Exam 4C
Chem 1142
Spring 2015

Name: KEY

Multiple Choice. [3 pts ea.] Choose the best response on the scantron sheet. [**66 pts total.**]

Q1. The second law of thermodynamics states:
a) The entropy of the universe is always decreasing
b) The energy of the universe is a constant
c) The entropy of a perfect crystalline substance at absolute zero is 0
d) The entropy of the universe is always increasing
e) The free energy change for a spontaneous process is positive

Q2. The following substance is likely to have the *lowest* entropy at 25 °C:
a) $H_2O(l)$ b) $H_2(g)$ c) $F_2(g)$ d) $C_6H_{12}O_6(s)$ e) $Na(s)$

small, uncomplicated SOLID.

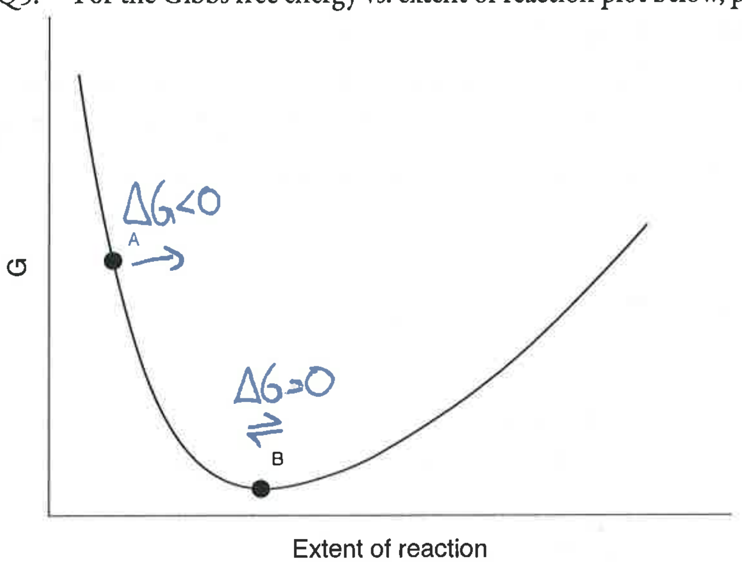
Q3. Which of the following processes is likely to have $\Delta S > 0$?
a) $H_2O(l) \rightarrow H_2O(s)$ b) $N_2H_4(l) + O_2(g) \rightarrow N_2(g) + 2H_2O(g)$
c) $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$ d) $H_2O(g) \rightarrow H_2O(s)$
e) $Na(l) \rightarrow Na(s)$

surr gain heat!

$\Delta S_{surr} = \frac{q}{T} = \frac{+1500\,J}{298\,K} = +5.0\,J/K$

Q4. A reaction gives off 1500 J of heat at a temperature of 25 °C. What is ΔS_{surr}?
a) +60. J/°C b) −60. J/°C c) +5.0 J/K d) −5.0 J/K e) 0

Q5. For the Gibbs free energy vs. extent of reaction plot below, points A and B correspond to:



a) A = spontaneous forwards reaction, B = equilibrium
b) A = non-spontaneous forward reaction, B = equilibrium
c) A = spontaneous reverse reaction, B = spontaneous forwards reaction

d) A = spontaneous reverse reaction, B = spontaneous reverse reaction
e) A = non-spontaneous forward reaction, B = spontaneous reverse reaction

Q6. Not only does ΔG tell us whether a reaction is spontaneous or not, it is tells us:
a) the maximum amount of heat released
b) the maximum amount of useful work
c) the maximum amount of temperature produced
d) the maximum amount of entropy produced
e) the maximum value of the equilibrium constant

Q7. For which of the following reactions would $\Delta G^\circ = \Delta G_f^\circ$ ($NH_3(g)$)?
a) $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$
b) $2NH_3(g) + 3O_2(g) \rightarrow N_2(g) + 6H_2O(l)$
c) $N(g) + 3H(g) \rightarrow NH_3(g)$
d) $\frac{1}{2} N_2H_6(g) \rightarrow NH_3(g)$
e) $\frac{1}{2} N_2(g) + \frac{3}{2} H_2(g) \rightarrow NH_3(g)$

Q8. Which reaction conditions below correspond to a reaction that is *spontaneous* at low temperature:

Conditions	ΔH	ΔS
1.	+ve	+ve
2.	–ve	–ve
3.	+ve	–ve
4.	–ve	+ve

a) 1 only
b) 2 only
c) 4 only
d) 2 and 4
e) 1 and 3

Q9. At what temperature will a reaction with $\Delta H^\circ = +3.4$ kJ/mol and $\Delta S^\circ = +23$ J/mol·K become spontaneous?
a) It is always spontaneous
b) It is always non-spontaneous
c) 0.15 K
d) 150 K
e) 6.8 K

Q10. A reaction has $\Delta G^\circ = -5.0$ kJ/mol at a temperature of 25 °C. The equilibrium constant at this temperature is:
a) 2.5
b) 7.5
c) 240
d) 2.8×10^{10}
e) 6.3×10^{88}

Q11. A reaction has $\Delta G^\circ = -5.0$ kJ/mol at a temperature of 25 °C. If the reaction is at equilibrium ($Q = K$), then ΔG is equal to:
a) +5.0 kJ/mol
b) –5.0 kJ/mol
c) 0 kJ/mol
d) $\Delta H/T$
e) $-\Delta H/T$

Q12. A chemical reaction has an equilibrium constant of 12.9 at a temperature of 25 °C. ΔG° for this reaction is:
a) –6.34 kJ/mol
b) +1.9 kJ/mol
c) –63 J/mol
d) –5.3 J/mol
e) +23 J/K

Q13. Which combination of chemical equations below would give rise to an overall equation with a *large* equilibrium constant?

i) $A + B \rightarrow C$ $\quad \Delta G^\circ = +3.0$ kJ/mol
ii) $D \rightarrow E + F$ $\quad \Delta G^\circ = +12.0$ kJ/mol
iii) $G + H \rightarrow I + J$ $\quad \Delta G^\circ = -9.0$ kJ/mol

a) ii and iii
b) i and ii
c) i and iii
d) i, ii, and iii
e) no combinations of i, ii, and iii will give rise to an overall equation with a large equilibrium constant

Q14. What's the oxidation number of S in $S_2O_6^{2-}$?
a) +2
b) +3
c) + 4
d) + 5
e) + 6

Q15. In a galvanic cell, electrons flow from:
a) anode to cathode
b) electrode to solution
c) solution to salt-bridge
d) cathode to salt-bridge
e) cathode to anode

Q16. The purpose of a salt-bridge in a galvanic cell is:

a) to conduct electrons from one solution to the other
b) to conduct electrons from the electrodes to the solutions
c) to keep the solutions electrically neutral
d) to couple with the cell reactions to make them spontaneous
e) to prevent the pH of the solutions from changing

Q17. Predict the cell voltage produced in the following galvanic cell:

$Pb(s) \mid Pb^{2+}(aq, 1M) \parallel Ag^{+}(aq, 1M) \mid Ag(s)$

$E^\circ_{cell} = E^\circ_{Ag^+/Ag} - E^\circ_{Pb^{2+}/Pb} = +0.80V - -0.13V = +0.93V$

a) 0.67 V b) −0.67 V c) 0.93 V d) +1.47 V e) +1.73 V

Q18. Using the table of standard reduction potentials on the back page, predict which of the following chemical equations will be spontaneous under standard conditions:

i) $2Ag + Cu^{2+} \rightarrow Cu + 2Ag^{+}$ ✗
ii) $Zn + Cu^{2+} \rightarrow Cu + Zn^{2+}$ ✓
iii) $2Au + 3Cu^{2+} \rightarrow 3Cu + 2Au^{3+}$ ✗

$Au^{3+} + 3e^- \rightarrow Au$ $E^\circ = +1.50V$
$Ag^+ + e^- \rightarrow Ag$ $E^\circ = +0.80V$
$Cu^{2+} + 2e^- \rightarrow Cu$ $E^\circ = +0.34V$
$Zn^{2+} + 2e^- \rightarrow Zn$ $E^\circ = -0.76V$

more likely →
more likely ←

a) i only b) ii only c) iii only d) i and ii only e) ii and iii only

Q19. A reaction with a large and positive value of ΔG° will have:

$\Delta G^\circ = -nFE^\circ_{cell}$

a) a positive value of E_{cell}° as well as a negative equilibrium constant
b) a positive value of E_{cell}° as well as a small equilibrium constant
c) a positive value of E_{cell}° as well as a large equilibrium constant
d) a negative value of E_{cell}° as well as a negative equilibrium constant
e) a negative value of E_{cell}° as well as a small equilibrium constant

$\Delta G^\circ = -RT\ln K$, $K = e^{-\Delta G^\circ/RT}$ (≪ 1)

Q20. The cell $Zn|Zn^{2+}(aq)||Ag^{+}(aq)|Ag(s)$ has a cell voltage under standard conditions of E_{cell}°. If the concentration of Ag^{+} ions is reduced to 0.010 M, the cell voltage will become:

$E = E^\circ - \frac{RT}{nF}\ln Q$

a) larger b) smaller c) opposite in sign d) no change e) impossible to predict

Q21. An electrochemical cell that consumes electrical energy in order to drive an otherwise non-spontaneous reaction is known as:

a) Electrolytic cell b) Voltaic cell c) Battery d) Fuel cell e) Galvanic cell

Q22. How many moles of electrons flow when a current of 30. Amps flows for 1.0 hour?

a) 1.1 mol b) 1800 mol c) 0.019 mol d) 3.1×10^{-4} mol e) 30. mol

$Q = I \cdot t$
$= \frac{30C}{s} \times 1.0h \times \frac{3600s}{1h} = 108,000C$

mol e^-?

$108,000C \times \frac{1 mol e^-}{96,500C} = 1.1 mol$

$Zn \rightarrow Zn^{2+} + 2e^-$
$2(e^- + Ag^+ \rightarrow Ag)$

$Zn + 2Ag^+ \rightarrow Zn^{2+} + 2Ag$

$Q = \frac{[Zn^{2+}]}{[Ag^+]^2}$

if $[Ag^+]\downarrow$, $Q\uparrow$, $\ln Q\uparrow$, $E\downarrow$

$E = E^\circ - \frac{RT}{nF}\ln Q$

Short Response.
Show ALL work to receive credit.

Q23. [9 pts.] Calculate $\Delta G°$, $\Delta H°$, $\Delta S°$, and K for the following reaction at a temperature of –35 °C:

$$2N_2(g) + O_2(g) \rightarrow 2N_2O(g)$$

Substance	$\Delta H°_f$ (kJ/mol)	$S°$ (J/mol·K)
$N_2(g)$	0	191.5
$O_2(g)$	0	205.0
$N_2O(g)$	81.6	220.0

$\Delta H° = \sum \Delta H_f°(\text{Prods}) - (\text{Reacts})$

$= [2 \times 81.6\ \text{kJ/mol}] - [2\times 0 + 1\times 0] = +163.2\ \text{kJ/mol}$ 2

$\Delta S° = \sum S°(\text{Prods}) - (\text{Reacts})$

$= [2\times 220.0\ \text{J/mol·K}] - [2\times 191.5\ \text{J/mol·K} + 1\times 205.0\ \text{J/mol·K}]$

$= -148.0\ \text{J/mol·K}$ 2

$\Delta G° = \Delta H° - T\Delta S°$

$T = -35 + 273 = 238\text{K}$ 1

$\Delta G° = 163.2\ \frac{\text{kJ}}{\text{mol}} - 238\text{K} \times -0.1480\ \frac{\text{kJ}}{\text{mol·K}}$

$= +198.4\ \text{kJ/mol}$ 2

$\Delta G° = -RT\ln K$

$\Rightarrow \ln K = -\frac{\Delta G°}{RT}$

$\Rightarrow K = e^{-\Delta G°/RT} = e^{\frac{-198{,}400\ \text{J/mol}}{8.3145\ \frac{\text{J}}{\text{mol·K}} \times 238\text{K}}} = 2.87\times 10^{-44}$ 2

(small!!)

Q24. [8 pts.] Balance the following redox equation using the half-reaction method:

$\overset{0}{Se} + \overset{+3}{Cr}(OH)_3 \rightarrow \overset{0}{Cr} + \overset{+4}{Se}O_3^{2-}$ (BASIC conditions)

red: $Cr(OH)_3 \rightarrow Cr$; ox: $Se \rightarrow SeO_3^{2-}$

$(3e^- + 3H^+ + Cr(OH)_3 \rightarrow Cr + 3H_2O) \times 4$ +2 ✓ +2

$(3H_2O + Se \rightarrow SeO_3^{2-} + 6H^+ + 4e^-) \times 3$ +2

$12H^+ + 4Cr(OH)_3 + 9H_2O + 3Se \xrightarrow{12e^-} 4Cr + 12H_2O + 3SeO_3^{2-} + 18H^+$

$\Rightarrow 4Cr(OH)_3 + 3Se + 6OH^- \rightarrow 4Cr + 3H_2O + 3SeO_3^{2-} + 6H^+ + 6OH^- \rightarrow + 6H_2O$

OH⁻ +2

$\Rightarrow$

$$4Cr(OH)_3 + 3Se + 6OH^- \rightarrow 4Cr + 9H_2O + 3SeO_3^{2-}$$

balances ✓

Q25. [9 pts.] Calculate $E°_{cell}$, E_{cell}, and K for the following cell at 25 °C.

$Ni(s)|Ni^{2+}(aq, 0.10\ M)||Cr^{3+}(aq, 0.0050\ M)|Cr(s)$

Hint: be sure to write out the balanced chemical equation before you calculate E_{cell}!

$(Ni \rightarrow Ni^{2+} + 2e^-) \times 3$

$(3e^- + Cr^{3+} \rightarrow Cr) \times 2$

$3Ni + 2Cr^{3+} \xrightarrow{6e^-} 3Ni^{2+} + 2Cr$ (2)

$Q = [Ni^{2+}]^3 / [Cr^{3+}]^2$

$= 0.10^3 / 0.0050^2 = 40.$

$E°_{cell} = E°_{Cr^{3+}/Cr} - E°_{Ni^{2+}/Ni}$

$= -0.74V - (-0.25V)$

$= -0.49V$ (2)

$E = E° - \frac{RT}{nF} \ln Q$ (2)

$= -0.49V - \frac{8.3145 J/mol \cdot K \times 298K}{6 \times 96{,}500\ C/mol} \cdot \ln 40.$

$= -0.49V - 0.016V$

$= -0.506V$ (1)

$E°_{cell} = \frac{RT}{nF} \ln K \Rightarrow \ln K = \frac{nFE°_{cell}}{RT}$

$\Rightarrow K = e^{nFE°_{cell}/RT}$ (2)

$\Rightarrow K = e^{\frac{6 \times 96{,}500 C/mol \times -0.49V}{8.3145 J/mol \cdot K \times 298K}} = 1.87 \times 10^{-50}$

Q26. [8 pts.] Molten Fe_2O_3 is electrolyzed for 24-hours using a current of 1200 A. Predict the mass of Fe formed.

$2Fe_2O_3 \rightarrow 4Fe + 3O_2$

$12e^- + 4Fe^{3+} \rightarrow 4Fe$ or $3e^- + Fe^{3+} \rightarrow Fe$ 2

$Q = It = 1200 \frac{C}{s} \times 24 h \times \frac{60 min}{1 h} \times \frac{60 s}{1 min} = 1.03 \times 10^8 C$ 2

mol e^-

$1.03 \times 10^8 C \times \frac{1 mol\ e^-}{96{,}500 C} = 1.07 \times 10^3 mol\ e^-$ 2

g Fe

$1.07 \times 10^3 mol\ e^- \times \frac{4 mol\ Fe}{12 mol\ e^-} \times \frac{55.85 g\ Fe}{1 mol\ Fe} = 2.0 \times 10^4 g\ Fe$ 2

$= 20.$ Kg

Useful Information

Table 19.1 Standard Reduction Potentials at 25°C*

Half-Reaction	$E°$(V)
$F_2(g) + 2e^- \longrightarrow 2F^-(aq)$	+2.87
$O_3(g) + 2H^+(aq) + 2e^- \longrightarrow O_2(g) + H_2O$	+2.07
$Co^{3+}(aq) + e^- \longrightarrow Co^{2+}(aq)$	+1.82
$H_2O_2(aq) + 2H^+(aq) + 2e^- \longrightarrow 2H_2O$	+1.77
$PbO_2(s) + 4H^+(aq) + SO_4^{2-}(aq) + 2e^- \longrightarrow PbSO_4(s) + 2H_2O$	+1.70
$Ce^{4+}(aq) + e^- \longrightarrow Ce^{3+}(aq)$	+1.61
$MnO_4^-(aq) + 8H^+(aq) + 5e^- \longrightarrow Mn^{2+}(aq) + 4H_2O$	+1.51
$Au^{3+}(aq) + 3e^- \longrightarrow Au(s)$	+1.50
$Cl_2(g) + 2e^- \longrightarrow 2Cl^-(aq)$	+1.36
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \longrightarrow 2Cr^{3+}(aq) + 7H_2O$	+1.33
$MnO_2(s) + 4H^+(aq) + 2e^- \longrightarrow Mn^{2+}(aq) + 2H_2O$	+1.23
$O_2(g) + 4H^+(aq) + 4e^- \longrightarrow 2H_2O$	+1.23
$Br_2(l) + 2e^- \longrightarrow 2Br^-(aq)$	+1.07
$NO_3^-(aq) + 4H^+(aq) + 3e^- \longrightarrow NO(g) + 2H_2O$	+0.96
$2Hg^{2+}(aq) + 2e^- \longrightarrow Hg_2^{2+}(aq)$	+0.92
$Hg_2^{2+}(aq) + 2e^- \longrightarrow 2Hg(l)$	+0.85
$Ag^+(aq) + e^- \longrightarrow Ag(s)$	+0.80
$Fe^{3+}(aq) + e^- \longrightarrow Fe^{2+}(aq)$	+0.77
$O_2(g) + 2H^+(aq) + 2e^- \longrightarrow H_2O_2(aq)$	+0.68
$MnO_4^-(aq) + 2H_2O + 3e^- \longrightarrow MnO_2(s) + 4OH^-(aq)$	+0.59
$I_2(s) + 2e^- \longrightarrow 2I^-(aq)$	+0.53
$O_2(g) + 2H_2O + 4e^- \longrightarrow 4OH^-(aq)$	+0.40
$Cu^{2+}(aq) + 2e^- \longrightarrow Cu(s)$	+0.34
$AgCl(s) + e^- \longrightarrow Ag(s) + Cl^-(aq)$	+0.22
$SO_4^{2-}(aq) + 4H^+(aq) + 2e^- \longrightarrow SO_2(g) + 2H_2O$	+0.20
$Cu^{2+}(aq) + e^- \longrightarrow Cu^+(aq)$	+0.15
$Sn^{4+}(aq) + 2e^- \longrightarrow Sn^{2+}(aq)$	+0.13
$2H^+(aq) + 2e^- \longrightarrow H_2(g)$	0.00
$Pb^{2+}(aq) + 2e^- \longrightarrow Pb(s)$	−0.13
$Sn^{2+}(aq) + 2e^- \longrightarrow Sn(s)$	−0.14
$Ni^{2+}(aq) + 2e^- \longrightarrow Ni(s)$	−0.25
$Co^{2+}(aq) + 2e^- \longrightarrow Co(s)$	−0.28
$PbSO_4(s) + 2e^- \longrightarrow Pb(s) + SO_4^{2-}(aq)$	−0.31
$Cd^{2+}(aq) + 2e^- \longrightarrow Cd(s)$	−0.40
$Fe^{2+}(aq) + 2e^- \longrightarrow Fe(s)$	−0.44
$Cr^{3+}(aq) + 3e^- \longrightarrow Cr(s)$	−0.74
$Zn^{2+}(aq) + 2e^- \longrightarrow Zn(s)$	−0.76
$2H_2O + 2e^- \longrightarrow H_2(g) + 2OH^-(aq)$	−0.83
$Mn^{2+}(aq) + 2e^- \longrightarrow Mn(s)$	−1.18
$Al^{3+}(aq) + 3e^- \longrightarrow Al(s)$	−1.66
$Be^{2+}(aq) + 2e^- \longrightarrow Be(s)$	−1.85
$Mg^{2+}(aq) + 2e^- \longrightarrow Mg(s)$	−2.37
$Na^+(aq) + e^- \longrightarrow Na(s)$	−2.71
$Ca^{2+}(aq) + 2e^- \longrightarrow Ca(s)$	−2.87
$Sr^{2+}(aq) + 2e^- \longrightarrow Sr(s)$	−2.89
$Ba^{2+}(aq) + 2e^- \longrightarrow Ba(s)$	−2.90
$K^+(aq) + e^- \longrightarrow K(s)$	−2.93
$Li^+(aq) + e^- \longrightarrow Li(s)$	−3.05

Useful Information

$N_A = 6.022 \times 10^{23}\ \text{mol}^{-1}$

Given: $ax^2 + bx + c$, then $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

$K_w = [H_3O^+][OH^-] = 1.0 \times 10^{-14}$ at 25 °C.

$\text{pH} = -\log[H_3O^+]$

$\text{pH} + \text{pOH} = 14.00$ (at 25 °C)

$K_aK_b = K_w$

$R = 8.3145\ \text{J/mol·K} = 0.08206\ \text{L·atm/mol·K}$

$$\text{pH} = \text{p}K_a + \log\frac{[\text{Base}]}{[\text{Acid}]}$$

$M_1V_1 = M_2V_2$

$\Delta G = -nFE_{cell}$

$\Delta G^o = -nFE^o_{cell}$

$$E^o_{cell} = \frac{RT}{nF}\ln K$$

$$E_{cell} = E^o_{cell} - \frac{RT}{nF}\ln Q$$

$E^o_{cell} = E^o_{cathode} - E^o_{anode}$

$F = 96{,}500\ \text{C/mol e}^-$

$1\ \text{V} = 1\ \text{J/C}$

$R = 8.3145\ \text{J·mol}^{-1}\text{·K}^{-1}$

$Q\ (\text{charge}) = I \cdot t$

$\Delta G = \Delta H - T\Delta S$

$\Delta S_{surr} = q_{surr}/T$

$\Delta G = \Delta G^o + RT\ln Q$

$\Delta G^o = -RT\ln K$

Periodic Table of the Elements

IA 1	IIA 2	3	4	5	6	7	8	9	10	11	12	IIIA 13	IVA 14	VA 15	VIA 16	VIIA 17	VIIIA 18
1 H 1.01																	2 He 4.00
3 Li 6.94	4 Be 9.01											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.61	33 As 74.92160	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc [98]	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29
55 Cs 132.91	56 Ba* 137.33	71 Lu 174.97	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.20	83 Bi 208.98	84 Po [210]	85 At [210]	86 Rn [222]
87 Fr [223]	88 Ra** [226]	103 Lr [262]	104 Rf [261]	105 Db [262]	106 Sg [266]	107 Bh [264]	108 Hs [265]	109 Mt [268]	110 [269]	111 [272]	112 [277]	113	114 [285]	115	116 [289]	117	118 [293]

*	57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm [145]	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04
**	89 Ac [227]	90 Th 232.04	91 Pa 231.04	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]