

Course Code: PHU5300  
Course Title: Nuclear and Particle Physics  
Date: 14<sup>th</sup> March 2022  
Time: 01:30 pm to 03:30 pm  
Duration: 2 Hours

#### GENERAL INSTRUCTIONS TO CANDIDATES

- Read all instructions carefully before answering the questions.
- Unless specified, standard symbols have their usual meanings.
- This question paper consists of **06 Essay type questions** in 04 pages.
- Answer **only ANY FOUR (04)** questions.
- Non-programmable calculators are allowed.
- Write your answers in the answer book / single sheets provided at the examination hall. Question / section numbers should be written against relevant answers.
- Write your **Index Number** in the spaces provided in the answer book / single sheets.
- Also write all other details requested in the answer book.
- Having any form of unauthorized documents / mobile phones in your possession is a punishable offense.

**Answer only ANY FOUR (04) questions.**

**Useful Physical Constants / Conversions**

$$\text{Mass of } {}^{235}_{92}\text{U in amu} = 235.0439$$

$$\text{Mass of } {}^{99}_{40}\text{Zr in amu} = 98.9165$$

$$\text{Mass of } {}^{134}_{52}\text{Te in amu} = 133.9115$$

$$\text{Mass of n in amu} = 1.0089$$

$$\text{Avogadro number} = 6.022 \times 10^{23} \text{ mol}^{-1}$$

$$1 \text{ GW} = 1 \times 10^9 \text{ J s}^{-1}$$

$$1 \text{ MeV} = 1.6022 \times 10^{-13} \text{ J}$$

$$1 \text{ amu} = 931.5 \text{ MeV}/c^2$$

**Note:** Standard symbols have their usual meanings.

- (01) (a) Explain the similarities between a 'liquid drop' and an 'atomic nucleus'.
- (b) Based on semi-empirical mass formula, binding energy of a nucleus can be expressed as:
- $$E_B(A, Z) = a_V A - a_S A^{2/3} - a_C \frac{Z(Z-1)}{A^{1/3}} - a_{\text{asy}} \frac{(A-2Z)^2}{A} \pm \delta(A, Z)$$
- Identify each and every term in the above formula.
- (c) Describe the contribution of the following terms in the above formula,
- Surface energy term
  - Volume energy term
  - Asymmetric energy term
- (02) (a) Derive the exponential law,  $N(t) = N_0 e^{-\lambda t}$ , for the decay of radioactive elements. Here,  $N(t)$  is the number of radioactive atoms remaining at time,  $t$ ,  $N_0$  is the number of atoms at  $t = 0$ , and  $\lambda$  is the radioactive decay constant, which depends on the particular radioactive element.
- (b) State the assumptions made in the above derivation.
- (c) At present the relative isotopic abundance of  $\text{U}^{235}$  to  $\text{U}^{238}$  is 0.0072. Half-lives of  $\text{U}^{235}$  and  $\text{U}^{238}$  are respectively  $7.13 \times 10^8$  years and  $4.51 \times 10^9$  years. Assuming that the initial amounts of  $\text{U}^{235}$  and  $\text{U}^{238}$  were same at the time of formation of the earth, estimate the age of the earth.

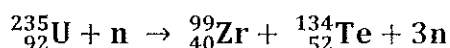
- (03) (a) What is "Q value" of a nuclear reaction.
- (b) Write down the expression for Q value in the case of a typical  $\alpha$  decay. Identify the terms used in your expression.
- (c) When a nucleus of mass  $M_x$  is bombarded with a particle of mass  $m_x$ , the product particle of mass  $m_y$  is ejected at an angle of  $90^\circ$  with the direction of bombarding particle.

Show that the Q-value can be expressed as,

$$Q = K_y \left( 1 + \frac{m_y}{M_y} \right) - K_x \left( 1 - \frac{m_x}{M_x} \right)$$

where,  $M_y$  is mass of the product nucleus,  $K_x$  is kinetic energy of the nucleus and  $K_y$  is kinetic energy of the product nucleus.

- (04) (a) Discuss the differences between the nuclear fission and nuclear fusion.
- (b) Determine the Q value of the following nuclear fission reaction.



- (c) Using the Q value obtained in the above reaction, calculate the amount, in kg, of  ${}_{92}^{235}\text{U}$  required to generate 2 GW power for 30 days.

- (05) (a) State four universal conservation laws applicable to all elementary particle reactions.
- (b) State any three family conservation laws applicable to all elementary particle reactions.
- (c) Determine which conservation law/laws is/are violated in each of the following forbidden reaction.

(i)  $\mu^+ \rightarrow e^+ + \nu_e$

(ii)  $\pi^+ \rightarrow \mu^+ + \bar{\nu}_\mu$

(iii)  $n \rightarrow e^+ + e^-$

(iv)  $\pi^+ + p \rightarrow \mu^+ + e^+ + \pi^0$

(06) (a) Briefly explain the design and the working principle of a **Cyclotron**, with the help of suitable sketches.

(c) State the significance of the cyclotron frequency.

(b) A cyclotron is used to accelerate a particle with charge  $q$  and mass  $m$  in a magnetic induction  $B$ . Show that the cyclotron frequency,  $f$ , can be given by,

$$f = \frac{qB}{2\pi m}$$

(d) State two applications of the cyclotron.

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