22.54 Neutron Interactions and Applications
(Spring 2002)

Problem Set No. 4 **Due: March 12, 2002**

1. Determine the kinetic energy at which the wavelength of a neutron is comparable to: (a) the diameter of a nucleus, (b) an atomic diameter, (c) the interatomic spacing in graphite, and (d) the diameter of a nuclear reactor core. (Only rough estimates are required.)

2. a. When 10 MeV neutrons strike ^{232}Th, what is the temperature of the compound nucleus that is formed?
b. What is the most probable energy of the inelastic neutrons?
c. What is the average energy of the inelastic neutrons?

3. A free neutron is unstable against beta decay with a half-life of 11.1 min. Determine the relative probability that a neutron will undergo beta-decay before being absorbed in an infinite medium. Estimate this probability for a thermal neutron in H_2O.

4. Suppose that the total cross section of rhodium has been measured and the following values have been obtained for the resonance parameters of a well-isolated resonance at E_0 = 1.26 eV: σ_0 = 5000 b, Γ = 0.156 eV, and σ_s = 5.5 b. Plot the value of the total cross section for values of the energy between 0.2 and 40 eV. Calculate the thermal absorption cross section and compare this with the measured value of 156 b. (Assume that resonance scattering can be neglected.)

5. The partial widths of the first resonance in ^{236}U at 5.49 eV are Γ_γ=0.029 eV and Γ_n=0.0018 eV. Plot the Doppler-broadened capture cross section at the temperature of 0°K, 20°C, and 1000°C. [Use the tabulated $\psi(\xi,x)$ function in the Duderstadt and Hamilton handout.]

6. Boron-10 is often used as a thermal-neutron shield material because of its high absorption cross section. Noting that full-density boron has an atom density of 0.128 x 10^{24} per cm^3, calculate for a beam of 0.025-eV neutrons:
a. The absorption mean free path for ^{10}B
b. The fraction transmitted through a 1-mm-slab of ^{10}B
c. The relative (fractional) density of ^{10}B required for the 1-mm slab to attenuate the beam to 1 percent of its initial strength

7. In the fission of a heavy nuclide, approximately 160 to 180 MeV of kinetic energy initially is imparted to the fission fragments, which quickly give up their energy by ionizing collisions in the surrounding medium. The remaining 30 to 40 MeV of the fission energy is deposited away from the fission site by prompt and delayed fission gamma photons, neutrons, neutrinos, and β-decay of the fission fragments. What is the rate at which heat must be removed from a 0.1-g sample of ^{252}Cf assuming that all fission fragments and alpha particles (6.1 MeV) are stopped in the sample or its encapsulation?

8. The energies of the excited states of two hypothetical nuclei of mass numbers 10 and 11 are gi en in the table below. All energies are in MeV and measured from the ground state. The binding energy of the last neutron in these nuclei is 6.10 MeV and 4.80 MeV, respectively, and the absorption cross section is negligible.

A = 10	*A = 11*
1.60	2.00
3.00	4.50
4.00	4.60
4.25	5.20
4.60	5.70
5.10	6.00
6.15	6..35
6.20	6.70
6.25	7.20
6.95	8.00
7.80	etc.
etc.	

Make a rough plot of the total and inelastic cross sections of nuclide A=10 as a function of the laboratory energy of incident neutrons. Show clearly at what energies resonances may be expected to occur, and indicate the inelastic threshold.

9. The incompressible liquid drop model of the nucleus gives us an estimate of Z^2/A, sometimes referred to as the "fissionability parameter." Z^2/A provides an indication of whether a heavy nuclide will be stable against deformations that could lead to fission, that is, distortions from sphericity can no longer be counteracted by surface energy.
a. What is this (dimensionless) critical value?
b. Describe the origin of the competing forces that result in the fissionability parameter. How do they depend on A?
c. Can a nuclide with Z^2/A slightly less than the critical value fission? Discuss.

10. A neutron is absorbed in a ^{235}U nucleus at $t = 0$. Describe a probable life history of the resulting ^{236}U and its successors on the assumption that it undergoes fission. Give order of magnitude estimates of characteristic times at which various events occur. Describe the various particles injected into the system as a result of this fission.

11. An isotope that decays by ejecting alpha particles with energies 6.82 MeV (10%) and 4.30 MeV (90%) is mixed intimately with a large amount of beryllium. For an (α, n) source using 40 GBq of this mixture, estimate the neutron emission rate and sketch the energy spectrum of the emitted neutrons.

12. Gamma rays interacting with ^{9}Be or ^{2}H produce "photoneutrons." Write the reaction equation for each and calculate the threshold gamma energy.