Chemistry 485

Spring, 2o1o — Final Exam

100 Points

Distributed: Mon., 3 May 2o1o, 12:45 — Due: Mon., 3 May 2o1o, 2:45 pm

The questions in this exam may require information that can be found in the attached figure, the table, or the equation sheet. Scored on 100 point basis, 10 pts. extra credit.

1. Ten Short Answers (5 points each).
   (a) What is the atomic number, Z, of the beta-stable isotope with A=101?
   (b) Write a (completely) balanced reaction for the β^+ decay of ^{50}Mn.
   (c) The half-life of ^{50}Mn is 0.28 seconds, and must be produced in a nuclear reaction each time it is needed. What fraction of a sample of ^{50}Mn will remain 1.00 second after it is produced?
   (d) Write a balanced nuclear reaction for the production of ^{50}Mn from the stable isotope ^{46}Ti with a ^{6}Li beam.
   (e) Make an estimate of the geometrical cross section for the reaction of ^{46}Ti with ^{6}Li.
   (f) Calculate the Coulomb barrier in the center of mass system for the reaction of ^{46}Ti with ^{6}Li.
   (g) The cross sections for ALL neutron induced reactions increase at very low energies with the same slope on a log-log graph. What is the underlying cause for this uniform increase in the cross sections for neutron induced reactions at very low energies.
   (h) Give an explanation for the enhanced stability of ^{4}He nuclei based on the simple shell model.
   (i) Make an estimate of the typical (or average) mass number of krypton fragments (before decay) produced by fission of ^{236}U.
   (j) What is the common feature of the three fissile nuclei: ^{233}U, ^{235}U, and ^{239}Pu that allows them to be fissionable with thermal neutrons that is distinctly different from ^{238}U, for example?

2. (20 points) The ^{201}Tl isotope is often used in a nuclear medical procedure to study blood flow in the heart. This nucleus has a nuclear angular momentum and parity of I=$1/2^+$ and decays by electron capture. The ground state nuclear angular momentum of the daughter (^{201}Hg) is I=$3/2^-$ The decay leads to a I=$1/2^-$ excited state at 0.167 MeV in the daughter. The decay of the excited state is observed as part of the blood flow study. (A) What is the lowest multipolarity and character of this transition from the excited state to the ground state in ^{201}Hg? (B) What is the single particle decay rate (/s) for this transition?

3. (20 points) The Fermi-2 nuclear power plant operates near Detroit with a typical thermal efficiency of approximately 30% to produce approximately 1100 MW of electrical power (MWe). (A) Make an estimate of the number of fission reactions occurring per second in the operating reactor if the thermal energy output is 195 MeV/fission of ^{236}U. (B) What is the mass of ^{235}U that is consumed by this reactor operating continuously for 1.00 year at the 1100 MWe power level?

4. (20 points total, 4 points each) Indicate whether each of the following questions about nuclear reactions in space is true or false.

   (a) The main reaction occurring in our Sun involves the production of positrons.

   (b) The Sun produces elements up to iron by nuclear reactions.

   (c) Most of the elements in the solar system were produced in one general nuclear reaction.

   (d) The s-process can only produce nuclei with Z $<$ 83 (bismuth) by the slow capture of neutrons.

   (e) The ratio of isotopes in two different chemical elements are often used to determine the age of meteorites and other objects in the solar system.

	1																	18
1	1 H 1.0079	2											13	14	15	16	17	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	3	4	5	6	7	8	9	10	11	12	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)

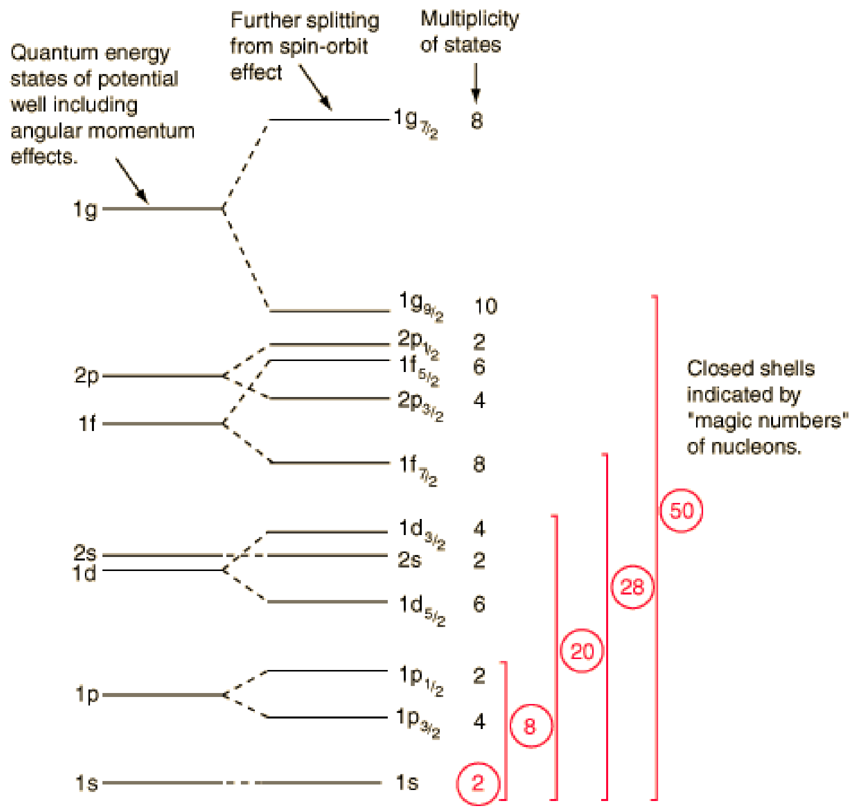

Table 1: Table of single particle decay rates for nuclear transitions, for an energy in MeV.

Angular Momentum	Electric $\Delta\pi$	Electric $\lambda_{SP}(\mathrm{s}^{-1})$	Magnetic $\Delta\pi$	Magnetic $\lambda_{SP}(\mathrm{s}^{-1})$
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	$3.27\text{x}10^{-6}A^{2}E_\gamma^9$

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^{2}u = 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 = 1.602x10^{-19}J

1 Ci = 3.7x10^{10} Bq, 1 Bq = 1/s

k_B = 1.380x10^{-23}J/K

1 yr = 365.25 d = 8766 hr = 525,960 m = 3.156x10^7 s

$\hbar$ c = 197.49 MeV-fm

Potentially Useful Equations

$r = 1.2 \text{ fm } A^{1/3}$

$V_{sphere} = 4\pi \, r^3/3$

$A_{sphere} = 4\pi \, r^2$

$A = \lambda N$

$\lambda = 1/\tau = ln2/T_{1/2}$

$\lambda = 0.693/T_{1/2}$

$F(x) \; = \; -\frac{d}{dx}V(x)$

$\rho(R) = \rho_0/(1 + e^{(r-R)/a})$

$F_{coulomb} = -q_1q_2e^2/4\pi\epsilon_0 r^2$

$V_{coulomb} = q_1q_2e^2/4\pi\epsilon_0 r$

$V_{coulomb} = Z_1Z_2 1.439 \text{MeVfm}/r$

$E = mc^2$

$E^2_{total} = (m_0c^2)^2 + (pc)^2$

$E_{total} = \gamma m_0 c^2$

$\lambda_{deB} = h/p = h/mv$

$p = m \, v$

$T_{nonRel} \; = \; \frac{1}{2} \, m \, v^2 \; = \; p^2/2m$

$E_{photon} = h \, \nu$

$\lambda \, \nu = c$

$E_{photon} \; = \; p \, c$

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

$\Delta(Z, A) = M(Z, A) - A$

$BE(Z, A) = a_V A - a_S A^{2/3} - a_C \frac{Z^2}{A^{1/3}} - a_A \frac{(A-2Z)^2}{A} \pm \delta$

$Z_A \approx \frac{A}{2} \frac{81}{80+0.6A^{2/3}}$

$\frac{dN_1}{dt} = -\lambda_1 N_1$

$N_1(t) = N^0_1 e^{-\lambda_1 t}$

$A_1(t) = A^0_1 e^{-\lambda_1 t}$

$\frac{dN_2}{dt} = \lambda_1 N_1 - \lambda_2 N_2$

$N_2(t) = \frac{\lambda_1}{\lambda_2-\lambda_1} N^0_1 \left(e^{-\lambda_1 t} - e^{-\lambda_2 t}\right) + N^0_2 e^{-\lambda_2 t}$

$A_2 = R\left(1 - e^{-\lambda_2 t}\right)$

$R = \rho_A \sigma \phi$

$\rho_A = \rho_n x$

continue

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

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

$\mathrm{E^o_C/2E^o_S} = 1$ $Z^2/A = 49.1$ $\mathrm{R_1/R_2} = \rho_2\sqrt{\mathrm{A_1}}/\rho_1\sqrt{\mathrm{A_2}}$

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

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

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

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

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