CHM 1311 - E **Second Midterm** **Nov 25 – 2015**

(Prof. S. Gambarotta)

Your Name: ___________________ **Student #: ______________**

1. The solution key will be posted today on the web. Solutions will be worked out in the next DGD.
2. Data sheets and Periodic Table and important values are at the end.
3. A few scratch sheets are at the very end. Report in the booklet the minimum amount of calculations to show your reasoning.

1. (**3 points**) Phosgene is a toxic gas prepared by the reaction of carbon monoxide with chlorine:

$$CO(g) + Cl_2(g) \longrightarrow COCl_2(g)$$

These data were obtained in a kinetics study of its formation:

Experiment	Initial Rate (mol/L·s)	Initial [CO] (mol/L)	Initial [Cl_2] (mol/L)
1	1.29×10^{-29}	1.00	0.100
2	1.33×10^{-30}	0.100	0.100
3	1.30×10^{-29}	0.100	1.00
4	1.32×10^{-31}	0.100	0.0100

a. Write the rate law for the formation of phosgene.
b. Calculate the average value of the rate constant.

a) To find the order for CO, first identify the reaction experiments in which [CO] changes but [Cl_2] is constant. Use experiments 1 and 2 to find the order with respect to [CO]. Set up a ratio of the rate laws for experiments 1 and 2 and fill in the values given for rates and concentrations and solve for m, the order with respect to [CO].

$$\frac{\text{rate}_{\text{exp 1}}}{\text{rate}_{\text{exp 2}}} = \left(\frac{[CO]_{\text{exp 1}}}{[CO]_{\text{exp 2}}}\right)^m$$

$$\frac{1.29\times10^{-29}\ \text{mol/L•min}}{1.33\times10^{-30}\ \text{mol/L•min}} = \left(\frac{1.00\ \text{mol/L}}{0.100\ \text{mol/L}}\right)^m$$

$9.699 = (10.0)^m$
log (9.699) = m log (10.0)
$m = 0.9867 = 1$
The reaction is first order with respect to [CO].
To find the order for Cl_2, first identify the reaction experiments in which [Cl_2] changes but [CO] is constant. Use experiments 2 and 3 to find the order with respect to [Cl_2]. Set up a ratio of the rate laws for experiments 2 and 3 and fill in the values given for rates and concentrations and solve for n, the order with respect to [Cl_2].

$$\frac{\text{rate}_{\text{exp 3}}}{\text{rate}_{\text{exp 2}}} = \left(\frac{[Cl_2]_{\text{exp 3}}}{[Cl_2]_{\text{exp 2}}}\right)^n$$

$$\frac{1.30\times10^{-29}\ \text{mol/L•min}}{1.33\times10^{-30}\ \text{mol/L•min}} = \left(\frac{1.00\ \text{mol/L}}{0.100\ \text{mol/L}}\right)^n$$

$9.774 = (10.0)^n$
log (9.774) = n log (10.0)
$n = 0.9901 = 1$
The reaction is first order with respect to [Cl_2].

Rate = $\boldsymbol{k}$**[CO][Cl_2]**

b) k = rate/[CO][Cl_2]

Exp 1: $k_1 = (1.29\text{x}10^{-29}$ mol/L•s)/[1.00 mol/L][0.100 mol/L] = $1.29\text{x}10^{-28}$ L/mol•s
Exp 2: $k_2 = (1.33\text{x}10^{-30}$ mol/L•s)/[0.100 mol/L][0.100 mol/L] = $1.33\text{x}10^{-28}$ L/mol•s
Exp 3: $k_3 = (1.30\text{x}10^{-29}$ mol/L•s)/[0.100 mol/L][1.00 mol/L] = $1.30\text{x}10^{-28}$ L/mol•s
Exp 4: $k_4 = (1.32\text{x}10^{-31}$ mol/L•s)/[0.100 mol/L][0.0100 mol/L] = $1.32\text{x}10^{-28}$ L/mol•s

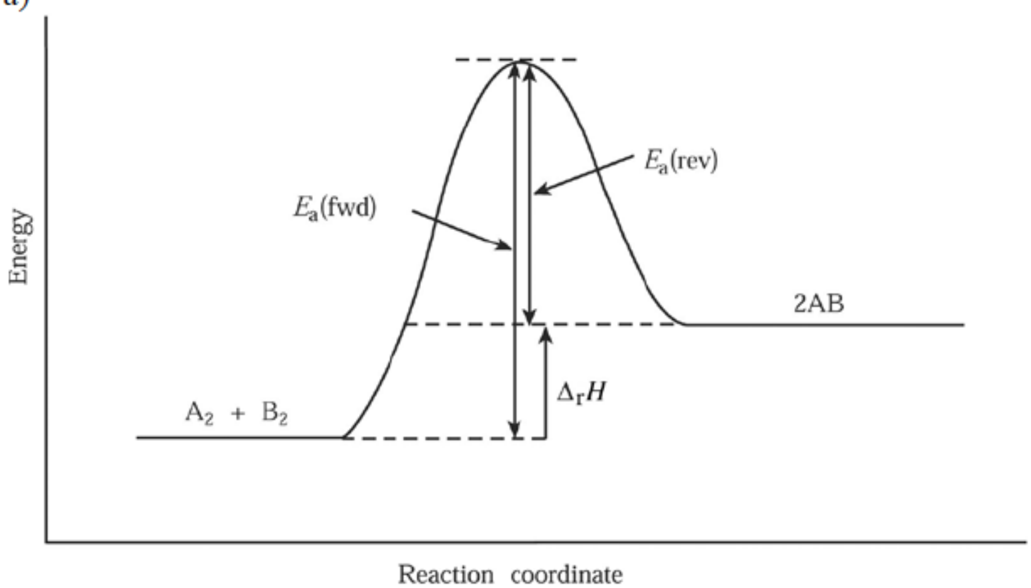
$k_{avg} = (1.29\text{x}10^{-28} + 1.33\text{x}10^{-28} + 1.30\text{x}10^{-28} + 1.32\text{x}10^{-28})$ L/mol•s/4 = **$1.31\text{x}10^{-28}$ L/mol•s**

2. (**1 point**) For the following reaction, $E_{a(fwd)}$ = 125 kJ/mol and $E_{a(rev)}$ = 85 kJ/mol:

$$A_2 + B_2 \longrightarrow 2AB$$

Assuming that the reaction occurs in one step,
(a) draw a reaction energy diagram;
(b) calculate $\Delta_r H°$;
(c) sketch a possible transition state.

Solution:
a)



b) $\Delta_r H = E_{a(fwd)} - E_{a(rev)}$ = 125 kJ/mol – 85 kJ/mol = **40 kJ/mol**

c)
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A . . . . . B
|           |
A . . . . . B
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3. (**2 points**) For the following reaction, K = 0.262 at 1000°C:

$$C(s) + 2H_2(g) \rightleftharpoons CH_4(g)$$

At equilibrium, P_{H_2} is 1.22 bar. What is the equilibrium partial pressure of $CH_4(g)$?

$C(s) + 2H_2(g) \rightleftharpoons CH_4(g)$

$$K = \frac{p_{CH_4}}{p^2_{H_2}} = 0.262$$

$$p_{CH_4} = K \cdot p^2_{H_2} = (0.262)(1.22)^2 = 0.38996 \text{ bar} = \mathbf{0.390\ bar}$$

4. (**3 points**) Nitrogen dioxide decomposes according to the following reaction, where $K = 4.48 \times 10^{-13}$ at a certain temperature:

$$2NO_2(g) \rightleftharpoons 2NO(g) + O_2(g)$$

If 0.75 bar of NO_2 is added to a container and allowed to come to equilibrium, what are the equilibrium partial pressures of $NO(g)$ and $O_2(g)$?

$2NO_2(g) \rightleftharpoons 2NO(g) + O_2(g)$ There is a 2:2:1 mole ratio between reactants and products.

Pressure (bar)	$2NO_2(g)$	$\rightleftharpoons$	$2NO(g)$	+	$O_2(g)$	
Initial	0.75		0		0	
Change	– 2x		+2x		+x	(2:2:1 mole ratio)
Equilibrium	0.75 – 2x		2x		x	

$$K = 4.48\text{x}10^{-13} = \frac{p^2_{NO}\, p_{O_2}}{p^2_{NO_2}} = \frac{(2x)^2(x)}{(0.75 - 2x)^2}$$

Assume 0.75 bar – 2x ≈ 0.75 bar

$$4.48\text{x}10^{-13} = \frac{(4x^2)(x)}{(0.75)^2} = \frac{(4x^3)}{(0.75)^2}$$

$x = 3.979\text{x}10^{-5}$ bar = $\mathbf{4.0x10^{-5}}$ **bar O_2** (assumption is justified)

$p_{NO} = 2x = 2(3.979\text{x}10^{-5}\text{ bar}) = 7.958\text{x}10^{-5}$ bar = $\mathbf{8.0x10^{-5}}$ **bar NO**

5. (**3 points**) Compound A decomposes according to the following equation:

$$A(g) \rightleftharpoons 2B(g) + C(g)$$

A sealed 1.00-L container initially contains 1.75×10^{-3} mol of $A(g)$, 1.25×10^{-3} mol of

B(g), and 6.50×10^{-4} mol of C(g) at 100°C. At equilibrium, [A] is 2.15×10^{-3} mol/L. Find [B] and [C].

Initial concentrations:

$[A] = (1.75x10^{-3}\text{ mol})/(1.00\text{ L}) = 1.75x10^{-3}\text{ mol/L}$

$[B] = (1.25x10^{-3}\text{ mol})/(1.00\text{ L}) = 1.25x10^{-3}\text{ mol/L}$

$[C] = (6.50x10^{-4}\text{ mol})/(1.00\text{ L}) = 6.50x10^{-4}\text{ mol/L}$

Concentration (mol/L)	A(g)	⇌	2B(g)	+	C(g)
Initial	$1.75x10^{-3}$		$1.25x10^{-3}$		$6.50x10^{-4}$
Change	$-x$		$+2x$		$+x$
Equilibrium	$1.75x10^{-3} - x$		$1.25x10^{-3} + 2x$		$6.50x10^{-4} + x$

$[A]_{eq} = 2.15x10^{-3} = 1.75x10^{-3} - x$

$x = -0.00040$

$[B]_{eq} = 1.25x10^{-3} + 2x = \mathbf{4.5x10^{-4}\text{ mol/L}}$

$[C]_{eq} = 6.50x10^{-4} + x = \mathbf{2.5x10^{-4}\text{ mol/L}}$

6. (**1 point**) What is the pH of a solution 0.75 mol/L of NaF? [K_a(HF) = 6.8×10^{-4}]

The fluoride ion, F^-, acts as the base as shown by the following equation:

$$F^-(aq) + H_2O(l) \rightleftharpoons HF(aq) + OH^-(aq)$$

Because NaF is a soluble salt, $[F^-]$ = [NaF]. The sodium ion is from a strong base; therefore, it will not affect the pH, and can be ignored.

Concentration (mol/L)	$F^-(aq)$	+	$H_2O(l)$	⇌	$HF(aq)$	+	$OH^-(aq)$
Initial	0.75		—		0		0
Change	$-x$				$+x$		$+x$
Equilibrium	$0.75 - x$				x		x

$$K_b \text{ of } F^- = \frac{K_w}{K_a} = \frac{1.0x10^{-14}}{6.8x10^{-4}} = 1.470588x10^{-11}$$

$$K_b = 1.470588x10^{-11} = \frac{[HF][OH^-]}{[F^-]}$$

$$K_b == 1.470588x10^{-11} = \frac{[x][x]}{[0.75 - x]}$$

Assume x is small compared to 0.75.

$$K_b = 1.470588x10^{-11} = \frac{(x)(x)}{(0.75)}$$

$x = 3.3210558x10^{-6}$ mol/L OH^-

Check assumption: $(3.3210558x10^{-6}/0.75)$ x 100% = 0.0004% error, so the assumption is valid.

$[H]^+ = K_w/[OH^-] = (1.0x10^{-14})/(3.3210558x10^{-6}) = 3.01109x10^{-9}$ mol/L H^+

pH = $-\log [H^+] = -\log (3.01109x10^{-9}) = 8.521276 = \mathbf{8.52}$

7. (**5 points**) Sodium hypochlorite solution, sold as chlorine bleach, is potentially dangerous because of the basicity of ClO^-, the active bleaching ingredient. (Assume that

d of solution = 1.0 g/mL.)
a. What is $[OH^-]$ in an aqueous solution that is 6.5% NaClO by mass?
What is the pH of the solution? $K_a(HClO) = 2.9 \times 10^{-8}$

Plan: First, calculate the initial concentration (mol/L) of ClO^- from the mass percent. Then, set up reaction table with base dissociation of ClO^-. Find the K_b for ClO^- from the equation $K_w = K_a \times K_b$, using the K_a for HClO from Appendix C.

Solution:

Concentration (mol/L) of ClO^- =

$$\left(\frac{1 \text{ mL solution}}{10^{-3} \text{ L solution}}\right)\left(\frac{1.0 \text{ g solution}}{1 \text{ mL solution}}\right)\left(\frac{6.5\% \text{ NaClO}}{100\% \text{ Solution}}\right)\left(\frac{1 \text{ mol NaClO}}{74.44 \text{ g NaClO}}\right)\left(\frac{1 \text{ mol ClO}^-}{1 \text{ mol NaClO}}\right)$$

$= 0.873186 \text{ mol/L ClO}^-$

The sodium ion is from a strong base; therefore, it will not affect the pH, and can be ignored.

Concentration (mol/L)	$ClO^-(aq)$	+	$H_2O(l)$	$\rightleftharpoons$	$HClO(aq)$	+	$OH^-(aq)$
Initial	0.873186		—		0		0
Change	–x				+x		+x
Equilibrium	0.873186 – x				x		x

$$K_b \text{ of ClO}^- = \frac{K_w}{K_a} = \frac{1.0\text{x}10^{-14}}{2.9\text{x}10^{-8}} = 3.448275862\text{x}10^{-7}$$

$$K_b = 3.448275862\text{x}10^{-7} = \frac{[HClO][OH^-]}{[ClO^-]}$$

$$K_b = 3.448275862\text{x}10^{-7} = \frac{[x][x]}{[0.873186 - x]}$$

Assume x is small compared to 0.873186.

$$K_b = 3.448275862\text{x}10^{-7} = \frac{(x)(x)}{(0.873186)}$$

$x = 5.4872\text{x}10^{-4} = \mathbf{5.5x10^{-4}}$ **mol/L OH⁻**

Check assumption that x is small compared to 0.873186:

$$\frac{5.4872\text{x}10^{-4}}{0.873186}(100\%) = 0.006\% \text{ error, so the assumption is valid.}$$

$$[H]^+ = \frac{K_w}{[OH^-]} = \frac{1.0\text{x}10^{-14}}{5.4872\text{x}10^{-4}} = 1.82242\text{x}10^{-11} \text{ mol/L H}^+$$

pH = $-\log[H^+] = -\log(1.82242\text{x}10^{-11}) = 10.73935 = \mathbf{10.74}$

8. (**4 points**) A buffer that contains 1.05 mol/L B and 0.750 mol/L BH^+ has a pH of 9.50. What is the pH after 0.0050 mol of HCl is added to 0.500 L of this solution?

Determine the pK_a of the acid from the concentrations of the conjugate acid and base and the pH of the solution. This requires the Henderson-Hasselbalch equation.

$$\text{pH} = \text{p}K_a + \log\left(\frac{[\text{base}]}{[\text{acid}]}\right)$$

$$9.50 = \text{p}K_a + \log\left(\frac{[\text{B}]}{[\text{BH}^+]}\right) = \text{p}K_a + \log\left(\frac{[1.05]}{[0.750]}\right)$$

$$9.50 = \text{p}K_a + 0.1461280357$$

$$\text{p}K_a = 9.353872 = 9.35$$

Determine the amount (mol) of conjugate acid (BH^+) and conjugate base (B).

amount (mol) of BH^+ = (0.500 L)(0.750 mol BH^+/L) = 0.375 mol BH^+

amount (mol) of B = (0.500 L)(1.05 mol B/L) = 0.525 mol B

The reaction is:

	B(*aq*)	+	HCl(*aq*)	→	BH^+(*aq*)	+	Cl^- (*aq*)	+	H_2O(*l*)
Initial	0.525 mol		0.0050 mol		0.375 mol				
Change	–0.0050 mol		–0.0050 mol		+0.0050 mol				
Final	0.520 mol		0 mol		0.380 mol				

HCl is the limiting reagent. The addition of 0.0050 mol HCl will produce 0.0050 mol BH^+ and consume 0.0050 mol of B.

Then

$$\text{pH} = \text{p}K_a + \log\left(\frac{n_{\text{base}}}{n_{\text{acid}}}\right)$$

$$\text{pH} = 9.353872 + \log\left(\frac{[0.520]}{[0.380]}\right) = 9.490092 = \mathbf{9.49}$$

Gas Laws

$PV = nRT$

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

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

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

$$E_K = \frac{1}{2}m\text{v}^2$$

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

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

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

Equilibrium

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

Acid/Base

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

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

$pH + pOH = 14$

$K_a \times K_b = K_W$

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

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

Thermochemistry

$\Delta U = q + W$

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

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

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

$q = ms\Delta T$

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

The atom

$E = h\nu$

$c = \nu\lambda$

$E = -B/n^2$

Kinetics

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

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

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

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

$\ln(k_2/k_1) = (-Ea/R)(1/T_2 - 1/T_1)$

Data For Water

Density = 1.00 g/mL (at 25°C)
s = 2.13 J g^{-1} K^{-1} (solid)
s = 4.184 J g^{-1} K^{-1} (liquid) $\Delta H°_{fus}$ = 6.02 kJ mol^{-1}
s = 2.01 J g^{-1} K^{-1} (gas) $\Delta H°_{vap}$ = 40.7 kJ mol^{-1}

Constants and Conversion Factors

1 mmHg = 1 torr   760 mmHg = 1 atm   1 atm = 101.325 kPa   1 atm = 1.013
1 cm^3 = 1 mL   1000 mL = 1 L   1000 L = 1 m^3

Avogadro's Number	N	6.022×10^{23} mol^{-1}
Boltzmann's constant	k	1.30866×10^{-23} $J \cdot K^{-1}$
Faraday's constant	F	96,485 $C \cdot mol^{-1}$
Gas constant	R	8.31451 $J \cdot K^{-1} \cdot mol^{-1}$
	R	0.08206 $atm \cdot L \cdot K^{-1} \cdot mol^{-1}$
	R	8.31451 $m^3 Pa \cdot K^{-1} \cdot mol^{-1}$
	R	0.0831451 bar $L \cdot K^{-1} \cdot mol^{-1}$
Planck's constant	h	6.62608×10^{-34} J·s
Speed of Light	c	2.99792458×10^{8} $m \cdot s^{-1}$

Table of Ionization Constants

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}

Table of Solubility Product Constants

Compound	K_{sp}	Compound	K_{sp}
$Mg(OH)_2$	1.2×10^{-11}	PbI_2	7.1×10^{-9}
AgCl	1.8×10^{-10}	$PbCl_2$	1.9×10^{-5}
$CaSO_4$	9.1×10^{-6}	Ag_2CO_3	8.5×10^{-12}
AgI	1.5×10^{-16}	ZnS	2.0×10^{-25}
BaF_2	1.0×10^{-6}	$FePO_4$	1.3×10^{-22}

Mokeur's Periodic table of the elements

Symbol — Atomic number — Relative atomic mass — Electronegativity — Most frequent oxidation number — Name

H 1
1.00794
2.1 1+
Hydrogen

	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIII	9 VIII	10 VIII	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.