THE UNIVERSITY OF NEW SOUTH WALES
SCHOOL OF PHYSICS

PHYS3050 NUCLEAR PHYSICS
TUTORIAL PROBLEMS

These problems are intended to illustrate and reinforce the course material. It is important to work through these problems, or attempt to.

1. Using the $r \alpha A^{1/3}$ observation, estimate the average mass density of a nucleus. [2.3×10^{17} kg m^{-3}]
2. [Ashby & Miller 13.3]. Estimate the rest energy of 1 Å^3 of nuclear matter. [21 kJ]
3. [A&M 13.8]. Calculate the distance of closest approach of a 12 MeV deuteron to a Silver nucleus. [5.6 fm]
4. [Krane 3.9]. Calculate the binding energy per nucleon of (a) ^{7}Li and (b) ^{56}Fe. [5.607 MeV; 8.790 MeV].
5. [K 3.11]. Calculate the mass defect of ^{238}U. [47.306 MeV].
6. [K 3.13]. Calculate the neutron separation energy of ^{91}Zr [7.195 MeV].
7. [K 3.13]. Calculate the proton separation energy of ^{197}Au [5.783 MeV].
8. [A&M 14.7] A π^o meson decays into two gamma-rays. If the π^o is at rest, calculate the energy of each gamma-ray [67.5 MeV].
9. [K 4.1]. Calculate the minimum photon energy necessary to dissociate the deuteron i.e. $\gamma + d \rightarrow p + n$. Take the deuteron binding energy to be 2.224589 MeV and use a non-relativistic approach. [2.226219 MeV].
10. [A&M 14.11]. On the basis of tabulated masses, which of the isobars, ^{17}N, ^{17}O and ^{17}F, would you expect to be the most stable ? [^{17}O].
11. [K 5.1] Give the expected shell-model spin and parity assignments for the ground states of (a) ^{7}Li; (b) ^{11}B; (c) ^{15}C; (d) ^{17}F; (e) ^{31}P and (f) ^{141}Pr. [(a) 3/2 and –1; (b) 3/2 and –1; (c) 5/2 and +1; (d) 5/2 and +1; (e) 1/2 and +1; (f) 5/2 and +1].
12. [K5.7] Calculate the shell-model quadrupole moment of ^{209}Bi ($I = 9/2^-$). [–0.22 b]. Compare with the experimental value of –0.37 b.
13. [K5.2] The low-lying energy levels of ^{13}C are: Ground state (1/2–); 3.09 MeV (1/2+); 3.68 MeV (3/2–) and 3.85 MeV (5/2+). Interpret these states according to the shell-model.
14. [K10.7]. A certain decay process leads to final states in an even-Z, even-N nucleus and gives only three γ rays of energies 100, 200 and 300 keV, whose multipolarities are E1, E2 and E3, respectively. Construct two possible level schemes for this nucleus and label the states with their most likely spin-parity assignments.
15. [Serway et al 15.17]. By considering the quark makeup of the various particles, deduce the identity of the unknown particle in the reaction

$\Sigma^0 + p \rightarrow \Sigma^+ + \gamma + ?$ [n].

16. [K9.9]. Supply the missing component(s) in the following processes

$\bar{\nu} + {}^3He \rightarrow$ $\quad$ ${}^6He \rightarrow {}^6Li + e^- +$

$e^- + {}^8B \rightarrow$ $\quad$ $\nu + {}^{12}C \rightarrow$

${}^{40}K \rightarrow \nu +$ $\quad$ ${}^{40}K \rightarrow \bar{\nu} +$

17. [K9.4]. The maximum kinetic energy of the positron spectrum emitted in the decay ${}^{11}C \rightarrow {}^{11}B$ is 1.983±0.003 MeV. Use this information and the known mass of ${}^{11}B$ to calculate the mass of ${}^{11}C$ [11.012531±0.000003 u].

18. [Serway 45.59]. A by-product of some fission reactors is ^{239}Pu which is an α-emitter with a half-life of 24,120 years. Consider 1 kg of ^{239}Pu at t=0. (a) What is the number of ^{239}Pu nuclei at t=0 ? (b) What is the initial activity ? (c) For how long would you need to store the Plutonium until it had decayed to a safe activity level of 0.1 Bq ? [2.52 x 10^{24}, 2.305 x 10^{12} Bq, 1.1 million years].

19. [A&M 15.14]. Calculate the Q value for the β^- decay of ^{108}Ag. [1.64 MeV].

20. [A&M 15.19]. On the basis of Q values, determine if the ^{98}Tc nucleus can decay by (a) β^- decay, (b) β^+ decay, (c) electron capture.

21. [S 46.31]. A 2 MeV neutron is emitted in a fission reactor. If it loses half of its kinetic energy in each collision with a moderator atom, how many collisions must it undergo to achieve thermal energy (0.039 eV) ? [26]

22. [S 46.37]. Assume a deuteron and a triton are at rest when they fuse according to $d + t \rightarrow \alpha + n$. This reaction has a Q value of 17.6 MeV. Determine the kinetic energies acquired by the α and the n. [3.5 MeV, 14.1 MeV].

23. [Rohlf 11.15]. If the activity of a substance drops by a factor of 32 in 5 seconds, what is its half-life ? [1 s].

24. [R 11.26]. Show that the decay $n \rightarrow p + e^-$ cannot conserve angular momentum.

25. [R 17.16]. Which of the following strong interactions are allowed ? If a process is forbidden, state the reason.

$\bar{p} + p \rightarrow \pi^0 + n$ $\quad$ $\pi^- + p \rightarrow K^0 + n$

$p + p \rightarrow \pi^+ + n + n$ $\quad$ $\bar{p} + p \rightarrow \pi^0 + \pi^+ + \pi^-$

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

26. [K 18.6]. Analyse the following decays or reactions for possible violations of the basic conservation laws. In each case, state which conservation laws, if any, are violated and through

which interaction the process will most likely proceed (if at all):

(a) $\pi^+ + p \to p + p + \bar{n}$

(b) $\Sigma^+ \to n + e^+ + \nu_e$

(c) $K^+ \to \pi^+ + e^+ + e^-$

(d) $\pi^- + p \to \Lambda^0 + \Sigma^0$

(e) $K^+ \to \pi^+ + \pi^+ + \pi^0 + \pi^-$

(f) $K^+ \to \pi^+ + e^+ + \mu^-$

(g) $\Lambda^0 + p \to \Sigma^+ + n$

(h) $\Lambda^0 \to p + K^-$

27. [K 18.7]. Analyse the following decays according to their quark content:

(a) $\Omega^- \to \Lambda^0 + K^-$

(b) $K^+ \to \pi^+ + \pi^0$

(c) $\Xi^- \to \Lambda^0 + \pi^-$

(d) $\Lambda_c^+ \to p + \overline{K}^0$

28. [K 18.8]. Analyse the following reactions according to their quark content:

(a) $K^- + p \to \Omega^- + K^+ + K^0$

(b) $p + p \to p + \pi^+ + \Lambda^0 + K^0$

(c) $K^- + p \to \Xi^- + K^+$

(d) $\pi^- + n \to \Delta^- + \pi^0$

29. [K 17.4]. Find which of the following reactions are forbidden by one or more conservation laws. Give all violated laws in each case.

(a) $K^+ + n \to \Sigma^+ + \pi^0$

(b) $\pi^- + n \to K^+ + \Lambda^0$

(c) $K^- + p \to n + \Lambda^0$

(d) $\pi^- + p \to \Sigma^+ + K^-$

(e) $\pi^- + p \to \Xi^- + K^+ + \overline{K}^0$

(f) $d + d \to \alpha + \pi^0$