2+2+1+3)

SECTION B

(This section has 4 questions numbered 3 to 6. Answer any three questions in this section.)

3) **a)** What is the significance of the parameters, scattering length a, and effective range r_o? At what energies, would the scattering of neutron by molecular hydrogen be coherent and why? (consider the inter-atomic distance to be 7.8 nm)

b) Using arguments based on wave functions, explain why excited states do not exist in a deuteron nucleus.

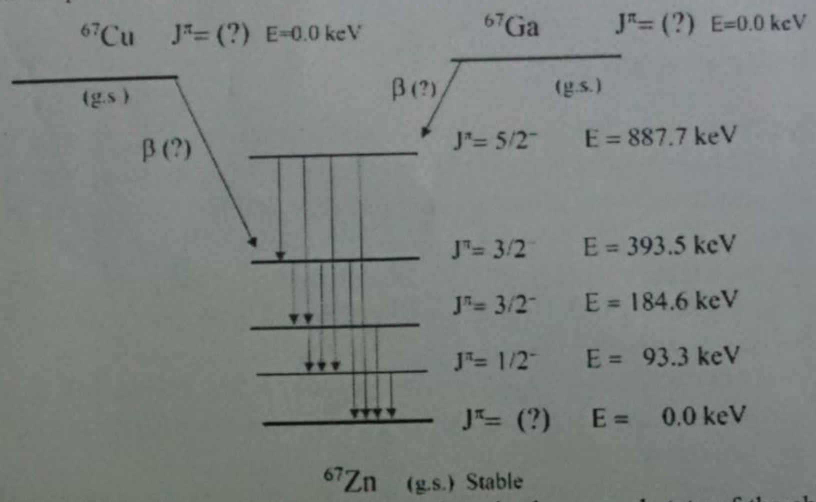
c) In the low energy limit, calculate the phase shift δ_o for s-wave scattering of a particle of mass m and incident energy E by a potential barrier

$$V(r) = V_o \text{ for } r \le R, \quad = 0 \quad r > R,$$

with $E < V_o$. Find the total scattering cross section (σ) in this low energy limit. Comment on the value of σ in the infinite barrier limit.

(3+3+4)

4) $^{67}_{30}Zn$ can be produced from ^{67}Cu or ^{67}Ga via beta decay as shown in the figure.



a) What are the neutron and proton configurations in the ground state of the above three nuclei in the framework of the single particle shell model?

b) Find out the ground state spin parity (J^π) of all the three nuclei and estimate the magnetic moments.

c) Find out the types of beta decay responsible for the production of Zn nuclei from Cu and Ga with an appropriate equation. [Given: $M_A(^{67}Ga)$ = 66.9282017u, $M_A(^{67}Zn)$ = 66.9271273 u, $M_A(^{67}Cu)$ = 66.9277303 u, m_e = 0.511 MeV]. Justify the above decay diagram based on the available energy from beta decay.

d) Based on the selection rules for beta-decay, classify the above decays and comment on the spin direction of the emitted beta particle.

(2+3+3+2)

5) **a)** What information about the nucleus can be obtained from an electron scattering experiment? Find the mean square radius of ^{56}Ni nuclei, assuming it to be a spherical nucleus with sharp boundary. Explain qualitatively, if there will be any effect on the mean square radius if the density distribution diffuses at the surface of the nuclei.

b) Consider a system of a neutron and proton (may not be a deuteron). List the various possible states specifying clearly its angular momentum, spin, and iso-spin quantum numbers.

c) Consider the wave function of neutron and proton as, $\psi_n = \binom{1}{0}$ and $\psi_p = \binom{0}{1}$ with iso-spin components $T_{Z_n} = +\frac{1}{2}$ and $T_{Z_p} = -\frac{1}{2}$ respectively. What is the appropriate definition of T_Z for nucleon-nucleon systems? If the iso-spin operator (*T*) satisfy the eigenvalue relation, $T^2\,\Psi_{nn} = B\,\Psi_{nn}$ then determine the eigen value B of the neutron-neutron system.

(4+2+4)

6) a) What are the basic assumptions of the single particle shell model?

b) What shape of the potential is most appropriate to explain the single particle energy states in the nuclear shell model and why? What is the reason for introducing the total momentum, **J** = **L** + **S** in this model. How does this affect the labeling of the states?

c) Consider a spin-orbit interaction potential, $V_{SL} = -\frac{a}{\omega}\frac{1}{r}\frac{dV}{dr} < l.s >$, where $V(r) = \frac{1}{2}m\omega^2 r^2$ and a is the strength of the spin-orbit coupling. An energy difference of 2 MeV observed between two levels of the same angular momentum (l) state arises due to spin-orbit interaction with the strength parameter a equal to 0.68 x 10^{-3}. Estimate the angular momentum (l) in unit of $\hbar$ for this degenerate state of a nucleus of mass 64. The constant $\hbar\omega$ for harmonic oscillator potential is $41/A^{1/3}$ MeV. Where A is the mass number.

(2+4+4)

SECTION C

(This section has 3 questions numbered 7 to 9. Answer any two questions in this section.)

7) Describe the Cowan-Reines experiment and discuss how anti-neutrino (then called neutrino) was discovered?

(8)

8) a) What do you understand by Iso-spin and Strangeness? Discuss.

b) Describe how mesons were classified into an octet, draw the octet diagram and give the quark content of these mesons.

(3+5)

9) a) What do you understand by the quark model of particle physics?

b) What were the inherent weaknesses of the quark model and how were they overcome or explained?

(5+3)

General Data:

1 unified mass unit (u) = 931.5 MeV/c^2
Planck's constant h = 6.63 x 10^{-34} Js
Boltzmann's constant k = 1.38 x 10^{-23} JK^{-1}
Avogadro's number = 6.022 x 10^{23} (g-mole)$^{-1}$
Permittivity constant ε_o = 8.85 x 10^{-12} Fm^{-1}
Fundamental charge unit e = 1.60 x 10^{-19} C
speed of light (vacuum) c = 3.0 x 10^8 m/s
electron mass(m_e) = 9.11 x 10^{-31} kg = 5.4858 x 10^{-4} u = 0.511 MeV/c^2
neutron mass (m_n) = 1.6749 x 10^{-27} kg = 1.008665 u = 939.573 MeV/c^2
proton mass (m_p) = 1.6726 x 10^{-27} kg = 1.0072765 u = 938.280 MeV/c^2
1 year = 3.156 x 10^7 s