2021

PHYSICS — HONOURS

Paper : DSE-B-1(b)

(Nuclear and Particle Physics)

Full Marks : 65

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 nos.*** **1** and **2**, and ***any four*** questions from the rest.

1. Answer ***any five*** questions : 2×5

(a) Why does the B.E./A drop from its average value both for lighter as well as heavier nuclei?

(b) Find the Q value of the following nuclear reaction :

$$^{7}_{3}\text{Li} + ^{1}_{1}\text{H} \rightarrow ^{4}_{2}\text{He} + ^{4}_{2}\text{He}$$

Give, atomic mass of $^{7}_{3}$Li, $^{4}_{2}$He and $^{1}_{1}$H are 7.016004 u, 4.002603 u, and 1.007825 u respectively. Can this nuclear reaction be produced by protons accelerated to an energy as low as 0.15 MeV?

(c) The amplitude of the RF voltage applied in a proton linear accelerator is 400 kV and its frequency is 200 MHz. Calculate the length of the 10th drift-tube of the accelerator.

(d) Using the single particle shell model, calculate the spin and parity of $^{39}_{19}$K nucleus in its ground state.

(e) What is the minimum velocity of a charged particle so that it will produce Cherenkov radiation while passing through a dielectric medium of refractive index 1.5?

(f) What information about the nuclear force do you get from the study of the binding energy difference of mirror nuclei? Explain.

(g) Explain in terms of quark model, why a meson with charge, Q = – 1 and strangeness, S = +1 is not observed.

2. Answer ***any three*** questions :

(a) Define nuclear reaction cross-section. On what factors does the nuclear reaction cross-section depend?

Find out the mean free path of thermal neutrons in ^{59}Co. Given, the density of ^{59}Co is 8.9×10^{3} kg/m^{3} and the reaction cross-section of ^{59}Co for thermal neutrons is 35b. 1+1+3

(b) Is it possible to observe pair production of γ-ray in free space? Explain your answer. What is the predominant way of energy loss of 200 KeV γ-ray parsing through lead? Justify your answer. 3+2

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(c) Explain the working principle of a photomultiplier tube (PMT). The secondary electron emission coefficient of each dynode in a PMT is 8. What is the number of electrons collected at the anode for each electron emitted from the photocathode of the PMT if it uses 10 dynodes? 3+2

(d) Explain why an electron cannot be accelerated in a classical cyclotron. How is this difficulty circumvented with betatron? 2+3

(e) (i) Explain the saturation of average binding energy per nucleon from the short range nature of nuclear force.

(ii) Explain β-decay in terms of quark model. 2+3

3. The semi-empirical mass formula, neglecting the pairing energy term, is given by

$$M\ (A, Z) = Z\ M_H + Nm_n - a_1 A + a_2 A^{2/3} + a_3 \frac{Z^2}{A^{1/3}} + a_4 \frac{(A-2Z)^2}{A}$$

where a_1 = 0.016919 u, a_2 = 0.019114 u, a_3 = 0.0007626 u, a_4 = 0.02544 u, M_H = 1.00784 u, and m_n = 1.008664 u. Symbols have their conventional significance.

(a) Using this formula, show that M (A, Z) follows a parabolic variation with Z for a group of isobars.

(b) Find out an expression for the atomic number for the most stable isobar and hence identify the most stable isobar corresponding to mass number A = 109.

(c) What would be stable isobar corresponding to A = 109 if the symmetry energy term in the mass formula were not taken into account? Hence comment on the importance of the symmetry energy term. 2+(2+1)+(3+2)

4. (a) To slow down neutrons, what will be the preferable choice of material between paraffin blocks and lead blocks? Explain your answer.

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

(c) Consider an alpha particle of energy 5 MeV experiences a head-on collision with a gold (Z = 79) nucleus. Estimate the radius of the nucleus.

(d) The α-spectrum is discrete but the β-spectrum is continuous. – Explain. 3+2+2+3

5. (a) Write down the Bethe formula for the energy loss of a heavy charged particle due to ionization while passing through a matter, and explain each term therein. Consider an alpha particle and a proton having same initial energy passing through a medium. Which one will have higher range? Explain.

(b) Given the specific ionization by an alpha particle in a medium is inversely proportional to its instantaneous velocity. Show that the range of the alpha particle $R \propto E^{3/2}$, E being the initial energy of the alpha particle.

(c) Mention any one practical application of Bragg curve. (2+3)+3+2

6. (a) Consider a gas detector of coaxial cylindrical geometry with anode wire of radius a and cathode of radius b. Show that the maximum radial electric field inside the detector is given by

$$E_{max} = \frac{V}{a \ln(b/a)}$$

where V is potential applied on the anode with respect to the cathode. Why is the anode wire made very thin?

(b) Show the variation of the number of ion pairs formed in a gas detector for α and β-particles with the anode potential graphically in a single plot. Mark different regions in the plot.

(c) What do you mean by the resolving time of a GM counter? A GM counter has a resolving time of 100 μs. What will be the actual count rate if the observed count rate is 2000 per minute?

(3+1)+(2+1)+(1+2)

7. (a) Consider the reaction

$$\gamma + {}^{2}_{1}\mathrm{H} \rightarrow {}^{1}_{1}\mathrm{H} + {}^{1}_{0}\mathrm{n}$$

The energy of the incident γ-ray is 2.62 MeV and the kinetic energy produced in this process is 0.225 MeV. Given mass of ${}^{2}_{1}\mathrm{H} = 2.014102\,\mathrm{u}$ and mass of ${}^{1}_{1}\mathrm{H} = 1.007825\ \mathrm{u}$.

Find the mass of neutron.

(b) Give a rough estimate of difference in binding energy of ${}^{3}_{1}\mathrm{H}$ and ${}^{3}_{2}\mathrm{He}$ considering only the Coloumb term.

(c) A fixed frequency cyclotron has its dees of radius 1 m and uses a magnetic field of 1.5 T. Find the operational frequency of the cyclotron for accelerating protons. What is the maximum energy of acceleration that can be achieved with this cyclotron for protons? Given, charge-to-mass ratio of proton is 9.58×10^7 C/kg. 4+2+(2+2)

8. (a) What are resonance particles?

(b) Explain the eightfold way in reference to the baryon decuplet.

(c) Why is the reaction $\Xi^- \rightarrow n^0 + \pi^-$ never observed in nature?

(d) Check whether both the strangeness and the third component of isospin remain conserved in the following reactions. Hence conclude whether the reactions occur via strong interaction.

(i) $\Omega^- \rightarrow \Lambda^0 + K^-$

(ii) $K^- + p \rightarrow K^+ + \Xi^-$ 2+3+2+3