Department of Nuclear Engineering
University of California
Berkeley, California

Final Examination
NE 101, Fall 2004
Open Book for This Semester's Materials Only

NOTES:
1. Unless otherwise specified all numerical results must be given to 3 significant figures.
2. PLEASE GIVE US THE MEANS TO GIVE YOU PARTIAL CREDIT. PLEASE WRITE AS CLEARLY AS YOU CAN.
3. PLEASE DON'T GIVE US TWO ANSWERS TO A QUESTION. WE WILL ONLY EXAMINE THE WRONG ONE.
4. We enjoyed having you in class and we wish you the very best in the future!!

1. (6 points) A 1μg sample of ^{235}U is irradiated in a thermal flux of 3×10^{13} cm^{-2} s^{-1} for a period of 100 s. The thermal neutron fission cross section is 583 b and the neutron capture cross section is 98 b. Calculate

a. the number of fissions that take place.

b. the number of atoms of ^{236}U that are produced.

2. (16 points) The nuclide $^{88}_{35}Br$ ($I^{\pi} = 2^{-}$) is a delayed neutron precursor. Draw a level diagram representing the precursor, the neutron emitter and the final nucleus plus a free neutron. Label the grounds states with the appropriate $^{A}_{Z}El$ and then enter the following information on the diagram (please show all calculations clearly).

a. the ground state spins and parities of the three nuclides. You can assume that the nuclei are spherical.

b. the value of Q_{β^-} for the precursor.

c. the neutron binding energy in the emitter.

d. assuming that decay of $^{88}_{35}Br$ to levels above the neutron binding energy in the emitter takes place only by allowed transitions, indicate the possible spins and parities of these levels.

e. Assuming that neutron emission from the levels in part d always goes directly to the ground state of the final nucleus, indicate the possible <u>orbital</u> angular momenta of the emitted neutrons. Do this for all of the states in your answer to part d.

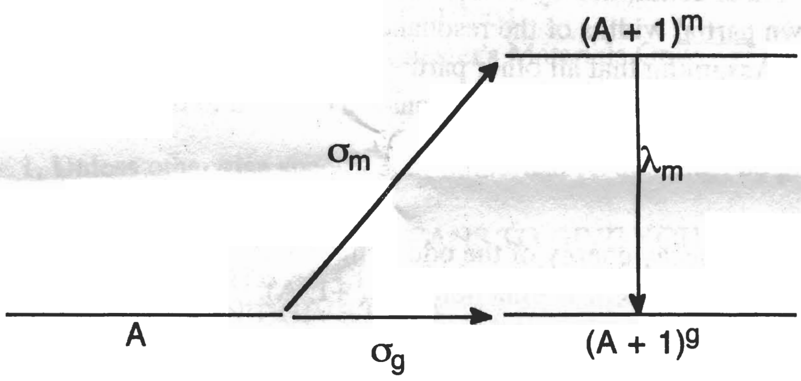
3. (12 points) $^{8}_{4}Be$ decays entirely by "fission" into 2 α particles. The ground state has a level width of $\Gamma = 6.8 \pm 0.2$ eV and a mass excess of 4.9417 MeV.

a. what is the half life of $^{8}_{4}Be$?
b. what is the Q value for this decay?
c. taking the hard-sphere radius of the α particle as 2.08 fm, estimate the height of the Coulomb barrier involved in this decay.
d. based on your result in part c, discuss whether the simple barrier penetration model we developed for α decay should be applicable to estimate the half life of $^{8}_{4}Be$.

4. (18 points) $^{89}_{40}Zr$ has an isomer that undergoes EC/β^+ decay to a $3/2^-$ level in $^{89}_{39}Y$ at an excitation energy of 1.507 MeV above the ground state. The isomer decays solely by a γ-ray transition to the ground state.

a. write down the neutron and proton configuration of the ground state of $^{89}_{40}Zr$ according to the spherical shell model and give the expected spin and parity.
b. write down the most likely neutron and proton configuration of the metastable state $^{89m}_{40}Zr$ according to the spherical shell model and give its expected spin and parity assuming its the first excited state.
c. write down the most likely neutron and proton configuration of the ground state $^{89}_{39}Y$ according to the spherical shell model and give the expected spin and parity.
d. based on your answer to part b, what kind of an EC/β^+ transition is involved in the decay of $^{89m}_{40}Zr$ to the 1.507 MeV level in $^{89}_{39}Y$?
e. based on your answer to part c, what is (are) the multipolarity (multipolarities) most likely to be seen in the γ-ray emission from the 1.507 MeV level in $^{89}_{39}Y$ to the ground state?
f. estimate the half life of the 1.507 MeV level if it decayed solely by γ-ray emission by the fastest multipolarity allowed by conservation laws.

5. (10 points) Neutron capture by a hypothetical nucleus A produces both a metastable state, $(A+1)^m$, and the ground state, $(A+1)^g$ in (A + 1) as shown below. The metastable state decays to the ground state with decay constant λ_m and the ground state of (A+1) is stable.



If ϕ is the constant neutron flux, the target is initially pure A and N_A^o is the initial number of atoms of A,

a. write down the rate equations governing the time rate of change of A, $(A + 1)^m$ and $(A + 1)^g$ during the irradiation.
b. solve the rate equations to derive an expression for the time dependence of $(A+1)^m$ during the irradiation.

6. (12 points) Provide explanations/answers for the following observations.

a. The first excited state of a nuclide is an isomer with measurable lifetime. A pure sample initially containing N_m^o atoms of the isomer is counted with a detector that measures the photons emitted in its decay with 100% efficiency. The number of photons counted when all N_m^o atoms have decayed is only a small fraction of N_m^o.

b. A pure sample containing N_o atoms of a nuclide that is unstable with respect to β^+ emission is counted with a detector that measures the positrons with 100% efficiency. The number of positrons counted when all N_o atoms have decayed is only a small fraction of N_o.

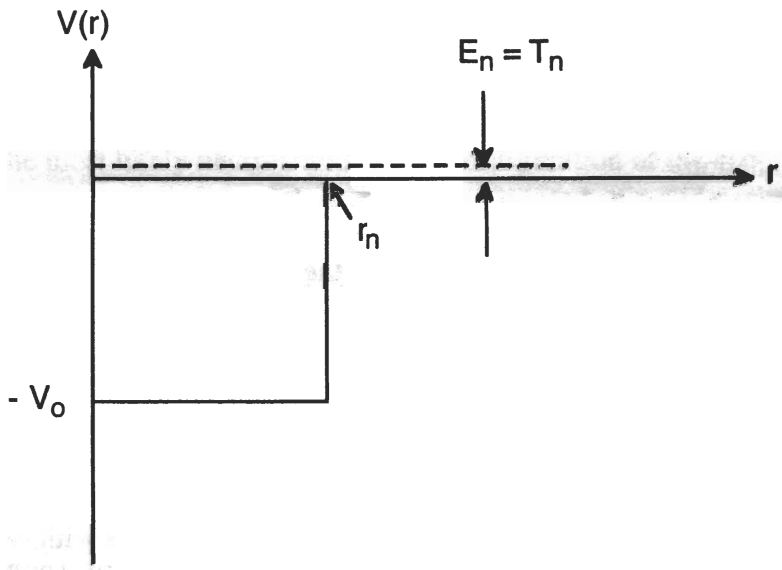
c. The absorption cross section of a nuclide is accurately measured and found to be smaller than the well-known total cross section. It is also known that reactions such as (n, p), (n, α), etc., all have negative Q values. Experimental errors are negligible.

d. A nuclide that can decay by EC/β^+ is produced in a cyclotron, fully stripped of all orbital electrons and forced to undergo continuous rotations in vacuum by a constant magnetic field normal to the plane of the orbit of the ions. The half life is measured with a device that can detect positrons and x rays. What can you say about the half life that this experiment would yield?

7. (10 points) As shown in Figure 13.27, pg. XIII.51, the cross section for the reaction $^{197}Au\ (n_{th},\gamma)\ ^{198}Au$ is dominated by a single resonance with a centroid energy $E_o = 5.810$ eV. The known partial widths of the resonance have the values $\Gamma_n(E_o) = 0.0044$ eV and $\Gamma_\gamma = 0.112$ eV. Assuming that all other partial widths are negligibly small, calculate the ratio of the capture cross section at the resonance centroid to the capture cross section at 0.0257 eV if only this single resonance existed.

8. (6 points) The β^- decay energy of the odd-A nuclide $M(Z_A - 1, A)$ is known to be δ_o. Predict the β^- decay energy of the nuclide $M(Z_A + 1, A)$.

9. (10 points) Show that the transmission coefficient for $l_n = 0$ neutron emission from an excited state at an energy just above the neutron binding energy must vary as $\sqrt{E_n}$ by reference to the following simple model.



The potential function experienced by a neutron is a finite potential well of depth $-V_o$ that extends from the center of mass of the system to the nuclear radius r_n. The total energy of the neutron at $r \geq r_n$, E_n is just the kinetic energy of the neutron, T_n as indicated in the figure. The potential depth Vo is on the order of - 40 MeV. Assuming that $T_n << |V_o|$,

a. write down the equation that represents the transmission coefficient as discussed in the discussion of barrier penetration in Chapter IX.
b. Using conservation of energy, write down an expression for the ratio of the magnitudes of the neutron velocity in the regions $r \geq r_n$ and $r < r_n$.
c. combine these with your understanding of the flux of neutrons in the two regions to show that this leads to the $\sqrt{E_n}$ - dependence noted above.