

THE OPEN UNIVERSITY OF SRI LANKA

DEPARTMENT OF PHYSICS

B.S.C. 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 Data:

Charge on an electron, $e = 1.6 \times 10^{-19} \text{ C}$

Permittivity of free space $\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$

$$\frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ Nm}^2 \text{ C}^{-2},$$

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

Avogadro's number = 6.02×10^{23} atoms per mole,

$$1 \text{ u} = 931.5 \text{ MeV}$$

Mass of an electron $m_e = 9.1 \times 10^{-31} \text{ kg}$

Planck's constant $h = 6.63 \times 10^{-34} \text{ Js}$,

$$\hbar = \frac{h}{2\pi} = 1.06 \times 10^{-34} \text{ Js},$$

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J},$$

Velocity of light $C = 3 \times 10^8 \text{ ms}^{-1}$

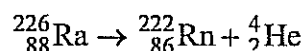
(01) (a) Derive the decay law $N = N_0 e^{-\lambda t}$

(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 sample of uranium ore resulted from decay of ^{238}U and that the ratio of $^{206}\text{Pb}/^{238}\text{U}$ is 0.60. How old is the ore? (Half-life of $^{238}\text{U} = 4.47 \times 10^9$ years)
- (d) A small amount of solution containing ^{24}Na radionuclide with activity $2.0 \times 10^3 \text{ Bq}$ 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.



Calculate the Q value for this process.

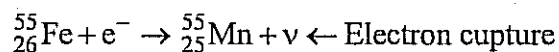
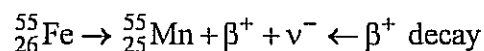
(The Atomic masses are:

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

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

$$^4_2\text{He} = 4.002605\text{u})$$

- (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:



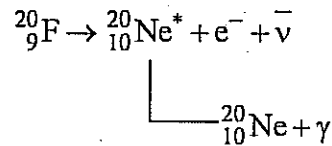
(The Atomic masses are:

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

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

$$m_e = 0.000549\text{u})$$

- (d) ${}^{20}_9\text{F}$ decays to the ground state of ${}^{20}_{10}\text{Ne}$ as follows.



Where ${}^{20}_{10}\text{Ne}^*$ is an excited state of ${}^{20}_{10}\text{Ne}$

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 ${}^{20}_9\text{F}$.

[Atomic mass of Ne = 19.99244u]

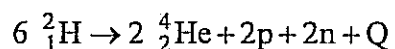
- (03) (a) Consider a chain disintegration which starts with a pure radioactive source containing N_0 parent nuclei at time $t = 0$. If N_1 and N_2 are the number of parent and daughter nuclei at a time t , show that

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

Where λ_1 and λ_2 are the decay constants of the parent and daughter nuclei, respectively. Further, if $\lambda_1 \ll \lambda_2$ 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 ${}^{238}\text{U}$. 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 ${}^{235}\text{U}$ undergoes fission in a reactor, about 200 MeV of energy is liberated. Suppose that a reactor using ${}^{235}\text{U}$ 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



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

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) $\text{p} + \text{p} \rightarrow \text{p} + \text{p} + \pi^0$ (iii) $\text{p} + \bar{\text{p}} \rightarrow \mu^+ + \text{e}^-$
- (ii) $\text{n} \rightarrow \text{p} + \text{e}^- + \bar{\nu}_e$ (iv) $\mu^- \rightarrow \text{e}^- + \gamma$
- (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)

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