2025

PHYSICS — HONOURS

Paper : DSCC-10

(Nuclear and Particle Physics)

Full Marks : 75

The figures in the margin indicate full marks.

Candidates are required to give their answers in their own words as far as practicable.

Answer ***question no.* 1** and ***any five*** questions from the rest.

1. Answer ***any five*** questions : 3×5

(a) Using the uncertainty principle show that electron cannot be a part of nucleus.

(b) Using single particle shell model, calculate the spin and parity of $_9F^{19}$ nucleus in its ground state.

(c) Justify that the time scale of direct nuclear reactions is of the order of 10^{-22} s.

(d) Explain what is meant by charge-symmetry and charge-independence of the nuclear force.

(e) What is stripping reaction? Give an example of it.

(f) What are the advantages of semiconductor detectors amongst all types of radiation detectors?

(g) Neutron is electrically neutral, but has a magnetic moment $-1.91\ \mu_N$. Explain the reason. Explain why free proton cannot decay to neutron, positron and photon (gamma).

(h) The decay $\Xi^- \rightarrow \Lambda^\circ + \pi^-$ is observed in nature, whereas the apparently similar decay $\Xi^- \rightarrow n^\circ + \pi^-$ is never observed. — Why?

2. (a) Find the distance of closest approach of 1 MeV proton incident on gold nucleus ($Z = 79$) for head-on collision.

(b) Why does the binding fraction drop from its average value both for lighter as well as heavier nuclei?

(c) What are mirror nuclei? Give an example. Find out the mass difference between two mirror nuclei in terms of their mass number by using the semi-empirical mass formula.

(d) In a mass spectrometer study of an ion, the following values of $\frac{q}{m}$ are observed :

4.81×10^6 C-kg^{-1}; 9.62×10^6 C-kg^{-1}; 4.56×10^6 C-kg^{-1} and 4.35×10^6 C-kg^{-1}.

Explain the observation. 2+2+(2+3)+3

Please Turn Over

3. (a) Consider a β^- decay ${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + \beta^-$ where inside the nucleus a neutron is converted to proton: $n \rightarrow p^+ + \beta^-$. Keeping in mind the experimental plot of beta decay spectrum clearly explain which conservation principle does this decay violate? What other conservation principle does this decay violate? Hence explain the necessity of third particle in the decay product apart from Y and β^-. What can be the charge and spin of this particle? What is the name of this particle?

(b) What are the Fermi and Gamow-Teller transitions in beta decay?

(c) What is Geiger Nuttal law in α decay? (1+1+2+2+1)+3+2

4. (a) Outline the similarities between a nucleus and a liquid drop. Why the Weizsacker mass formula is called the semi-empirical mass formula?

(b) In semi-empirical mass formula, explain surface energy and Coulomb energy correction terms. How does the symmetry term explain nuclei with $N = Z$ are more stable for low A but not for high A?

(c) Show that, $\gamma \rightarrow e^+ + e^-$ process cannot take place in vacuum. (2+1)+(2+2+2)+3

5. (a) Consider the following reaction where X is the target nucleus at rest, a is the projectile, Y is the residual nucleus and b is the outgoing particle : $a + X \rightarrow Y + b$.

Draw the appropriate vector diagram of the above reaction in the centre of mass frame.

(b) Explain Bohr's independence hypothesis on compound nuclear reaction.

(c) Using liquid drop model of nucleus find the conditions of spontaneous symmetric fission to occur.

(d) Explain the role of moderators in a nuclear reactor. 3+3+3+3

6. (a) Define threshold energy and derive an expression for the threshold energy Q of an endoergic reaction.

(b) Find the minimum energy in the laboratory system that a proton must have in order to initiate the reaction

$$p + d + 2.22 \text{ MeV} \rightarrow p + p + n.$$

Given $M(p) = 1.007825$ u; $M(d) = 2.014102$ u; $M(n) = 1.008665$ u.

(c) What do you mean by thermal neutrons? Indicate their key role in nuclear reaction. Why does U^{235} not U^{238} undergo fission with thermal neutrons? (1+4)+3+(1+1+2)

7. (a) Explain briefly why the cyclotron principle is not used to accelerate protons and heavier ions to very high energy.

(b) Why is it necessary to increase the length of the successive tubes in a linear accelerator (LINAC)? Show that the length of the nth tube of a LINAC is proportional to $\sqrt{n}$.

(c) What do you mean by plateau region of a GM counter? A GM counter has dead time of 200 μs. What is the true counting rate when the observed rate is 1000 per minute?

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

8. (a) Explain with reasons whether the following reactions are allowed or forbidden :

(i) $p \rightarrow \pi^+ + \pi^- + e^+$

(ii) $\Lambda^\circ \rightarrow \pi^+ + \pi^-$

(iii) $e^+ + e^- \rightarrow \mu^+ + \pi^-$

(b) What is strangeness? Name a particle with non-zero strangeness. Is it a good quantum number under all fundamental interactions?

(c) An isospin singlet baryon has strangeness of –3. Determine the hypercharge and electric charge of the baryon. Do you identify the baryon? (2+2+2)+(1+1+1)+3

9. (a) What are the fundamental interactions in nature? Arrange them in ascending order of their relative strengths. What are the particles that mediate these interactions?

(b) Draw the I_3-Y plot for the $J^p = \frac{1}{2}^+$ baryon octet.

(c) Write down Gell-Mann-Nishijima formula.

(d) How does the $p-p$ chain differ from the CNO cycle in stars? (1+1+2)+3+2+3