October 1995

Ph.D. Qualifying Examination
Interactions

1. (20 min.) This question concerns three thermal equilibrium radiation sources for which the maximum radiant intensities occur for photons of 1 eV, 100 eV, and 100,000 eV.

The following constants and equations may be relevant to this question:

$\hbar = 6.58 \times 10^{-16}$ eV-sec. $k = 8.63 \times 10^{-5}$ eV/K

$\lambda_{max}T = 2.90 \times 10^{-3}$ m•K

$\sigma_{\text{Stefan-Boltzmann}} = 5.67 \times 10^{-8}$ W/m^2/K^4 $= 3.54 \times 10^{11}$eV/sec/m^2/K^4

(a) (10 min) What radiant energy intensities do these sources emit?

(b) (4 min) At what distance from the 100 eV source should an observer be located in order that the energy flux from that source be equal to the energy flux from the 1 eV source at 1 meter? In both cases you should assume the source is small compared to the distance.

(c) (6 min) For each of these three sources, describe the physical processes typically responsible for the radiation and what part of the molecule, atom, or nucleus they arise from.

2. (15 min.) A 100 MeV photon is absorbed by a deuteron that is initially at rest. Find the excitation energy of the recoil nucleus.

3. (15 min.) A nuclear reactor is in the shape of a spherical shell. The inner radius is R_1 and the outer radius is R_2. There is a vacuum both inside and outside of the spherical shell. The reactor contains uniform, monoenergetic, isotropic neutron sources of strength S_V n/cm^3-sec. The total macroscopic cross section of the reactor is Σ. Find the scalar flux density of uncollided neutrons at the center of the reactor.

4. (20 min.) If one kilogram of bismuth is irradiated for 100 days in a **thermal** flux of 10^{14} n/cm^2-s at a temperature of 200°C, what weight of ^{210}Po will be present at end of irradiation? When will the amount of ^{210}Po peak following irradiation and how many curies will be present at that time? The decay scheme and 2200 m/s cross section are shown below:

$${}^{209}_{83}\text{Bi} + {}^{1}_{0}\text{n} \xrightarrow[\text{0.024 barns}]{} {}^{210}_{83}\text{Bi} \xrightarrow[\text{5 days}]{} {}^{210}_{84}\text{Po} \xrightarrow[\text{138 days}]{} {}^{206}_{82}\text{Pb} \ \text{(stable)}$$

Assume that cross sections for Bi-210 and Po-210 are negligible.

5. (20 min.) A 2-inch diameter, 1.00 foot long cylindrical BF_3 counter (dimensions are for active volume) is exposed to beams of neutrons aligned with the detector centerline (neutrons are coming end-on into the detector). The tube contains 100 torr of $^{10}BF_3$. There are 760 torr in an atmosphere and assume perfect gas laws apply, i.e., there 22.414 liters per mole at STP. The 2200 m/s cross section for ^{10}B(n, alpha) is 3838 barns. Assuming 100% counting efficiency for all alphas produced, calculate the counter efficiency per unit beam fluence for 1 eV neutrons and for 200 eV neutrons.

6. (20 min.) A gas-flow proportional counter is used to measure the half-life of an isotope produced at a reactor. Only one isotope is present and an initial 15 minute count (starting at time 0.00) yields 9278 counts. Another 15 minute count started exactly 30 minutes after first count (starting time for this count: 30 minutes after time 0.00) yields 928 counts. The background count rate is known to be 30 counts per minute.

   a) calculate the half-life.
   b) calculate the error in the half-life determination

7. (10 min.) Uranium (i.e., ^{235}U) is used in proportional counters (called fission counters) employed in the startup instrumentation of many nuclear reactors.

   Answer the following questions:

   a. (20%) how is the uranium incorporated in the detector?
   b. (20%) what is the detection mechanism?
   c. (60%) what are the advantages of this type of detector over the more usual boron trifluoride counters?