Georgia Institute of Technology

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

Ph.D. Qualifier Exam

Spring Semester 2010

_______________ 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.

Q1. It is well known that a ground-state ^{27}Al nucleus can capture a thermal neutron and become an excited ^{28}Al nucleus. Use the atomic mass table (Attachment A) to determine the energy (measured from the ground state) of the excited ^{28}Al nucleus? If the ground state of ^{28}Al is known to be unstable, what is the ultimate stable nucleus that the excited ^{28}Al nucleus will most likely decay to? Why? What is total amount of energy (and in what form?) that will be released during the entire decay process? Make an attempt to draw the decay scheme.

Q2. The first resonance of neutron cross section for ^{16}O is observed at E_n = 443 keV in the laboratory system. (a) What energy, measured from the ground state of ^{17}O, is the excited state which gives rise to the above resonance? (b) If the total width (Γ) of the resonance is 41 keV, what is the most probable reaction type of this resonance? e.g. (n,γ), elastic, inelastic),.etc. Why? (c) Is Doppler effect (due to elevated temperatures) important to this resonance? Why or why not?

Attachment A

Atomic Masses

The data presented here represent a selection of the atomic masses presented in "The 1995 update to the atomic mass evaluation" by G.Audi and A.H.Wapstra, Nuclear Physics *A595* vol. 4 p.409–480, December 25, 1995. The masses represent the best evaluated data, i.e., *recommended* masses, and are given as the mass excesses in keV and masses in atomic mass units, u. Although no errors are given, they typically range from less than 1 keV to several hundred keV. When the highest accuracy is needed, the reader should refer to the original article or the downloadable forms from the National Nuclear Data Center available at http:// www.nndc.bnl.gov.

The nuclides included in the table are those for which mass measurements have been made, for which the ground states have known half-lives and where the half-lives are are long compared to the characteristic nuclear time. The columns in the table represent

1. The atomic number Z.
2. The chemical symbol El.
3. The mass number A.
4. The mass excess in keV.
5. The mass in atomic mass units u.

0	n	1	8071.32	1.0086649
1	H	1	7288.97	1.0078250
		2	13135.72	2.0141018
		3	14949.79	3.0160493
2	He	3	14931.20	3.0160293
		4	2424.91	4.0026032
		5	11386.23	5.0122236
		6	17594.12	6.0188881
		7	26110.26	7.0280305
		8	31597.98	8.0339218
3	Li	6	14086.31	6.0151223
		7	14907.67	7.0160040
		8	20946.19	8.0224867
		9	24953.90	9.0267891
		10	33050.23	10.0354809
		11	40795.86	11.0437961
4	Be	7	15769.49	7.0169292
		8	4941.66	8.0053051
		9	11347.58	9.0121821
		10	12606.58	10.0135337
		11	20173.97	11.0216576
5	B	8	22921.00	8.0246067
		10	12050.76	10.0129370
		11	8667.98	11.0093055
		12	13368.90	12.0143521
		13	16562.21	13.0177803
		14	23663.73	14.0254041
		15	28966.94	15.0310973
		17	43716.11	17.0469314
6	C	9	28913.65	9.0310401
		10	15698.57	10.0168531
		11	10650.53	11.0114338
		12	0.00	12.0000000
		13	3125.01	13.0033548
		14	3019.89	14.0032420
		15	9873.14	15.0105993
		16	13694.12	16.0147012
		17	21036.59	17.0225837
		18	24924.04	18.0267570
		19	32833.38	19.0352481
		20	37560.06	20.0403224
7	N	12	17338.08	12.0186132
		13	5345.46	13.0057386
		14	2863.42	14.0030740
		15	101.44	15.0001089
		16	5683.43	16.0061014
		17	7870.82	17.0084497
		18	13117.14	18.0140818
		19	15860.45	19.0170269
		20	21766.49	20.0233673
		21	25231.91	21.0270876
		22	32080.89	22.0344402
8	O	13	23110.74	13.0248104
		14	8006.46	14.0085953
		15	2855.39	15.0030654
		16	–4737.00	15.9949146
		17	–809.00	16.9991315
		18	–782.06	17.9991604
		19	3333.57	19.0035787
		20	3796.91	20.0040767
		21	8061.74	21.0086546
		22	9284.35	22.0099672
		23	14616.37	23.0156913
		24	18974.46	24.0203699
13	Al	23	6767.21	23.0072649
		24	–55.04	23.9999409
		25	–8915.74	24.9904286
		26	–12210.34	25.9868917
		27	–17196.83	26.9815384
		28	–16850.55	27.9819102
		29	–18215.50	28.9804449
		30	–15872.37	29.9829603
		31	–14954.18	30.9839460
		32	–11062.07	31.9881244
		33	–8504.92	32.9908696
		34	–2862.24	33.9969273
		35	–58.08	34.9999376
14	Si	24	10754.76	24.0115457
		25	3825.31	25.0041066
		26	–7144.62	25.9923299
		27	–12384.43	26.9867048
		28	–21492.79	27.9769265
		29	–21895.03	28.9764947
		30	–24432.88	29.9737702
		31	–22948.96	30.9753633
		32	–24080.86	31.9741481
		33	–20492.38	32.9780005
		34	–19956.56	33.9785758
		35	–14359.76	34.9845842
		36	–12400.64	35.9866874
15	P	27	–752.98	26.9991916
		28	–7161.02	27.9923123
		29	–16951.91	28.9818014
		30	–20200.56	29.9783138
		31	–24440.99	30.9737615
		32	–24305.32	31.9739072
		33	–26337.73	32.9717253
		34	–24557.55	33.9736364
		35	–24857.61	34.9733143
		36	–20250.84	35.9782598
		37	–18994.71	36.9796083
		38	–14466.10	37.9844700
		39	–12649.69	38.9864200
		40	–8336.87	39.9910500
		41	–4843.77	40.9948000

The planck's constant: $\hbar = \frac{h}{2\pi} = 6.58217 \times 10^{-16}$ eV.sec

Q3. Pu-241 decays by beta emission 99.9975% of the time (Am-241) and by alpha emission 0.0025% of the time (U-237). [It also decays by spontaneous fission which is at such a low probability that we will ignore it.] If you start with 10 grams of pure Pu-241. After 90 days which of the two progeny (U-237 and Am-241) will have the largest activity (Bq)? How much activity (Bq) does it have?

Nuclide	Z	Half-Life	A
Pu-241	94	14.29 years	241.057 amu
Am-241	95	432.2 years	237.049 amu
U-237	92	6.75 days	241.057 amu

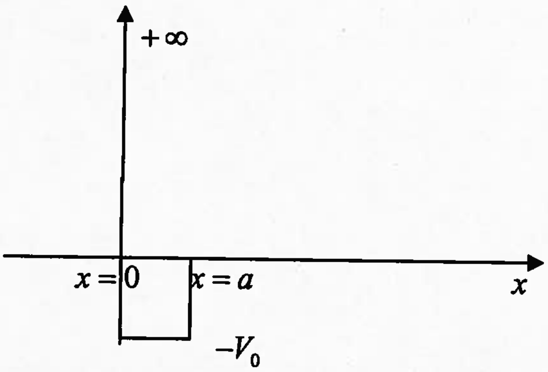
Q4. Under the proper conditions, two alpha particles can combine to produce ^{7}Li nucleus.

a. What is the other product from that reaction?
b. What minimum kinetic energy must one of the alpha particles have to make the reaction proceed if the other alpha particle is at rest?
c. Would it take less kinetic energy to have ^{3}He and ^{4}He interact to form a ^{7}Li nucleus? Assume that the ^{4}He is the projectile and the ^{3}He is at rest.
d. What kinetic energy does the ^{7}Li nucleus recoil with part c?

Nuclear Wallet Cards

Nuclide Z	El	A	Jπ	Δ (MeV)	$T_{1/2}$, Γ, or Abundance	Decay Mode
0	n	1	1/2+	8.071	10.24 m 2	β−
1	H	1	1/2+	7.289	99.985% *1*	
		2	1+	13.136	0.015% *1*	
		3	1/2+	14.950	12.32 y 2	β−
		4	2−	25.9	4.6 MeV *9*	n
		5		32.9	5.7 MeV *21*	n
		6	(2−)	41.9	1.6 MeV *4*	n
		7		49s	29×10^{-23} y *7*	
2	He	3	1/2+	14.931	0.000137% *3*	
		4	0+	2.425	99.999863% *3*	
		5	3/2−	11.39	0.60 MeV 2	α, n
		6	0+	17.595	806.7 ms *15*	β−
		7	(3/2)−	26.10	150 keV *20*	n
		8	0+	31.598	119.0 ms *16*	β−, β−n 16%
		9	(1/2−)	40.94	65 keV *37*	n
		10	0+	48.81	0.17 MeV *11*	2n?
3	Li	3		28s	unstable	p?
		4	2−	25.3	6.03 MeV	p
		5	3/2−	11.68	≈1.5 MeV	α, p
		6	1+	14.087	7.59% *4*	
		7	3/2−	14.908	92.41% *4*	
		8	2+	20.947	838 ms *6*	β−, β−α
		9	3/2−	24.954	178.3 ms *4*	β−, β−n 50.8%
		10	(1−,2−)	33.05	1.2 MeV *3*	n
		11	3/2−	40.80	8.59 ms *14*	β−, β−nα 0.027%, β−n
		12		50.1s	<10 ns	n?
4	Be	5	(1/2+)	38s	?	p
		6	0+	18.376	92 keV 6	p, α
		7	3/2−	15.770	53.22 d *6*	ε
		8	0+	4.942	6.8 eV *17*	α
		9	3/2−	11.348	100%	
		10	0+	12.607	1.51×10^{6} y *6*	β−
		11	1/2+	20.174	13.81 s *8*	β−, β−α 3.1%
		12	0+	25.08	21.49 ms *3*	β−, β−n≤1%
		13	(1/2−)	33.25	2.7×10^{-21} s *18*	n
		14	0+	40.0	4.84 ms *10*	β−, β−n 94%, β−2n 6%
		15		49.8s	<200 ns	n?
		16	0+	57.7s	<200 ns	2n?
5	B	6		43.6s	unstable	2p?
		7	(3/2−)	27.87	1.4 MeV *2*	p, α
		8	2+	22.921	770 ms *3*	ε, εα
		9	3/2−	12.416	0.54 keV *21*	p,
		10	3+	12.051	19.8% *3*	
		11	3/2−	8.668	80.2% *3*	
		12	1+	13.369	20.20 ms *2*	β−, β−3α 1.58%
		13	3/2−	16.562	17.33 ms *17*	β−
		14	2−	23.66	12.5 ms 5	β−, β−n 6.04%
		15		28.97	9.93 ms 7	β−, β−n 93.6%, β−2n 0.4%

Q5. For the following 1D potential function,



$$V(x) = \begin{cases} +\infty, x < 0 \\ -V_0, 0 \le x \le a \\ 0, x > a \end{cases}$$

where V_0 is positive.

a. Assuming particles are incident from $x = +\infty$ in the direction toward $-\infty$, with energies $E > 0$, write down the Schrodinger equations for different regions.
b. Using boundary conditions, solve the Schrodinger equation. Evaluate all undetermined coefficients in terms of a single common coefficient, but do not attempt to normalize the wave function.
c. In the region $x > a$, based on the solution of b), calculate the wave reflection coefficient.

Q6. A beam of deuterons with unknown energy are bombarding a stationary ^{12}C target. The following reaction occurs:

$$^{2}H + ^{12}C \rightarrow ^{4}He + ^{10}B$$

The energy of the emitted alpha particles can be accurately measured. Those at 90 degrees to the incident beam are found to have energy 8.18 MeV while those at 60 degrees are of 10.84 MeV. Use this information to find the energy of the deuteron beam and the Q value for the reaction. (For simplicity, you may assume that the nuclear mass is proportional to the atomic mass number.)