



Midterm exam 2016, questions and answers

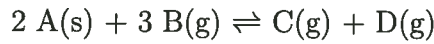
Principles of Chemistry (University of Ottawa)

**1 point**

At 1.00 atm and 0.0°C, for the melting of ice,  $H_2O(s) \rightleftharpoons H_2O(l)$ , will the entropy change in the environment,  $\Delta S_{environment}$ , be negative, positive, or zero? Please circle your answer.

**9 points**

For the reaction



the equilibrium constant is 0.488 at 25.0°C and 0.177 at 75.0°C. Making the approximation that  $\Delta H^\circ$  and  $\Delta S^\circ$  do not vary with temperature, calculate the values of  $\Delta H^\circ$ ,  $\Delta S^\circ$ , and the equilibrium constant,  $K$ , at 50.0°C. Taking into account that B, C, and D are gases, calculate the values of  $\Delta U^\circ$ ,  $Q$ , and  $W$  for this reaction under a constant pressure of 1.00 atm at 25.0°C.

① FIND  $\Delta H^\circ$

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

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

$$= \frac{-8.3145 \ln\left(\frac{0.177}{0.488}\right)}{\left(\frac{1}{348.15} - \frac{1}{298.15}\right)}$$

$$\Delta H^\circ = -17506 \text{ J} = \boxed{-17.5 \text{ kJ}}$$

② FIND  $\Delta G^\circ @ 25^\circ\text{C}$

$$\Delta G^\circ_{25} = -RT \ln K_{25}$$

$$= -8.3145 (298.15) \ln(0.488)$$

$$\Delta G^\circ_{25} = 1179 \text{ J}$$

③ FIND  $\Delta S^\circ$

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

$$\Delta S^\circ = \frac{\Delta H^\circ - \Delta G^\circ}{T}$$

$$= \frac{-17506 - 1179}{298.15}$$

$$\Delta S^\circ = \boxed{-64.7 \text{ J/K}}$$

④ FIND  $\Delta G^\circ_{50}$

$$\Delta G^\circ_{50} = \Delta H^\circ - T \Delta S^\circ$$

$$= (-17506) - (323.15)(-64.7)$$

$$\Delta G^\circ_{50} = 3402 \text{ J}$$

⑤ FIND  $K_{50}$

$$K_{50} = e^{-\frac{\Delta G^\circ}{RT}}$$

$$= e^{-\frac{(3402)}{(8.3145)(323.15)}}$$

$$\boxed{K_{50} = 0.282}$$

⑥ At constant pressure,  $\Delta H = \boxed{Q} = -17.5 \text{ kJ}$

⑦ FIND  $\Delta U^\circ$

$$\Delta H^\circ = \Delta U^\circ + RT \Delta n_{gas}$$

$$\Delta U^\circ = \Delta H^\circ - RT \Delta n_{gas}$$

$$= -17506 - (8.3145)(298.15)(-1)$$

$$= -15027 \text{ J}$$

$$\boxed{\Delta U^\circ = -15.0 \text{ kJ}}$$

⑧ FIND  $W$

$$\Delta U = Q + W$$

$$W = \Delta U - Q$$

$$= -15.0 - (-17.5)$$

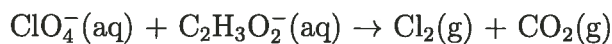
$$\boxed{W = +2.5 \text{ kJ}}$$

**1 point**

Among He(g), N<sub>2</sub>(g), NH<sub>3</sub>(aq), NH<sub>4</sub><sup>+</sup>(aq), Na(s), Na<sup>+</sup>(aq), NaCl(s), Cl<sup>-</sup>(aq), Cl<sub>2</sub>(g), and Ar(g), which is the best Bronsted-Lowry acid? Please circle your answer.

**9 points**

Balance the following chemical equation, in basic solution,



### 1 point

Among He(g), N<sub>2</sub>(g), NH<sub>3</sub>(aq), NH<sub>4</sub><sup>+</sup>(aq), Na(s), Na<sup>+</sup>(aq), NaCl(s), Cl<sup>-</sup>(aq), Cl<sub>2</sub>(g), and Ar(g), which is the best Bronsted-Lowry base? Please circle your answer.

### 9 points

At a temperature of 25.0°C, we dissolve 1.22 g of an acid, HA, in enough water to produce 25.0 mL of solution. The pH of this solution is 1.55. We titrate this solution with a 0.155 M NaOH solution and we need 27.7 mL of this solution to attain the equivalence point.

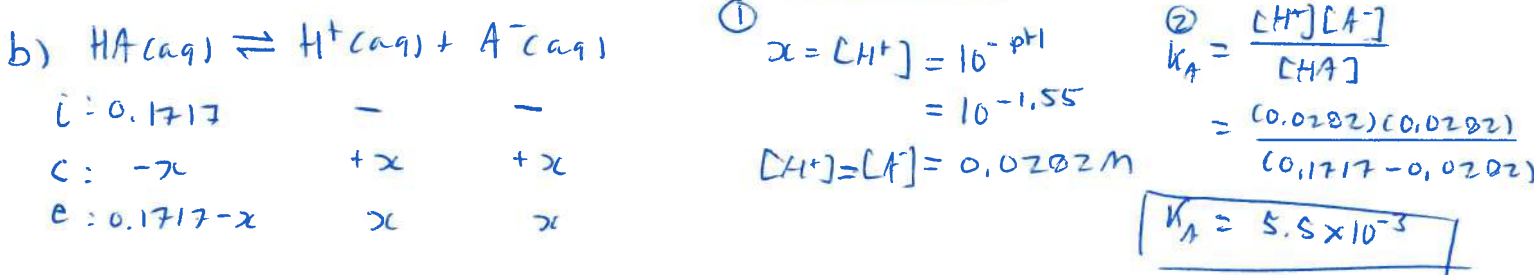
- (a) (3 points) What is the molar mass of HA?  
 (b) (4 points) What is the dissociation constant, K<sub>A</sub>, of HA?  
 (b) (2 points) What would be the pH of a 1.000 M solution of NaA?

a) ①  $C_A V_A = C_B V_B$   
 $C_A = \frac{C_B V_B}{V_A}$   
 $= \frac{(0.155)(27.7)}{(25.0)}$   
 $C_A = 0.1717 M$

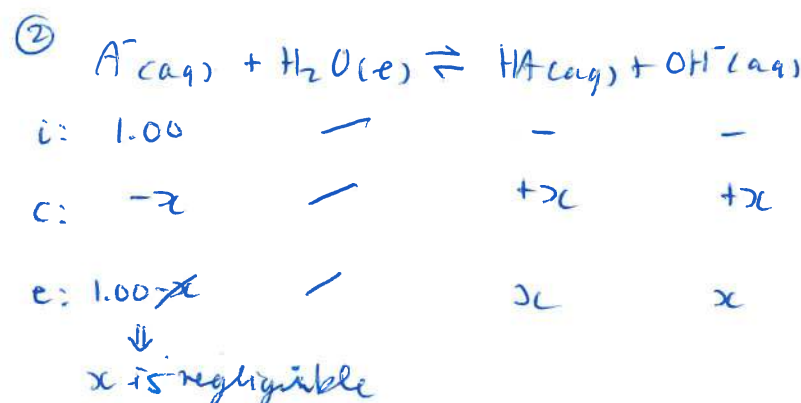
$0.1717 \text{ mol} \rightarrow 1000 \text{ mL}$   
 $x \rightarrow 25.0 \text{ mL}$  }  $x = 0.0042925$

②  $M = \frac{m}{n}$   
 $= \frac{1.22 \text{ g}}{0.0042925 \text{ mol}}$

$M = 284 \text{ g/mol}$



①  $K_B = \frac{K_{water}}{K_A}$   
 $= \frac{1.0 \times 10^{-14}}{5.5 \times 10^{-3}}$   
 $= 1.8 \times 10^{-12}$



③  $K_b = \frac{[AA] [OH^-]}{[A^-]}$   
 $1.8 \times 10^{-12} = \frac{x^2}{1.00}$

④  $\text{pOH} = 5.87$   
 so  
 $\text{pH} = 8.13$

$x = 1.34 \times 10^{-6}$

### 1 point

Among He(g), N<sub>2</sub>(g), NH<sub>3</sub>(aq), NH<sub>4</sub><sup>+</sup>(aq), Na(s), Na<sup>+</sup>(aq), NaCl(s), Cl<sup>-</sup>(aq), Cl<sub>2</sub>(g), and Ar(g), which is the best reducing agent? Please circle your answer.

### 9 points

- (a) (5 points) For the reaction  $2 A(aq) \rightleftharpoons B(aq) + 2 C(aq)$ , the equilibrium constant is 9.88. If the concentration of B(aq) is 0.244 M and the concentration of C(aq) is 0.311 M, what concentration of A(aq) would be necessary to have a value of  $\Delta G$  equal to -4.00 kJ? The temperature is 25.0°C throughout.
- (b) (4 points) For the reaction  $3 A(g) \rightleftharpoons 2 B(g) + C(g)$ , we start with only pure A(g). We attain equilibrium. At equilibrium, the total pressure is 7.00 atm, and the partial pressure of B(g) is 2.50 atm. What is the value of  $\Delta G^\circ$  for this reaction? The temperature is 25.0°C throughout.

8) ① FIND  $\Delta G^\circ$

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

$$= -(8.3145)(298.15) \ln(9.88)$$

$$\Delta G^\circ = -5678 \text{ J}$$

② FIND Q

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

$$RT \ln Q = \Delta G - \Delta G^\circ$$

$$\ln Q = \frac{\Delta G - \Delta G^\circ}{RT}$$

$$Q = e^{\frac{\Delta G - \Delta G^\circ}{RT}}$$

$$Q = e^{\frac{(-4000) + 5678}{(8.3145)(298.15)}}$$

$$Q = 0.6769$$

③ FIND [A]

$$Q = \frac{[B][C]^2}{[A]^2}$$

$$[A] = \sqrt{\frac{[B][C]^2}{Q}}$$

$$[A] = \sqrt{\frac{(0.244)(0.311)^2}{1.968}}$$

$$[A] = 0.110 \text{ M}$$

9) b)



i: ??

c: -3x

e: ??

-

+2x

2x

-

+x

x

①  $P_B = 2.50 \text{ atm}$

$$2x = 2.50 \text{ atm}$$

$$x = 1.25 \text{ atm} = P_C$$

②  $P_t = P_A + P_B + P_C$

$$P_A = P_t - P_B - P_C$$

$$= 7.00 - 2.50 - 1.25$$

$$P_A = 3.25 \text{ atm}$$

③  $K = \frac{P_B^2 P_C}{P_A^3}$

$$K = \frac{(2.50)^2 (1.25)}{(3.25)^3}$$

$$K = 0.2276$$

④  $\Delta G^\circ = -RT \ln K$

$$= -(8.3145)(298.15) \ln(0.2276)$$

$$\Delta G^\circ = +3.67 \text{ kJ}$$

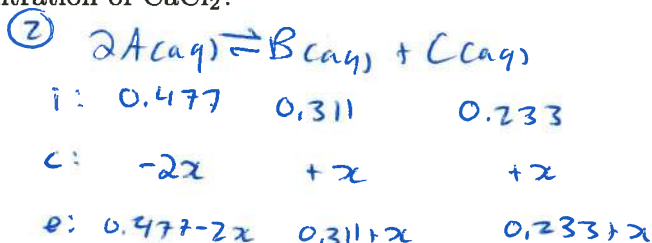
### 1 point

Among He(g), N<sub>2</sub>(g), NH<sub>3</sub>(aq), NH<sub>4</sub><sup>+</sup>(aq), Na(s), Na<sup>+</sup>(aq), NaCl(s), Cl<sup>-</sup>(aq), Cl<sub>2</sub>(g), and Ar(g), which is the best oxidizing agent? Please circle your answer.

### 9 points

- (a) (5 points) For the reaction  $2 A(aq) \rightleftharpoons B(aq) + C(aq)$ , the value of  $\Delta G^\circ$  is  $-3.70$  kJ (or kJ/mol) at  $25^\circ\text{C}$ . The initial concentrations of A(aq), B(aq), and C(aq) are  $0.477$  M,  $0.311$  M, and  $0.233$  M, respectively. What will be the concentration of A(aq) once we attain equilibrium at  $25.0^\circ\text{C}$ ?
- (b) (4 points) We have  $500.0$  mL of an aqueous solution of  $\text{CaCl}_2$  ( $\text{CaCl}_2$  is a strong electrolyte). We add an excess  $\text{AgNO}_3$  so as to produce an  $\text{AgCl}(s)$  precipitate. The mass of  $\text{AgCl}$  produced is  $2.222$  g. What was the original concentration of  $\text{CaCl}_2$ ?

$$\textcircled{1} \quad a) \quad K = e^{-\Delta G^\circ / RT}$$
$$= e^{-(-3700) / (8.3145(298.15))}$$
$$= 4.448$$



$$\textcircled{3} \quad K = \frac{[B][C]}{[A]^2}$$

$$4.448 = \frac{(0.311+x)(0.233+x)}{(0.477-2x)^2}$$

$$4.448 = \frac{x^2 + 0.544x + 0.0725}{4x^2 - 1.908x + 0.2275}$$

$$0 = 16.792x^2 - 9.0308x + 0.9394$$

$$a = 16.792$$
$$b = -9.0308$$
$$c = 0.9394$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$
$$= \frac{9.0308 \pm 4.2962}{2(16.792)}$$

$$x_1 = \cancel{0.3968} \quad x_2 = 0.1410$$

impossible

$$\textcircled{4} \quad [A] = 0.477 - 2x = 0.477 - 2(0.1410) = \boxed{0.195 \text{ M}}$$

$$b) \quad \textcircled{1} \quad n_{\text{AgCl}} = n_{\text{AgCl}} = \frac{2.222 \text{ g}}{(107.9 + 35.45) \text{ g/mol}}$$
$$= 0.015501 \text{ mol}$$

$$\textcircled{2} \quad n_{\text{CaCl}_2} = \frac{1}{2} n_{\text{AgCl}}$$
$$= \frac{0.015501 \text{ mol}}{2}$$

$$n_{\text{CaCl}_2} = 0.007750 \text{ mol}$$

$$\textcircled{3} \quad [\text{CaCl}_2] = \frac{0.007750 \text{ mol}}{0.0500 \text{ L}}$$

$$= \boxed{0.1550 \text{ mol/L}}$$