UNIVERSITY OF RUHUNA

BACHELOR OF SCIENCE (SPECIAL) DEGREE LEVEL II (SEMESTER II) EXAMINATION JANUARY 2013

Subject: Nuclear and Particle Physics
Course Unit: PHY4084 | Time: Three hours

Answer **six(06)** questions only

All symbols have their usual meaning

1. (a) Calculate the Q values for the following α-decays between ground state levels of the nuclei

    i. $^{208}Po \rightarrow ^{204}Pb + \alpha$

    ii. $^{230}Th \rightarrow ^{226}Ra + \alpha$

    (The following are the atomic masses in units of u

^{204}Pb -	203.973044,	^{230}Th -	230.033134,
^{226}Ra -	226.025410,	^{208}Po -	207.981246,
^{4}He -	4.002603)		

    (b) What are the kinetic energies of the α-particles and the nuclei in the final state if the decays proceed from rest?

2. The following are atomic masses in units of u

Electron -	0.000549,	$^{152}_{62}Sm$ -	151.919756,
Neutron -	1.008665,	$^{152}_{63}Eu$ -	151.921749,
$^{1}_{1}H$ -	1.007825,	$^{152}_{64}Sm$ -	151.919794

    (a) What is the Q-value of the reaction $^{152}Eu(n,p)$?

    (b) What types of weak-interaction decay can occur for ^{152}Eu? (Give at least two decays)

    (c) What is the maximum energy of the particles emitted in each of the processes given in (b)?

3. The measured spins, parities and magnetic moments of some nuclei are

   (a) ${}^{43}_{20}Ca(\frac{7^-}{2}, -1.32\mu_N)$

   (b) ${}^{93}_{41}Nb(\frac{9^+}{2}, 6.12\mu_N)$

   (c) ${}^{137}_{56}Ba(\frac{3^+}{2}, 0.931\mu_N)$

   (d) ${}^{197}_{79}Au(\frac{3^+}{2}, 0.145\mu_N)$

   (e) ${}^{26}_{13}Al(5^+, \text{not known})$

   Compare these values with the predictions of the shell model.
   (The magnetic moment predicted by the shell model is

$$\mu = \frac{\mu_N}{j(j+1)}\{g_l[l(l+1) + j(j+1) - s(s+1)] + g_s[s(s+1) + j(j+1) - l(l+1)]\}$$

   For proton state $g_l = 1$ and $g_s = 5.586$, and for neutron state $g_l = 0$ and $g_s = -3.826$)

4. (a) Consider nuclei with small nucleon number A and such that $Z = N = A/2$. Neglecting the pairing term, show that the semi-empirical mass formula then gives the binding energy per nucleon

$$B/A = a - bA^{-1/3} - (d/4)A^{2/3}$$

   where a, b, and d are constants.

   (b) Show that this expression reaches maximum for $Z = A/2 = 26$

   (c) Assume a Uranium (${}^{236}_{92}U$)breaks up spontaneously into two roughly equal parts. Estimate the reduction in electrostatic energy of the nuclei.(Assume uniform charge distribution; nuclear radius $= 1.2 \times 10^{-13}A^{1/3}$ cm)
   (The semi-empirical mass formula
   $M(Z, A) = ZM_p + (A - Z)M_n - a_vA + a_sA^{2/3} + a_c\frac{Z^2}{A^{1/3}} + a_a\frac{(A - 2Z)^2}{A} \pm \frac{a_p}{A^{3/4}}$
   $a_v = 15.75\,\text{MeV}, a_s = 17.8\,\text{MeV}, a_c = 0.71\,\text{MeV}, \text{and } a_a = 23.70\,\text{MeV}$)

5. Consider the nuclear reaction $X(x, y)Y$

   (a) Obtain the Q equation of the reaction

   (b) Use Q equation to find threshold energy of x.

   (c) Calculate the threshold energy of the incident particle in the reaction

$${}^{4}_{2}He +^{14}_{7} N \rightarrow^{17}_{8} O +^{1}_{1} H$$

   (The atomic masses are: $M(^{14}N) = 14.003074\,\text{u}$, $M(^{4}He) = 4.002603\,\text{u}$, $M(^{17}O) = 16.999132\,\text{u}$, and $M(^{1}H) = 1.007825\,\text{u}$)

6. Explain, briefly, the classification of particles in to Hadrons, Leptons, Baryons, Mesons and Gauge Bosons.
   List all conserved quantities in a particle interaction taking place under week interaction. Which of the following reactions are allowed under weak interaction? For each allowed reaction, explain diagrammatically the process indicating the relevant gauge boson.
   (a) $\gamma \rightarrow e^+ + e^-$
   (b) $n \rightarrow p + e^- + \nu_e$
   (c) $n + \nu_e \rightarrow p + e^-$
   (d) $\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$
   (e) $\mu^- \rightarrow e^+ + \nu_\mu + \bar{\nu}_e$
   (f) $\tau^+ \rightarrow \mu^+ + \bar{\nu}_\tau + \nu_\mu$
   (g) $t \rightarrow b + e^+ + \nu_e$

7. Define the Parity Operator P. Find the possible Eigen values of P.
   A system of two particles is bounded under a spherically symmetric potential. Show that the parity is conserved having a definite parity for the system.
   What is the effect of P on following quantities? Give reasons for your answer.

$$\bar{p},\ \bar{\sigma},\ \bar{E},\ \bar{B},\ \bar{\sigma}\cdot\bar{E},\ \bar{\sigma}\cdot\bar{B}$$

   A particle decayed into two identical particles of spin 1/2. Two particles are in the states of

$$Y_{l=1}^{m=1} = A\sin\theta e^{i\phi}$$

   (a) Find the parity of the initial particle
   (b) Find the possible values for the spin of the initial particle
   (c) The two particle state emits a photon making a transition to the state given by

$$Y_0^0 = \frac{1}{\sqrt{4\pi}}$$

   Find the parity of the photon emitted.

8. What quantities must be conserved under strong interaction? Which of the above quantities are not conserved under electromagnetic interaction?
   (a) Which of the following reactions are allowed under strong interactions?
   Explain each of the allowed process diagrammatically in terms of interaction of quarks and gluons.
      i. $K^- + p \rightarrow \pi^0 + \Sigma^-$
      ii. $K^- + p \rightarrow \pi^0 + \Lambda^-$
      iii. $\pi^- + p \rightarrow \Sigma^- + K^+$
      iv. $K^+ + p \rightarrow \Lambda + K^0$

v. $\pi^- + p \rightarrow \Lambda + K^0$

(b) Top and anti-top quark production and a possible decay process in a proton-antiproton collider are given below.

$$\bar{p} + p \rightarrow \bar{t} + t$$
$$t \longrightarrow W^+ + \bar{b}$$
$$\bar{t} \longrightarrow W^- + b$$
$$W^+ \longrightarrow e^+ + \nu_e$$
$$W^- \longrightarrow d + \bar{u}$$

i. Classify each reaction.

ii. What do you expect to see in the detector? Explain, briefly, with reasons.

9. Answer any three of the following parts.

(a) How would you explain the interaction two electrically charged particles.

i. Classically

ii. Quantum Mechanically

(b) Explain, briefly, two types of main accelerators. Which of the two could attain the highest center of mass energy? Explain with reasons for your answer. Why physicists build accelerators with highest possible center of mass energy?

(c) Why free quarks are not found experimentally? Explain, briefly, with reasons for your answer.
What is meant by "jets" of particles? Describe, with reasons, the formation of jets in a $p + \bar{p}$ collision.

(d) The matter that has been observed in the universe is known to be made of particles but not of antiparticles. If the "Big Bang" model of the Universe is correct, how could you possibly explain this observation?