LAST NAME: ____

FIRST NAME: ____

Student Number: ____

CHM 1311 A
Midterm #2 A
Fall 2014

Please keep your work covered at all times and keep your eyes on your own paper! Cheating or any appearance of cheating will result in an F in the course and possible expulsion from the university.

There are 10 pages in this test. A periodic table, data tables, and a formula sheet are provided at the end. You may gently remove these pages off and use them to cover your work. Any scratch work should be done on the back of these pages.

Please show all work to receive partial credit.

You have 80 minutes to complete the test.

Question	Points Possible	Points Earned	TA Initial
1	20		
2	10		
3	10		
4	10		
5	10		
TOTAL	50		

1. (10 pts) Short Answer Questions

a. For the majority of reactions, reaction rate is fastest when: Using $k = Ae^{-Ea/RT}$

E_a high, T low E_a high, T high E_a low, T low E_a low, T high

b. Benzoic acid is titrated with sodium hydroxide. At the equivalence point, the pH will be:

ACIDIC NEUTRAL BASIC IMPOSSIBLE TO PREDICT

At the EQ PT: benzoate ion hydrolyzes: $C_6H_5COO^- + H_2O \leftrightarrows C_6H_5COOH + OH^-$

c. The steady-state assumption states that intermediates are consumed at a constant rate.

TRUE FALSE

It states that intermediates are PRODUCED and CONSUMED at EQUAL RATES.

d. For the reaction $2\,A \leftrightarrows B + 3\,C$ the value of K is 44.5 at 25°C. The value of K for the reaction $2\,B + 6\,C \leftrightarrows 4\,A$ would be ____$K' = 1/K^2 = 5.05\text{x}10^{-4}$_________________.

e. Predict the products of the following acid-base reaction. Is K > or < 1?

$N_3^- + HF \leftrightarrows$ __HN_3 + F^-______________ K > 1 K < 1

$K_a = 6.6 \text{ x } 10^{-4}$ $K_a = 1.9 \text{ x } 10^{-5}$

f. For a second order reaction, the plot of _____1/concentration___________ versus time will yield a straight line, with a slope equal to ____k______; its unit is ____$M^{-1}s^{-1}$_______.

g. A chemical equilibrium can be considered to be "going to completion" when the value of K is at least 10^{-10} 10^{-5} 10 10^5 or greater.

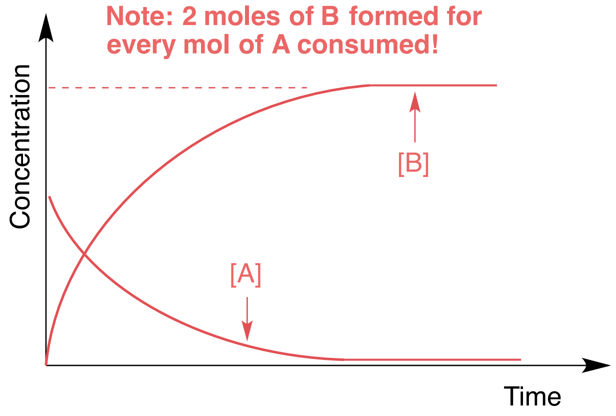
h. The conjugate acid and conjugate base of HPO_4^{2-} are ______ $H_2PO_4^-$ ___________ and ________ PO_4^{3-} ________ respectively.

BONUS:

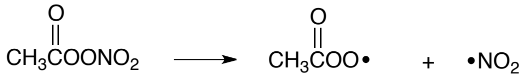
Draw representative concentration lines/curves for both A and B as a function of time in the following first-order decomposition:

$$A \rightarrow 2\,B$$

Don't forget to label your lines/curves!


Note: 2 moles of B formed for every mol of A consumed!

2. Peroxyacetyl nitrate (PAN) is an air pollutant produced during photochemical smog events. PAN is unstable and dissociates into peroxyacetyl radicals and nitrogen dioxide.



$$CH_3\overset{\overset{O}{\|}}{C}OONO_2 \longrightarrow CH_3\overset{\overset{O}{\|}}{C}OO\bullet \quad + \quad \bullet NO_2$$

PAN

NOTE: THIS IS TAKEN FROM MIDTERM 2 2012

a) (3 pts) Using the data in the table below, derive a rate law for the decomposition of PAN at 25.0°C, as well as the value of the rate constant (with appropriate units).

Trial	Initial [PAN] (M)	Initial Rate (M/min)
1	8.30×10^{-10}	1.92×10^{-11}
2	1.66×10^{-9}	3.84×10^{-11}
3	2.49×10^{-9}	5.78×10^{-11}

Or: **Trials 1 & 2: [PAN] x 2 → rate x 2**
Trials 1 & 3: [PAN] x 3 → rate x 3

∴ rate = k[PAN] (it's first order)

$$k = \frac{\text{rate}}{[\text{PAN}]} = \frac{1.92 \times 10^{-11}\text{M} \cdot \text{min}^{-1}}{8.30 \times 10^{-10}\text{M}} = 2.31 \times 10^{-2}\ \text{min}^{-1}$$

Rate law is: ___**rate = k[PAN]**__________

Rate constant is: ___**k = 0.0231 min^{-1}**________

b) (2 pts) The decomposition of PAN has a half-life of 35.0 hr at 0.00°C. What is the rate constant for this reaction at this temperature? Use the same units as part (a).

It's first order, so:

$$t_{1/2} = \frac{\ln 2}{k} \qquad \therefore k = \frac{\ln 2}{t_{1/2}} = \frac{\ln 2}{35.0\ \text{hr}} \bullet \frac{1\ \text{hr}}{60\ \text{min}} = 3.30 \times 10^{-4}\ \text{min}^{-1}$$

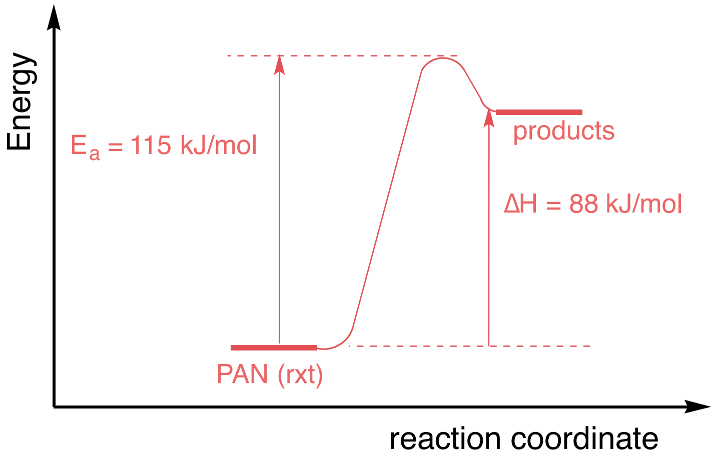
c) (3 pts) What is the activation energy, in kJ/mol, for this reaction?

$k_1 = 2.31 \times 10^{-2}$ min^{-1} @ $T_1 = 298$ K
$k_2 = 3.30 \times 10^{-4}$ min^{-1} @ $T_2 = 273$ K

$$\ln\left(\frac{k_2}{k_1}\right) = -\frac{E_a}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right) \quad \Rightarrow \quad \ln\left(\frac{3.30 \times 10^{-4}\text{min}^{-1}}{2.31 \times 10^{-2}\text{min}^{-1}}\right) = -\frac{E_a}{8.3145\text{J} \cdot \text{mol}^{-1}\text{K}^{-1}}\left(\frac{1}{273\text{K}} - \frac{1}{298\text{K}}\right)$$

Solve for E_a:
$E_a = 1.15 \times 10^5$ J/mol = 115 kJ/mol

d) (2 pts) The enthalpy for the decomposition of PAN is about 88 kJ/mol. On the axes provided, draw a representative reaction profile for this reaction, *with labels*.



3. Rick Grimes and his group of survivors are dealing with a major lack of resources in the zombie apocalypse. Their current water source is contaminated and needs to be treated with chlorine to be disinfected. Eugene suggests they produce the needed chlorine *via* the gas-phase electrolysis of salt:

$$2\ NaCl\ (g) \leftrightarrows 2\ Na(g) + Cl_2(g)$$

a) (6 pts) The above reaction is carried out at 750 K using 1.25 kg of salt in a 35.0 L reaction vessel. If only 0.120 kg of chlorine gas is obtained at equilibrium, what is the value of K_C at this temperature?

THIS IS JUST A TYPE 1 EQUILIBRIUM PROBLEM

$$\frac{?\ \text{initial mol NaCl}}{\text{L}} = 1.25\ \text{kg} \times \frac{1000\ \text{g}}{1\ \text{kg}} \times \frac{\text{mol NaCl}}{58.44\ \text{g NaCl}} \times \frac{1}{35.0\ \text{L}} = 0.6111\ \text{mol/L NaCl initial}$$

$$\frac{?\ \text{EQM mol Cl}_2}{\text{L}} = 0.120\ \text{kg} \times \frac{1000\ \text{g}}{1\ \text{kg}} \times \frac{\text{mol Cl}_2}{70.90\ \text{g Cl}_2} \times \frac{1}{35.0\ \text{L}} = 0.0484\ \text{mol/L Cl}_2\ @\ \text{EQM}$$

	$2\ NaCl\ (g)$ $\leftrightarrows$	$2\ Na(g)$ +	$Cl_2(g)$
I	0.6111	0	0
C	$-2x$	$+2x$	$+x$
	-2(0.0484)	+2(0.0484)	+0.0484
E	0.5143	0.0968	0.0484

$$K_C = \frac{[Na]^2[Cl_2]}{[NaCl]^2} = \frac{(0.0968)^2(0.0484)}{(0.5143)^2} = 1.71x10^{-3}$$

Answer = ______________________

b) (2 pts) What is the value of K_P at 750 K?

$$K_P = K_C(RT)^{\Delta n_{gas}} = (1.71x10^{-3})(0.083145 \times 750)^{3-2} = 0.107$$

Answer = _____0.107_____

c) (2 pts)The equilibrium mixture from part (a) is transferred to a 20.0 L container. What is the qualitative effect on the value of K_C? Explain, in one or two sentences.

The volume of the new container is SMALLER than the volume of the original container. This means that the equilibrium will shift to the side that contains FEWER gas particles (to accommodate the decrease in available space). In this case, the equilibrium will shift to the LEFT and so K will DECREASE.

4. **You wish to determine the pH of a 0.0200 M solution of NH_4NO_2.**

THIS QUESTION WAS COVERED IN DGD#9

a) **(2 pts) The K_b of ammonia is 1.8x10^{-5}. What is the K_a value of its conjugate acid?**

$$K_a = \frac{K_W}{K_b} = \frac{1.0x10^{-14}}{1.8x10^{-5}} = 5.56x10^{-10}$$

Answer = ______________________

b) **(6 pts) Determine the $[H_3O^+]$ and $[OH^-]$ produced by the hydrolysis (if any) of 0.0200 M NH_4NO_2.**

Both ions will hydrolyze, so two ICE tables are necessary:

	NH_4^+ +	H_2O ⇆	H_3O^+ +	NH_3
I	0.0200	-	0	0
C	$-x$	-	$+x$	$+x$
E	$0.0200 - x$	-	x	x

$$K_a = \frac{[H_3O^+][NH_3]}{[NH_4^+]}$$

$$5.56x10^{-10} = \frac{x^2}{0.0200 - x} \approx \frac{x^2}{0.0200}$$

$$\therefore x \approx 3.33\text{x}10^{-6}\ M = [H_3O^+]$$

$$\text{Check: } \frac{3.33\text{x}10^{-6}}{0.0200} \times 100\% = 0.02\% \longrightarrow \text{PASSES}$$

	NO_2^- +	H_2O ⇆	OH^- +	HNO_2
I	0.0200	-	0	0
C	$-x$	-	$+x$	$+x$
E	$0.0200 - x$	-	x	x

$$K_b = \frac{K_W}{K_a} = \frac{[OH^-][HNO_2]}{[NO_2^-]}$$

$$\frac{1.0x10^{-14}}{7.2x10^{-4}} = \frac{x^2}{0.0200 - x} \approx \frac{x^2}{0.0200}$$

$$\therefore x \approx 5.27\text{x}10^{-7}\ M = [OH^-]$$

$$\text{Check: } \frac{5.27\text{x}10^{-7}}{0.0200} \times 100\% = 0.003\% \longrightarrow \text{PASSES}$$

$[H_3O^+]$ = ____3.33x10^{-6} M_______ $[OH^-]$ = ___5.27x10^{-7} M______

c) **(2 pts) Calculate the expected pH of the solution.**

$[H_3O^+] > [OH^-]$, therefore, the excess H_3O^+ will determine the pH of the solution:

leftover $[H_3O^+]$ = 3.33x10^{-6} – 5.27x10^{-7} = 2.80x10^{-6} M

pH = –log(2.80x10^{-6}) = 5.55

Answer = _____5.55_________

5. Your lab TA asks you to prepare a buffer solution with a pH of 7.40. The following reagents are all available to you: 550 mL of 0.200 M formic acid, 450 mL of 0.200 M hypochlorous acid, solid sodium formate and solid sodium hypochlorite.

THIS IS A SLIGHTLY MODIFIED VERSION OF THE EXAMPLES IN THE COURSE NOTES

a) (2 pts) Which 2 ingredients will you use to prepare the desired buffer?

$HCOOH/HCOO^-$ $pK_a = -\log(1.8\times10^{-4}) = 3.74$

$HOCl/OCl^-$ $pK_a = -\log(2.9\times10^{-8}) = 7.54$

Therefore, hypochlorous acid/sodium hypochlorite is the appropriate choice.

b) (2 pts) What is the base/acid ratio in the desired buffer?

$$pH = pK_a + \log\left(\frac{[OCl^-]}{[HOCl]}\right)$$

$$\therefore \frac{[OCl^-]}{[HOCl]} = 10^{pH-pK_a} = 10^{7.40\text{-}7.54} = 0.724$$

Answer: _____0.724________

c) (3 pts) What mass (in g) of solid base must you dissolve in the corresponding acid solution to achieve the desired buffer pH?

$$\frac{[OCl^-]}{[HOCl]} = 0.724$$

$$\therefore [OCl^-] = 0.724 \times [HOCl] = 0.724 \times 0.200\ M = 0.145\ M$$

$$?\ g\ NaOCl = 0.450\ L \times \frac{0.145\ mol\ OCl^-}{L} \times \frac{1\ mol\ NaOCl}{1\ mol\ OCl^-} \times \frac{74.44\ g\ NaOCl}{mol\ NaOCl}$$

$$= 4.86\ g$$

Answer: _____4.86 g_______

d) (3 pts) If 1.00 mL of 1.00 M NaOH is added to the buffer solution, what will be the new pH?

$$?\ mol\ OH^-\ added = 0.00100\ L \times \frac{1.00\ mol\ OH^-}{L} = 0.00100\ mol$$

$$?\ mol\ OCl^-\ initial = 0.450\ L \times \frac{0.145\ mol\ OCl^-}{L} = 0.06525\ mol$$

$$?\ mol\ HOCl\ initial = 0.450\ L \times \frac{0.200\ mol\ HOCl}{L} = 0.0900\ mol$$

	$HOCl$ +	OH^- ⇆	OCl^- +	H_2O
B	0.0900		0.06525	-
A		0.001		-
M	-0.001	-0.001	+0.001	-
A	0.0890	0	0.06625	-

$$pH = pK_a + \log\left(\frac{[OCl^-]}{[HOCl]}\right) = 7.54 + \log\left(\frac{0.06625}{0.0890}\right) = 7.41$$

Answer: __________7.41_______

Gas Laws

$PV = nRT$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$P_T = P_1 + P_2 + P_3 + \ldots$

$P_A = \chi_A P_T$

$$d = \frac{m}{V} = \frac{P \cdot MM}{RT}$$

$$E_K = \frac{1}{2} m\overline{u^2}$$

$$u_{rms} = \sqrt{\frac{3RT}{MM}}$$

$$\frac{\text{Rate A}}{\text{Rate B}} = \sqrt{\frac{MM_B}{MM_A}}$$

$$\left(P + \frac{n^2a}{V^2}\right)\left(V - nb\right) = nRT$$

Equilibrium

$K_P = K_C(RT^{)\Delta n}$

$$\ln\left(\frac{K_2}{K_1}\right) = -\frac{\Delta H^o}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

Acid/Base

$pOH = -\log[OH^-]$

$pH = -\log[H^+]$

$pH + pOH = 14$

$K_a \text{ x } K_b = K_W$

$pH = pK_a + \log [A^-]/[HA]$

$$pH = \frac{pK_{a1} + pK_{a2}}{2}$$

Thermochemistry

$\Delta U = q + W$

$W_{system} = -P\Delta V = -\Delta nRT$

$\Delta H = \Delta U + P\Delta V$

$q_P = \Delta U + P\Delta V$

$q = mc\Delta T$

$q = n\Delta H$

$\Delta H_{rxn}° = \sum n\Delta H_f°(pdts) - \sum n\Delta H_f°(rxts)$

The atom

$E = h\nu$

$c = \nu\lambda$

$E = -B/n^2$

Kinetics

$[A]_t = [A]_o - kt$

$\ln[A]_t = \ln[A]_o - kt$

$1/[A]_t = 1/[A]_o + kt$

$k = Ae^{(-Ea/RT)}$

$$\ln\left(\frac{k_2}{k_1}\right) = -\frac{E_a}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

Other

$n = m/MM$

$C = n/V$

$$\%\text{yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$$

$$\chi_A = \frac{n_A}{n_T}$$

Data For Water

c = 2.13 J g^{-1} K^{-1} (solid)
c = 4.184 J g^{-1} K^{-1} (liquid)
c = 2.01 J g^{-1} K^{-1} (gas)

Density = 1.00 g/mL (at 25°C)
ΔH°_{fus} = 6.02 kJ mol^{-1}
ΔH°_{vap} = 40.7 kJ mol^{-1}

Constants and Conversion Factors

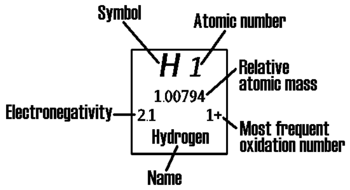
1 mmHg = 1 torr	1 cm^3 = 1 mL
760 mmHg = 1 atm	1000 mL = 1 L
1 atm = 101.325 kPa	1000 L = 1 m^3
1 atm = 1.013125 bar	1 mol = 22.7 L at STP

Avogadro's Number	N_A	$6.022\text{x}10^{23}$	mol^{-1}
Boltzmann's constant	k_B	$1.38065\text{x}10^{-23}$	$J \bullet K^{-1}$
Gas constant	R	8.31451	$J \bullet mol^{-1} \bullet K^{-1}$
	R	0.08206	$L \bullet atm \bullet mol^{-1} \bullet K^{-1}$
	R	8.31451	$m^3 \bullet Pa \bullet mol^{-1} \bullet K^{-1}$
	R	8.31451	$L \bullet kPa \bullet mol^{-1} \bullet K^{-1}$
	R	0.0831451	$bar \bullet L \bullet mol^{-1} \bullet K^{-1}$
Planck's constant	h	$6.62608\text{x}10^{-34}$	$J \bullet s$
Speed of Light	c	$2.99792458\text{x}10^{8}$	$m \bullet s^{-1}$

Table of Ionization Constants at 25.0°C

Acid		K_a =
Iodic acid	$HIO_3 + H_2O \rightleftharpoons H_3O^+ + IO_3^-$	1.6×10^{-1}
Chlorous acid	$HClO_2 + H_2O \rightleftharpoons H_3O^+ + ClO_2^-$	1.1×10^{-2}
Chloroacetic acid	$HC_2H_2ClO_2 + H_2O \rightleftharpoons H_3O^+ + C_2H_2ClO_2^-$	1.4×10^{-3}
Nitrous acid	$HNO_2 + H_2O \rightleftharpoons H_3O^+ + NO_2^-$	7.2×10^{-4}
Hydrofluoric acid	$HF + H_2O \rightleftharpoons H_3O^+ + F^-$	6.6×10^{-4}
Formic acid	$HCHO_2 + H_2O \rightleftharpoons H_3O^+ + CHO_2^-$	1.8×10^{-4}
Benzoic acid	$HC_7H_5O_2 + H_2O \rightleftharpoons H_3O^+ + C_7H_5O_2^-$	6.3×10^{-5}
Hydrazoic acid	$HN_3 + H_2O \rightleftharpoons H_3O^+ + N_3^-$	1.9×10^{-5}
Acetic acid	$HC_2H_3O_2 + H_2O \rightleftharpoons H_3O^+ + C_2H_3O_2^-$	1.8×10^{-5}
Hypochlorous acid	$HOCl + H_2O \rightleftharpoons H_3O^+ + OCl^-$	2.9×10^{-8}
Hydrocyanic acid	$HCN + H_2O \rightleftharpoons H_3O^+ + CN^-$	6.2×10^{-10}
Phenol	$HOC_6H_5 + H_2O \rightleftharpoons H_3O^+ + C_6H_5O^-$	1.0×10^{-10}
Hydrogen peroxide	$H_2O_2 + H_2O \rightleftharpoons H_3O^+ + HO_2^-$	1.8×10^{-12}

Mokeur's Periodic table of the elements



	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIII	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	*H 1* 1.00794 2.1 1+ Hydrogen																	*He 2* 4.002602 - - Helium
2	**Li 3** 6.941 1.0 1+ Lithium	**Be 4** 9.012182 1.5 2+ Beryllium											**B 5** 10.811 2.0 3+ Boron	**C 6** 12.011 2.5 4+,4- Carbon	*N 7* 14.00674 3.0 3+,3- Nitrogen	*O 8* 15.9994 3.5 2- Oxygen	*F 9* 18.9984032 4.0 1- Fluorine	*Ne 10* 20.1797 - - Neon
3	**Na 11** 22.989768 0.9 1+ Sodium	**Mg 12** 24.3050 1.2 2+ Magnesium											**Al 13** 26.981539 1.5 3+ Aluminum	**Si 14** 28.0855 1.8 4+ Silicon	**P 15** 30.973762 2.1 5+ Phosphorus	**S 16** 32.066 1.8 4+ Sulfur	*Cl 17* 35.4527 3.0 1- Chlorine	*Ar 18* 39.948 - - Argon
4	**K 19** 39.0983 0.8 1+ Potassium	**Ca 20** 40.078 1.0 2+ Calcium	**Sc 21** 44.955910 1.3 3+ Scandium	**Ti 22** 47.88 1.5 4+ Titanium	**V 23** 50.9415 1.6 5+ Vanadium	**Cr 24** 51.9961 1.6 3+ Chromium	**Mn 25** 54.93805 1.5 2+ Manganese	**Fe 26** 55.847 1.8 3+ Iron	**Co 27** 58.9332 1.8 2+ Cobalt	**Ni 28** 58.6934 1.8 2+ Nickel	**Cu 29** 63.546 1.9 2+ Copper	**Zn 30** 65.39 1.6 2+ Zinc	***Ga 31*** 69.723 1.6 3+ Gallium	**Ge 32** 72.61 1.6 4+ Germanium	**As 33** 74.92159 2.0 3+,3- Arsenic	**Se 34** 78.96 2.4 4+ Selenium	***Br 35*** 79.904 2.8 1- Bromine	*Kr 36* 83.80 - - Krypton
5	**Rb 37** 85.4678 0.8 1+ Rubidium	**Sr 38** 87.62 1.0 2+ Strontium	**Y 39** 88.90585 1.3 3+ Yttrium	**Zr 40** 91.224 1.4 4+ Zirconium	**Nb 41** 92.90638 1.6 5+ Niobium	**Mo 42** 95.94 1.8 6+ Molybdenum	Tc 43 98.9063 1.9 7+ Technetium	**Ru 44** 101.57 2.2 3+,4+ Ruthenium	**Rh 45** 102.9055 2.2 3+ Rhodium	**Pd 46** 106.42 2.2 2+ Palladium	**Ag 47** 107.8682 1.9 1+ Silver	**Cd 48** 112.411 1.7 2+ Cadmium	**In 49** 114.82 1.7 3+ Indium	**Sn 50** 118.71 1.8 4+ Tin	**Sb 51** 121.757 1.9 3+,3- Antimony	**Te 52** 127.60 2.1 4+ Tellurium	**I 53** 126.90447 2.5 1- Iodine	*Xe 54* 131.29 - - Xenon
6	***Cs 55*** 132.90543 0.7 1+ Cesium	**Ba 56** 137.327 0.9 2+ Barium	**La 57** 138.9055 1.1 3+ Lanthanum	**Hf 72** 178.49 1.3 4+ Hafnium	**Ta 73** 180.9479 1.5 5+ Tantalum	**W 74** 183.85 1.7 6+ Tungsten	**Re 75** 186.207 1.9 7+ Rhenium	**Os 76** 190.2 2.2 4+ Osmium	**Ir 77** 192.22 2.2 4+ Iridium	**Pt 78** 195.08 2.2 4+ Platinum	**Au 79** 196.96654 2.4 3+ Gold	***Hg 80*** 200.59 1.9 2+ Mercury	**Tl 81** 204.3833 1.8 1+ Thallium	**Pb 82** 207.2 1.8 2+ Lead	**Bi 83** 208.98037 1.9 3+ Bismuth	**Po 84** 208.9824 2.0 2+ Polonium	**At 85** 209.9871 2.2 1- Astatine	*Rn 86* 222.0176 - - Radon
7	***Fr 87*** 223.0197 0.7 1+ Francium	**Ra 88** 226.0254 0.9 2+ Radium	**Ac 89** 227.0278 1.1 3+ Actinium	Rf 104 261.11 - - Rutherfordium	Db 105 262.11 - - Dubnium	Sg 106 263.12 - - Seaborgium	Bh 107 262.12 - - Bohrium	Hs 108 264 - - Hassium	Mt 109 266.1378 - - Meitnerium	Uun 110 269 - - Ununnilium	Uuu 111 272 - - Unununium	Uu 112 277 - - Ununbium		Uuq 114 289 - - Ununquadium		Uuh 116 289 - - Ununhexium		Uuo 118 293 - - Ununoctium

6	**Ce 58** 140.115 1.1 3+ Cerium	**Pr 59** 140.90765 1.1 3+ Praseodymium	**Nd 60** 144.24 1.1 3+ Neodymium	Pm 61 144.9127 1.1 3+ Promethium	**Sm 62** 150.36 1.2 3+ Samarium	**Eu 63** 151.965 1.2 3+ Europium	**Gd 64** 157.25 1.2 3+ Gadolinium	**Tb 65** 168.92534 1.2 3+ Terbium	**Dy 66** 162.50 1.2 3+ Dysposium	**Ho 67** 164.93032 1.2 3+ Holmium	**Er 68** 167.26 1.2 3+ Erbium	**Tm 69** 168.93421 1.2 3+ Thulium	**Yb 70** 173.04 1.1 3+ Ytterbium	**Lu 71** 174.967 1.2 3+ Lutetium
7	**Th 90** 232.0381 1.3 4+ Thorium	**Pa 91** 231.03588 1.5 5+ Protactinium	**U 92** 238.0289 1.4 6+ Uranium	Np 93 237.082 1.3 5+ Neptunium	Pu 94 244.0642 1.3 4+ Plutonium	Am 95 243.0614 1.3 3+ Americium	Cm 96 247 1.3 3+ Curium	Bk 97 247.0703 1.3 3+ Berkelium	Cf 98 251.0796 1.3 3+ Californium	Es 99 252.03 1.3 - Einsteinium	Fm 100 257.0951 1.3 - Fermium	Md 101 258.01 1.3 - Mendelevium	No 102 259.1009 1.3 - Nobelium	Lr 103 260.1053 - - Lawrencium

Under normal conditions, bold symbols correspond to solid state, bold italic correspond to liquid state, italic correspond to gaseous state and normal correspond to synthetic elements.