THE OPEN UNIVERSITY OF SRI LANKA
DEPARTMENT OF PHYSICS
B.SC DEGREE PROGRAMME – 2014/2015
LEVEL 05
NUCLEAR AND PARTICLE PHYSICS – PYU3160
FINAL EXAMINATION

Time allowed: Two hours (2 hrs.)

Date : 18th October 2015 **Time : 1.30pm -3.30pm**

Answer FOUR (04) questions only.

(Useful Data :

Charge on an electron, e	$= 1.6 \times 10^{-19}$ C
Avogadro's number	$= 6.02 \times 10^{23}$ atoms per mole,
1u	= 931.5 MeV
Mass of an electron m_e	$= 9.1 \times 10^{-31}$ kg
Velocity of light, c	$= 3 \times 10^{8}$ ms^{-1}
1 eV	$= 1.6 \times 10^{-19}$ J

1. a) Explain what is meant by nuclear fission and fusion.

b) Natural uranium contains 0.7% of $^{235}_{92}U$. When a U^{235} nucleus is fissioned, approximately 200 MeV of energy is released.
Calculate the total energy released, in joules, when the U^{235} content of 1 kg natural uranium is completely fissioned.

c) One of the fusion processes by which energy is generated inside the Sun is called the proton-proton cycle. This involves fusing four protons step by step to form a helium-4 nucleus.

$$^{1}_{1}p + ^{1}_{1}p \rightarrow ^{2}_{1}H + ^{0}_{1}e + Q_1$$

$$^{2}_{1}H + ^{1}_{1}p \rightarrow ^{3}_{2}He + Q_2$$

$$^{3}_{2}He + ^{3}_{2}He \rightarrow ^{4}_{2}He + 2^{1}_{1}p + Q_3$$

Calculate the energy released in each reaction and hence calculate the total energy released when four protons are fused to form a $^{4}_{2}He$ nucleus.
Atomic masses:
Proton = 1.00728 u

Positron = 0.00055 u

$^{2}_{1}H$ atom = 2.01410 u

$^{3}_{2}He$ atom = 3.01603 u

$^{4}_{2}He$ atom = 4.00260 u

d) Consider the fusion reaction,

$6^{2}_{1}H \rightarrow 2^{4}_{2}He + 2p + 2n + Q$

$Q = 43$ MeV

Determine the amount of energy that will be generated by fusing all the nuclei in 1 Kg of deuterium in such a reaction.

2. a) What are the properties of α, β and γ radiation.

b) Consider the isobars $^{37}_{18}Ar$ and $^{37}_{17}Cl$, with atomic masses 36.978416u and 36.977540u respectively.

i. Determine whether it is energetically possible for the transmutation of $^{37}_{18}Ar$ to $^{37}_{17}Cl$ to occur by electron capture or positron emission?

ii. Calculate the disintegration energy (Q)

iii. Show that the kinetic energy (k) of the recoil nucleus can be given by the equation

$$k = \frac{Q^2}{2Mc^2}$$

where,

M = The mass of the daughter nucleus

c = The velocity of light

c) Consider the mirror nuclei $^{11}_{6}C$ and $^{11}_{5}B$ which have atomic masses 11.014922u and 11.012735u respectively.

i. Complete the reaction $^{11}_{6}C + ^{11}_{5}B + \ldots\ldots\ldots\ldots\ldots\ldots$

ii. Is this nuclear disintegration possible?

iii. What would be the average energy of the particle ejected?(Atomic mass of positron = $0.00055u$)

3. a) i. Explain the meaning of the term mass difference and state the relationship between the mass difference and the binding energy of a nucleus.

ii. Sketch a graph of nuclear binding energy per nucleon verses mass number for the naturally occurring isotopes and show how it may be used to account for the possibility of energy release by nuclear fission and by nuclear fusion

b) i. Write down the semi-empirical mass formula for the mass of an atom, stating clearly the assumptions made, if any.

ii. Describe the significance of each term in the semi empirical mass formula.

iii. Use the mass formula to deduce the Z value of the most stable isobar of mass number (A) 131. Assume the following values :

Coulomb energy coefficient = 0.60 MeV

Asymmetry coefficient = $18MeV$

$m_n - m_p = 0.78\ Mev$

m_n = Mass of the neutron

m_p = Mass of the proton

4. a) Consider a chain disintegration which starts with a pure radioactive source containing N_o parent nuclei at time t = 0. If N_1 and N_2 are the number of parent and daughter nuclei at a time t, show that

$$N_2 = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_0 \left[e^{-\lambda_1 t} - e^{-\lambda_2 t}\right]$$

where λ_1 and λ_2 are the decay constants of the parent and daughter nuclei, respectively. Further, if $\lambda_1 << \lambda_2$ and the half-life of the parent nucleus is very long as compared to t, then show that the daughter nucleus approaches a constant value given by $N_2 = \frac{\lambda_1}{\lambda_2} N_0$

b) It has been experimentally observed that uranium minerals that are sufficiently old to have attained radioactive secular equilibrium contain one atom of radium for every 2.8 x 10^6 atoms of ^{238}U. If the half-life of radium is 1620 years, calculate that of uranium.

5. (A) Discuss briefly the four fundamental forces in nature. What are the characteristics of the conservation laws of baryon number and lepton number.

(B) a) Identify the missing neutrinos in the following reactions or decays.

(i) $\mu^{+} \rightarrow e^{+} + ?$

(ii) $K^{+} \rightarrow \pi^{0} + e^{+} + ?$

(iii) $\pi^{-} \rightarrow \mu^{-} + ?$

(iv) $? + p \rightarrow n + e^{+}$

(b) Determine which of the following decays or reactions is not allowed and explain why.

(i) $n \rightarrow p + e^{-} + \nu_{e}$

(ii) $\pi^{-} + p \rightarrow \pi^{-} + \Sigma^{+}$

(iii) $\Xi^{0} \rightarrow n + \pi^{0}$

(iv) $p + p \rightarrow p + p + \pi^{0}$

(c) (a) Consider particles with the following quark composition. Determine their quantum numbers (baryon, lepton, charge and so on) and the particle names.

(i) *uds* (ii) $\overline{sss}$ (iii) *uss* (iv) udd

(b) Analyze the following reactions using the quark composition and show that each conserve the net number of each type of quark.

(i) $\pi^{-} + p \rightarrow K^{+} + \Sigma^{+}$

(ii) $\pi^{-} + p \rightarrow K^{0} + \wedge^{0}$

6. (a) Discuss the basic principle of operation of a linear accelerator.

(b) What are the advantages and disadvantages of cyclotrons and linear accelerators.

(c) There are *n* electrodes in a linear accelerator. Show that in order for the ion to be in phase with the alternating voltage when it crosses from one electrode to the other, the length of successive electrodes must be $\ell_{1}\sqrt{n}$, where ℓ_{1} is the length of the first electrode.