Georgia Institute of Technology

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

Ph.D. Qualifier Exam

Fall Semester 2007

_______________ Your ID Code

Radiation Physics (Day 1)

<u>Instructions</u>

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:

1. A gold foil weighing 3.5 mg is irradiated by a thermal-neutron flux density of 10^{13} n cm^{-2} s^{-1}. The interaction cross section is $\sigma = 96 \times 10^{-24}$ cm^2/atom, and the half-life, $\tau_{1/2} = 2.70$ d for ^{198}Au. The value of Avogadro's constant is 6.023×10^{23} atoms/mole. The gram-atomic weight of gold is 197.0 g/mole. One curie (1 Ci) is 3.7×10^{10} Bq.

   a) How long will it take for the foil to achieve an activity of 100 mCi of ^{198}Au?
   b) What is the equilibrium level of activity?
   c) How long would it have taken to reach the same activity if the decay of ^{198}Au were negligible during that time?
   d) What is the true activity reached at that time?

2. Answer the following questions regarding photon interactions with media. State your assumptions if necessary.

   a) Is the Compton mass attenuation coefficient larger in carbon (Z= 6; A=12) or lead (Z=82; A=207)? Why?
   b) On the basis of the Klein-Nishna theory, what is the ratio of the Compton interaction cross sections per atom for lead and carbon?
   c) Suppose two photons with $h\nu$ = 2 and 20 MeV, respectively, undergo pair production interactions with a medium. What is the average energy of the charged particles resulting from pair production in the nuclear field for each photon? What is the average energy of the charged particles resulting from pair production in the electron field (i.e., triplet production) for each photon?

3. Answer the following questions regarding charged particle interactions with media. State your assumptions if necessary.

   a) Compare the passage of charged and uncharged particles through matter. What is the approximate probability of a single charged particle achieving a pathlength equal to twice its range? What is the approximate probability of a single photon having a pathlength twice as great as the mean free path $1/\mu$ (Assume the photon is totally absorbed in its first interaction).
   b) Briefly describe the general types of interactions that contribute to the collision stopping power, $(dT/\rho dx)_c$.

4. The semi-empirical nuclear binding energy formula is given below:

$$B = a_1 A - a_2 A^{2/3} - a_3 Z^2 A^{-1/3} - a_4 (N-Z)^2 A^{-1} \pm a_5 A^{-1/2}$$

   where $a_1 = 15.56$ MeV, $a_2 = 17.23$ MeV, $a_3 = 0.7$ MeV, $a_4 = 23.28$ MeV, and $a_5 = 12.0$ MeV

   (a) Explain the physical meaning of each of the five terms in the above formula.

(b) Use the formula to calculate the mass of ${}^{208}_{82}Pb$ nucleus. Other data needed: $m_n = 1.008665$ u, $m_p = 1.0072765$ u, and $1\text{ u} = 931.494$ MeV

(c) Discuss the discrepancy between your result of (b) and that shown in Attachment A.

5. In an alloyed Pu(Be) neutron source, neutrons are produced from the interactions of alpha particles (emitted from ^{238}Pu) with the ^{9}Be nuclei. That is,

$$^{238}Pu \rightarrow {}^{234}U + {}^{4}_{2}He$$

and

$${}^{9}_{4}Be + {}^{4}_{2}He \rightarrow {}^{1}_{0}n + {}^{12}_{6}C$$

(a) Use the mass table (Attachment A) to calculate the kinetic energy of the alpha particle.

(b) Given that the nuclear radius obeys the formula, $R = 1.25 \times A^{1/3}$ fm and that $\dfrac{e^2}{4\pi\varepsilon_0} = 1.44$ $MeV\ fm$, use the classical approach to estimate the coulomb barrier (in MeV) for the above (α,n) reaction.

(c) Use the classical approach to estimate the cross section (in barns) for the above (α,n) reaction, and discuss how the cross section should be modified by the quantum-mechanical approach.

6. The first resonance is observed at E_n = 2.077 MeV in the neutron total cross section for ${}^{1}_{0}n + {}^{12}C \rightarrow {}^{13}C$ in a laboratory experiment. (a) What energy, measured from the ground state of ^{13}C, is the excited state which gives rise to the above resonance? (b) If the total width (Γ) of the resonance is 8 keV, what is the most probable reaction type of this resonance? e.g. (n,γ), (n, elastic), (n, inelastic),.. etc. Why?

NRE/MP Radiation Physics – Cont'd.

Nuclear properties

Nuclide ($_zXA$)	Mass excess (μu)	Abundance or half-life
$_{80}$Hg192	−34429	ε4.85 h
193	−33356	β^+3.80 h
194	−34619	ε440 y
195	−33366	β^+9.9 h
196	−34185	0.15%
197	−32804	ε64.14 h
198	−33248	9.97%
199	−31738	16.87%
200	−31691	23.10%
201	−29715	13.18%
202	−29374	29.86%
203	−27142	β^-46.612 d
204	−26524	6.87%
205	−23944	β^-5.2 m
206	−22501	β^-8.15 m
$_{81}$Tl198	−29533	β^+5.3 h
199	−30188	β^+7.42 h
200	−29054	β^+26.1 h
201	−29196	ε72.912 h
202	−27909	β^+12.23 d
203	−27671	29.524%
204	−26151	β^-3.78 y
205	−25588	70.476%
206	−23905	β^-4.199 m
207	−22592	β^-4.77 m
208	−17995	β^-3.053 m
$_{82}$Pb200	−28185	ε21.5 h
201	−27150	β^+9.33 h
202	−27856	ε52.5 ky
203	−26625	ε51.873 h
204	−26971	1.4%
205	−25533	ε15.3 My
206	−25551	24.1%
207	−24119	22.1%
208	−23364	52.4%
209	−18926	β^-3.253 h
210	−15827	β^-22.3 y
211	−11269	β^-36.1 m
212	−8112	β^-10.64 h
$_{83}$Bi204	−22194	β^+11.22 h
205	−22625	β^+15.31 d
206	−21517	β^+6.243 d
207	−21545	β^+31.55 y
208	−20273	β^+368 ky

Nuclide ($_zXA$)	Mass excess (μu)	Abundance or half-life
209	−19617	100%
210	−15895	β^-5.013 d
211	−12742	α2.14 m
212	−8728	β^-60.55 m
213	−5625	β^-45.59 m
214	−1301	β^-19.9 m
$_{84}$Po204	−19693	β^+3.53 h
205	−18834	β^+1.66 h
206	−19535	β^+8.8 d
207	−18422	β^+5.80 h
208	−18769	α2.898 y
209	−17585	α102 y
210	−17143	α138.376 d
211	−13363	α516 ms
212	−11148	α299 ns
$_{85}$At208	−13417	β^+1.63 h
209	−13841	β^+5.41 h
210	−12869	β^+8.1 h
211	−12520	ε7.214 h
212	−9266	α314 ms
213	−7079	α125 ns
214	−3644	α558 ns
215	−1359	α100 μs
216	2409	α300 μs
217	4710	α32.3 ms
218	8682	α1.5 s
219	11294	α56 s
$_{86}$Rn212	−9311	α23.9 m
213	−6132	α25.0 ms
214	−4654	α270 ns
215	−1271	α2.30 μs
216	258	α45 μs
217	3914	α540 μs
218	5587	α35 ms
219	9475	α3.96 s
220	11384	α55.6 s
221	15459	β^-25 m
222	17570	α3.8235 d
$_{87}$Fr219	9241	α20 ms
220	12312	α27.4 s
221	14246	α4.9 m
222	17544	β^-14.2 m
223	19731	β^-21.8 m

Nuclide ($_zXA$)	Mass excess (μu)	Abundance or half-life
224	23231	β^-3.30 m
225	25607	β^-4.0 m
226	29340	β^-49 s
227	31831	β^-2.47 m
$_{88}$Ra222	15361	α38.0 s
223	18497	α11.435 d
224	20202	α3.66 d
225	23604	β^-14.9 d
226	25403	α1.600 ky
227	29171	β^-42.2 m
228	31064	β^-5.75 y
$_{89}$Ac223	19126	α2.10 m
224	21708	β^+2.9 h
225	23221	α10.0 d
226	26090	β^-29.37 h
227	27747	β^-21.773 y
228	31015	β^-6.15 h
229	32926	β^-62.7 m
230	36028	β^-122 s
231	38551	β^-7.5 m
$_{90}$Th226	24891	α30.57 m
227	27699	α18.72 d
228	28731	α1.9131 y
229	31755	α7.34 ky
230	33127	α75.38 ky
231	36297	β^-25.52 h
232	38050	100%
233	41577	β^-22.3 m
234	43596	β^-24.10 d
$_{91}$Pa229	32088	ε1.50 d
230	34533	β^+17.4 d
231	35879	α32.76 ky
232	38582	β^-1.31 d
233	40240	β^-26.967 d
234	43302	β^-6.70 h
235	45432	β^-24.5 m
$_{92}$U230	33927	α20.8 d
231	36289	ε4.2 d
232	37146	α68.9 y
233	39628	α159.2 ky
234	40946	0.0055%
235	43923	0.720%

Nuclear properties

Nuclide ($_zXA$)	Mass excess (μu)	Abundance or half-life
236	45562	α23.42 My
237	48724	β^-6.75 d
238	50783	99.2745%
239	54288	β^-23.45 m
$_{93}$Np234	42888	β^+4.4 d
235	44056	ε396.1 d
236	46560	ε154 ky
237	48167	α2.144 My
238	50940	β^-2.117 d
239	52931	β^-2.3565 d
$_{94}$Pu236	46048	α2.858 y
237	48404	ε45.2 d
238	49553	α87.7 y
239	52157	α24.11 ky
240	53807	α6.564 ky
241	56845	β^-14.35 y
242	58737	α373.3 ky
243	61997	β^-4.956 h
244	64198	α80.8 My
$_{95}$Am240	55288	β^+50.8 h
241	56823	α432.2 y
242	59543	β^-16.02 h
243	61373	α7.37 ky
244	64279	β^-10.1 h
$_{96}$Cm242	58829	α162.8 d
243	61382	α29.1 y
244	62746	α18.10 y
245	65486	α8.5 ky
246	67218	α4.73 ky
247	70347	α15.6 My
248	72342	α340 ky

Nuclide ($_zXA$)	Mass excess (μu)	Abundance or half-life
249	75947	β^-64.15 m
250	78350	f 9 ky
$_{97}$Bk245	66355	ε4.94 d
246	68664	β^+1.80 d
247	70299	α1.38 ky
248	73076	α9 y
249	74980	β^-320 d
$_{98}$Cf250	76400	α13.08 y
251	79580	α900 y
252	81619	α2.645 y
253	85127	β^-17.81 d
254	87317	f 60.5 d
255	91037	β^-85 m
256	93441	f 12.3 m
$_{99}$Es251	79983	ε33 h
252	82974	α471.7 d
253	84818	α20.47 d
254	88016	α275.7 d
255	90267	β^-39.8 d
$_{100}$Fm251	81567	β^+5.30 h
252	82460	α25.39 h
253	85176	ε3.00 d
254	86848	α3.240 h
255	89955	α20.07 h
256	91767	f 157.6 m
257	95099	α100.5 d
$_{101}$Md255	91075	β^+27 m
256	94053	β^+78.1 m
257	95535	ε5.52 h
258	98426	α51.50 d

Nuclide ($_zXA$)	Mass excess (μu)	Abundance or half-life
$_{102}$No252	88966	α2.30 s
253	90650	α? 1.7 m
254	90949	α? 55 s
255	93232	α3.1 m
$_{103}$Lr257	99603	α646 ms
258	101879	α3.9 s
259	102996	α6.3 s
260	105572	α3.0 m
261	106946	f? α? 39 m
262	109695	β^+? 3.6 h
$_{104}$Rf257	103071	α4.7 s
258	103565	f 12 ms
259	105626	α2.7 s
260	106431	f 20.1 ms
261	108750	α65 s
262	109920	f 2.06 s
$_{105}$Db261	112110	α1.8 s
262	114150	f 34 s
263	115073	f 29 s
$_{106}$Sg265	121064	α16 s
266	121933	α20 s
$_{107}$Bh266	127011	α? 1 s
267	127741	α? 15 s
$_{108}$Hs268	132153	α? 2 s
269	134118	α13 s
$_{109}$Mt270	140720	α? 2 s