THE OPEN UNIVERSITY OF SRI LANKA

DEPARTMENT OF PHYSICS

B.SC. DEGREE PROGRAMME – 2011/2012

LEVEL 05

NUCLEAR AND PARTICLE PHYSICS - PYU 3160

FINAL EXAMINATION

Time allowed: Two hours (2 hrs.)

Date: 15th November 2012 **Time: 1.30 pm – 3.30 pm**

Answer FOUR (04) questions only.

(Useful Date:

Charge on an electron, e $= 1.6\times10^{-19}$C

Permittivity of free space $\varepsilon_0 = 8.85\times10^{-12}C^2N^{-1}m^{-2}$

$$\frac{1}{4\pi\varepsilon_0} = 9\times10^9 Nm^2C^{-2},$$

$$1fm = 10^{-15}m,$$

Avogadro's number $= 6.02\times10^{23}$ atoms per mole,

$1u = 931.5$ MeV

Mass of an electron $m_e = 9.1\times10^{-31}$kg

Planck's constant h $= 6.63\times10^{-34}$Js,

$$\hbar = \frac{h}{2\pi} = 1.06\times10^{-34}Js,$$

$$1eV = 1.6\times10^{-19}J,$$

Velocity of light $C = 3\times10^8 ms^{-1}$)

(01) (a) Derive the decay law $N = N_0e^{-\lambda t}$

(b) At a certain instant, a piece of radioactive material contains 10^{12} atoms. The half life of the material is 30 days.

(i) Calculate the number of disintegrations in the first second.
(ii) What time will elapse before 10^4 atoms remain?

(c) Assume that all the ^{206}Pb found in a given sar ,le of uranium ore resulted from decay of ^{238}U and that the ratio of $^{206}Pb/^{238}U$ is 0.60. How old is the ore? (Half-life of $^{238}U = 4.47 \times 10^9$ years)

(d) A small amount of solution containing ^{24}Na radionuclide with activity 2.0×10^3 Bq was injected in the blood stream of a man. The activity of 1 cm^3 of blood sample taken 5 hours later turned out to be 16 disintegration per minute per cm^3. The half-life of ^{24}Na is 15 hours. Estimate the volume of the man's blood.

(02) (a) What are the properties of α, β and γ radiations.

(b) (i) The ^{226}Ra nucleus undergoes alpha decay according to equation given below.

$$^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$$

Calculate the Q value for this process.

(The Atomic masses are:

$$^{226}_{88}Ra = 226.025403u$$

$$^{222}_{86}Rn = 222.017570u$$

$$^{4}_{2}He = 4.002605u)$$

(ii) Suppose you measured the kinetic energy of the alpha particle from this decay. Would you measure 4.87 MeV?

(c) Show that ^{55}Fe may undergo electron capture, but not β^+ decay.
The two possible reactions are:

$$^{55}_{26}Fe \rightarrow {}^{55}_{25}Mn + \beta^+ + \nu^- \leftarrow \beta^+ \text{ decay}$$

$$^{55}_{26}Fe + e^- \rightarrow {}^{55}_{25}Mn + \nu \leftarrow \text{Electron cupture}$$

(The Atomic masses are:

$$^{55}_{26}Fe = 54.938298u$$

$$^{55}_{25}Mn = 54.938050u$$

$$m_e = 0.000549u)$$

(d) $^{20}_{9}F$ decays to the ground state of $^{20}_{10}Ne$ as follows.

$$^{20}_{9}F \rightarrow {}^{20}_{10}Ne^{*} + e^{-} + \bar{\nu}$$
$$\qquad\qquad\qquad\qquad\quad \Big\downarrow$$
$$\qquad\qquad\qquad\qquad\quad {}^{20}_{10}Ne + \gamma$$

Where $^{20}_{10}Ne^{*}$ is an excited state of $^{20}_{10}Ne$
If the maximum kinetic energy of the emitted electrons is 5.4 MeV and γ - ray energy is 1.6 MeV determine the mass of $^{20}_{9}F$.
[Atomic mass of Ne = 19.99244u]

(03) (a) Consider a chain disintegration which starts with a pure radioactive source containing N_0 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 2.8×10^6 atoms of ^{238}U. If the half-life of radium is 1620 years, calculate that of uranium.

(04) (a) What is meant by fusion and fission? Give one specific example of each kind of reaction, explaining how each is induced.

(b) When an atom of ^{235}U undergoes fission in a reactor, about 200 MeV of energy is liberated. Suppose that a reactor using ^{235}U has an output of 700 MW and is 20% efficient.

(i) How many uranium atoms does it consume in one day?
(ii) What mass of uranium does it consume each day?

(c) Consider the fusion reaction

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

$$\mathrm{Q} = 43\mathrm{MeV}$$

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

(05) (a) (i) Write down the characteristics of the four fundamental forces in nature.

(ii) Discuss briefly the conservation laws in particle interactions.

(b) (i) Explain the meanings of the terms: boson, fermion, hadron, lepton and baryon.

(ii) Give one example of a particle for each of the above.

(c) What are quarks? Describe the basic properties of quarks.

(d) Determine which of the following reactions can occur. For those that cannot occur determine the conservation law (or laws) that each violates.

(i) $\mathrm{p} + \mathrm{p} \rightarrow \mathrm{p} + \mathrm{p} + \pi^{0}$ (iii) $\mathrm{p} + \bar{\mathrm{p}} \rightarrow \mu^{+} + \mathrm{e}^{-}$

(ii) $\mathrm{n} \rightarrow \mathrm{p} + \mathrm{e}^{-} + \bar{\nu}_{\mathrm{e}}$ (iv) $\mu^{-} \rightarrow \mathrm{e}^{-} + \gamma$

(06) (a) Discuss the basic principle of operation of cyclotrons.

(b) What are the advantages and disadvantages of Cyclotrons and Synchrocyclotrons.

(c) A RF potential having peak potential of 25 kV and a magnetic field of 1.5T are applied in a cyclotron to accelerate protons. The accelerated protons are extracted from the dees at a radius of 0.5 m from the centre of the dees.

Find,

(i) the maximum energy acquired by the protons.

(ii) the frequency of RF oscillator.

(iii) the number of revolutions made by protons to achieve maximum energy.

(The mass of proton = 1.67×10^{-27} kg)