Georgia Institute of Technology

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

Ph.D. Qualifier Exam

Fall Semester 2011

_______________ 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.

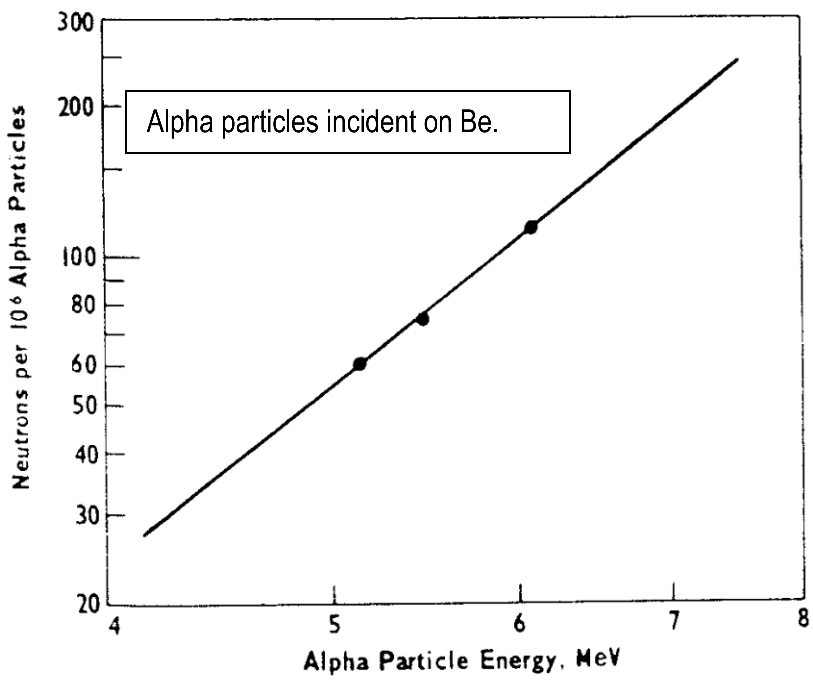
NRE/MP Radiation Physics

<u>Answer any 4 of the following 6 questions</u>.

Q1. Cm-244 alpha decays but also spontaneously fissions $1.4(10^{-6})$ of the time. Its decay product Pu-240 also alpha decays and has a much smaller spontaneous fission branching ratio. U-236, the decay product of Pu-240 alpha decay also alpha decays with such a low SF branching ratio that it will be considered negligible. Assume that you start with 100 milligrams of pure Cm-244. **After 50 years of decay**, compute the following:

a) The activity of Cm-244 (appropriate units of Bq)
b) The activity of Pu-240 (appropriate units of Bq)
c) The number of neutrons emitted from a mixture of that amount of Pu-240 and Cm-244 with beryllium.

Nuclide	Z	Mass Excess, Δ (MeV)	Half Life	Spontaneous fission Branching Ratio	Average number of neutrons emitted per SF
Cm-244	96	58.454	18.1 years	$1.4(10^{-6})$	2.72
Pu-240	94	50.127	6561 years	$5.7(10^{-8})$	2.16
He-4	2	2.425	-----	---	---
U-236	92	42.446	$2.342(10^{7})$ years	negligible	---



Q2. The Bethe equation for stopping power in a medium is:

$$(-\frac{dE}{dx})_{coll} = \frac{4\pi k_0{}^2 z^2 e^4 n}{m_e c^2 \beta^2}(\ln\frac{2m_e c^2 \beta^2}{I(1-\beta^2)} - \beta^2)$$

(i) State what quantity each term in the right hand side represents (It is not necessary to provide numerical values).

(ii) Indicate which variables depend on the type of radiation and which variables depend on the nature of the medium.

(iii) Quantitatively compare the stopping power of a medium with regards to proton radiation and alpha particle radiation if the proton and the alpha particle have the same velocity

(iv) Repeat (iii.) when the proton and the alpha particle have the same kinetic energy (assume β^2 << 1 in this case)

Q3. In a semiclassical treatment of charged particle collisions with matter, one can describe the energy loss during collisions in terms of the impact parameter b. By considering the uncertainty principle in quantum mechanics, find the effective minimum impact parameter for soft collisions with energy transfer less than ε.

Given: The momentum transfer δp from the incident particle to the struck electron with the rest mass m_0 in soft collisions is related to the energy transfer T according to $\delta p = (2m_0T)^{1/2}$. There is a spread Δp in the transverse momentum of electron. Note the uncertainty principle can be described by the following equation: $\Delta p \Delta x \geq h$.

NRE/MP Radiation Physics – Cont'd.

Q4. It is well known that a ground-state ^{235}U nucleus can capture a thermal neutron to become an excited ^{236}U nucleus, which then undergoes gamma decays. Use the atomic mass table (<u>Attachment A</u>) to determine: (a) the possible assignments of spin and parity (i.e. I^{π}) of the excited ^{236}U nucleus, and (b) the total amount of energy carried away by the gamma rays.

APPENDIX C

	Z	A	Atomic mass (u)	I^{π}	*Abundance* or Half-life
		208	207.979717	(5^+)	0.368 My (ε)
		209	208.980374	$\frac{9}{2}^-$	*100 %*
		210	209.984095	1^-	5.01 d (β^-)
		211	210.987255	$\frac{9}{2}^-$	2.15 m (α)
		212	211.991255	1^-	60.6 m (β^-)
	84	206	205.980456	0^+	8.8 d (ε)
		207	206.981570	$\frac{5}{2}^-$	5.8 h (ε)
		208	207.981222	0^+	2.90 y (α)
		209	208.982404	$\frac{1}{2}^-$	102 y (α)
		210	209.982848	0^+	138.4 d (α)
		211	210.986627	$\frac{9}{2}^+$	0.52 s (α)
	85	208	207.986510	6^+	1.63 h (ε)
		209	208.986149	$\frac{9}{2}^-$	5.4 h (ε)
		210	209.987126	5^+	8.3 h (ε)
		211	210.987469	$\frac{9}{2}^-$	7.21 h (ε)
		212	211.990725	(1^-)	0.31 s (α)
		213	212.992911	$\frac{9}{2}^-$	0.11 μs (α)
	86	207	206.990690	$\frac{5}{2}^-$	9.3 m (ε)
		210	209.989669	0^+	2.4 h (α)
		211	210.990576	$\frac{1}{2}^-$	14.6 h (ε)
		212	211.990697	0^+	24 m (α)
		218	218.005580	0^+	35 ms (α)
		222	222.017571	0^+	3.82 d (α)
		224		0^+	107 m (β^-)
	87	209	208.995870	$\frac{9}{2}^-$	50 s (α)
		212	211.996130	5^+	20 m (ε)
		215	215.000310	$\frac{9}{2}^-$	0.12 μs (α)
		220	220.012293	1	27.4 s (α)
		223	223.019733	$(\frac{3}{2})$	21.8 m (β^-)
		232	232.038051	0^+	*100 %*
		233	233.041577	$(\frac{1}{2}^+)$	22.3 m (β^-)
Pa	91	229	229.032073	$(\frac{5}{2}^+)$	1.4 d (ε)
		230	230.034527	(2^-)	17.7 d (ε)
		231	231.035880	$\frac{3}{2}^-$	32,800 y (α)
		232	232.038565	(2^-)	1.31 d (β^-)
		233	233.040243	$\frac{3}{2}^-$	27.0 d (β^-)
U	92	233	233.039628	$\frac{5}{2}^+$	0.1592 My (α)
		234	234.040947	0^+	0.245 My (α)
		235	235.043924	$\frac{7}{2}^-$	*0.720%*
		236	236.045563	0^+	23.42 My (α)
		237	237.048725	$\frac{1}{2}^+$	6.75 d (β^-)
		238	238.050785	0^+	*99.275%*
		239	239.054290	$\frac{5}{2}^+$	23.5 m (β^-)
Np	93	236	236.046550	(6^-)	0.11 My (ε)
		237	237.048168	$\frac{5}{2}^+$	2.14 My (α)
		238	238.050941	2^+	2.117 d (β^-)
		239	239.052933	$\frac{5}{2}^+$	2.36 d (β^-)
Pu	94	237	237.048401	$\frac{7}{2}^-$	45.3 d (ε)
		238	238.049555	0^+	87.74 y (α)
		239	239.052158	$\frac{1}{2}^+$	24,100 y (α)
		240	240.053808	0^+	6570 y (α)
		241	241.056846	$\frac{5}{2}^+$	14.4 y (β^-)
		242	242.058737	0^+	0.376 My (α)
		243	243.061998	$\frac{7}{2}^+$	4.96 h (β^-)
Am	95	240	240.055278	(3^-)	50.9 h (ε)
		241	241.056824	$\frac{5}{2}^-$	433 y (α)

Q5. A radiation detection device has an output of $Y = aX + b$, where a, b are constants and X is Poisson-distributed radiation counts. If the system is calibrated well, $a = 1, b = 0$. Now, we use such a counter without calibration to measure two different radioactive samples. The samples are long-lived, and you may ignore their activity change during the measurement. The measurements are repeated many times. For the first sample, the measurements give a variance of 1935.8 and a mean value of 1100.1; for the second sample, the measurements give a variance of 3871.1 and a mean value of 2099.8. Calibrate the counter from these measurements (i.e. find a, b values).

Q6. Hypothetical radioactive nuclei decay with an unknown initial number at t = 0. At t = 1 min, we find 1205 nuclei are left. At t = 2 min, we find 515 nuclei are left.

a. What is your estimate of the decay constant? What is the variance of your estimate?
b. At t = 3 min, we find 210 nuclei are left. How will you update your estimate of the decay constant such that the variance of your estimate is minimized? What is your estimate of the decay constant and what is the variance of your estimate?