THE UNIVERSITY OF CALGARY
FACULTY OF SCIENCE
MIDTERM
CHEMISTRY 209

Date: Wednesday October 30th, 2013 Time: 7:00pm – 9:00pm

FIRST NAME: Answer **LAST NAME:** Key

After writing your name, please fill in ID # on next page!

Please circle your lecture section number below.

Lec. 01 Dr. Sandblom **Lec. 02 Dr. E. Sullivan**

(Tu/Th 2:00 pm) **(Tu/Th 12:30 pm)**

This is a closed-book examination. The use of camera devices, MP3 Players and headphones, or wireless access devices such as cell phones, Blackberries, etc., during the examination will not be allowed.

Only non-programmable calculators are permitted. A Chemical Data Sheet is provided at the end of the exam and can be removed for quick reference.

All questions must be answered to obtain full marks. The answers to the multiple choice section must be entered on the optical score sheet within the 2 hour exam. The answers to the long answer questions must be written in the space provided on the question sheets **AND** written in **non-erasable ink** to be eligible for re-grading.

This test consists of **17 multiple choice** questions **worth 2 marks each** (total 34 marks) and **5 long answer** questions (total 26 marks). The total value for the test is **60 marks**. The exam has 14 pages make sure you have all 14 pages.

AT THE END OF THE EXAMINATION, HAND IN THE OPTICAL SCORE SHEET AND THE ENTIRE EXAM PAPER

Failing to encode this Exam Booklet or your Optical Score Sheet correctly, for your name, ID and lecture section, will result in the loss of two marks.

ID…………………	Q18…… Q19……. Q20……. Q21……. Q22……. DO NOT WRITE IN THIS BOX, FOR GRADING PURPOSES ONLY!

SECTION I - Machine graded section (Total value 34)
To be answered on provided Optical Score Sheet

1. The reaction between aluminum (Al) and bromine (Br_2) gives a white solid Al_2Br_6. If we had 50.0 grams of Br_2 and 13.0 grams of Al, how much Al_2Br_6 could we make?

$$2Al + 3Br_2 \rightarrow Al_2Br_6$$

a) 13.0 g
b) 17.1 g
c) 55.5 g
d) 128 g
e) 167 g

mw $Br_2 = 2 \times 79.9g = 159.8 g/mol$
Al 26.98 g/mol
$Al_2Br_6 = 2(26.98) + 6(79.9) = 533.36$ g/mol
$0.104 mol\ Al_2Br_6 \times 533.36 g/mol = 55.6 g$

$30 g\ Br_2 \times \frac{1 mol}{159.8 g} = 0.313 mol\ Br_2$
Can make $0.313 mol\ Br_2 \times \frac{1 Al_2Br_6}{3 mol\ Br_2} = \underline{0.104 mol\ Al_2Br_6}$ L.R.
$13 g\ Al \times \frac{1 mol}{26.98 g} = 0.482 mol\ Al$
Can make $0.482 mol\ Al \times \frac{1 Al_2Br_6}{2 mol\ Al} = 0.24 mol\ Al_2Br_6$

2. What is the molarity of 43.2 g of CO_2(g) at 32.0 °C and a pressure of 720.0 torr?

a) 3.79×10^{-2} M
b) 3.4×10^{-2} M
c) 2.7×10^{-1} M
d) 3.56×10^{-3} M
e) 16.0 M

$PV = nRT$
$P = 720/760 = 0.947 atm$
$T = 32 + 273.15 = 305.15 K$
$n = 43.2 g \times \frac{1 mol\ CO_2}{44.01 g\ CO_2} = 0.982 mol$

$V = \frac{nRT}{P} = \frac{0.982 \cdot 0.08205 \cdot 305.15}{0.947}$
$V = 26 L$
$M = \frac{n}{V} = \frac{0.982}{26}$

3. A compound is found to contain 62.0% C, 10.4% H and 27.6% O. If the molecular weight for this compound was between 170 and 190 a.m.u, what is its molecular formula?

a) $C_6H_{14}O_4$
b) $C_7H_{16}O_4$
c) $C_8H_{14}O_3$
d) $C_9H_{18}O_3$
e) $C_{10}H_{12}O_2$

assume 100g
$\therefore 62 g\ C / 12.01 g/mol = 5.16 mol$
$10.4 g\ H / 1.01 g/mol = 10.297 mol$
$27.6 / 16 g/mol = 1.725 mol$

$C_{\frac{5.16}{1.725}} H_{\frac{10.297}{1.725}} O_{\frac{1.725}{1.725}}$
C_3H_6O mw = 58.09 but mw = 170-190
$2(58.09) = 116.18$
$3(58.09) = 174.27$
$\therefore C_9H_{18}O_3$

4. If the fading of phenolphthalein was a first order reaction, which of the following plots would be linear?

   a) $k_1' t = -\ln [Ph^{2-}] + \ln [Ph^{2-}]_0$ would be linear

   b) $\dfrac{1}{[Ph^{2-}]} = k_2't + \dfrac{1}{[Ph^{2-}]_0}$ would be linear

   c) $k_0' t = [Ph^{2-}]_0 - [Ph^{2-}]$ would be linear

   d) All of the above would be linear

   e) None of the above would be linear

5. For the reaction below, the following data were collected at constant temperature. Determine the correct rate law for this reaction.

$$A(g) + 2B(g) \rightarrow 2C(g) + 2D(g)$$

Trial	Initial [A] (mol/L)	Initial [B] (mol/L)	Initial Rate (mol/(L·min))
1	0.125	0.200	7.25
2	0.375	0.200	21.75
3	0.250	0.400	14.50
4	0.375	0.400	21.75

   a) Rate = k[A] [B]
   b) Rate = $k[A]^2$ [B]
   c) Rate = k[A] $[B]^2$
   d) Rate = k[A]
   e) Rate = $k[A]^3$

$\dfrac{Rate_4}{Rate_3} = \dfrac{21.75}{14.50} = \dfrac{\cancel{k}[0.375]^m \cancel{[0.400]^n}}{\cancel{k}[0.250]^m \cancel{[0.400]^n}}$ $1.5 = 1.5^m$ $m = 1$

$\dfrac{Rate_4}{Rate_2} \Rightarrow \dfrac{21.75}{21.75} = \dfrac{\cancel{k}\cancel{[0.375]^m}[0.400]^n}{\cancel{k}\cancel{[0.375]^m}[0.200]^n}$ $1 = 2^n$ $n = 0$, Zero order in B

6. Sulfuryl chloride, $SO_2Cl_2(g)$, decomposes at high temperature to form $SO_2(g)$ and $Cl_2(g)$. The rate constant at a certain temperature is 4.68×10^{-5} s^{-1}. What is the order of the reaction?

units s^{-1}, ∴ 1st order

   a) Zero
   b) First
   c) Second
   d) Third
   e) More information is needed to determine the order.

7. Carbon-14 is a radioactive isotope that decays with a half-life of 5730 years. What is the first-order rate constant for its decay, in units of years^{-1}?

$t_{1/2} = \frac{0.693}{k}$ $k = \frac{0.693}{t_{1/2}} = \frac{0.693}{5730 \text{ years}} = 1.21 \times 10^{-4} \text{ years}^{-1}$

a) 5.25×10^{-5} years^{-1}
b) 1.21×10^{-4} years^{-1}
c) 1.75×10^{-4} years^{-1}
d) 3.49×10^{-4} years^{-1}
e) 3.97×10^{3} years^{-1}

8. A rate constant obeys the Arrhenius equation, has a factor *A* of 2.2×10^{13} s^{-1} and an activation energy of 150. kJ mol^{-1}. What is the value of the rate constant at 227°C, in s^{-1}?

$T = 227°C + 273.15 = 500.15 \text{ K}$

$k = Ae^{-E_a/RT}$

$k = 2.2 \times 10^{13} \text{ s}^{-1} e^{-\frac{150000 \text{ J/mol}}{(8.314 \text{ J/mol}\cdot\text{K})500.15\text{K}}}$

$k = 2.2 \times 10^{13} \text{ s}^{-1} e^{-36.07289235}$

a) 2.1×10^{13} s^{-1}
b) 6.7×10^{-22} s^{-1}
c) 1.5×10^{11} s^{-1}
d) 4.7×10^{-3} s^{-1}
e) 9.4×10^{-3} s^{-1}

9. What is the molecularity of the following elementary reaction?

$$NH_2Cl(aq) + OH^-(aq) \rightarrow NHCl^-(aq) + H_2O(l)$$

1 2

a) Unimolecular
b) Bimolecular ←
c) Termolecular
d) Tetramolecular
e) Need to know the reaction order before molecularity can be determined.

10. Carbon monoxide and chlorine combine in an equilibrium reaction to produce the highly toxic product, phosgene ($COCl_2$):

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

0.010 0.010 0.070

$Q_c = \frac{[COCl_2]}{[CO][Cl_2]} = \frac{0.070}{0.010^2} = 700$

$Q_c = 700 > K_c$

If the equilibrium constant for this reaction is $K_c = 248$, predict, if possible, what will happen when 0.010 moles of CO, 0.010 moles of Cl_2 and 0.070 moles of $COCl_2$ are combined in a 1.0 L container?

a) The reaction will proceed to the right, since $Q_c > K_c$.
b) The reaction will proceed to the right, since $Q_c < K_c$.
c) The reaction is at equilibrium, and no change in concentrations will occur.
d) The reaction will proceed to the left, since $Q_c < K_c$.
e) The reaction will proceed to the left, since $Q_c > K_c$.

11. Consider the following two equilibria and their respective equilibrium constants:

$NO(g) + \frac{1}{2}O_2(g) \rightleftharpoons NO_2(g)$ K_1

$2NO_2(g) \rightleftharpoons 2NO(g) + O_2(g)$ K_2

Which one of the following is the correct relationship between the equilibrium constants K_1 & K_2?

a) $K_2 = (1/K_1)^2$
b) $K_2 = 2/K_1$
c) $K_2 = -K_1/2$
d) $K_2 = 1/(2K_1)$
e) $K_2 = 1/(2K_1)^2$

12. What would be the pH of a 0.23 M solution of sodium lactate, NaC_2H_5OCOO? (The K_a of lactic acid, C_2H_5OCOOH, is 1.4×10^{-4}).

0.23 M $K_b = \frac{K_w}{K_a} = \frac{1.0\times10^{-14}}{1.4\times10^{-4}} = 7.14\times10^{-11}$

a) 5.39
b) 8.61
c) 9.51
d) 10.80
e) 11.75

$K_b = \frac{x^2}{0.23 - x} \approx \frac{x^2}{0.23}$

small

$x = \sqrt{(7.14\times10^{-11})(0.23)}$

$x = 4.053\times10^{-6}$

$-\log 4.053\times10^{-6} = pOH = 5.39$

$pH = 8.61$

13. What would be the K_b of sodium benzoate, NaC_6H_5COO, if the pK_a of benzoic acid, C_6H_5COOH, is 4.20?

$K_a = 10^{-pK_a} = 10^{-4.20} = 6.30957 \times 10^{-5}$

$K_b = \frac{K_w}{K_a} = \frac{1.00 \times 10^{-14}}{6.31 \times 10^{-5}} = 1.6 \times 10^{-10}$

a) 7.1×10^{-11}
b) 1.4×10^{-4}
c) 1.6×10^{-10}
d) 4.1×10^{-3}
e) 3.86×10^{-4}

14. A 2.0 L solution contains 0.86 moles of a weak base A^-. At equilibrium the pH = 9.47, what is the K_b of A^-?

0.86 moles/2.00 L = 0.43 M

$A^- + H_2O \rightleftharpoons HA + OH^-$

0.43−x x x

a) 2.0×10^{-9}
b) 3.4×10^{-10}
c) 2.9×10^{-10}
d) 7.9×10^{-10}
e) 8.7×10^{-10}

pH = 9.47

pOH = 4.53 $[OH^-] = 2.95 \times 10^{-5}$

$K_b = \frac{x^2}{0.43-x} = \frac{(2.95 \times 10^{-5})^2}{0.43 - 2.95 \times 10^{-5}}$

$K_b = \frac{8.7 \times 10^{-10}}{0.4299705} = 2.0 \times 10^{-9}$

15. Which of the following would be considered a buffered solution?

a) 1.0 M NaOH / 1.0 M HCl
b) 0.10 M NH_4Cl / 0.10 M NH_3
c) 0.10 M HOCl / 0.10 M NaCl
d) 0.10 M NaF / 0.10 M NaCl
e) None would be, they are all salts

Conjugates Acid/Base pair

$NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$

16. The complex A_2B has is found to have a solubility of 9.3×10^{-5} mol/L at 30°C, what is the K_{sp} for the complex A_2B?

$A_2B \rightleftharpoons 2A^+ + B^{2-}$ $x = 9.3 \times 10^{-5}$

2x x

a) 8.6×10^{-9}
b) 1.6×10^{-12}
c) 3.2×10^{-12}
d) 2.0×10^{-13}
e) 8.0×10^{-13}

$K_{sp} = (2x)^2 x = 4x^3 = 4(9.3 \times 10^{-5})^3 = 3.2 \times 10^{-12}$

17. What is the molar solubility of $PbCl_2$ (K_{sp} = 1.7 x 10^{-5} at 25°C) in a 0.025 M NaCl solution?

a) 6.8 x 10^{-4} M
b) 4.1 x 10^{-3} M
c) 1.6 x 10^{-2} M
d) 2.6 x 10^{-2} M
e) 2.7 x 10^{-2} M

**********END OF MULTIPLE CHOICE**********

<u>SECTION II: To be graded manually (Total value 26)</u>

Answers must be <u>written in non-erasable ink</u> to be considered for re-grading!

For full marks <u>show all your work.</u>

QUESTION 18 VALUE 5 MARKS

18. Methane, $CH_4(g)$, and $O_2(g)$ undergo a combustion reaction that produces $CO_2(g)$ and $H_2O(g)$.

a) [1 point] Write the balanced equation for this reaction.

$$CH_4 + 2O_2 \xrightarrow{\Delta} CO_2 + 2H_2O$$

b) [2 points] How many grams of CH_4 would exist in a 1.0 L container at 320 K and 1100 torr?

$$PV = nRT \qquad n = \frac{PV}{RT} = \frac{1.447\,atm \cdot 1.0L}{0.08205 \cdot 320} = 5.51 \times 10^{-2} \text{ moles}$$

$$mw = CH_4 = 16.05 \, g/mol$$

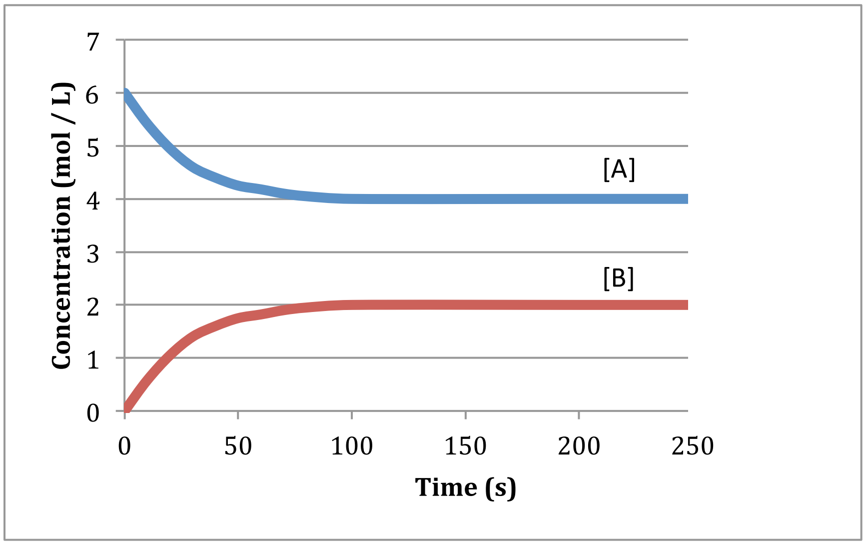
0.88 or 0.89g of CH_4

c) [2 points] How many mL of $O_2(g)$ will be needed to react with this if the $O_2(g)$ is at 320 K & 760 torr?

$$V = \frac{\left(5.51 \times 10^{-2} \text{ moles } CH_4 \times \frac{2 \text{ moles } O_2}{1 \text{ mole } CH_4}\right) \cdot 0.08205 \cdot 320\,K}{1\,atm} = 2.9 \times 10^{3} \text{ mL}$$

QUESTION 19 VALUE 6 MARKS

19. For the questions on this page, please refer to the diagram below showing how concentrations change over time for the conversion of A to B.



a) [1 point] Calculate the average rate of consumption of A between 0 s to 100 s.		
$\frac{4-6\ M}{100-0\ s} = 0.02\ Ms^{-1}$		
b) [1 point] At 200 seconds, the reaction has stopped because the reaction is complete.	Circle:	True False
c) [1 point] The rate of formation of B initially is equal in magnitude to the rate of consumption of A.	Circle:	True False
d) [1 point]The K_c for this reaction can be calculated based on the information in the diagram.	Circle:	True False

e) [1 point] Explain your choice in part (d) using one to two grammatically correctly sentences.
We can calculate the equilibrium b/c we have the equilibrium concentrations on the graph. $K_c = \frac{2}{4} = 0.5$
f) [1 point] At 300 seconds, more A is added so that [A] = 6.0 M. Calculate Q_c and describe what will happen to the concentration of [B].
$Q_c = 2/6 = 1/3 < 1/2$, ∴ The reaction will proceed to the right to make more B.

QUESTION 20 VALUE 5 MARKS

20. For the questions on this page, please refer to this mechanism for a hypothetical reaction.

Step 1:	$A + B \rightarrow X + Y$	Slow step
Step 2:	$A + X \rightarrow Y$	Fast step

a) [1 point] Write the overall reaction.	
$2A + B \rightarrow 2Y$	
b) [1 point] Predict a rate law for this reaction.	Rate $= k[A][B]$
c) [1 point] What role does X play in this mechanism? *[A one-word answer is sufficient]*	X is an intermediate

d) [2 points] A catalyst is added to this reaction. Write one or two grammatically correct sentences to describe what happens to the rate of the reaction and how the reaction energy diagram could be changed.

A catalyst will catalyze a step(s) within the reaction mechanism by lowering the activation energy, making it easier/faster to form product.

QUESTION 21 VALUE 4 MARKS

21. Vinegar is a 0.83 M solution of acetic acid. If the acetic acid in vinegar is 0.47% dissociated or ionized, calculate K_a for acetic acid.

$x = 0.47\%$ of 0.83

0.0047×0.83

$= 3.9 \times 10^{-3}$

	$CH_3COOH + H_2O$	$\rightleftharpoons$	CH_3COO^-	$+ H_3O^+$
I	0.83			
C	-3.9×10^{-3}		$+3.9\times10^{-3}$	$+3.9\times10^{-3}$
E	$0.83-3.9\times10^{-3}$		3.9×10^{-3}	3.9×10^{-3}

$$K_a = \frac{(3.9\times10^{-3})^2}{0.83-3.9\times10^{-3}}$$

$$K_a = 1.8\times10^{-5}$$

QUESTION 22 VALUE 6 MARKS

22. A 0.10 M HCN solution having a volume of 20.0 mL, is titrated with 0.050 M NaOH. The K_a of HCN is 6.2×10^{-10}.

a) [2 points] What is the pH before any base is added to the solution?

	$HCN + H_2O$	$\rightleftharpoons$	CN^-	$+ H_3O^+$
I	0.10			
C	$-x$		$+x$	$+x$
E	$0.10-x$		x	x

$$6.2\times10^{-10} = \frac{x^2}{0.10-x} \approx \frac{x^2}{0.10}$$

$$x = 7.9\times10^{-6}\,M$$

$$pH = 5.10$$

Check: $\frac{7.9\times10^{-6}}{0.10}\times100\% = 7.9\times10^{-3} < 5\%$ ✓

b) [2 points] What is the pH after 19. mL of 0.050 M NaOH is added to the solution?

$0.019L \times 0.050\,moles/L = 9.5\times10^{-4}$ moles NaOH
$0.020\,L \times 0.10\,moles/L = 2.0\times10^{-3}$ moles HCN

	HCN	+ NaOH	→	Na^+CN^- + H_2O
I	0.002	0.00095		
C	−0.00095	−0.00095		+ 0.00095
F	0.00105	0		0.00095

$pka = -\log 6.2\times10^{-10}$
$pka = 9.21$

$HH \Rightarrow pH = pK_a + \log\left(\frac{9.5\times10^{-4}}{1.05\times10^{-3}}\right)$

$pH = 9.21 + \log 0.904761904$

$pH = 9.17$

c) [2 points] What is the pH after 40. mL of 0.050 M NaOH is added to the solution?

$0.040\,L \times 0.050\,moles/L = 2.0\times10^{-3}$ moles NaOH

HCN	+ NaOH	→ CN^- + Na^+ + H_2O
2 mmol	2 mmol	
−2 mmol	−2 mmol	+2 mmol
0	0	2 mmol

$\frac{2.0\,mmol}{60\,mL} = 0.033M$

	CN^- + H_2O ⇌	HCN	+ OH^-
I	0.033M		
C	−x	+x	+x
E	0.033−x	x	x

$K_b = \frac{K_w}{K_a} = \frac{1\times10^{-14}}{6.2\times10^{-10}} = 1.61\times10^{-5}$

$K_b = \frac{x^2}{0.033-x}$ $\quad 1.61\times10^{-5} \approx \frac{x^2}{0.033}$

$x = 7.3\times10^{-4} = [OH^-]$

$pH = 10.86$

*********END OF WRITTEN ANSWER SECTION*********

1 1A	2 2A	3	4	5	6	7	8	9	10	11	12	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1 **H** 1.008																	2 **He** 4.003
3 **Li** 6.941	4 **Be** 9.012											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** 47.88	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** 65.38	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	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** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
55 **Cs** 132.9	56 **Ba** 137.3	57* **La** 138.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.9	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** 226.0	89** **Ac** (227)	104 **Rf** (261)	105 **Ha** (262)	106 **Sg** (263)	107 **Ns** (262)	108 **Hs** (265)	109 **Mt** (266)	110 **Uun** (269)	111 **Uuu** (272)							

Lanthanides *	58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.3	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0
Actinides **	90 **Th** 232.0	91 **Pa** 231.0	92 **U** 238.0	93 **Np** 237.0	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** (260)

Strong Acids: HCl, HBr, HI, HNO_3, H_2SO_4, $HClO_4$
Strong Bases: Hydroxides of Group 1A (Li to Cs) and Group 2A (Ca, Sr, Ba)

Constants:
Gas constant, *R* = 0.08205 L atm mol^{-1} K^{-1}
= 8.314 J mol^{-1} K^{-1} or 0.08314 bar L mol^{-1} K^{-1}
Avogadro's number: N_A = 6.022 x 10^{23} mol^{-1}
Faraday: F = 96,485 C / mol electrons
Planck's constant *h* = 6.626 x 10^{-34}Js
Speed of light , c = 2.998x 10^8m/s
Rydberg constant, R = 1.09678 x 10^{-7} m^{-1}

Conversion factors:
1 J = 1 kg m^2 s^{-2} 1 Pa = 1 kg m s^{-2}
T K = *T* °C + 273.15
1 L atm = 101.3 J
1atm = 760.0 torr = 101.3 kPa = 760.0 mm Hg = 1.013 bar
1 L = 10^{-3} m^3
1 C = 1 J / V   1 A = 1 C s^{-1}
STP conditions: 0 °C, 1 atm

$$[A]_t = -kt + [A]_0 \qquad \ln[A]_t = -kt + \ln[A]_0 \qquad \frac{1}{[A]_t} = kt + \frac{1}{[A]_0} \qquad \ln\left(\frac{[A]_0}{[A]_t}\right) = kt$$

$$t_{1/2} = \frac{[A]_0}{2k} \qquad t_{1/2} = \frac{0.693}{k} \qquad t_{1/2} = \frac{1}{k[A]_0} \qquad k = Ae^{\frac{-E_a}{RT}} \qquad \ln\left(\frac{K_2}{K_1}\right) = \frac{\Delta H}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$$\ln\left(\frac{k_2}{k_1}\right) = \frac{E_a}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right) \qquad PV = nRT \qquad K_p = K_c(RT)^{\Delta n} \qquad ax^2 + bx + c = 0$$

$$\mathrm{pH} = -\log[\mathrm{H}^+] \qquad K_w = K_a K_b \qquad K_{sp} = 1 / K_d \qquad K_f = 1 / K_d \qquad x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$\mathrm{pH} = \mathrm{p}K_a + \log\left(\frac{[\text{cong. base}]}{[\text{cong. acid}]}\right) \quad \text{or} \quad \mathrm{pOH} = \mathrm{p}K_b + \log\left(\frac{[\text{cong. acid}]}{[\text{cong. base}]}\right)$$

$$\mathrm{E}^\circ = \mathrm{E}^\circ_{\text{cathode}} - \mathrm{E}^\circ_{\text{anode}} \qquad \mathrm{E} = \mathrm{E}^\circ - \frac{0.0592}{n_e}\log \mathrm{Q} \qquad \mathrm{E}^\circ = \frac{0.0592}{n_e}\log K \quad \text{or} \quad n\mathrm{FE}^\circ = \mathrm{RT}\ln\mathrm{K}$$

$$q = It \qquad q = n_e F \qquad c = \lambda\nu \qquad E = h\nu \qquad E = mc^2 \qquad \frac{1}{\lambda} = \mathrm{R}\left(\frac{1}{\mathrm{n_1}^2} - \frac{1}{\mathrm{n_2}^2}\right) \qquad \Delta\mathrm{E} = -\mathrm{R_H}\left(\frac{\mathrm{Z}^2}{\mathrm{n_f}^2} - \frac{\mathrm{Z}^2}{\mathrm{n_i}^2}\right)$$

$$\mathrm{E} = -\mathrm{R_H}\left(\frac{\mathrm{Z}}{\mathrm{n}}\right)^2 \quad \text{or} \quad \mathrm{E_n} = -\frac{\mathrm{R}hc}{\mathrm{n}^2} \quad \text{for single electron species}$$