Université d'Ottawa · University of Ottawa

Faculté des science
Chimie

Faculty of Science
Chemistry

CHM 1301 and
CHM 1311 B

DATE: December 14, 2009 — Dr. Rashmi Venkateswaran
9:30 am

TIME: 3 hours

FULL STUDENT NAME: (Print)______________________________________

STUDENT NUMBER:____

COURSE CODE: (Please circle) CHM 1301 CHM 1311B

INSTRUCTIONS:

1. Write your answers on the exam. Please BOLD or HIGHLIGHT your final answer.

2. You are allowed to use electronic calculators during the exam (TI 30X, TI 34, TI 36).

3. Equations and constants are given on pages 18 and 19. A periodic table of the elements is included (page 20).

4. **Use the correct number of significant figures at all times.**

5. Marks allotted to each question are shown in brackets. The exam is out of 100.

7. Use the back of sheets for rough work. Three extra (blank) pages (15, 16 and 17) have also been included.

8. You are advised to read through the exam paper before you begin to write. Answer first those questions that you can do right away, proceeding to more difficult questions thereafter. Allow about ten minutes near the end of the exam period to read quickly through your answers, checking for obvious errors.

Quest.	1	2	3	4	5	6	7	8	9	10	
Marks	/10	/10	/10	/10	/10	/10	/10	/10	/10	/10	/100

(10) 1. The human eye contains a molecule called 11-cis-retinal that changes conformation when struck with light of sufficient energy. The change in conformation triggers a series of events that results in an electrical signal being sent to the brain. The minimum energy required to change the conformation of 11-cis-retinal within the eye is about 164 kJ/mol. Calculate the longest wavelength visible to the human eye.

10^{-19} J — E of ONE photon

$h = 6.626 \times 10^{-34}$ Js

$\nu \to$ freq

$E = h\nu = \frac{hc}{\lambda}$ $\qquad E = \frac{E}{mol} \times \#mol$

[2]

$E = \frac{E}{photon} \cdot \#photons$

1 nm = 10^{-9} m

$164 \times 10^{3} \frac{J}{mol} = \frac{E}{photon} \cdot 6.022 \times 10^{23} \frac{photons}{mol}$

$\frac{E}{photon} = \frac{164 \times 10^{3} \frac{J}{mol}}{6.022 \times 10^{23} \frac{pt}{mol}} = 2.72 \times 10^{-19} \frac{J}{photon} = \frac{hc}{\lambda}$

$\nu = \frac{c}{\lambda}$ ($c \to$ spd of light, $\lambda \to$ wavelength)

$\lambda = \frac{hc}{E} = \frac{(6.626 \times 10^{-34})(3.00 \times 10^{8})}{2.72 \times 10^{-19}} = 7.30 \times 10^{-7}$ m $= 730$ nm

(b) A green leaf has a surface area of 2.50 cm^2. If solar radiation, having an average wavelength of 504 nm is 1.00 x 10^3 W/m^2, how many photons strike the leaf every second? (1 W = 1 J/s)

$\lambda = \frac{hc}{E} = \frac{(Js)(\frac{m}{s})}{J/photon}$

$\frac{E}{photon} = \frac{hc}{\lambda} = \frac{(6.626 \times 10^{-34} Js)(3.00 \times 10^{8} \frac{m}{s})}{504 \times 10^{-9} m} = 3.94 \times 10^{-19} \frac{J}{photon}$

[3]

$P = 1.00 \times 10^{3} \frac{W}{m^2} = 1.00 \times 10^{3} \frac{J}{m^2 s}$

$E = P \cdot SA = 1.00 \times 10^{3} \frac{J}{m^2 s} \cdot 2.50 \times 10^{-4} m^2 = 0.250 \frac{J}{s}$

$2.50 cm^2 = 2.50 (cm)^2 = 2.5 (10^{-2} m)^2 = 2.5 \times 10^{-4} m^2$

$E = \frac{E}{photon} \times \#photons \Rightarrow \#photons = \frac{E}{\frac{E}{photon}} = \frac{0.250 \frac{J}{s}}{3.94 \times 10^{-19} \frac{J}{photon}} = 6.35 \times 10^{17} \frac{phot}{s}$

(c) How many photons at 660 nm must be absorbed to melt 5.0 x 10^2 g of ice? It takes 334 J to melt 1 g of ice at 0°C.

$E = \frac{hc}{\lambda} = \frac{(6.626 \times 10^{-34} Js)(3.00 \times 10^{8} \frac{m}{s})}{660 \times 10^{-9} m} = 3.01 \times 10^{-19} \frac{J}{photon}$

$E = \frac{E}{g} \times \#g = 334 \frac{J}{g} \times 5.0 \times 10^{2} g = 1.7 \times 10^{5} J$

[3]

$E = \frac{E}{photon} \times \#photons \qquad \#photons = \frac{E}{E/photon} = \frac{1.7 \times 10^{5} J}{3.01 \times 10^{-19} \frac{J}{photon}} = 5.5 \times 10^{23}$ photons

(d) What is the velocity of an electron emitted by a metal whose threshold frequency is 2.25 x 10^{14} s^{-1} when it is exposed to visible light of wavelength 5.00 x 10^2 nm?

$h\nu = \frac{hc}{\lambda} = \frac{(6.626 \times 10^{-34} Js)(3.00 \times 10^{8} \frac{m}{s})}{5.00 \times 10^{2} \times 10^{-9} m} = 3.98 \times 10^{-19}$ J/photon

$KE = h\nu - BE$

$= 3.98 \times 10^{-19} \frac{J}{photon} - 1.49 \times 10^{-19} \frac{J}{photon}$

[2]

$= 2.49 \times 10^{-19}$ J/photon

$BE = h\nu = (6.626 \times 10^{-34} Js)(2.25 \times 10^{14} s^{-1}) = 1.49 \times 10^{-19}$ J/photon

$2.49 \times 10^{-19} J = \frac{1}{2} m v^2 = \frac{1}{2}(9.109 \times 10^{-31} kg) v^2$

$v^2 = 5.47 \times 10^{11} \qquad v = 7.39 \times 10^{5}$ m/s

(10) 2. A 5.00 L vessel contains 25.0 g PCl_3 and 3.00 g of O_2 at 15.0 °C. The vessel is heated to 200.0 °C and the contents react to give $POCl_3$. What is the final pressure in the vessel assuming that the reaction goes to completion and that all reactants and products are in the gas phase?

$$PCl_3(g) + \frac{1}{2} O_2(g) \longrightarrow POCl_3(g)$$

25.0 g   3.00 g

$$n_{PCl_3} = \frac{m}{MM} = \frac{25.0\,g}{137.32\,\frac{g}{mol}} = 0.182\ mol \qquad MM_{PCl_3} = 30.97 + (35.45)3 = 137.32\ \frac{g}{mol}$$

[6]

$$n_{O_2} = \frac{m}{MM} = \frac{3.00\,g}{32.00\,\frac{g}{mol}} = 0.0938\ mol$$

$n_{O_2} : n_{PCl_3} = 1 : 2$ ∴ PCl_3 is the limiting reagent.

$2(0.0938) = 0.1875 > n_{PCl_3}$

Since rxn goes to completion PCl_3 is completely consumed

$$n_{O_2,\,remaining} = \left[0.0938 - \tfrac{1}{2}(0.182)\right] mol = 2.8 \times 10^{-3}$$

n_{POCl_3} produced $= n_{PCl_3} = 0.182$ mol

∴ $n_{TOT} = n_{O_2} + n_{POCl_3} = 0.185$ mol

$$\therefore P_{TOT} = \frac{n_{TOT}RT}{V} = \frac{(0.185\,mol)(0.08206\,\frac{L\,atm}{mol\,K})(473.2\,K)}{5.00\,L} = \boxed{1.44\ atm}$$

If 26.8 g of $POCl_3$ is actually produced, what is the percent yield of the reaction?

[4]

$$m_{POCl_3} = n \cdot MM = (0.182\,mol)(153.32\,\frac{g}{mol}) = 27.9\ g$$

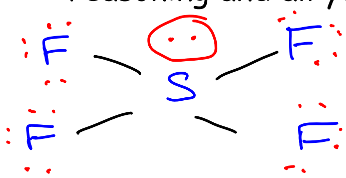
$MM_{POCl_3} = 30.97 + 16.00 + 3(35.45) = 153.32\ \frac{g}{mol}$

$$\therefore \%\,yield = \frac{26.8}{27.9} \times 100\% = \boxed{96.0\,\%}$$

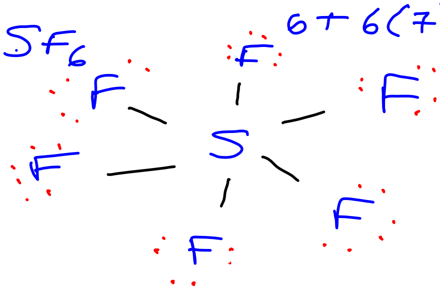
(10) 3. Sulfur reacts with fluorine to form a pair of neutral molecules, SF_4 and SF_6, that in turn form positive and negative ions, SF_3^+ and SF_5^-.

(a) Draw the Lewis structures of each species above. Show your reasoning and all your work.

SF_4
$6 + 4(7)$
$= 34e^-$
$8e^-$
$26e^-$
$26e^-$
0

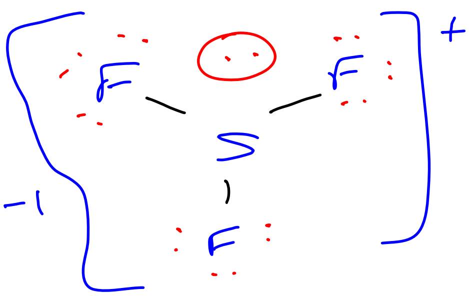


SF_6 $6 + 6(7) = 48e^-$
$-12e^-$
$36e^-$
$36e^-$
0

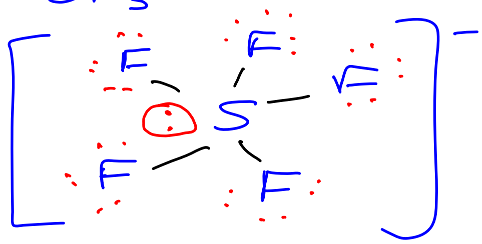


[2]

SF_3^+
$6 + 3(7) - 1$
$= 26e^-$
$6e^-$
$20e^-$
$20e^-$
0



SF_5^- $6 + 5(7) + 1 = 42e^-$
$-10e^-$
$32e^-$
$-32e^-$
0



(b) Using VSEPR, determine the geometry and shape of each species.

[4]

SF_4 – trigonal bipyramidal geometry; see-saw shape
SF_6 – octahedral geometry and shape
SF_3^+ – tetrahedral geometry; trigonal pyramid shape
SF_5^- – octahedral geometry; square pyramidal shape

(c) Determine the formal charges on all the atoms in the structures in (b).

[2]

SF_4: $S_{FC} = 6 - 2 - 4 = 0$; $F_{FC} = 7 - 6 - 1 = 0$
SF_6: $S_{FC} = 6 - 0 - 6 = 0$; $F_{FC} = 7 - 6 - 1 = 0$
SF_3^+: $S_{FC} = 6 - 2 - 3 = +1$; $F_{FC} = 7 - 6 - 1 = 0$
SF_5^-: $S_{FC} = 6 - 2 - 5 = -1$; $F_{FC} = 7 - 6 - 1 = 0$

(d) What are the major bond angles in each species likely to be?

[2]

SF_4: $90°, 180°, <120°$
SF_6: $90°, 180°$
SF_3^+: $<109.5°$
SF_5^-: $90°, 180°$

(10) 4. Adiponitrile, a key intermediate in the manufacture of nylon, is made industrially by an electrolytic process that reduces acrylonitrile:

Anode: $2\ H_2O \rightarrow O_2 + 4\ H^+ + 4\ e^-$

Cathode: $2\ CH_2{=}CHCN + 2\ H^+ + 2\ e^- \rightarrow NC(CH_2)_4NC$
Acrylonitrile → adiponitrile

i) Write the overall balanced cell reaction.

[1]

$2H_2O + 4CH_2{=}CHCN \longrightarrow O_2 + 2NC(CH_2)_4NC$

ii) What mass of adiponitrile is produced in 10.0 h in a cell that has a constant current of 3.00×10^3 A?

[3]

$Q = It = (3.00 \times 10^3 A)(10.0 h)\left(\frac{60 min}{h}\right)\left(\frac{60 s}{min}\right)$
$= 1.08 \times 10^8 C$

$z = \frac{Q}{F} = \frac{1.08 \times 10^8 C}{96485 C/mol} = 1.12 \times 10^3 mol\ e^-$

2 mol e^- → 1 mol adiponitrile

∴ 1.12×10^3 mol e^- → 5.60×10^2 mol adiponitrile

$m_{AN} = n \cdot MM = (5.60 \times 10^2 mol) \times 108\ g/mol = 6.05 \times 10^4 g = 60.5\ kg$

iii) What volume of O_2 at 740. mm Hg and 25.0 °C is produced as a byproduct?

[3]

$n_{O_2} = \frac{1}{2} n_{AN} = \frac{1}{2}(5.60 \times 10^2) = 2.80 \times 10^2 mol$

$V = \frac{nRT}{P} = \frac{(2.80 \times 10^2 mol)(0.08206 \frac{L\,atm}{mol\,K})(298.2 K)}{\frac{740. mmHg}{760 mmHg/atm}}$

$= 7.04 \times 10^3\ L$

iv) The K_{sp} of CuI is 1.1×10^{-12}. Calculate E_{cell} for the following:

$Cu(s) + Cu^+ \longrightarrow Cu(s) + Cu^+$

for conc cell, $E^\circ = 0$

Cu (s) | CuI (s) | I^- (aq) (1.0 M) || Cu^+ (aq) (1.0 M) | Cu (s)

[3]

$[Cu^+]_{anode}$ ∴ $K_{sp} = [Cu^+][I^-] = [Cu^+](1.0 M) = 1.1 \times 10^{-12}$
$[Cu^+] = 1.1 \times 10^{-12} M$

$E = E^\circ - \frac{RT}{zF} \ln \frac{[Cu^+]_{anode}}{[Cu^+]_{cath}} = -\frac{(8.314 \frac{J}{mol\,K})(298 K)}{(1)(96485 \frac{C}{mol})} \ln \frac{1.1 \times 10^{-12}}{1.0}$

$= 0.71\ V$

(10) 5. (a) Initial rate data is given below for the reaction

$$A + B \rightarrow C$$

Experiment	T (K)	[A] (M)	[B] (M)	Initial Rate of Formation of C (M/s)
1	700	0.20	0.10	1.8×10^{-5}
2	700	0.40	0.10	3.6×10^{-5}
3	700	0.10	0.20	3.6×10^{-5}
→ 4	600	0. 50	0.50	4.3×10^{-5}

NOTE T is different !!

(i) What is the rate law for this reaction?

$Rate = k[A]^m[B]^n$

using 1 & 2 : double [A], rate doubles ∴ m = 1

using 2 & 3 $\frac{Rate\ 2}{Rate\ 3} = \frac{k(0.40)(0.10)^n}{k(0.10)(0.20)^n} = 4\left(\frac{1}{2}\right)^n = \frac{3.6\times10^{-5}}{3.6\times10^{-5}} = 1$

[3]

$\left(\frac{1}{2}\right)^n = \frac{1}{4} = \left(\frac{1}{2}\right)^2$

∴ n = 2

$Rate = k[A][B]^2$

(ii) What is the rate constant for this reaction with the correct units at each temperature?

T = 700K

$3.6\times10^{-5}\ M/s = k\,(0.10M)(0.20M)^2$

$k = 9.0\times10^{-3}\ M^{-2}s^{-1}$

[3]

T = 600K

$4.3\times10^{-5}\ M/s = k\,(0.50M)(0.50M)^2$

$k = 3.4\times10^{-4}\ M^{-2}s^{-1}$

(iii) What is the activation energy for this reaction?

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

[1.5]

$\ln\frac{9.0\times10^{-3}}{3.4\times10^{-4}} = \frac{E_a}{8.314\ \frac{J}{mol\,K}}\left(\frac{1}{600\,K} - \frac{1}{700\,K}\right)$

$E_a = 110\ \frac{kJ}{mol}$ (because 2 sf)

b) A two-step mechanism has been proposed for the reaction of nitric oxide and bromine:

$$NO\ (g) + Br_2\ (g) \rightarrow NOBr_2\ (g)$$
$$NOBr_2\ (g) + NO\ (g) \rightarrow 2\ NOBr\ (g)$$

i) What is the overall reaction?

$2NO(g) + Br_2(g) \longrightarrow 2NOBr(g)$

[0.5]

ii) What is the role of $NOBr_2$ in the reaction?

intermediate

[0.5]

iii) What is the predicted rate law if the first step is much slower than the second step?

[1]

$\text{Rate} = k[NO][Br_2]$

iv) The observed rate law is Rate = $k[NO]^2[Br_2]$. What can you conclude about the rate-determining step?

It is NOT the first step!

[0.5]

(10) 6. (a) A 0.0100 mol sample of solid $Cd(OH)_2$ ($K_{sp} = 5.3 \times 10^{-15}$) in 100.0 mL of water is titrated with 0.100 M HNO_3.

i) What is the molar solubility of $Cd(OH)_2$ in pure water? What is the pH of the solution before the addition of any HNO_3?

$Cd(OH)_2(s) \rightleftharpoons Cd^{2+} + 2OH^-$
$\quad x \quad 2x$

[1.5] $K_{sp} = 5.3\times10^{-15} = [Cd^{2+}][OH^-]^2 = (x)(2x)^2$

$5.3\times10^{-15} = 4x^3$

$x = 1.1\times10^{-5}$ M $\quad [OH^-] = 2x = 2.2\times10^{-5}$ M

$pOH = -\log(2.2\times10^{-5}) = 4.66 \quad pH = 14 - pOH = \boxed{9.34}$

ii) What is the pH of the solution after the addition of 90.0 mL of 0.100 M HNO_3?

$[Cd(OH)_2] = 0.100$ M $\quad [HNO_3] = 0.100$ M

$Cd(OH)_2 + 2HNO_3 \rightleftharpoons Cd(NO_3)_2 + 2H_2O$

[2] $0.100\left(\frac{100}{190}\right) \quad 0.100\left(\frac{90}{190}\right) \quad -$

$5.26\times10^{-2} \quad 4.74\times10^{-2}$ M

$-2.37\times10^{-2} \quad -4.74\times10^{-2}$ M $\quad 2.37\times10^{-2}$

2.89×10^{-2} M $\quad$ —

$K_{sp} = [Cd^{2+}][OH^-]^2 = (2.37\times10^{-2})[OH^-]^2 = 5.3\times10^{-15}$

$[OH^-] = 4.7\times10^{-7}$ M $\quad pOH = 6.33 \quad pH = 14 - pOH = \boxed{7.67}$

iii) What volume of 0.100 M HNO_3 is required to completely neutralize the $Cd(OH)_2$?

$Cd(OH)_2 + 2HNO_3 \rightarrow Cd(NO_3)_2 + 2H_2O$

[1] $n_{Cd(OH)_2} = 0.0100$ mol $\quad n_{OH^-} = 2\times(0.0100) = 0.0200$ mol

$n_{H} = 0.0200\text{ mol} = MV = (0.100\text{ M})V$

$V = 0.200$ L $= \boxed{200.\text{ mL}}$

(b) Calculate the molar solubility of barium fluoride in 0.15 M sodium fluoride. $K_{sp} = 2.45 \times 10^{-5}$.

$BaF_2(s) \rightleftharpoons Ba^{2+}(aq) + 2F^-(aq)$

[2]

	$BaF_2(s)$	Ba^{2+}	$2F^-$
I	–	–	0.15M
C	–	x	$2x$
E	–	x	$2x + 0.15$

$K_{sp} = 2.45\times10^{-5} = [Ba^{2+}][F^-]^2 = x(2x+0.15)^2$

assume $2x \ll 0.15 \quad \therefore 2x + 0.15 \approx 0.15$

$2.45\times10^{-5} = x(0.15)^2 \quad x = 1.1\times10^{-3}$ M

assumption justified

$\therefore$ Molar solubility $= \boxed{1.1\times10^{-3}\text{ M}}$

$N_2O_4 = 2(14) + 4(16) = 92.0\ g/mol$

(c) A 14.58 g quantity of N_2O_4 (g) was placed in a 1.000 L vessel at 400.0 K. The gas decomposed to give an equilibrium mixture of N_2O_4 (g) and NO_2 (g) having a total pressure of 9.15 atm. Find the value of K_c for the balanced reaction.

$N_2O_{4(g)} \rightleftharpoons 2NO_{2(g)}$

[3]

	N_2O_4	NO_2
I	5.20 atm	—
C	$-x$	$2x$
E	$5.20 - x$	$2x$

$P_{N_2O_4} = \frac{nRT}{V} = \frac{m}{MM}\frac{RT}{V}$

$= \frac{(14.58\ g)(0.08206)(400.0\ K)}{(92.0\ g/mol)(1.000\ L)}$

$= 5.20$ atm

$5.20 - x + 2x = 9.15$ atm

$x = 3.95$ atm

$P_{N_2O_4} = (5.20 - 3.95)$ atm $= 1.25$ atm

$P_{NO_2} = 2(3.95\ atm) = 7.90$ atm

$P = \frac{n}{V}RT$

$\frac{n}{V} = \frac{P}{RT}$

$K_p = \frac{P_{NO_2}^2}{P_{N_2O_4}} = \frac{(7.90)^2}{1.25} = 49.9$

$K_p = K_c (RT)^{\Delta n}$

$K_c = K_p (RT)^{-\Delta n} = (49.9)[(0.08206)(400\ K)] = (1.52)$

If the volume of the vessel were doubled at constant temperature, would the composition of the mixture change? Explain your reasoning.

[0.5] Yes. Double V means rxn shifts to form more products (bigger number of moles). So composition will change.

(10) 7. (a) Sodium benzoate (C_6H_5COONa) is used as a food preservative. Calculate the pH of a 0.050 M solution of this salt. K_a for benzoic acid is 6.5×10^{-5}.

$K_b = \frac{K_w}{K_a} = \frac{1.0\times10^{-14}}{6.5\times10^{-5}} = 1.5\times10^{-10}$

$C_6H_5COO^- + H_2O \rightleftharpoons C_6H_5COOH + OH^-$

	$C_6H_5COO^-$	C_6H_5COOH	OH^-
I	0.050	–	–
C	−x	x	x
E	0.050 − x	x	x

[4]

$K_b = \frac{[C_6H_5COOH][OH^-]}{[C_6H_5COO^-]} = 1.5\times10^{-10} = \frac{x^2}{0.050-x}$

assume $x \ll 0.050$ ∴ $0.050 - x \approx 0.050$

$1.5\times10^{-10} = \frac{x^2}{0.050}$

$x = [OH^-] = 2.8\times10^{-6}$ M $pOH = -\log 2.8\times10^{-6} = 5.56$ ∴ $pH = 14 - pOH = 8.44$

(b) Can the above solution be considered as a buffer? Explain your answer as completely as possible.

[2] No. The weak conj base does not produce enough acid on dissociation to be considered a buffer.

(c) Given a buret filled with 0.10 M acetic acid ($K_a = 1.8 \times 10^{-5}$) and a second buret filled with 0.15 M sodium acetate, what volume of each solution should be mixed together to produce 20.0 mL of a solution with a pH of 4.85?

Don't forget dilution factors! let V of acid be x since V_{tot} = 20 mL let V_{base} = 20 − x

$CH_3COOH + H_2O \rightleftharpoons CH_3COO^- + H_3O^+$

$0.10\left(\frac{x}{20}\right)$ $0.15\left(\frac{20-x}{20}\right)$

$pH = pK_a + \log\frac{A^-}{HA}$

[4]

$4.85 = -\log(1.8\times10^{-5}) + \log\frac{0.15\left(\frac{20-x}{20}\right)}{0.10\left(\frac{x}{20}\right)}$

$= -\log(1.8\times10^{-5}) + \log\frac{0.15(20-x)}{0.10x}$

$\log\frac{0.15(20-x)}{0.10x} = 0.11$ $\frac{0.15(20-x)}{0.10x} = 10^{0.11} = 1.27$

$\frac{20-x}{x} = 1.27\left(\frac{0.10}{0.15}\right) = 0.85$

$20 - x = 0.85x$ $20 = 1.85x$ $x = 11$ mL

∴ 11 mL acid; 9 mL conj base

(10) 8. (a) Consider the Haber synthesis of gaseous ammonia ($\Delta H°_f$ = -46.1 kJ/mol, $\Delta G°_f$ = -16.5 kJ/mol) from its elements, hydrogen and nitrogen gases.

(i) Write the balanced equation for the reaction.

[1]

$3H_{2(g)} + N_{2(g)} \rightarrow 2NH_{3(g)}$

(ii) Using only the above data, calculate ΔH° and ΔS° for the reaction at 25.0 °C.

[2]

$\Delta H°_{rxn} = 2\Delta H°_{f,NH_3} = 2(-46.1\ \frac{kJ}{mol}) = -92.2\ \frac{kJ}{mol}$

$\Delta G°_{rxn} = 2\Delta G°_{f,NH_3} = 2(-16.5\ \frac{kJ}{mol}) = -33.0\ \frac{kJ}{mol}$

$\Delta G° = \Delta H° - T\Delta S°$ $\quad -33.0\times10^3\ \frac{J}{mol} = -92.2\times10^3\ \frac{J}{mol} - 298\Delta S°$

$\Delta S° = -199\ \frac{J}{mol\ K}$

(iii) Account for the sign of ΔS°.

[1]

4 mol of gas are forming 2 mol of a gas entropy should decrease.

(iv) Is the reaction spontaneous under standard-state conditions at 25°C? Explain as fully as possible.

[1]

Yes as ΔG° is negative

(v) What are the equilibrium constants K_p and K_c for the reaction at 350. K? Assume that ΔH° and ΔS° are independent of temperature.

[2]

Since all gases $K_{eq} = K_p$

K@298 $\Delta G° = -33.0\times10^3\ \frac{J}{mol} = -RT\ln K = -(8.314\ \frac{J}{mol K})(298K)\ln K$

$K = 6.1\times10^5$

$\ln\frac{K_1}{K_2} = \frac{\Delta H°}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$ $\quad \ln\frac{K_1}{6.1\times10^5} = \frac{-92.2\times10^3\ \frac{J}{mol}}{8.314\ \frac{J}{mol K}}\left(\frac{1}{298} - \frac{1}{350}\right)$

$K_1 = 2.4\times10^3 = K_p$

$K_p = K_c(RT)^{\Delta n}$ $\quad K_c = K_p(RT)^{-\Delta n} = 2.4\times10^3\left[(0.08206)(350)\right]^{-(-2)}$

$K_c = 2.0\times10^6$

b) A 110.0 g piece of molybdenum metal is heated to 100.0 °C and placed in a calorimeter that contains 150.0 g water at 24.6 °C. The system reaches equilibrium at a final temperature of 28.0 °C. Calculate the specific heat capacity of molybdenum metal. The specific heat capacity of water is 4.184 J/g°C.

$$-q_{met} = q_{H_2O}$$

$$-(mc\Delta T)_{met} = (mc\Delta T)_{H_2O}$$

$$-(110.0\,g)(c)(28.0 - 100.0\,°C) = (150.0\,g)(4.184\,\tfrac{J}{g°C})(28.0 - 24.6\,°C)$$

[3]

$$c = 0.269\,\frac{J}{g°C}$$

(10) 9. Salicylic acid, used in the manufacture of aspirin, contains only the elements C, H, and O and has only one acidic hydrogen. When 1.00 g of salicylic acid undergoes complete combustion, 2.23 g of carbon dioxide and 0.39 g of water are obtained. When 1.00 g of salicylic acid is titrated with 0.100 M NaOH, 72.4 mL of the base is needed for complete reaction. What are the EMPIRICAL and MOLECULAR formulae of salicylic acid?

$$n_C = n_{CO_2} = \frac{m}{MM} = \frac{2.23\,g}{44.0\,\frac{g}{mol}} = \underline{5.07\times10^{-2}\,mol}$$

$$m_C = n\cdot MM = (5.07\times10^{-2}\,mol)(12\,\tfrac{g}{mol}) = 0.608\,g$$

$$n_H = 2n_{H_2O} = \frac{2m}{MM} = \frac{2(0.39\,g)}{18.0\,g/mol} = \underline{4.33\times10^{-2}\,mol}$$

$$m_H = n\cdot MM = (4.33\times10^{-2}\,mol)(1.00794\,\tfrac{g}{mol}) = 4.37\times10^{-2}\,g$$

$$m_O = m_{compound} - m_C - m_H$$
$$= (1.00 - 0.608 - 4.37\times10^{-2})\,g$$
$$= 0.35\,g$$

$$n_O = \frac{m}{MM} = \frac{0.35\,g}{16.0\,g/mol} = \underline{2.18\times10^{-2}\,mol}$$

$$C_{\frac{5.07\times10^{-2}}{2.18\times10^{-2}}}\,H_{\frac{4.33\times10^{-2}}{2.18\times10^{-2}}}\,O_{\frac{2.18\times10^{-2}}{2.18\times10^{-2}}}$$

$$(C_{2.33}H_2O)\times 3 \qquad \boxed{C_7H_6O_3} \text{ empirical formula}$$

$$MM_{emp\ unit} = 7(12) + 6(1) + 3(16) = 138\,\tfrac{g}{mol}$$

$$n_{Base} = MV = (0.100\,M)(72.4\times10^{-3}\,L) = 72.4\times10^{-4}\,mol$$

since only 1 titratable proton in acid

$$n_{acid} = n_{base} = 72.4\times10^{-4}\,mole$$

$$MM_{acid} = \frac{m}{n} = \frac{1.00\,g}{72.4\times10^{-4}\,mole} = 138\,\tfrac{g}{mol}$$

$\therefore$ Empirical & Molecular formula are SAME!

(10) 10. You have been asked to join RH Stephen Harper in Copenhagen for the summit on environmental issues. You will be required to demonstrate your ability to show how chemistry is intricately connected with all environmental issues. Write a 1-2 page essay that CLEARLY demonstrates your knowledge of the underlying chemistry in ONE of the following topics: quantum chemistry, electrochemistry, acids and bases, equilibrium, kinetics, gas laws, or thermodynamics. In an essay of minimum length 1 page and using at least 3 chemical concepts (clearly explained), prepare your speech on how chemistry is critical to an issue related to the environment.

Multiple answers were accepted

Gas Law

$PV = nRT$

$P_{Total} = P_1 + P_2 + P_3 + \ldots$

$d = m / V = P(MM) / RT$

$KE = (1/2)mv_{av}^2$

$$\sqrt{\bar{v}^2} = \sqrt{\frac{3RT}{M}}$$

$$\frac{RateA}{RateB} = \sqrt{\frac{M_b}{M_a}}$$

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

1 atm = 760 Torr = 760 mm Hg = 1.01325×10^5 Pa

Equilibrium

$K_p = K(RT)^{\Delta n}$

$K = [C]^c[D]^d/[A]^a[B]^b$

$K_{sp} = [C]^c[D]^d$

Acid/Base

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

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

$pH + pOH = 14$

$K_a \times K_b = K_w$

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

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

Concentration (M) = n/V

Electrochemistry

$\Delta G^o = -nFE^o$

$$E = E^o - \frac{RT}{nF}\ln(Q)$$

$$\text{Or } E = E^o - \frac{0.059}{n}\log(Q) \text{ at } 25^oC$$

$Q = I \cdot t$

Quantum Mechanics

$\lambda \cdot \nu = c$

$E = h \cdot \nu$

$$m = \frac{h}{\lambda c}$$

$E = \frac{1}{2} m u^2$

$\lambda = h/mu$

Energy of state = -2.178×10^{-18} J / n^2

$\Delta x \cdot \Delta p \geq h / 4\pi$

$E = -C(1/n^2)$

Liquids and Colligative Properties

$\ln(P_1/P_2) = \Delta H^o/R\ (1/T_2 - 1/T_1)$

$P_{solution} = X_{solvent} \cdot P^o_{solvent}$

$\Delta T_{BP} = K_{BP} \cdot m$

$\Delta T_{FP} = K_{FP} \cdot m$

$\Delta T = K \cdot m \cdot i$

$\Pi = cRT$

molality = mol solute/mass solvent (kg)

General Information: $$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Thermodynamics

$\Delta U = q$

$w_{system} = \Delta P \Delta V$

$\Delta E = q + w$

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

$q_p = \Delta E + P\Delta V$

$\Delta E = nCv\Delta T$

$\Delta H = q_p = m\ c\ \Delta T$

$C_p = C_v + R$

$\Delta H_{rxn}° = \Delta n_p \Delta H_f \Delta(\text{products}) -$

$\Delta n_r \Delta H_f \Delta(\text{reactants})$

$q_{rev} = -w_{max} = nRT \ln (V_2/V_1)$

$\Delta S = q_{rev} / T$

$\Delta S_{T1\text{-}T2} = nC_p \ln(T_2/T_1)$

$\Delta S_{T1\text{-}T2} = nC_v \ln(T_2/T_1)$

$$\Delta S^0_{surroundigs} = \frac{q_{surroundigs}}{T} = \frac{-\Delta H_{sys}}{T}$$

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

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

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

$\ln(K_1/K_2) = \Delta H^o/R\ (1/T_2 - 1/T_1)$

Kinetics

$Rate = k\ [A]^x[B]^y[C]^z$

$Rate = k$

$Rate = k[A]$

$Rate = k[A]^2$

$[A] = -kt + [A]_0$

$\ln[A] = -kt + \ln[A]_0$

$1/[A] = kt + 1/[A]_0$

$t = [A]_0 / 2k$

$\ln 2 = kt$

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

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

Bonding

$DE = k\ (Q_1 Q_2 / r)$

$DH_{rxn} = Sn_p D(\text{reactants}) -$

$Sn_r D(\text{products})$

Formal Charge = #valence e^- in free atom - #lone pair e^- - 1/2(# bonding e^-)

Data For Water and Other Constants

Density d = 1.00 g/mL (25°C) $C = 4.184\ J\ g^{-1}\ °C^{-1}$ (liquid) $K_w = 1.00 \times 10^{-14}$

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	$L \cdot atm \cdot K^{-1} \cdot mol^{-1}$
Mass of Electron	m_e	$9.10938188 \times 10^{-31}$	kg
Planck's constant	h	6.62608×10^{-34}	$J \cdot s$
Speed of Light	c	2.99792458×10^{8}	$m \cdot s^{-1}$

Mokeur's Periodic table of the elements

Key: Symbol, Atomic number — *H 1* — Relative atomic mass (1.00794) — Electronegativity (2.1) — Most frequent oxidation number (1+) — Name (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.