

**STELLA MARIS COLLEGE (AUTONOMOUS), CHENNAI – 600 086**  
(For candidates admitted during the academic year 2023-2024 & thereafter)

**M.Sc. DEGREE EXAMINATION, APRIL 2026**  
**BRANCH III - PHYSICS**  
**FOURTH SEMESTER**

**COURSE : CORE**  
**PAPER : NUCLEAR AND ELEMENTARY PARTICLE PHYSICS**  
**SUBJECT CODE : 23PH/PC/NP44**  
**TIME : 3 HOURS** **MAX.MAKRS : 100**

Q. No.	SECTION A ANSWER ALL QUESTIONS (10 x 3=30)	CO	KL
1	Define Binding Energy and explain its significance in nuclear stability.	1	1
2	What are mirror nuclei? Give an example and explain how they help in measuring nuclear radius.	1	1
3	State the main assumptions of the Fermi gas model of the nucleus.	1	1
4	What are "Magic Numbers" in the context of the nuclear shell model?	1	1
5	Distinguish between nuclear fission and nuclear fusion with one example each.	2	2
6	State the conservation laws that must be obeyed during a nuclear reaction.	2	2
7	State the Geiger-Nuttall Law and explain its importance in Alpha decay.	2	2
8	Briefly explain Pauli's Neutrino Hypothesis to account for the continuous Beta-ray spectrum.	2	2
9	List the four fundamental interactions in nature in increasing order of their strength.	3	3
10	What are Quarks? Name the six "flavors" of quarks.	3	3
Q. No.	SECTION B Part A ANSWER ANY TWO QUESTIONS (2x 5 = 10)	CO	KL
11	Calculate the Q-value of the reaction: ${}^2_1\text{H} + {}^3_1\text{H} \rightarrow {}^4_2\text{He} + {}^1_0\text{n}$ Given: $m({}^2_1\text{H}) = 2.014102 \text{ u}$ ; $m({}^3_1\text{H}) = 3.016049 \text{ u}$ ; $m({}^4_2\text{He}) = 4.002603 \text{ u}$ ; $m({}^1_0\text{n}) = 1.008665 \text{ u}$ ; $1 \text{ u} = 931.5 \text{ MeV}$ .	3	3
12	If the range of an alpha particle in air is 4 cm, estimate its energy using the Geiger-Nuttall empirical relationship.	3	3

13	Using the quark model, determine: a) The quark composition of the $K^+$ meson b) Its electric charge c) Its strangeness Given: Quark charges: $u = +\frac{2}{3}e$ ; $d = -\frac{1}{3}e$ ; $s = -\frac{1}{3}e$ ; $\bar{s} = +\frac{1}{3}e$ Strangeness: $s = -1$ ; $\bar{s} = +1$	3	3
	<b>Part B</b> <b>ANSWER ANY SIX QUESTIONS (6x 5 = 30)</b>		
14	Describe the Meson theory of nuclear forces and explain how it accounts for the exchange nature of these forces.	4	4
15	Discuss the similarities between a nucleus and a liquid drop. Mention the semi-empirical mass formula.	4	4
16	Explain the Breit-Wigner single level formula and its application in neutron resonances at low energy.	4	4
17	Derive the relationship between range and energy for alpha particles.	4	4
18	Explain the Gellman-Okubo mass formula for octets and decuplet hadrons.	4	4
19	Explain the ground state of a Deuteron and why it has no excited states.	4	4
20	Describe the general features and classification of nuclear reactors.	4	4
21	Discuss Gamow-Teller selection rules in the context of Beta decay.	4	4
<b>Q. No.</b>	<b>SECTION C</b> <b>ANSWER ANY TWO QUESTIONS (2 x15=30)</b>	<b>CO</b>	<b>KL</b>
22	Describe the electron scattering method for the measurement of nuclear radius. Include the derivation and experimental setup.	5	5
23	Elaborate on the Nuclear Shell Model. Discuss the spin-orbit interaction and how the model predicts the magic numbers and nuclear parity.	5	5
24	Explain the mechanism of a Compound Nucleus reaction. Discuss the formation and decay stages with relevant energy level diagrams.	5	5
25	Discuss the classification of elementary particles based on their mass, spin, and interactions.	5	5

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## SCHEME

**STELLA MARIS COLLEGE (AUTONOMOUS), CHENNAI – 86**  
**(For the candidates admitted from the academic year 2023-2024 and thereafter)**

**M.Sc. DEGREE EXAMINATION, APRIL 2026**  
**BRANCH III PHYSICS**  
**FOURTH SEMESTER**

**COURSE: PC**

**Title of the Course: NUCLEAR AND ELEMENTARY PARTICLE PHYSICS**

**Course Code: 23PH/PC/NP44**

**TIME: 3 hours**

**MAX. MARKS: 100**

Q. No.	SECTION A ANSWER ALL QUESTIONS (10 x 3=30)	CO	KL
1	Define Binding Energy and explain its significance in nuclear stability. Binding energy is the energy required to separate a nucleus into its individual nucleons. Higher binding energy per nucleon indicates greater nuclear stability.	1	1
2	What are mirror nuclei? Give an example and explain how they help in measuring nuclear radius. Mirror nuclei are pairs with interchanged proton and neutron numbers, e.g., ${}^{15}_8\text{O}$ , ${}^{15}_7\text{N}$ . Comparing their energy levels helps estimate nuclear radius by studying Coulomb energy differences.	1	1
3	State the main assumptions of the Fermi gas model of the nucleus. Nucleons move independently inside the nucleus as free particles in a constant potential well. They obey the Pauli exclusion principle and fill energy levels up to the Fermi energy.	1	1
4	What are "Magic Numbers" in the context of the nuclear shell model? Magic numbers are specific numbers of protons or neutrons (2, 8, 20, 28, 50, 82, 126) that give extra stability. They correspond to completely filled nuclear shells.	1	1
5	Distinguish between nuclear fission and nuclear fusion with one example each. Fission is the splitting of a heavy nucleus into lighter nuclei, e.g., ${}^{235}_{92}\text{U}$ fission. Fusion is the combination of light nuclei to form a heavier nucleus, e.g., deuterium–tritium fusion.	2	2
6	State the conservation laws that must be obeyed during a nuclear reaction.	2	2

	Conservation of mass-energy, linear momentum, angular momentum, charge, and nucleon number must hold. Other conserved quantities include parity (in strong interactions) and lepton number (in weak interactions).		
7	State the Geiger-Nuttall Law and explain its importance in Alpha decay. The Geiger–Nuttall law states that the logarithm of the decay constant is proportional to the inverse square root of alpha particle energy. It shows that higher energy alpha emitters have shorter half-lives.	2	2
8	Briefly explain Pauli’s Neutrino Hypothesis to account for the continuous Beta-ray spectrum. Pauli proposed the neutrino as an additional neutral particle emitted in beta decay. Its presence ensures conservation of energy and momentum, explaining the continuous spectrum.	2	2
9	List the four fundamental interactions in nature in increasing order of their strength. Gravitational < Weak < Electromagnetic < Strong interaction. The strong interaction is the most powerful at nuclear scales.	3	3
10	What are Quarks? Name the six "flavors" of quarks mentioned in the syllabus. Quarks are fundamental particles that combine to form hadrons such as protons and neutrons. The six flavors are up, down, strange, charm, bottom (beauty), and top (truth).	3	3
<b>Q. No.</b>	<b>SECTION B</b>	<b>CO</b>	<b>KL</b>
	<b>Part A</b> <b>ANSWER ANY TWO QUESTIONS (2x 5 = 10)</b>		
11	Calculate the Q-value of the reaction: ${}^2_1\text{H} + {}^3_1\text{H} \rightarrow {}^4_2\text{He} + {}^1_0\text{n}$ Given: $m({}^2_1\text{H}) = 2.014102 \text{ u}$ ; $m({}^3_1\text{H}) = 3.016049 \text{ u}$ ; $m({}^4_2\text{He}) = 4.002603 \text{ u}$ ; $m({}^1_0\text{n}) = 1.008665 \text{ u}$ ; $1 \text{ u} = 931.5 \text{ MeV}$ . <u>Solution:</u> $Q = (m_{\text{reactants}} - m_{\text{products}}) c^2$ $Q = [(2.014102+3.016049)-(4.002603+1.008665)] \text{ u}$ $Q = [5.030151 - 5.011268] = 0.018883 \text{ u}$ $Q = 0.018883 \times 931.5 \approx 17.589 \text{ MeV}$ .	3	3
12	If the range of an alpha particle in air is 4 cm, estimate its energy using the Geiger-Nuttall empirical relationship. <u>Solution:</u> The Geiger Nuttall empirical relation is, : $R = 0.318 E^{3/2}$ Rearrange the formula to solve for E: $E = (R / 0.318)^{2/3}$ $E = (4 / 0.318)^{2/3}$ $E = (12.57)^{2/3} = 5.41 \text{ MeV}$	3	3
13	Using the quark model, determine: a) The quark composition of the $\text{K}^+$ meson b) Its electric charge c) Its strangeness Quark charges: $u = +\frac{2}{3}e$ ; $d = -\frac{1}{3}e$ ;	3	3

	$s = -\frac{1}{3}e; \bar{s} = +\frac{1}{3}e$ Strangeness: $s = -1; \bar{s} = +1$ <u>Solution:</u> (a) Quark composition, $K^+ = u\bar{s}$ (b) Quark electric charge, $Q = Q_u + Q_{\bar{s}} = \frac{2}{3} + \frac{1}{3} = +1e$ (c) Strangeness, $\bar{s} = +1$		
	<b>Part B</b> <b>ANSWER ANY SIX QUESTIONS (6x 5 = 30)</b>		
14	Describe the Meson theory of nuclear forces and explain how it accounts for the exchange nature of these forces. Hint: Yukawa proposed that nuclear force arises due to exchange of $\pi$ -mesons between nucleons. Range of force is inversely proportional to meson mass ( $R \sim \hbar/mc$ )	4	4
15	Discuss the similarities between a nucleus and a liquid drop. Mention the semi-empirical mass formula. Hint: Compare short-range nuclear force with intermolecular forces and constant density property. Write the semi-empirical mass formula with volume, surface, Coulomb, asymmetry, and pairing terms.	4	4
16	Explain the Breit-Wigner single level formula and its application in neutron resonances at low energy. Hint: Start from resonance scattering and expression for cross-section near resonance energy. Show dependence on resonance energy $E_r$ and width $\Gamma$ .	4	4
17	Derive the relationship between range and energy for alpha particles. Hint: Use stopping power concept ( $-dE/dx$ ) and integrate over distance. Result gives empirical relation $R \propto E^{3/2}$ .	4	4
18	Explain the Gellman-Okubo mass formula for octets and decuplet hadrons. Hint: Use SU(3) symmetry and express hadron masses in terms of hypercharge and isospin. Apply formula separately for baryon octet and decuplet.	4	4
19	Explain the ground state of a Deuteron and why it has no excited states. Hint: Deuteron has spin 1 and positive parity with mainly $^3S_1$ state. Weak binding energy ( $\sim 2.2$ MeV) prevents existence of excited bound states.	4	4
20	Describe the general features and classification of nuclear reactors. Hint: Mention components: fuel, moderator, control rods, coolant, shielding. Classify as thermal/fast reactors and breeder/non-breeder types.	4	4
21	Discuss Gamow-Teller selection rules in the context of Beta decay. Hint: Occurs when nuclear spin changes ( $\Delta J=0, \pm 1$ but not $0 \rightarrow 0$ ). Parity remains unchanged; involves spin flip of nucleon.	4	4
<b>Q. No.</b>	<b>SECTION C</b> <b>ANSWER ANY TWO QUESTIONS (2 x15 = 30)</b>	<b>CO</b>	<b>KL</b>
22	Describe the electron scattering method for the	5	5

	measurement of nuclear radius. Include the derivation and experimental setup.		
23	Elaborate on the Nuclear Shell Model. Discuss the spin-orbit interaction and how the model predicts the magic numbers and nuclear parity.	5	5
24	Explain the mechanism of a Compound Nucleus reaction. Discuss the formation and decay stages with relevant energy level diagrams.	5	5
25	Discuss the classification of elementary particles based on their mass, spin, and interactions.	5	5