Georgia Institute of Technology

The George W. Woodruff School of Mechanical Engineering
Nuclear & Radiological Engineering/Medical Physics Program

Ph.D. Qualifier Exam

Spring Semester 2012

_______________ Your ID Code

Radiation Physics (Day 1)

Instructions

1. Use a separate page for each answer sheet (no front to back answers).
2. The question number should be shown on each answer sheet.
3. ANSWER 4 OF 6 QUESTIONS ONLY.
4. Staple your question sheet to your answer sheets and turn in.

NRE/MP Radiation Physics

Answer any 4 of the following 6 questions.

Any nuclear data or physical constants you need should be in the Nuclear Wallet Cards booklets.

Q1. The $^{34}S(n,p)^{34}P$ reaction induced by 14 MeV neutrons from a DT reaction can be used to analyze the amount of sulfur in coal. ^{34}P has a 12.43 second half-life and emits a 2130 keV gamma ray in 25% of its decays. ^{34}S is 4.21% by atom of elemental sulfur. The cross section for the reaction is 85.2 mb. The DT neutron generator can be operated at 10^{11} n/sec; however, the closest that sample can be located to the source is 10 cm away. Assume that the neutron source is isotropic and we have a 6.5 gram sample of coal which has 0.2 g of sulfur per sample.

a. What is the saturated activity of ^{34}P in such a sample?

b. If you irradiate it for 1 minute, what is the ^{34}P activity?

c. The sample is irradiated for 1 minute and then counted for 1 minute. What is the ^{34}P activity at the end of the count?

d. The irradiation/count cycle is repeated 10 times for the sample and the counts under the photopeak summed for the 10 cycles. If the total number of counts recorded in the photopeak is 3700, what is the detector efficiency for the counting arrangement?

e. Life is never perfect as chlorine in the coal can also produce ^{34}P and has a cross section of 52.4 mb via the $^{37}Cl(n,\alpha)\,^{34}P$ reaction. ^{37}Cl is 25.23% by atom of elemental Cl. What fraction of a gram of chlorine must be present in the sample if the activity of the ^{34}P from this reaction is equal to that from the sulfur reaction (part b)?

Q2. The positron emitting isotope ^{15}O, which has important medical applications, can be produced via the reaction $^{12}C(\alpha,n)\,^{15}O$. The cross section reaches a peak when the energy of the incident α particles is 14.6 MeV. Calculate (a) the excited energy level (measured from the ground) of the compound nuclear state, (b) the possible I^{π} assignments of the above compound nuclear state, and (c) the energy range of the emitting neutrons.

Q3. The isotope ^{18}F is a radionuclide used in medical diagnoses of tumors and, although usually produced by the $^{18}O(p,n)^{18}F$ reaction, it can also be produced by irradiating lithium carbonate ($LiCO_3$) with neutrons. The neutrons interact with ^{6}Li to produce tritons (nuclei of ^{3}H) which in turn interact with the oxygen to produce ^{18}F.

a. What are the two nuclear reactions?
b. Calculate the Q-value for each reaction,
c. Calculate the threshold energy for each reaction,
d. Can thermal neutrons be used to create ^{18}F?

Q4. State true/false with explanations (no explanations = 0 points)

a. A linear attenuation coefficient of 0.58 cm^{-1} for 800 keV photons in copper (ρ = 8.94g/cm^3) corresponds to an atomic cross section of nearly 7 barns.
b. A deuteron transfers less energy to an electron in a single head on collision than a triton.
c. A 4 MeV neutron scattered elastically by ^{12}C through an angle of 45 degrees loses nearly 10% of its energy in the single collision.
d. Elastic Scattering interactions do not result in an exchange of energy.
e. The microscopic cross section is the projected area of the nucleus available for particle nucleus interactions.

Q5. At t=0, there are exactly N_0 hypothetical radioactive nuclei. The estimated decay constant of these nuclei is λ'. To obtain a more accurate measurement of the decay constant, we can wait for a time of T and calculate the decay constant based on the residual number of nuclei. Find the optimal T value (in terms of λ') that gives the most accurate measurement of the decay constant.

Q6. A 10keV photon interacts with a free electron (with 0 initial kinetic energy) via Compton scattering. Due to the low photon energy, the differential Compton cross section can be approximated as $\frac{d\sigma_C}{d\Omega} \approx (r_e^2/2)(1+\cos^2\theta)$, where r_e is the classical electron radius and θ is the scattering angle. Calculate the mean kinetic energy of the recoil electron.