Chemistry 485

Spring, 2o1o — Practice Exam #2

Distributed: Wed., 21 Apr. 2o1o — Due: Wed., 28 Apr. 2o1o

1. Short Answers. The questions in this practice exam may require information on masses or mass defects for various nuclides.

   (a) ^{40}K is the isotope responsible for a large fraction of the gamma-ray background on earth and it can decay to ^{40}Ar or ^{40}Ca. (A) Write balanced reactions for the electron capture and β^+ decay of this nucleus. (B) Determine if positron emission is energetically allowed for ^{40}K.

   (b) ^{10}B is used as a neutron absorbing material due to its high cross section for the (n,α) reaction. This reaction actually produces the product ^{7}Li in the nuclear ground state and in its first excited state. (A) What does the simple nuclear shell model predict for the spin and parity of the ground state of ^{7}Li? (B) What does this model predict for the spin and parity of the excited state of ^{7}Li?

   (c) The vast majority of the material in our solar system is H and He that was made in the big bang. (A) Based on nuclear structure, why were heavier elements (Z>2) not produced in the big bang? (B) What is the source of energy for our sun? (C) Estimate the fraction of the iron isotopes found in the solar system that were produced in our sun. (D) ^{238}U can not be produced in the s-process, why?

   (d) The rate of energy-loss by a 10 MeV proton beam in a certain piece of material was found to be 23 MeV/cm. Use the Bethe-Bloch scaling to estimate the energy loss of a 240 MeV beam of $^{40}Ca^{20+}$ ions in the same piece of material.

   (e) One of the recent proposals by the US Dept. of Homeland Security is to replace the organic-based scintillators used to screen cargo trucks with inorganic (NaI) scintillators. This will be very expensive due to the difference in cost of material. What is the scientific basis for changing the material?

2. An estimate of the age of the material in the solar system can be made by assuming the relative amounts of ^{235}U and ^{238}U now (2.7x10^{-3} to 1, respectively) are the sole result of radioactive decay and that these two isotopes were originally produced in equal amounts. Hint: Set up one equation for the ratio of the number of atoms of ^{235}U to ^{238}U after a decay period.

3. The cross section for the ^{18}O(p,n) reaction is 0.30 barns. What is the activity of the ^{18}F product of this reaction if a sample of liquid water, 1mm thick, that is enriched to 100% ^{18}O is irradiated for 5.0 hours with a beam current of 0.50 μA? Recall that a current of 1 A = 1 Coulomb/second and the charge on a proton is 1.602x10^{-19} Coulombs.

4. A long story that was posted on the web that raises a few short questions.

   The question Posted on Web:

   Has Customs and Border Patrol (CBP) always had geiger counters at the customs checkpoint? When traveling back into the country with my father in late March, we were quickly pulled into a back room when we were approaching the desk to clear customs and asked if we had been in contact with any nuclear material recently. The CBP agents were all business and quite stern with us and basically tried the whole intimidation route. They told us that one of us tested positive for radioactive material and it then became apparent to me that it was my father who set it off because he had just had a cardiac perfusion test during which they inject radioactive isotopes that remain active in the body for a while. He had the test 7-8 days earlier. We explained this to the agents, and of course they asked for proof, of which we had none because this is not something we anticipated.

   The weird thing about this is I never saw a geiger counter anywhere. While in the back room, they used a device to determine what type of ionizing radiation my father was emitting (I guess to make sure it wasn't gamma waves he was emitting), but that was the only time I ever saw a geiger type machine. How did they localize the radiation to us while waiting in the customs queue? It was really crowded and the few times I've played with a geiger, the only way to determine the location of the radiation is to move closer to it which causes the geiger to become louder. I think I would have noticed someone closing in on me with a geiger. Has anyone else experienced anything else like this? Is this something new?

   The answer (sort-of) Posted on Web:

   They're at PVG [Shanghai], although without the intimidation. My wife set them off–a hoop that looks like the metal detector [probably not true] and then a second one at customs that looks like the theft-tag-detection pillars you see in many stores [probably true]. Note that if you know you're going to be traveling you ask for a card at the place that nuked you–they have a little thing that says how much of what isotope you got.

   We knew she would be slightly hot and got the card. She changed jackets at the last moment and left the card home. We got through LAS and SFO fine, it was only PVG that pinged and that was 10 half-lives after the test. They asked her about nuclear exposure, she immediately mentioned the test. No big deal, they didn't even attempt to isolate that it was her and not something she was carrying. We never left the vicinity of the detection machine and were on our way in a few minutes.

   (a) What isotope is used in heart perfusion studies? [Hint: I found a thallium isotope.]

   (b) What type of radiation was he emitting?

(c) By what factor is the activity reduced after 10 half-lives?

(d) How long is ten half-lives for this isotope?

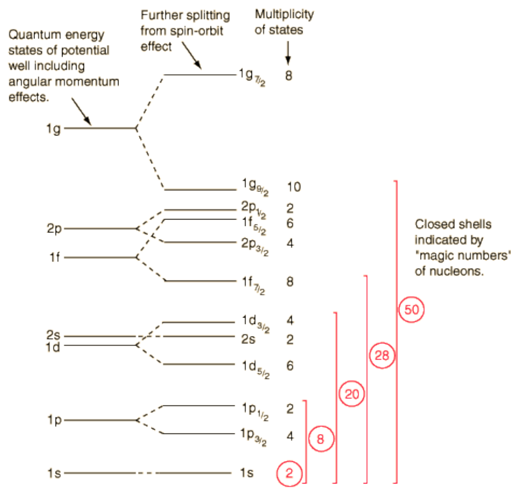

Table 1: Table of single particle decay rates for nuclear transitions.

Angular Momentum	Electric $\Delta\pi$	Electric $\lambda_{SP}(\text{s}^{-1})$	Magnetic $\Delta\pi$	Magnetic $\lambda_{SP}(\text{s}^{-1})$
1	yes	$1.03\text{x}10^{14}A^{2/3}E_{\gamma}^{3}$	no	$3.15\text{x}10^{13}E_{\gamma}^{3}$
2	no	$7.28\text{x}10^{7}A^{4/3}E_{\gamma}^{5}$	yes	$2.24\text{x}10^{7}A^{2/3}E_{\gamma}^{5}$
3	yes	$3.39\text{x}10^{1}A^{2}E\gamma^{7}$	no	$1.04\text{x}10^{1}A^{4/3}E_{\gamma}^{7}$
4	no	$1.07\text{x}10^{-5}A^{8/3}E_{\gamma}^{9}$	yes	$3.27\text{x}10^{-6}A^{2}E_{\gamma}^{9}$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H 1.0079																	2 He 4.0026
2	3 Li 6.939	4 Be 9.0122											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.183
3	11 Na 22.990	12 Mg 24.312											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.064	17 Cl 35.453	18 Ar 39.948
4	19 K 39.102	20 Ca 40.08	21 Sc 44.956	22 Ti 47.90	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.847	27 Co 58.933	28 Ni 58.71	29 Cu 63.54	30 Zn 65.37	31 Ga 69.72	32 Ge 72.59	33 As 74.922	34 Se 78.96	35 Br 79.909	36 Kr 83.80
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.905	40 Zr 91.22	41 Nb 92.906	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.90	46 Pd 106.4	47 Ag 107.87	48 Cd 112.40	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.90	54 Xe 131.30
6	55 Cs 132.90	56 Ba 137.34	*	72 Hf 178.49	73 Ta 180.95	74 W 183.85	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.09	79 Au 196.97	80 Hg 200.59	81 Tl 204.37	82 Pb 207.19	83 Bi 208.98	84 Po (210)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra (226)	**	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (265)	109 Mt (268)	110	111	112						

* Lathanides	57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.35	63 Eu 151.96	64 Gd 157.25	65 Tb 158.92	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
** Actinides	89 Ac (227)	90 Th 232.04	91 Pa 231.03	92 U 238.03	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

Potentially Useful Constants 26 Apr 10

$h = 6.626 \text{ x } 10^{-34}$ J sec — $c = 2.99792 \text{ x } 10^{8}$ m sec^{-1}

$N_A = 6.0221 \text{ x } 10^{23}$ mole^{-1} — hydrogen mass = $1.67263 \text{ x } 10^{-27}$ kg = 938.7906 MeV

1 MeV/c^2u = 931.50 — neutron mass = $1.67493 \text{ x } 10^{-27}$ kg = 939.5731 MeV

1. u = $1.6605 \text{ x } 10^{-27}$ kg — electron mass = $9.1094 \text{ x } 10^{-31}$ kg = 0.511 MeV

$e^2/4\pi\epsilon_0 = 1.439$ MeV-fm — electron charge = $1.60218 \text{ x } 10^{-19}$ Coul

$\epsilon_0 = 8.8542 \text{ x } 10^{-12}$Coulomb^2 J^{-1} m^{-1} — 1 eV = $1.602\text{x}10^{-19}$J

1 Ci = $3.7\text{x}10^{10}$ Bq, 1 Bq = 1/s — $k_B = 1.380\text{x}10^{-23}$J/K

1 yr = 365.25 d = 8766 hr = 525,960 m = $3.156\text{x}10^{7}$ s — $\hbar$ c = 197.49 MeV-fm

Potentially Useful Equations

$r = 1.2 \text{ fm } A^{1/3}$ — $V_{\text{sphere}} = 4\pi\ r^3/3$ — $A_{\text{sphere}} = 4\pi\ r^2$

$A = \lambda N$ — $\lambda = 1/\tau = ln2/T_{1/2}$ — $\lambda = 0.693/T_{1/2}$

$F(x) = -\frac{d}{dx}V(x)$ — $\rho(R) = \rho_0/(1 + e^{(r-R)/a})$

$F_{\text{coulomb}} = -q_1q_2e^2/4\pi\epsilon_0r^2$ — $V_{\text{coulomb}} = q_1q_2e^2/4\pi\epsilon_0 r$ — $V_{\text{coulomb}} = Z_1Z_2 1.439\text{MeVfm}/r$

$E = mc^2$ — $E^2_{\text{total}} = (m_0c^2)^2 + (pc)^2$ — $E_{\text{total}} = \gamma m_0c^2$

$\lambda_{\text{deB}} = h/p = h/mv$ — $p = m\ v$ — $T_{\text{nonRel}} = \frac{1}{2}\ m\ v^2 = p^2/2m$

$E_{\text{photon}} = h\ \nu$ — $\lambda\ \nu = c$ — $E_{\text{photon}} = p\ c$

$BE(Z,A) = [Z * M(^1H) + N * M(^1n) - M(Z,A)]c^2$ — $\Delta(Z,A) = M(Z,A) - A$

$BE(Z,A) = a_VA - a_SA^{2/3} - a_C\frac{Z^2}{A^{1/3}} - a_A\frac{(A-2Z)^2}{A} \pm \delta$ — $Z_A \approx \frac{A}{2}\frac{81}{80+0.6A^{2/3}}$

$\frac{dN_1}{dt} = -\lambda_1N_1$ — $N_1(t) = N_1^0e^{-\lambda_1t}$ — $A_1(t) = A_1^0e^{-\lambda_1t}$

$\frac{dN_2}{dt} = \lambda_1N_1 - \lambda_2N_2$ — $N_2(t) = \frac{\lambda_1}{\lambda_2-\lambda_1}N_1^0\left(e^{-\lambda_1t} - e^{-\lambda_2t}\right) + N_2^0e^{-\lambda_2t}$

$A_2 = R\left(1 - e^{-\lambda_2t}\right)$ — $R = \rho_A\sigma\phi$ — $\rho_A = \rho_n x$

continue

$\sigma_{Rxn} = \pi(R_1 + R_2)^2(1 - \frac{V_{Coul}}{E_{CMS}}) = \pi\left(\frac{(\ell_{max}+1)\lambda}{2\pi}\right)^2$

$\ell_{max} = \left[\frac{(R_1+R_2)}{\lambda/2\pi}\left(1 - \frac{V_{Coul}}{E_{CMS}}\right)^{1/2}\right] - 1$

$\mathrm{E_C^o/2E_S^o} = 1$

$Z^2/A = 49.1$

$\mathrm{R_1/R_2} = \rho_2\sqrt{\mathrm{A_1}}/\rho_1\sqrt{\mathrm{A_2}}$

$\frac{-\mathrm{dE}}{\mathrm{dx}} = \mathrm{S_{electronic}} + \mathrm{S_{nuclear-rxn}} + \mathrm{S_{nuclear-atomic}}$

$\frac{-\mathrm{dE}}{\mathrm{dx}} = \mathrm{K}\frac{\mathrm{Aq^2}}{\mathrm{E}}$

$\frac{-\mathrm{dE}}{\mathrm{dx}} = 0.3071\frac{\mathrm{MeV\ cm^2}}{\mathrm{g}}\rho\frac{\mathrm{Z_t q^2}}{\mathrm{A_t}\beta^2}\left[\ln\left(\frac{\mathrm{W_{max}}}{\mathrm{I}}\right) - \beta^2\right]$

$\mathrm{I = I_o e^{-\mu x}}, \mu = 1/\lambda$

$\mathrm{I = I_o e^{-\mu x}}, \rho\mu = 1/\mathrm{x_o}$

$\mathrm{I = I_o e^{-x/x_o}}$

$\mathrm{I = I_o e^{-\mu x}}, \mu = \rho_\mathrm{N}\sigma_\mathrm{Total}$