Nuclear Physics
Assignment # 2

Use masses of the nuclei given at the end of the book by Krane

1. Calculate the decay constant, mean lifetime, and half-life of a radionuclide whose activity diminishes by 6.6 % during 100 days.
   Ans : $8 \times 10^{-9}\ s^{-1}$, 4.0 and 2.8 years

2. The decay product of ^{238}U is ^{226}Ra which is contained in the former substance in the proportion of one atom per 2.80×10^6 uranium atoms. Find the half-life of ^{238}U, if it is known to be much longer than that of ^{226}Ra (equal to 1620 years).
   Ans : 4.5×10^9 years

3. A ^{27}Mg radionuclide of half-life 9.5 mins is produced at a constant rate of Q = 5.0×10^{10} nuclei per second. Determine the number of ^{27}Mg nuclei that would accumulate in the preparation over the time interval equal to its half-life.
   Ans : 2.0×10^{13}

4. A ^{138}Xe radionuclide produced at a constant rate of Q=1.0×10^{10} nuclei per sec goes through the following transformation chain with the following half-lives

$$^{138}\text{Xe} \xrightarrow{\text{17 min.}} {}^{138}\text{Cs} \xrightarrow{\text{32 min.}} {}^{138}\text{Ba (stable)}$$

   Calculate the combined activity of the given preparation 60 min. after the beginning of accumulation.
   Ans : 0.4 Ci

5. The Q-value (ground state to ground state) for alpha decay process from $^{238}_{94}$Pu (ground state spin 0^+) is 5.593 MeV. The parent nucleus decays to ground state, 0^+ at 0 keV, and four excited states of the daughter nucleus; 2^+ at 44 keV , 4^+ at 143 keV, 6^+ at 296 keV and 8^+ at 499 keV.

   (a) Calculate Q value for the alpha decay process (ground state to ground state) using SEMF.
   (b) Calculate change in Q-value with addition of neutron in Pu isotopes.
   (c) Calculate energies of the alpha particles.
   (d) Calculate Coulomb Barrier for alpha particles.
   (e) What is the barrier width (tunneling distance) for α-particles ejected from this nucleus.
   (f) Neglecting centrifugal barrier, calculate branching ratios for the decay processes. Compare your results with the experimental values 70.91 (0^+), 28.98 (2^+), 0.105 (4^+), 0.003 (6^+), and 6.8×10^{-6} (8^+).
   (g) Calculate the branching ratios including the centrifugal barrier and compare the results with experiments.

(h) Calculate half-life for the decay process. Assume a square well potential of depth $V = 40$ MeV.

6. ^{196}Au can decay by β^-, β^+, and EC. Find the Q values of the three decay modes. Masses of nuclei are given at the end of the book by Krane.

7. The maximum kinetic energy of the positron spectrum emitted in the decay $^{11}C \rightarrow^{11} B$ is 1.983 MeV. Use this information and the known mass of ^{11}B to calculate the mass of ^{11}C.

8. The β decay of ^{191}Os leads only to an excited state of ^{191}Ir at 171 keV. Compute the maximum kinetic energy of the β spectrum.

   Supply the missing component(s) in the following processes:
   (a) $\bar{\nu} +^3 He \rightarrow$
   (b) $^6He \rightarrow^6 Li + e^- +$
   (c) $e^- +^8 B \rightarrow$
   (d) $\nu +^{12} C \rightarrow$
   (e) $^{40}K \rightarrow \nu +$
   (f) $^{40}K \rightarrow \bar{\nu} +$

9. Classify the following decays according to degree of forbiddenness:
   (a) $^{89}Sr(\frac{5}{2}^+) \rightarrow^{89} Y(\frac{1}{2}^-)$
   (b) $^{97}Zr(\frac{1}{2}^+) \rightarrow^{97} Nb(\frac{1}{2}^-)$
   (c) $^{36}Cl(2^+) \rightarrow^{36} Ar(0^+)$
   (d) $^{26}Al(5^+) \rightarrow^{26} Mg(2^+)$

10. ^{20}Na decays to an excited state of ^{20}Ne through emission of positrons of maximum kinetic energy 5.55 MeV. The excited state decays by α emission to the ground state of ^{16}O. Compute the energy of the emitted α.

11. Following the β decay of ^{17}Ne, a highly excited state of ^{17}F emits a 10.597 MeV proton in decaying to the ground state of ^{16}O. What is the maximum energy of the positrons emitted in the decay of the ^{17}F excited state?

12. Compute the range of neutrino energies in the solar fusion reaction $p + p \rightarrow d + e^- + \nu$. Assume the initial protons to have negligible kinetic energies.

13. A certain $\beta-$decay process has three components, with maximum energies 0.672, 0.536 and 0.256 MeV. The first component has two coincident γ rays; 0.468 and 0.316 MeV, which are also coincident with each other. The second component has coincident γ rays of 0.604, 0.308, 0.136, 0.468, 0.612. 0.296, and 0.316 MeV. The third β component is in coincidence with all of the above, plus 0.885, 0.589, 0.416 and 0.280 MeV. Use this information to construct a decay scheme and find the mass difference between the nuclear ground states.

14. Using the information given in the Fig., 1 calculate the $\log_{10} ft_{1/2}$ value for the β-decay transitions from $7/2^+$ state of ^{137}Cs to the $\frac{11}{2}^-$ and $\frac{3}{2}^+$ (ground state) energy levels of ^{137}Ba. What type of transition would be expected in each case?

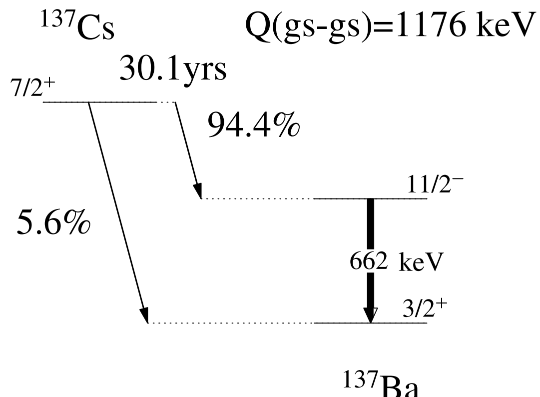

Fig. 1: Decay scheme of ^{137}Cs

15. For a light nucleus (A=10), compute the ratio of the emission probabilities for quadrupole and dipole radiation according to the Weisskopf estimates. Consider all possible choices for the parities of the initial and final states. Repeat for a heavy nucleus (A=200).

16. For the following γ transitions give all permitted multipoles and indicate which multipole might be the most intense in the emitted radiation; $9/2^- \to 7/2^+$ and $1/2^- \to 7/2^-$.

17. The isomeric 2^+ state of ^{60}Co at 58.6 keV decays to the 5^+ ground state. Internal conversion competes with gamma transitions; the observed internal conversion coefficients are $\alpha_K = 41$, $\alpha_L = 7$ and $\alpha_M = 1$. (a) Compute the expected half-life of the 2^+ state if the transition multipolarity is assumed to be M3, and compare with the observed half-life of 10.5 min. (b) if the transition also contained a small component of E4 radiation, how would your estimate for the half life be affected? (c) The 2^+ state also decays by direct β emission to ^{60}Ni. The maximum β energy is 1.55 MeV and the logft is 7.2. The 2^+ state decays 0.25% by β emission and 99.75% by γ emission and internal conversion. What is the effect on the calculated half-life of including the β emission?

18. In a study of the conversion electrons emitted in a decay process, the following electron energies were measured (in keV); 207.40, 204.64, 193.36, 157.57, 154.81, 143.53, 125.10, 75.27, 49.03, 46.27, 34.99. The electron binding energies are known to be 83.10 keV (K shell), 14.84 keV (L shell), 3.56 keV (M shell), and 0.80 keV (N shell). What is the minimum number of γ's that can produce the observed electron groups and what are the γ energies?

19. The Q value for the reaction $^9Be(p,d)^8Be$ is 559.5 keV. use this value along with the known masses of ^9Be, ^2H, ^1H to find the mass of ^8Be.

20. Calculate the Q value of the reaction $p +^4 He \to^2 H +^3 He$. What is the threshold energy for protons incident on He? For α's incident on hydrogen?

21. It is desired to study the low lying excited state of ^{35}Cl (1.219, 1.763, 2.646, 2.694, 3.003, 3.163 MeV) through the ^{32}S(α, p) reaction. With incident α particles of 5 MeV, which of these excited states can be reached?

22. Evaluate the lowest kinetic energy an incoming α-particle requires to overcome the Coulomb potential barrier of a ^{7}Li nucleus. Will this amount of energy be sufficient for the α-particle to activate the reaction $^7Li(\alpha, n)^{10}B$?