REV-01
MSP/37/19/24

2023/12

SET A

M.Sc. PHYSICS
THIRD SEMESTER
NUCLEAR PHYSICS
MSP – 301

[USE OMR FOR OBJECTIVE PART]

Duration: 3 hrs. **Full Marks: 70**

(Objective)

Time: 30 min. **Marks: 20**

Choose the correct answer from the following: ***1x20=20***

1. What role does binding energy play in the stability of a nucleus?
   a. Higher binding energy makes a nucleus more stable
   b. Lower binding energy makes a nucleus more stable
   c. Binding energy is unrelated to nuclear stability
   d. Binding energy determines the rate of radioactive decay

2. The contribution of the coulomb energy in the semi-empirical mass formula of a nucleus of mass number A and the atomic number Z is of the form (a is a constant)
   a. $aZA^{2/3}$
   b. $\frac{aZ^2}{A^{2/3}}$
   c. $-\frac{a(A-2Z)^2}{A}$
   d. $-\frac{aZ(Z-1)}{A^{1/3}}$

3. The missing particle in the following nuclear reaction is:
   $${}^1_1p \rightarrow {}^1_0n + e^- + ?$$
   a. e^+
   b. ν_e
   c. $\overline{\nu_e}$
   d. γ

4. The total angular momentum of a nucleus with even-A nuclei is
   a. integral multiple of $\hbar$
   b. even multiple of $\hbar$ only
   c. half-integral multiple of $\hbar$
   d. none of the above

5. In a proportional counter, the number of electrons produced is directly proportional to:
   a. The voltage applied to the detector
   b. The energy of the incident radiation
   c. The type of radiation being detected
   d. The atomic number of the material inside the counter

6. In an endoergic reaction, the energy of the products is:
   a. Greater than the energy of the reactants
   b. Equal to the energy of the reactants
   c. Less than the energy of the reactants
   d. Unchanged

7. If the Q value of a nuclear reaction is negative, what does it indicate?
   a. The reaction is not possible
   b. The reaction rate is constant
   c. Energy is released
   d. Energy is absorbed

8. According to Fermi's theory of allowed beta decay, the energy remains conserved in the decay process, the available energy being shared among the electrons and neutrinos. At the end point i.e. $Q=T_e$, the neutrino energy
   a. approaches to zero
   b. becomes equal to the energy of the emitted electrons
   c. becomes equal to the energy of the daughter nucleus
   d. becomes equal to the total energy released in the process

9. In Fermi's theory of beta decay, what particle is responsible for the weak force interaction in beta decay?
   a. Neutrinos
   b. Positron
   c. Electron
   d. Alpha particles

10. C.S. Wu's experiment provided experimental evidence for the violation of parity in which physical interaction?
   a. Weak
   b. Strong nuclear
   c. Electromagnetic
   d. Gravitational

11. What is the primary fusion product in a deuterium-deuterium fusion reaction?
   a. Helium-3
   b. Helium-4
   c. Tritium
   d. Neutron

12. In a Geiger-Muller counter, what does the "dead time" refer to?
   a. The time it takes for the device to start operating after turning it on
   b. The time it takes for a radiation event to be registered after entering the counter
   c. The time during which the counter cannot detect another radiation event after an initial one
   d. The total time the counter is operational before it needs to be recharged

13. In a nuclear reaction, what law ensures that the total number of nucleons (protons and neutrons) remains constant before and after the reaction?
   a. Law of Conservation of Energy
   b. Law of Conservation of Electric Charge
   c. Law of Conservation of Leptons
   d. Law of Conservation of Baryon Number

14. Which of the following particles is not typically involved in gamma-induced nuclear reactions?
   a. Gamma rays
   b. Electrons
   c. Neutrons
   d. None of these

15. The decay chain of the nucleus $^{238}_{92}U$ involves 8 alpha decays and 6 beta decays. The final nucleus at the end of the process will have
   a. Z=84, A=224
   b. Z=82, A=206
   c. Z=88, A=206
   d. Z=76, A=200

16. What is the type of the following nuclear reaction: $^{16}_{8}O + ^{4}_{2}He \rightarrow ^{1}_{0}n + ^{19}_{10}Ne$
   a. (α, n)
   b. (n, α)
   c. (p, n)
   d. (α, p)

17. The degenerate states (n, l) corresponding to energy level $\frac{7}{2}\hbar\omega$ are
    a. (2,0)(1,3)
    b. (2,0)(1,2)
    c. (2,0)(2,2)
    d. (2,0)(1,1)

18. The total number of nucleons filling up the shells with energy $\frac{5}{2}\hbar\omega$ are
    a. 2
    b. 4
    c. 6
    d. 8

19. Which particle is responsible for the strong nuclear force that binds protons and neutrons in a nucleus?
    a. Electron
    b. Photon
    c. Graviton
    d. Gluon

20. According to the Gell-Mann–Nishijima relation, what is the isospin of a down quark?
    a. 0
    b. 1
    c. +1/2
    d. -1/2

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Descriptive

Time : 2 hrs. 30 min. **Marks : 50**

[Answer question no.1 & any four (4) from the rest]

1. **a.** Derive the expression for the spin-orbit splitting ($\Delta\varepsilon_{ls}$) of two energy levels characterized by total angular momentum quantum numbers $j = l + \frac{1}{2}$ and $j = l - \frac{1}{2}$ within the framework of the single-particle shell model. **4+6=10**

   b. Illustrate the sequence of nuclear energy levels for a system with 82 nucleons based on the shell model, incorporating the effects of spin-orbit interaction.

2. **a.** Explain the graphical representation of the curve depicting binding energy per nucleon. **2+3+5 =10**

   b. Write an expression for the semi-empirical mass formula based on liquid drop model explaining each term associated with it.

   c. Using the shell model, predict the ground state spin-parity of $^{15}_{8}O$, $^{39}_{19}Kr$ and $^{20}_{10}Ne$.

3. Elaborate on Fermi's theory of nuclear beta decay, providing a detailed explanation. Subsequently, derive a mathematical expression for the number of final-state electrons within a momentum range from 'p' to '$p + dp$'. Also include a graphical representation to visually illustrate this concept. **10**

4. **a.** C. S. Wu's experiment involved the use of cobalt-60 nuclei and the emission of beta particles. Explain the experiment's significance in the context of weak interactions (diagram and description of the experimental setup is not required). **5+5=10**

   b. Write the general formula for both alpha-induced and deuteron-induced nuclear reactions. Give two examples for each type of reactions.

5. **a.** Explain the Bohr-Wheeler theory of nuclear fission and hence derive the expression for critical energy of deformation for lighter nuclei. **8+2=10**

b. Determine the amount of energy liberated during the nuclear fission of 1 kg of Uranium (^{235}U).

6. What is an endoergic reaction? Obtain an expression for the threshold energy required to initiate an endoergic reaction. **2+8=10**

7. **a.** Explain the concept of Q value in a nuclear reaction and its significance. **3+4+3 =10**

b. Calculate the Q-value for the given reaction and hence determine whether it is an exoergic or endoergic process.

$$^{14}_{7}N + ^{4}_{2}He \rightarrow ^{1}_{1}p + ^{17}_{8}O$$

Given: m_N: 14.003074 u , m_{He}: 4.002603 u , m_p: 1.007825 u , m_O: 16.999131 u

c. Explain the difference between endoergic and exoergic reaction.

8. **a.** Enumerate the fundamental particles of nature (leptons and quarks), including their symbols and key properties. **6+4=10**

b. List and explain the fundamental forces of nature, providing a detailed explanation of their unique properties.

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