NUCLEAR AND PARTICLE PHYSICS

NET/JRF (JUNE-2011)

Q1. The radius of a ${}^{64}_{29}Cu$ nucleus is measured to be 4.8×10^{-13} cm.

(A). The radius of a ${}^{27}_{12}Mg$ nucleus can be estimated to be

(a) 2.86×10^{-13} cm (b) 5.2×10^{-13} cm (c) 3.6×10^{-13} cm (d) 8.6×10^{-13} cm

Ans: (c)

Solution: Since $R = R_0(A)^{1/3} \Rightarrow \frac{R_{Mg}}{R_{Cu}} = \left(\frac{A_{Mg}}{A_{Cu}}\right)^{1/3} = \left(\frac{27}{64}\right)^{1/3}$

$$\Rightarrow \frac{R_{Mg}}{R_{Cu}} = \frac{3}{4} \Rightarrow R_{Mg} = \frac{3}{4} \times 4.8 \times 10^{-13} = 3.6 \times 10^{-13}\, cm.$$

(B). The root-mean-square (r.m.s) energy of a nucleon in a nucleus of atomic number A in its ground state varies as:

(a) $A^{4/3}$ (b) $A^{1/3}$ (c) $A^{-1/3}$ (d) $A^{-2/3}$

Ans: (c)

Q2. A beam of pions (π^+) is incident on a proton target, giving rise to the process

$$\pi^+ p \longrightarrow n + \pi^+ + \pi^+$$

(A). Assuming that the decay proceeds through strong interactions, the total isospin I and its third component I_3 for the decay products, are

(a) $I = \frac{3}{2}, I_3 = \frac{3}{2}$ (b) $I = \frac{5}{2}, I_3 = \frac{5}{2}$

(c) $I = \frac{5}{2}, I_3 = \frac{3}{2}$ (d) $I = \frac{1}{2}, I_3 = -\frac{1}{2}$

Ans: (c)

Solution: $\pi^+ + p \to n + \pi^+ + \pi^+;\quad I : \frac{1}{2} + 1 + 1 = \frac{5}{2},\quad I_3 : -\frac{1}{2} + 1 + 1 = \frac{3}{2}$

(B). Using isospin symmetry, the cross-section for the above process can be related to that of the process

(a) $\pi^- n \to p\pi^-\pi^-$ (b) $\pi^- \overline{p} \to \overline{n}\pi^-\pi^-$

(c) $\pi^+ n \to p\pi^+\pi^-$ (d) $\pi^+ \overline{p} \to n\pi^+\pi^-$

Ans: (c)

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Q3. According to the shell model the spin and parity of the two nuclei $^{125}_{51}Sb$ and $^{89}_{38}Sr$ are, respectively,

(a) $\left(\frac{5}{2}\right)^+$ and $\left(\frac{5}{2}\right)^+$ (b) $\left(\frac{5}{2}\right)^+$ and $\left(\frac{7}{2}\right)^+$

(c) $\left(\frac{7}{2}\right)^+$ and $\left(\frac{5}{2}\right)^+$ (d) $\left(\frac{7}{2}\right)^+$ and $\left(\frac{7}{2}\right)^+$

Ans: (d)

Q4. The difference in the Coulomb energy between the mirror nuclei $^{49}_{24}Cr$ and $^{49}_{25}Mn$ is $6.0\,MeV$. Assuming that the nuclei have a spherically symmetric charge distribution and that e^2 is approximately 1.0 *MeV-fm*, the radius of the $^{49}_{25}Mn$ nucleus is

(a) 4.9 $\times 10^{-13}$ m (b) 4.9 $\times 10^{-15}$ m

(c) 5.1 $\times 10^{-13}$ m (d) 5.1 $\times 10^{-15}$ m

Ans: (b) $$R = \frac{3e^2}{5\cdot\Delta W}\left(Z_1^2 - Z_2^2\right) = \frac{3\times 1\times 10^{-15}}{5\times 6}\left(25^2 - 24^2\right) = 4.9\times 10^{-15}\, m.$$

NET/JRF (JUNE-2012)

Q5. The ground state of $^{207}_{12}Pb$ nucleus has spin-parity $J^p = \frac{1^-}{2}$, while the first excited state has $J^p = \frac{5^-}{2}$.The electromagnetic radiation emitted when the nucleus makes a transition from the first excited state to ground state are

(a) E2 and E3 (b) M2 or E3 (c) E2 or M3 (d) M2 or M3

Ans: (c)

Solution: No parity change; $\Delta J = 2,3$

For E_l type, $\Delta\pi = (-1)^l$, (for no parity change $l = 2$)

For M_l type, $\Delta\pi = (-1)^{l+1}$, (for no parity change $l = 3$)

$\Delta J = 2$, No parity change $\rightarrow E2$; $\Delta J = 3$, No parity change $\rightarrow M3$

Q6. The dominant interactions underlying the following processes

A. $K^- + p \to \sum^- + \pi^+$, B. $\mu^- + \mu^+ \to K^- + K^+$, C. $\Sigma^+ \to p + \pi^0$ are

(a) A: strong, B: electromagnetic and; C: weak

(b) A: strong, B: weak and; C: weak

(c) A: weak, B: electromagnetic and; C: strong

(d) A: weak, B: electromagnetic and; C: weak

Ans: (a)

(A) $K^- + p \to \sum^- + \pi^+$ (Strong interaction)

$I_3 : -\frac{1}{2} + \frac{1}{2} \to -1 + 1$ (Conserved)

(B) $\mu^- + \mu^+ \to K^- + K^+$ (Electromagnetic interaction)

(C) $\Sigma^+ \to p + \pi^0$ (Weak interaction)

$I_3 : 1 \to \frac{1}{2} + 0$ (Not conserved)

NET/JRF (JUNE-2013)

Q7. The binding energy of a light nucleus (Z, A) in MeV is given by the approximate formula

$$B(A,Z) \approx 16A - 20A^{2/3} - \frac{3}{4}Z^2 A^{-1/3} + 30\frac{(N-Z)^2}{A}$$

where $N = A - Z$ is the neutron number. The value of Z of the most stable isobar for a given A is

(a) $\frac{A}{2}\left(1 - \frac{A^{2/3}}{160}\right)^{-1}$ (b) $\frac{A}{2}$

(c) $\frac{A}{2}\left(1 - \frac{A^{2/3}}{120}\right)^{-1}$ (d) $\frac{A}{2}\left(1 + \frac{A^{4/3}}{64}\right)^{-1}$

Ans: (a)

Solution: $\left.\frac{\partial B}{\partial Z}\right|_{Z=Z'} = 0 \Rightarrow Z' = \frac{A}{2}\left(1 - \frac{A^{2/3}}{160}\right)^{-1}$

Q8. A spin-1/2 particle A undergoes the delay

$$A \to B + C + D$$

where it is known that B and C are also spin-1/2 particles. The complete set of allowed values of the spin of the particle D is

(a) $\frac{1}{2}, 1, \frac{3}{2}, 2, \frac{5}{2}, 3, ...$ (b) 0, 1

(c) $\frac{1}{2}$ only (d) $\frac{1}{2}, \frac{3}{2}, \frac{5}{2}, \frac{7}{2}, ...$

Ans: (c)

Solution: Spin of the left side and combined spin of the products must be same to conserve the spin angular momentum conservation law.

Q9. Muons are produced through the annihilation of particle a and its antiplarticle, namely the process

$$a + \overline{a} \to \mu^+ + \mu^-$$

A muon has a rest mass of 105 MeV/c^2 and its proper life time is $2\mu s$. If the center of mass energy of the collision is 2.1 GeV in the laboratory frame that coincides with the center-of-mass frame, then the fraction of muons that will decay before they reach a detector placed 6 km away from the interaction point is

(a) e^{-1} (b) $1 - e^{-1}$

(c) $1 - e^{-2}$ (d) e^{-10}

Ans: (b)

Solution: $N = N_0 e^{-\lambda t} \Rightarrow \frac{N}{N_0} = e^{-\lambda t} = e^{-\frac{t}{\gamma\tau}}$

where $\tau = 2 \times 10^{-6} s$, $\gamma = \frac{2.1}{105} \times 10^3 = 20$ and $t = \frac{6 \times 10^3}{3 \times 10^8} = 2 \times 10^{-5}$ sec .

Thus $\frac{t}{\gamma\tau} = \frac{1}{2} \Rightarrow \frac{N}{N_0} = e^{-\frac{1}{2}} \approx 1 - e^{-1}$.

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Q10. The intrinsic electric dipole moment of a nucleus ${}_Z^A X$

(a) increases with Z, but independent of A

(b) decreases with Z, but independent of A

(c) is always zero

(d) increases with Z and A

Ans: (d)

Q11. According to the shell model, the total angular momentum (in units of $\hbar$) and the parity of the ground state of the ${}_3^7 Li$ nucleus is

(a) $\frac{3}{2}$ with negative parity (b) $\frac{3}{2}$ with positive parity

(c) $\frac{1}{2}$ with positive parity (d) $\frac{7}{2}$ with negative parity

Ans: (a)

Solution: $Z = 3, N = 4$

For odd $Z = 3$; $\left(s_{1/2}^2\right)\left(p_{3/2}^1\right) \Rightarrow j = 3/2, l = 1$ and parity $= (-1)^1 = -1$.

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Q12. The recently-discovered Higgs boson at the LHC experiment has a decay mode into a photon and a Z boson. If the rest masses of the Higgs and Z boson are 125 GeV/c^2 and 90 GeV/c^2 respectively, and the decaying Higgs particle is at rest, the energy of the photon will approximately be

(a) $35\sqrt{3}$ GeV (b) 35 GeV (c) 30 GeV (d) 15 GeV

Ans: (c)

Solution: Assume H is symbol of Higgs boson, $H \rightarrow Z + \gamma$

$$E_\gamma = \frac{E_H^2 - E_Z^2}{2E_H} = \frac{(125)^2 - (90)^2}{2 \times 125} = 30 GeV$$

Q13. In a classical model, a scalar (spin-0) meson consists of a quark and an antiquark bound by a potential

$$V(r) = ar + \frac{b}{r}$$

where $a = 200\,\text{MeV fm}^{-1}$ and $b = 100$ MeV fm. If the masses of the quark and antiquark are negligible, the mass of the meson can be estimated as approximately

(a) 141 MeV/c^2 (b) 283 MeV/c^2 (c) 353 MeV/c^2 (d) 425 MeV/c^2

Ans: (b)

Solution: At equilibrium separation the potential is minimum, thus the equilibrium separation can be determined as

$$\left.\frac{DV(r)}{dr}\right|_{r=r_0} = a - \frac{b}{r_0^2} = 0$$

$$\Rightarrow \quad r_0 = \sqrt{\frac{b}{a}} = \sqrt{\frac{100MeVfm^{-1}}{200MeVfm^{-1}}} = \frac{1}{\sqrt{2}}\, fm$$

The equilibrium separation between particles is also estimated by uncertainty principle

$$r_0 = c\Delta t \qquad \Rightarrow \quad r_0 = c\frac{\hbar}{\Delta E} \qquad (where, \Delta E \Delta t \approx \hbar)$$

Where, c is the velocity of the virtual meson

$$r_0 = c\frac{\hbar}{\Delta E} = \frac{200MeV.fm}{\Delta E(MeV)}$$

Using above two relation $\frac{200MeV.fm}{\Delta E(MeV)} = \frac{1}{\sqrt{2}}\, fm$

$$\Delta E = 200\sqrt{2} = 283MeV \Rightarrow \Delta E = \Delta m \times c^2$$

the mass of the meson $\Delta m = \frac{\Delta E}{c^2} = 283MeV/c^2$

NET/JRF (DEC-2014)

Q14. Consider the four processes

(i) $p^+ \to n + e^+ + \nu_e$ (ii) $\Lambda^0 \to p^+ + e^+ + \nu_e$

(iii) $\pi^+ \to e^+ + \nu_e$ (iv) $\pi^0 \to \gamma + \gamma$

which of the above is/are forbidden for free particles?

(a) only (ii) (b) (ii) and (iv) (c) (i) and (iv) (d) (i) and (ii)

Ans: (d)

Solution: (i) $p^+ \to n + e^+ + \nu_e$ [Not allowed]

It violate energy conservation. The mass of proton is less than mass of neutron. Free proton is stable and can not decay to neutron. Proton can decay to neutron only inside the nucleus, where energy violation is taken care by Heisenberg uncertainty principle.

(ii) $\Lambda^0 \to p^+ + e^+ + \nu_e$ [Not allowed]. In this decay charge is not conserved

(iii) $\pi^+ \to e^+ + \nu_e$ [allowed through Weak interaction]

(iv) $\pi^0 \to \gamma + \gamma$ [allowed through Electromagnetic interaction]

Q15. In deep inelastic scattering electrons are scattered off protons to determine if a proton has any internal structure. The energy of the electron for this must be at least

(a) $1.25 \times 10^9\, eV$ (b) $1.25 \times 10^{12}\, eV$ (c) $1.25 \times 10^6\, eV$ (d) $1.25 \times 10^8\, eV$

Ans: (b)

Solution: The internal structure of proton can only be determined if the wavelength of the incoming electron is nearly equal to the size of the proton

$$\text{i.e. } \lambda = R = 1.2A^{1/3}\left(fm\right) = 1.2\, fm = 1.2 \times 10^{-15}\, m$$

According to de-Broglie relation, $\lambda = \dfrac{h}{p} = \dfrac{h}{\sqrt{2mE}}$

This can be also written as $\lambda\left(\overset{0}{\mathrm{A}}\right) = \sqrt{\dfrac{150}{E\left(eV\right)}}$

$$\therefore E(eV) = \frac{150}{\left[\lambda\left(\overset{0}{\mathrm{A}}\right)\right]^2} = \frac{150}{\left(1.2\times10^{-5}\right)^2} = 1.04\times10^{12} \Rightarrow E = 1.04\times10^{12}\,eV$$

The bet suitable answer is option (b).

Q16. If the binding energy B of a nucleus (mass number A and charge Z) is given by

$$B = a_V A - a_S A^{2/3} - a_{sym}\frac{(2Z-A)^2}{A} - \frac{a_C Z^2}{A^{1/3}}$$

where $a_V = 16\,MeV$, $a_S = 16\,MeV$, $a_{sym} = 24\,MeV$ and $a_C = 0.75\,MeV$, then for the most stable isobar for a nucleus with $A = 216$ is

(a) 68 (b) 72 (c) 84 (d) 92

Ans: (c)

Solution: For the most stable isobar for a nucleus $\frac{dB}{dZ} = 0 \Rightarrow -a_{sym}\frac{2(2Z-A)\times 2}{A} - \frac{2a_C Z}{A^{1/3}} = 0$

$$\Rightarrow 24\frac{2(2Z-216)\times 2}{216} + 0.75\frac{2Z}{(216)^{1/3}} = 0 \Rightarrow \frac{4(2Z-216)}{9} + \frac{3}{4}\frac{2Z}{6} = 0$$

$$\Rightarrow \frac{4(2Z-216)}{9} + \frac{Z}{4} = 0 \Rightarrow 16(2Z-216) + 9Z = 0 \Rightarrow 41Z = 216\times16 \Rightarrow Z = 82.3$$

NET/JRF (JUNE-2015)

Q17. The reaction ${}_1^2D + {}_1^2D \rightarrow {}_2^4He + \pi^0$ cannot proceed via strong interactions because it violates the conservation of

(a) angular momentum (b) electric charge

(c) baryon number (d) isospin

Ans. (d)

Solution: ${}_1D^2 + {}_1D^2 \rightarrow {}_2He^4 + \pi^0$ (Not conserved)

$I: 0 \quad 0 \rightarrow 0 \quad 1$

This isopin is not conserved in above reaction.

Q18. Let us approximate the nuclear potential in the shell model by a three dimensional isotropic harmonic oscillator. Since the lowest two energy levels have angular momenta $l=0$ and $l=1$ respectively, which of the following two nuclei have magic numbers of protons and neutrons?

(a) ${}^{4}_{2}He$ and ${}^{16}_{8}O$ (b) ${}^{2}_{1}D$ and ${}^{8}_{4}Be$ (c) ${}^{4}_{2}He$ and ${}^{8}_{4}Be$ (d) ${}^{4}_{2}He$ and ${}^{12}_{6}C$

Ans. (a)

Solution: ${}_{2}He^{4}$ has $Z=2, N=2$

and ${}_{8}O^{16}$ has $Z=8, N=8$ magic numbers $(2,8,20,28,50,82,126)$

Q19. The charm quark s assigned a charm quantum number $C=1$. How should the Gellmann-Nishijima formula for electric charge be modified for four flavors of quarks?

(a) $I_3+\frac{1}{2}(B-S-C)$ (b) $I_3+\frac{1}{2}(B-S+C)$

(c) $I_3+\frac{1}{2}(B+S-C)$ (d) $I_3+\frac{1}{2}(B+S+C)$

Ans. (d)

Solution: From Gell-Mann-Nishijima formula $Q=I_3+\frac{1}{2}(B+S)$

For Quark it is generalized as $Q=I_3+\frac{1}{2}(B+S+C)$

NET/JRF (DEC-2015)

Q20. Consider the following processes involving free particles

(i) $\bar{n}\to\bar{p}+e^{+}+\bar{\nu}_e$ (ii) $\bar{p}+n\to\pi^{-}$

(iii) $p+n\to\pi^{+}+\pi^{0}+\pi^{0}$ (iv) $p+\bar{\nu}_e\to n+e^{+}$

Which of the following statements is true?

(a) Process (i) obeys all conservation laws

(b) Process (ii) conserves baryon number, but violates energy-momentum conservation

(c) process (iii) is not allowed by strong interaction but is allowed by weak interactions

(d) Process (iv) conserves baryon number, but violates lepton number conservation

Ans.: (b)

Solution: (i) $\bar{n} \rightarrow \bar{p} + e^{+} + \bar{v}_e$

q 0 -1 $+1$ 0 (conserved)

spin $-\frac{1}{2}$ $-\frac{1}{2}$ $-\frac{1}{2}$ $-\frac{1}{2}$ (not conserved)

Le 0 0 -1 -1 (not conserved)

(ii) Baryon number is conserved but energy and momentum conservation violated.

(iii) spin is not conserved

(iv) obeys all conservation laws.

Q21. Of the nuclei of mass number $A = 125$, the binding energy calculated from the liquid drop model (given that the coefficients for the Coulomb and the asymmetry energy are $a_c = 0.7\ MeV$ and $a_{sym} = 22.5\ MeV$ respectively) is a maximum for

(a) $^{125}_{54}Xe$ (b) $^{124}_{53}I$ (c) $^{125}_{52}Te$ (d) $^{125}_{51}Sb$

Ans.: (c)

Solution: $Z_0 = \dfrac{4a_a + a_c A^{-1/3}}{2a_c A^{-1/3} + 8a_a A^{-1}} = \dfrac{4a_0 A + a_c A^{2/3}}{8a_a + 2a_c A^{2/3}}$

$$\Rightarrow Z_0 = \frac{4 \times 22.5 \times 125 + 0.7\left(5^3\right)^{2/3}}{8 \times 22.5 + 2 \times 0.7\left(5^3\right)^{2/3}} \Rightarrow Z_0 = \frac{11250 + 17.5}{180 + 35} = \frac{11267.5}{215} = 52.4$$

$$\Rightarrow Z_0 \approx 52$$